MASS CUSTOMISATION AND SUSTAINABILITY IN HOUSING

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Edited by
Ercília H. Hirota
Carlos T. Formoso
John Onyango

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Preface

ZEMCH (Zero Energy Mass Custom Homes) is a network of academics and practitioners that was established with the aim to enhance industry-academia collaboration to tackle issues around the delivery of socially, economically and environmentally sustainable housing projects in both developed and developing countries.

A wide range of topics are involved in this network, such as energy-efficient buildings, environmental impacts of the construction industry, building performance, sustainable community development, innovation and industrialization, product development, design, post occupancy evaluation, information and communication technology, and construction management. Moreover, much emphasis is given to the necessity of accommodating wants and needs of individuals and society, which are assumed to be diverse and dynamic.

This e-book contains 24 papers that were reviewed by the scientific committee and presented at **ZEMCH 2014 Conference,** the third annual conference organised by this network. The previous ones were held in Glasgow, Scotland, and Miami, Florida, in 2012 and 2013, respectively. Londrina, the hosting city, located in the State of Paraná, Brazil was chosen as the venue in 2014 due to the efforts of the State University of Londrina in establishing a research initiative related to the design and construction of low-cost sustainable and mass-customized housebuilding projects. This theme is currently very relevant for Brazil, considering the huge amount of investments that have been made by the Federal Government in social housing and infrastructure systems.

The ZEMCH webpage (http://www.zemch.org) presents more information about the current activities of this network, and past conferences.

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LIVINGBOX: A MODULAR HABITATIVE UNIT

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LIVINGBOX: A MODULAR HABITATIVE UNIT

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Abstract

The project of a minimum expandable living unit: LIVINGBOX has been developed at the Laboratory of Building Design of the University of Trento (Italy). It can be used as a minimum dwelling for two people (40.50 m^2) or as a hotel room (18 m^2 + optional spaces) finished in every detail: interior finishing, furniture and technological systems. The furniture is integrated in walls and the inner space is flexible and changeable. The furniture, the inner spatial organization and the inner and outdoor finishing are customizable. The unit is built joining two precast modules. The dimensions of a single module are cm 249 x 999 x 300. LIVINGBOX has been designed to minimize the impact of the building on environmental matrixes: water, air, soil. The materials used are natural, recyclable or recycled. It is characterized by extensive use of wood to limit CO_2 emission into the atmosphere and it was designed as Zero Energy House. To reach this target it is equipped with systems for producing energy from renewable sources, so as to minimize use of fossil energy. In addition the unit is a low consumption building. The envelop transmittance value is between 0.20 and 0.25 W/m^2K, and the thermal lag of 10-15 h. To optimize the relationship between comfort and energy consumption LIVINGBOX is equipped with a modular home automation system. A prototype at real scale has been built as so to verify the real building possibilities. It was displayed in Milano (Italy) at beginning of October 2013 at the “MADE EXPO 2013”. The prototype was transported by 2 trucks from Roma to Milano to Campobasso (more or less 1500 Km) for testing the effective transportability and we could verify no inconvenience or crack on the interior and on the furniture. This is also a real demonstration that it is earthquake resistant building.

Keywords: *customization, transportable, active house, modular building, prefabrication.*

Introduction

Livingbox is a minimum expandable living unit developed at the Laboratory of Building Design of the University of Trento (Italy). It can be used as a minimum dwelling for two people, as an hotel room, a student’s room in University campus, a minimum dwelling for older people in protected structures. It is finished in every detail: interior finishing, furniture and technological systems. Several architects and researchers have developed similar ideas realizing small buildings paying attention to the transportability as Lisa Tilder and Stephen Tirk (USA) or ADD-A-ROOM (Sweden architecture studio). Other architects have paid particular attention to the use of dry constructive systems, such as Taylor Smyts Architects (Canada) or Crayg Chatman (Australia). Very interesting are the works of Jo Nagasaka and Schemate Architecture Office (Japan) or of Rintal Eggertsson (Richardson 2011 and Zamora, Sanchez and Paredes 2010).

During the design phase we paid attention to all these characteristics. One of the main features of Livingbox is the customization. The furniture of Livingbox is customizable and integrated in the walls so that the inner space is flexible and changeable during the day (living room, study, single or double bedroom). The outdoor walls are customizable with different constructive solutions. As example, they can be coated with different materials or to be built with different thickness of the insulation. One of the other most important aims of this design is the zero energy consumption. This target has been reached by combining the bioclimatic solutions with the good thermal behavior of the modular unit achieved with the constructive solutions, following the main criteria applied in the buildings realized for the "solar decathlon".

The transportation

The habitative unit is built joining two precast industrialized basic modules (Fig. 1). One is specialized and equipped with the bathroom and the kitchen including pipes, heating pump, tank, heating system, electrical system, control devices panel and touch screen for managing building automation. The second is free and available for any functional attribution (Kaufmann and Remick 2009 and Knaack, Chung-Klatte and Hasselbach 2012).

Figure1: The prototype of the modular habitative unit built with two basic modular modules

The dimensions of a single module are 2.49 m (width) x 9.99 m (length) x 2.99 m (height). With these dimensions (Fig. 2), it can be transported, for the Italian code of the road traffic, with a truck trailer without being classified as a "special cargo". It can also be transported by railway wagons to minimize the CO_2 emission.

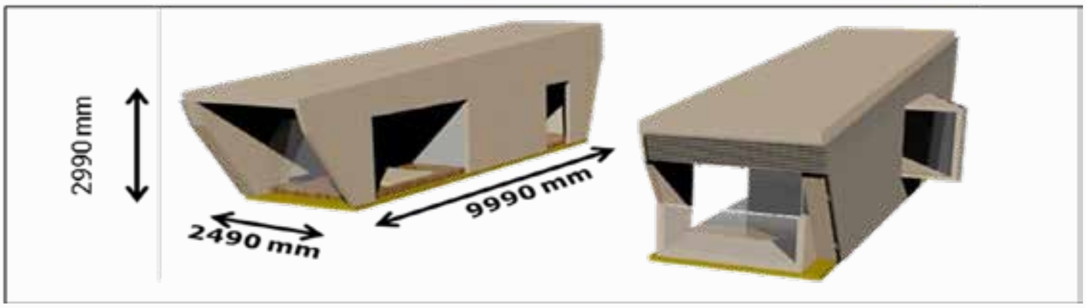

Figure 2: The two basic modular modules

The typological solutions

The living unit is articulated in a fixed block kitchen-bath and in a large multi-purpose space that can be articulated during the day. The unit can be expanded from 40.50 to 60.80 m^2 net. In this last case the kitchen and the bathroom block are bigger (Mira and Minquet 2012 and Smith 2010). The units can be put together for generating terraced houses or block houses up to three floors. The living unit can be organized functionally also in different way (Fig. 3).

One example could be the solution as hotel. In this case the space is articulated in a room of about 15.00 m^2, in a multi-functional space between the bedroom and the bathroom access, about 5.00 m^2, equipped with a wardrobe (length 2.40 m), and a bathroom, about 5.00 m^2. The units aggregation can generate different types of buildings: terraced houses, blocks up to three floors, or small settlements with the units spread over the land.

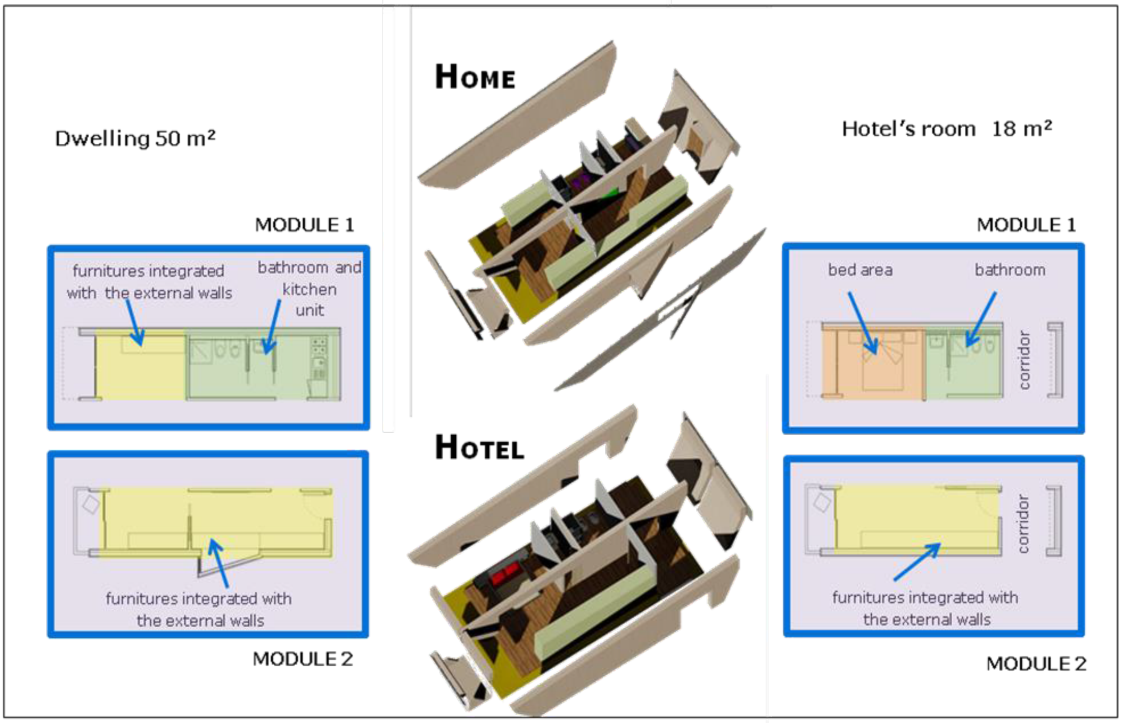

Figure 3: Different typological solutions

For its typological flexibility, Livingbox could be structured as a part of different building, maintaining the base concepts of transportability and modularity. It is possible to redesign the inner space realizing different typological solutions. For example, Livingbox could be used as a core unit for open-air restaurants, coffee shops, etc. The free aggregation of several units can realize resort and small settlements. Due to transportability, it can be used as emergency housing after earthquakes or catastrophes. At the moment, the idea of building resorts that, in case of emergency, can be moved into a crisis area in few days is being developed. So it could be possible to have emergency buildings in a few days, and at the same time do not store a large quantity of small manufactured components or tents to use in the case of crisis – this is what several nations are doing at the moment. A small quantity of tents can be used during the first week after the event and then, moving the buildings from the resort, it is possible provide more comfortable living, while waiting for the reconstruction. A negative example: after the last Aquila's heartquake the population had to live for more than 7 months in tents waiting for new wooden houses.

Customization

The unit can be customized from different points of view: constructive, technological and furnishings. The layout of the Livingbox walls and floors has been thought to follow the user needs for what concern the inner comfort. It means that it is possible to modify the layouts of the walls maintaining the same wooden panels. As example there is the possibility to maintain the insulation material modifying the thickness or changing totally the material. Significant, for what concern the last one situation, it is possible to have the external finishing as ventilated wall, or plastered. It is also possible to use rock wool instead sheep wool for insulation. This last choice, as example, could be related to the request fire resistance of the wall. In other cases, economic evaluations could be the basis for different choices. The cost of the unit can be higher or lower depending for the different solutions starting from the basic solution able to ensure the right comfort.

Several solutions have been thought to customize the unit improving the basic version, maintaining always the "concept" without modification to the basic structural solution. For what concern the heating an heat pump (COP=3.8), eventually powered by photovoltaic system (PV), is the base of the heating ventilation system (HV) and the production of sanitary hot water (SHW). At same time the PV system produces electricity for the artificial lighting and for all electrical devices. The water for sanitary use could be harvests from an integrated filtering system connected with the roof garden. Other step towards the customization is the introduction of the building automation to manage the different scenarios for the entertainment and for saving energy managing the daylighting, the heating and the natural ventilation. Equipped with the building automation and realized with sustainable solutions the modular unit is a “smart home”. In this case it could be connect to other similar unit equipped with analogous system for sharing information and energy and/or with the public net as part a smart district.

Livingbox could be a possible answer to new living behavior of the people of the developed countries and to the needs of the people of the developing countries (Bergdoll and Christensen 2008). For what concern the developed countries we can see that the family, in the patriarchal or matriarchal concept, is just a small part of the families. The new life style of the largest part of the society is more oriented to an individual existence or to the couple life. The actual women economic independence emphasizes this kind of situation. The young new generation does not need a big home, but they want space easy to manage, enough to ensure all the domestic and work activities (Zamora, Sanchez and Paredes 2010).

Figure 4: Flexibility of the inner environment: the living/sleeping area

For this reason the furniture of Livingbox is simple, integrated with the walls for taking less space, ensuring the possibility to carry out all the home activities (Fig. 4). The home must be small but sometime, must show the social level, for this a customized solution can be the answer and Livingbox could be that right. A big part of the people of the developing countries is moving towards the big metropolis and there is the request of small apartments at low cost. Several municipalities are planning new settlements for social housing. Livingbox could be an answer because the basic version (40.50 m^2) is a cheap answer for apartments for two people in four-storey buildings. The bigger solution, 60.80 m^2, is right for four people.

Constructive solutions

From a constructive point of view the main characteristic of Living Box is that it is built with load-bearing massive panels: Cross Laminated Panels (XLam). The constructive Xlam solution consists in building a load-bearing panel using three or more layers of boards. Each layer is orthogonal to the previous for offsetting the deformation or the movement of the boards (Schrentewein 2008). These last one are connected by glue, aluminum nails or beech pegs. The connections between the panels are with screws, steel corner plates and “hold-down”. In this way it is possible to build a box with good characteristics as earthquake resistant, free to be finished with different solutions for each kind of customization in terms of energy efficiency, aesthetic solutions or economic choices (Fig. 5).

Figure 5: The construction of the load bearing structure with XLam panels

Environmental impact

The constructive solutions have been designed to minimize the building impact on the environmental matrixes: water, air, soil (Friedman 2010). The used materials are natural, recyclable or recycled. The extensive use of wood reduces CO_2 emission in the atmosphere.

The wood used embodies around 9.5 tons of CO_2 giving a positive contribution to reduction the greenhouse effect. Even the other used materials, mostly recycled, were chosen through a Life Cycle Assessment (LCA) including the aspects that minimize the CO_2 emitted in the atmosphere during the construction, maintenance and disposal (Fig. 6). The used software for the LCA is "SimaPro2 and Ecoinvent is the used database. For several product was used the Environmental Product Declaration (EPD).

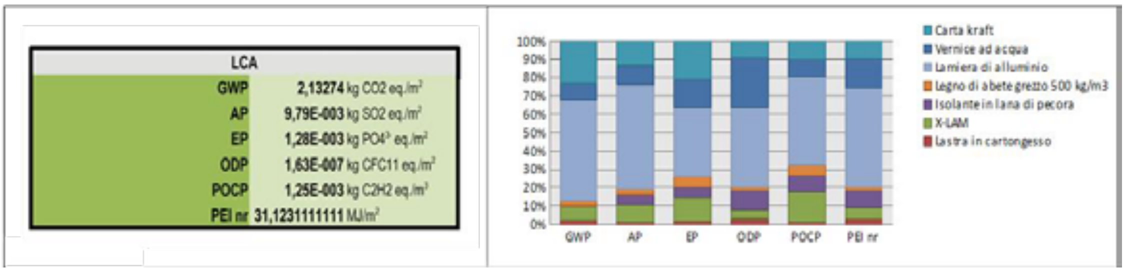

Figure 6: The LCA results of the LCA for the external walls

All constructive solutions combined with the architectonic choices have been studied to reduce the environment impact trough the best exploitation of the free contributions offered from the surroundings in terms of solar and wind contributions to produce clean energy.

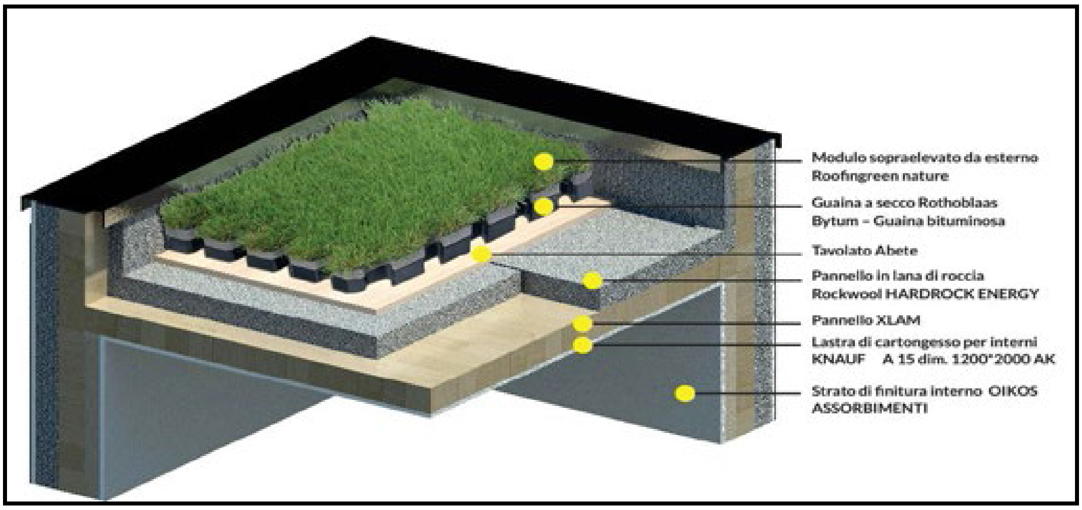

Figure 7: The constructive solution for the garden roof

The roof could be a "garden roof" to reduce the energy losses and at same time to minimize the heat island effect. It could be integrated with different systems for producing energy from renewable sources, as a solar active system or a small wind turbine, in order to minimize the fossil energy consumption (Fig. 7). A PV system can be integrated in the roof. With 16 modules and a surface of 20 m^2 it is possible to produce 5368 KWp/a. The heating is achieved with heat pump that produces also the sanitary hot water. All these constructive solutions make of Livingbox an Active House that uses the energy produced by itself giving the extra production to the net or to other users. The total energy demand of the house, calculated with Design Builder software, is 1181.11 kWh/a, articulated in 260.00 kWh/a for the lighting, 660.28 kWh/a for the heating and 260.83 kWh/year for the sanitary hot water. The positive balance is 1910.82 kWh/a of extra production. The consumption index for the different typologies are: lighting 6,42 kWh/(m^2x a), heating 16.30 kWh/(m^2x a), SHW 6,44 kWh/(m^2x a). The calculation have been developed simulating the building at Bolzano (Italy), lat. 46°29'53" North, long. 11°21'17" East.

The materials employed such as the paints are low-emissivity. An example in this direction is the water paint with acetic acid for aging the larch of the interior fittings or of the battens wooden finishing of the outer walls.

Bioclimatic solutions

The energy independence is improved upon even by design solutions that maximize the free contributions from the surroundings: solar screens, passive solar systems for SHW, mini-greenhouse, on the south façade, to assist in the winter heating and the natural ventilation for summer cooling. LIVINGBOX is opened to the south, totally closed, without windows, on the north front and partly opened to the east with a screened window to minimize the negative sun in summer (Fig. 8).

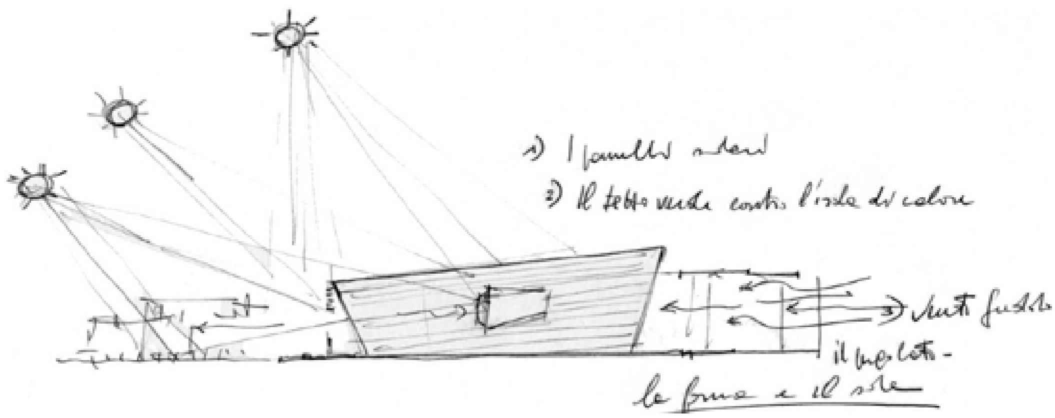

Figure 8: Sketch of the sun and wind exploitation

Roof and walls could be ventilated to decrease use of insulating membranes and to ensure the natural breathability (Roaf, Fuentes & Thomas 2003).

Thermal efficiency

The low consumption of the living unit is enhanced by the customizable envelop stratigraphy that can ensure a transmittance value between 0.20-0.25 W/m^{2}K, and a thermal lag between 10-15 h. The energy demand for the heating, with these constructive solutions, is 16.30 kW/m^2 x a).

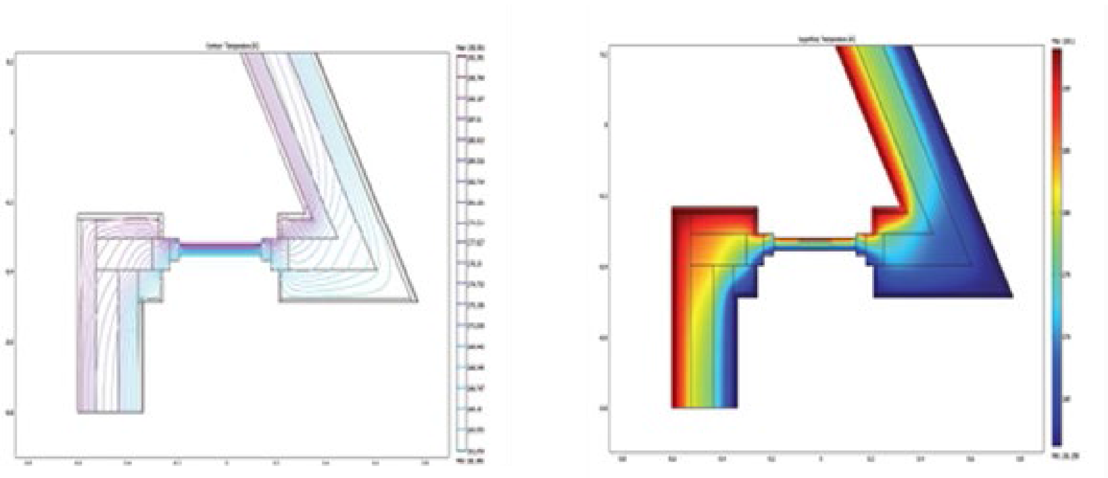

Figure 9: The representation of the eliminated thermal bridges

Particular attention has been paid to the prevention of the thermal bridges realizing a continuous insulated envelope in rock wool (Fig. 9). This thermal efficiency is approaching that of a "Passive Envelope" inspired by the “Passive Haus”.

Building automation

LIVINGBOX is equipped with a modular home automation system to optimize the relationship between comfort and energy consumption. This allows the lighting and the heating, the daylighting, the shading and the natural ventilation to be managed with integrated modular packages.

The scenarios are customizable for the different users and they can be activated from remote. In this way when the user will come home he will have the best inner environmental conditions. At same time the user can manage manually the different functions.

The prototype
A real scale prototype has been built so as to verify the building possibilities. It was developed as one of the possible variants at the "top" level. The prototype was built partially in Rom and finished in Milano for logistic solution (Slawik, Bergmann and Buchmeier 2010).

The walls are in load bearing Xlam panels with glued boards and have a thickness of 90 mm. The same kind of panels, with the thickness of 90 mm, are used as load bearing elements for the floor and the roof. The connections between the panels are made by screws (220 mm), steel angle plates (90x120x240x20 mm), hold-down (90x100x200x20 mm). The rear wall is plastered. The two lateral walls are ventilated finished with aluminum shingles. The layers of the external ventilated walls from inside to outside are: gypsum board (15 mm), sheep wool (50 mm), XLam panel (90 mm), mineral wool (80 mm), cement board (13 mm), aluminum shingles (5/10 mm). The layers of the plastered wall are the same; instead of the external aluminum shingles there is plaster. The roof stratification is from inside to outside is made up by the following layers: gypsum board (15 mm), XLam panel (90 mm), mineral wall (80 mm), boards (20) mm, (2)” roofingreen system” (120 mm).

The floor stratification is from inside to outside: wooden pavement (14 mm), spruce boards (20 mm), mineral wool (80 mm), Xlam load bearing panel (90mm), expanded clay (90 mm), bituminous membrane (8 mm).

The stresses received during the transportation between Rom and Milano were comparable with at least 15 of the Aquila's earthquake in 2012, and with several lighter earthquakes. After the trip the prototype did not present cracks (Fig. 10).

Figure 10: The arrival at Milano’s building site

Figure 11: Livingbox at Milano's Expo

It was displayed in Milano (Italy) at beginning of October 2013 at the "MADE EXPO 2013" (Fig. 11). At the end of exhibition the prototype was transported by 2 trucks, from Milano to Campobasso (more or less 900 Km) and it was possible to verify no inconvenience or crack in the interior and furniture (Fig. 12). This was a new demonstration that the building effectively is earthquake resistant.

Figure 12: The first stage of the transportation from Milano to Campobasso

Conclusion

Living Box is a concept, not a single project. It is possible to have more answers designed on the basis of a conceptual singular solution. In this way it allows to have an analogical serial production that allows costs to be reduced, but at same time to have a quality product accessible to different economic possibilities. Through the prototype it was possible to demonstrate the applicability of the concept in a real case showing the main characteristics of the building: the feasibility, the transportability, the earthquake resistance, the efficiency of the building automation in management of the home. Now the prototype will be used to test the real thermal and acoustic behavior and the efficiency of the building automation for energy saving.

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ENERGY RETROFITTING STRATEGIES FOR RESIDENTIAL BUILDINGS IN PALERMO

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ENERGY RETROFITTING STRATEGIES FOR RESIDENTIAL BUILDINGS IN PALERMO

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Abstract

The reduction of energy loss in the buildings from the sixties and seventies is one of the objectives set by the European standards and research programs in the near future. It is therefore increasingly important to define intervention strategies taking into account the cost-benefit analysis even considering the tax relief provided in different countries, especially in Italy, for the retrofitting. The paper presents the results of an investigation on a social housing district built in the 70s in Palermo by means of industrial technologies and energy characteristics similar to most of the residential buildings of the same period, not being entered into force the regulations on energy savings. After analyzing the heat loss data by conduction, ventilation and thermal bridges, for an entire building, we have chosen a series of interventions on various technical elements and components of the envelope (exterior walls, floors, roofs, windows, glasses, etc.). Among the various interventions, the most sustainable ones were considered, improving the environmental quality such as green roofs and green walls. Then the costs of these interventions and the possible compatible combinations were calculated, obtaining a series of actions, grouped into three strategies defined "enough", "good" and "excellent", in relation to sustainability and the amount of energy savings achieved by the standards provided by law. The projections of the costs- benefits of the several strategies identified were calculated in the short, medium and long term, taking into account tax benefits varying from 65% in 2014. The results of the study can be an useful tool for users, administrators and real estate investors, public or private, to choose the best intervention on the basis of available budget or energy improvements to be achieved. This study could easily be extended to the whole neighborhood and provide a model applicable to a large scale, in other contexts.

Keywords: *Mass customisation, housing, quality production, user participation, sustainable development, cost-performance, prefabrication.*

Introduction

Energy consumed for heating in residential environments and domestic hot water accounts for about 30% of national energy consumption, and represents about 25% of the total national carbon dioxide emissions, being one of the main causes of the greenhouse effect and the consequent rise in temperature of the globe. In recent years, several laws and regulations were enacted at the national, regional and local level, recommending different requirements and criteria for both the design of new buildings and the energy upgrading of existing buildings. Especially the last ones show high energy consumption, particularly those buildings built before the entering into force of the Italian law No. 373/1976.

The amount of energy necessary in a season to maintain heating at 20 °C and air-conditioning at 26 °C inside a building, is partly wasted by structures (roof, walls and windows) and partly by plants.

The total consumption of fuel to heat the building considered as case-study can be reduced from 20% to 40% just in the first year, with substantial benefits on the energy bill.

The paper analyzes, in fact, the public housing neighborhood, well-known as Sperone, built in Palermo during the '70s by means of industrial technologies, proposing retrofitting interventions improving the initial energy class, as the result of accurate analysis on current envelope energy losses.

Energy analysis of the case study

Among the buildings in the Sperone neighborhood, all typologically similar to each other, it was chosen as the case study, a building having a rectangular plan consisting of four apartments on each floor with different areas, referred to as D (114 sqm) and B (79 sqm). The building consists of 6 floors and 24 apartments, connected by two staircases (Fig. 1).


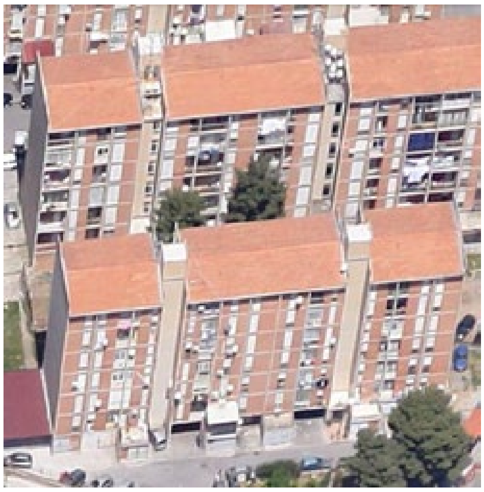

Figure 1: Plan of the neighborhood on the left, the case study on the right

The building has the peculiarity that it was built by means of the coffrage-tunnel technique. It consists of a series of r.c. walls, 14 cm thick, arranged transversely to the body of the building and r.c. slabs, approx 16 cm thick. The longitudinal walls are, however, cavity walls with hollow bricks, 12 cm thick, 10 cm air gap and 8 cm hollow brick.

The calculation of heat losses by transmission and ventilation was carried out by means of the standardized method of UNI TS 11300 and the one of the UNI EN ISO 10211 for the linear thermal transmittance of the thermal bridges. For these calculations, two different software by LBNL University of California were used; THERM 7.2 for calculating the transmittance of opaque surfaces and thermal bridges and WINDOWS 7.2 for the transmittance of transparent surfaces calculation.

The input data focused on the climatic characteristics in accordance with the Presidential Decree No. 412/93 which provides for the city of Palermo (climate zone B) internal temperature, Ti= 20 °C, and Te=5 °C, for the outside, 751 degree days and the period of heating from the 1st of December to the 31th March.

The following table shows the summary results of the energy analysis for each apartment, taking into account the different orientation and position in the various levels, according to the 2 identified different types. The technical elements of the envelope reported in the Table 1 are: the longitudinal outer walls (LOW), the r.c. transverse outer walls (TOW), the r.c. stairwell walls (SW), sheet steel windows (AW), r.c. roofs (R) and r.c. slabs (S).

Table 1: Dimensional values and thermal characteristics of the selected technical elements of the building envelope

	Area (sqm)	Transmittance ($Wsqm^{-1}K^{-1}$)	Ti-Te (°C)	Transmission Power (W)	Thermal bridges power (W)	Total power (W)
LOW	1208.52	0.961	15	17420	9167	26588
TOW	620.472	1.285	15	11959	2166	14125
SW	563.928	1.285	8	5797	3473	9270
AW	583.728	6.200	15	54286	16783	71070
R	384.944	0.805	15	4648		4648
S	384.944	2.725	9	9440		9440
Total				**103553**	**31590**	**135143**

It was then determined the energy consumption (PE) during the heating period and the average monthly temperatures for the city of Palermo, as reported in Table 2, where H is the transmission coefficient [WK^{-1}] calculated by total power (P)/(Ti -Te), equal to 135143 / (20-5) = 9009.6 WK^{-1}. The primary energy consumption per unit surface area in square meters (assuming an area of 2316 square meters) is equal to 99.98 $kWhsqm^{-1}$ and classifies the analyzed building in the energy class G, which, according to the Italian guidelines for building energy efficiency certification, approved by Ministerial Decree 26.6.2009, is 72.3 $kWhsqm^{-1}$.

Table 2: Primary Energy consumption of the case study

H=9009,6 WK^{-1}				
Month	Te	n days	time in seconds (s)	PE (KWh)
January	11.15	31	2678400	59322
February	12.00	28	2419200	53581
March	13.90	31	2678400	59322
December	12.85	31	2678400	59322
				Total PE 231550

Energy retrofit interventions

Several interventions on the wasting technical elements of the envelope were selected for the case study, which may be extendable to the other buildings of the neighborhood and to the building types that adopt other industrialized building techniques such as *coffrage-tunnel* and *banche et table*.

Such interventions were chosen according to their impact on improving energy consumption concerning both transmission losses of the several elements of the envelope, including the related thermal bridges. For each technical element from two to three possible interventions were identified, chosen from the most common ones in construction practice.

The longitudinal cavity walls (LOW) were particularly interested by three types of intervention, all aimed at maintaining brickwork. It was expected, therefore, the blowing in the air-cavity of perlite granules (intervention entitled P1) and interventions on the internal face of the walls (thermal coating) with polystyrene plates, 3 cm thick (P2) or with insulating plaster, 3 cm thick (P3).

The transverse reinforced concrete walls (TOW), characterized by the absence of openings, were interested by interventions on the entire external surface, allowing the elimination of thermal bridges. In particular, in addition to traditional insulation systems based on thermal coating with polystyrene plates, 4 cm thick (S2), or with thermal insulating plaster, 4 cm thick (S3), an innovative intervention, sustainable from the environmental point of view, was designed consisting of the so-called green wall, a vertical layer of green grass (S1) consisting of macroterma growing slowly and in a compact way, which changes color depending on the season, easily maintained thanks to irrigation system. In addition, this last type of intervention is particularly adapted to local climatic conditions varying between 27 °C and 35 °C.

The r.c. stairwell walls were provided only the two types of insulation with polystyrene plates, 4 cm thick, or thermal insulating plaster, well-established technique not involving particular difficulties of application.

The windows were designed to be replaced with new thermal break aluminum windows with double glazing, allowing to reach transmittance value up to 1.71 $Wm^{-1}K^{-1}$ or the replacement of the glass with triple-layer acoustic glass.

In analogy to the transverse walls, the roofs were interested by traditional intervention, consisting in the setting of an insulating layer, 6 cm thick polystyrene underlay layer, preceding the removal and replacement of the roof tiles, and an innovative intervention environmentally sustainable, by means of the construction of intensive green roof, made of insulating polyethylene foam drainage element, 10 cm thick, and about 20 cm of soil.
The last technical element where intervention is needed is the first floor slab separating the heated rooms of the apartments from the unheated garage. It was then considered an outer insulation layer made of polystyrene plates, 4 cm thick, or thermal insulation plaster of the same thickness.

The costs of these energy improving interventions were derived from the main regional price lists or price analysis by means of market surveys. Moreover, these costs include all necessary expenses (scaffolding, closing holes, divestitures, transport to the dump, finishes, etc.) for a complete intervention.

For each intervention, transmittance values were also calculated using the software THERM (Fig. 2), as shown in Table 3.

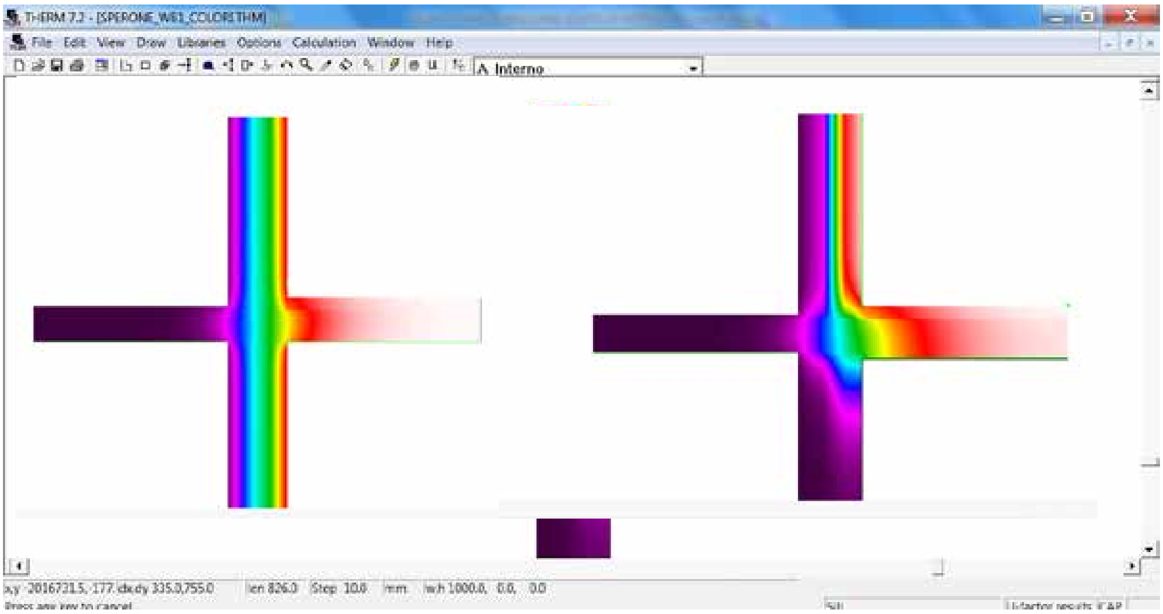

Figure 2: The isotherm curves in the wall-balcony junction before and after intervention

Table 3: Interventions for several technical elements of the envelope and relative costs

	Interventions		Cost ($€sqm^{-1}$)	Transmittance ($Wsqm^{-1}K^{-1}$)
Wall	P1	Perlite granules blowing	55.00	0.349
	P2	Internal thermal coating (3 cm polystyrene plates)	9.32	0.570
	P3	Thermal insulation plaster	45.00	0.735
	Se1	Green grass wall system	250.00	0.422
	Se2	ETICS with polystyrene plates (4 cm)	67.20	0.563
	Se3	Thermal insulation plaster with finishing (4 cm)	45.00	0.818
	Si1	Polystyrene plates (4 cm)	67.20	0.563
	Si2	Thermal insulation plaster with finishing (4 cm)	45.00	0.818
Window	I1	Thermal break aluminum windows	415.00	1.710
	I2	Replacement of single glaze with insulating glaze	55.00	2.820
Roof	C1	Intensive green roof	92.00	0.225
	C2	Polystyrene underlay layer (6 cm)	90.20	0.308
Slab	R1	Internal thermal coating (3 cm polystyrene plates)	9.32	0.762
	R2	Thermal insulation plaster	45.00	1.351

Considering that every energy efficiency retrofit intervention dealing with a generic transparent or opaque element produces the effect of reducing its transmittance U, for each intervention, the energy calculations in terms of transmission power (P), primary energy (PE), saved primary energy (SPE), annual savings (AS), intervention costs (C) were carried out, using the same methods used for the energy analysis (Table 4).

Table 4: The main indexes calculated for each intervention

Intervention	P (W)	PE (KWh)	SPE(KWh)	AS (€)	C (€)
P1	118211	202538	29012	2309	66468
P2	124326	213015	18535	1475	11263
P3	128891	220837	10713	853	54383
Se1	125657	215296	16254	1294	155118
Se2	127207	217951	13599	1082	41695
Se3	130010	222754	8796	700	27921
Si1	129935	222625	8925	710	37896
Si2	131774	225776	5774	459	25376
I1	83675	143365	88185	7018	242247
I2	96399	165166	66384	5283	32105
C1	131795	225812	5738	457	35414
C2	132274	226633	4917	391	34721
R1	128377	219956	11594	923	3587
R2	130383	223393	8157	649	17322

Cost-benefit analysis

The knowledge of the relationship between the costs of energy retrofit interventions and thermal performance of the building is today an interesting topic for contractors, for public administrations, engaged in the management of wide building stocks and for users. One of the greatest difficulties is in such cases the choice of intervention strategy. In the presented case study the different possible combinations were therefore analyzed, making a comparison in terms of energy improving, cost of the intervention and payback period in order to be able to make a conscious choice.

The costs for the realization of the different interventions of energy recovery and the economic return of the investment were examined.

To calculate the payback time, it was considered the primary energy consumption in the actual state and the several hypotheses of intervention (PE) to obtain the primary energy savings for the entire complex ΔPE. Considering that methane has a calorific value of 9.5 kWhcm^{-3} and a cost of 0.756 €cm^{-3}, the saving would be equal to PE/(9.5*0.756) per year.

In addition, the return on investment also takes account of the tax incentive provided for the Legislative Decree No. 63 of June 4th 2013, which provides for the improvement of the building envelope energy tax relief of 65% (up to € 60,000.00) for a flat type of a family of four.

The graph below (Fig. 3) shows the costs of the individual retrofitting considering tax incentive of 65% and the related cost savings within 5, 10, 15 and 20 years.

It was found that the cost of most interventions is recovered in a period between 10 and 15 years, while the interventions regarding with green walls and green roof recovered in over 20 years would need much more incentive. Only interventions based on thermal coating made of polystyrene plates and the replacement of single glass in the windows allow a return of the investment in about 2 years. It was found, moreover, that the intervention with thermal insulation plaster is less cost-effective than the same intervention with polystyrene plates, thus is not taken into account in any of the possible combinations of interventions.

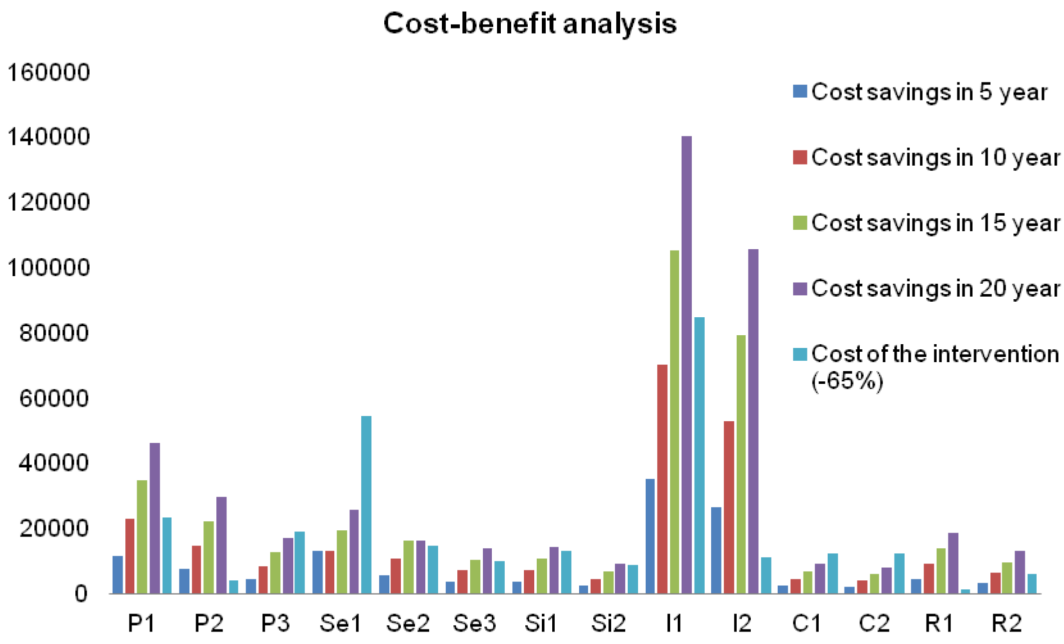

Figure 3: Cost-benefit analysis for each type of retrofit intervention

On the basis of cost-benefit analysis carried out, it was possible to identify three possible combinations of interventions that can be amortized over the short, medium and long term, corresponding to three levels of energy improvement: low, medium and high (see Table 5). The best intervention strategy for energy retrofitting was the one providing the combination of measures P1, Se1, Si1, I1, C1, R1, allowing to switch from the energy class G (Ep 99.98 kWhsqm^{-1}) to the energy class C (PE = 31.02 kWhsqm^{-2}) with a payback in 15 years. The average intervention is that which provides for the combination of interventions P2 , Se2 , Si1 , I1, C2 , R1, consisting in the application of polystyrene plates on the various elements of the envelope. This intervention allows to obtain a primary energy (PE) of 37.04 kWhsqm^{-1}, improving the energy efficiency class from G to D, amortizing the cost over 11 years (Fig. 4).

While the spending for the intervention strategy that guarantees a low level of energy savings, given by the combination of interventions P2, Se2, Si1, I2, C2, R1, and achieving energy class E (PE 46.46 kWhsqm^{-1}) is amortized in just 6 years.

Table 5: Main economic results of the retrofit interventions

	P (W)	PE (kWh)	Cost (€)	Annual saving (€)	Annual amortization (y)	PE per sqm (kWhsqm^{-1})	Energy class
Int. 1	41930	71841	189256	12709	15	31.02	**C**
Int. 2	50074	85795	129994	11599	11	37.04	**D**
Int. 3	72798	107596	56444	9864	6	46.46	**E**
Actual state	135144	231550				99.98	**G**

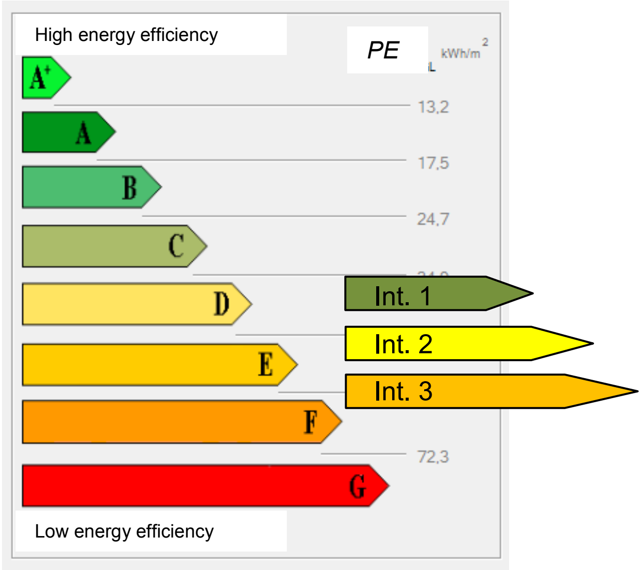

Figure 4: Energy class of the proposed retrofit intervention

Conclusions

From the comparison of the energy performance of the building before and after intervention, it is clear that all the technological solutions contribute to an improvement of the building's energy, bringing the overall performance of the building from G to C with a primary energy savings up to 69%, class D with a saving of 63% and the class E with a saving of 54%.

The choice between these three options is closely connected with the subject implementing the initiative (public administration, finance companies, property managers and individual users).

In fact, in the interventions to be applied to widespread neighborhoods, the choice of the type of intervention cannot be driven only by the need for energy efficiency, it is necessary to take account of environmental and urban aspects, aimed at improving the living conditions of the suburbs and reducing harmful emissions in the atmosphere.

Intervention No. 1, therefore, is more suitable in these conditions. While intervention No. 2 and intervention No. 3 are more suitable for an action driven by both the entire building and individual users. Its gross cost is 160 € sqm^{-1} for the intervention and 70 €cm^{-1} for the intervention.

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ASSESSING THE RISKS OF DAMPNESS AND MOULD GROWTH IN RENOVATED PROPERTIES

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ASSESSING THE RISKS OF DAMPNESS AND MOULD GROWTH IN RENOVATED PROPERTIES

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Abstract
A large portion of the UK housing stock was built before the introduction of the 1989's building regulations in which insulated cavity walls became mandatory. It is estimated that 65% of the UK housing stock have uninsulated walls and 49% have single glazed leaky windows making them inefficient in terms of energy performance. There have been great efforts during the recent years to improve the quality and energy performance of such buildings through retrofitting/refurbishment not only to improve the living standards of their occupants but also to achieve UK's carbon emission targets for 2050. Refurbishing such buildings to improve their quality/energy performance may, at the same time, increase the risk of poor indoor air quality (IAQ), condensation, dampness, and mould growth in these buildings. Many refurbished housing stock in the UK are facing similar problems. Damp and mould issues affect between 30-50% of new or refurbished buildings. There is therefore a need for appropriate design strategies not only to improve the quality and thermal performances of such buildings but also to reduce the aforementioned risks through better design, construction detailing, methods, and management processes. This paper reports on the first phase of a joint university/industry Knowledge Transfer project to address the above issues in renovated student accommodations in North West England. Temperature, relative humidity, CO_2, and meter readings are measured and recorded in three case study buildings. Results revealed a direct relationship between energy consumption, IAQ, and occupants' behaviours in the buildings. CO_2, Temperature, and RH levels were more acceptable in one of the case study buildings; however, its energy consumption was 7 times higher when compared with a similar building.

Keywords: *Refurbishment, damp, mould, indoor air quality, energy efficiency, domestic buildings.*

Introduction

With around 8.5 million over 60 years old properties, Britain has the oldest housing stock in the developed world (Energy Saving Trust 2007). A large portion of the UK housing stock was built before the introduction of the 1989's building regulations in which insulated cavity walls became mandatory. It is estimated that 65% of the UK housing stock have uninsulated walls and 49% have single glazed leaky windows making them inefficient in terms of energy performance (Building Research Establishment 2005).

Around one third of UK carbon emissions are related to the housing sector (English Heritage 2012 and Department of Energy Climate Change 2013) and considering the current replacement rates, it would take around 1000 years to renew the entire housing stock in the UK (Building Research Establishment 2014a, Energy Saving Trust 2007). More than 70% of the estimated housing stock in England in 2050 has already been constructed (English Heritage 2012). Improving the environmental performances of existing properties is therefore vital to achieve the UK Government's carbon emission targets aiming to reduce carbon emissions by 34% by 2020 and 80% by 2050 (Building Research Establishment (2014a), Department Energy Climate Change 2009 and Technology Strategy Board 2013).

Recently, considerable efforts have been made to improve the quality and energy performance of the existing buildings by retrofitting/refurbishment through national schemes such as the Green Deal Building Research Establishment (2014b) and Department of Energy and Climate Change (2010). This is not only to achieve the UK's carbon emission targets but also to improve the living standards of the UK population with a focus on vulnerable people helping them to enjoy "warmer" homes (HM Government 2011). There were around 35,000 excess winter deaths in 2008-9 in the UK which could have been avoided through warmer housing. Meanwhile, according to BRE it is estimated that by 2030 the current average annual energy bill of households (£1,124) could rise by 33% which may deteriorate the current issues with regards to the fuel poverty.

There are some direct health benefits associated with improved thermal comfort in dwellings (Department for Communities and Local Government 2007); however, refurbishing old properties (particularly those with existing damp and mould issues) to improve their energy performance may increase the risk of poor indoor air quality by, for example, reducing the ventilation rate and/or trapping the moisture inside the buildings and materials (English Heritage 2012 and Zolfagharifard 2014) resulting in even more damp and mould issues. Many refurbished housing stock in the UK are facing similar problems. Damp and mould issues, according to the Health and Safety Executive, affect between 30-50% of new or refurbished buildings (Zolfagharifard 2014).

Indoor dampness severity also depends on the climatic conditions and varies from country to country. According to the WHO, dampness affects around 10-50% of buildings in Europe, North America, Australia, India and Japan (World Health Organization 2009). According to DCLG (Department for Communities and Local Government 2014), in 2012, out of 22.0 million households in England, around 970,000 homes had some problems with damp. Condensation and mould were the most common issues affecting 3% of the properties followed by penetrating and rising damp affecting 3% and 2% of homes respectively.

Figure 1: Percentage of houses with damp problems (2012)
Source: Department for Communities and Local Government (2014).

Privately rented properties in the UK are the poorest in terms of energy performance (Building Research Establishment 2005) and damp related issues (Department for Communities and Local Government 2014). According to the Department for Communities and Local Government, some 9% of the private rented properties have problems with damp (Fig. 1) and around 33% do not meet the minimum standards for a decent home (Department for Communities and Local Government 2014).

This paper reports on an ongoing joint university/industry project to address the above issues in renovated student accommodations in North West England. It is aimed to develop strategies to reduce the risks of condensation, dampness and mould growth in renovated properties through better design, construction detailing, methods and management processes.

IAQ related health issues

Indoor air could be much more polluted than external air (World Health Organization 2006) and as people spend around 60-90% of their time indoor (Slezakova, Morais and Pereira 2012), even minor amounts of contaminants in buildings can significantly increase the occupants' exposure to the pollutants and affect their health (WHO 2009 and Crump, Dengel and Swainson 2009). It is estimated that poor indoor air quality (IAQ) is responsible for around two million disability adjusted life years (DALYs) per year, which is about 3% of the total burden of disease (BoD) due to all diseases in Europe (European Federation of Allergy and Airways Diseases Patients' Associations 2013).

Indoor air contaminants include CO, NO_2, odours, volatile organic compounds (VOCs), allergens, environmental tobacco smoke (ETS), damp and mould (Energy Saving Trust 2005, 2006a and Jantunen *et al.* 2011) which may result in Sick Building Syndromes (SBS). SBS have been increasing since the 1970s as old, naturally ventilated buildings are gradually being replaced with airtight, energy efficient buildings (Reidlich, Sparer and Cullen 1997). The main symptoms associated with SBS are: headaches; dry or itchy skin, eyes, nose, and throat; lack of concentration; runny or congested nose (Health and Safety Executive 2000, Reidlich, Sparer and Cullen 1997 and Zolfagharifard 2014).

Microbiological pollution in general and filamentous fungi (mould) in particular are of major indoor air pollutants (Energy Saving Trust 2006a, World Health Organization 2009). There is a proved relationship between exposure to dampness and various health issues such as allergies and asthma (Andersen *et al*. 2011, American Society of Heating, Refrigerating and Air Conditioning Engineers 2011, Gravesen *et al.* 1999, World Health Organization 2009, Piecková and Jesenská 1999 and Storey *et al.* 2004). The major reason for the microbial and mould growth is persistent dampness which may also result in survival of viruses and bacterial growth (Andersen *et al.* 2011, Institute of Medicine 2004 and World Health Organization 2009).

Dampness is an indicator of insufficient ventilation which may in turn result in excessive concentration of pollutants and poor IAQ. It is estimated that 11% of the IAQ associated BoDs is due to the building dampness (Jantunen *et al.* 2011). The risks associated with poor indoor environments are more severe for more vulnerable groups, such as children and older people considering their life styles and the amount of time spent at home (European Environment Agency 2011, Garrett *et al.* 1998, Jantunen *et al*. 2011, Slezakova, Morais and Pereira 2012 and World Health Organization 2006).

Health related building regulations and standards are not sufficiently covering the requirements for avoiding/controlling excessive moisture and dampness (World Health Organization 2009). Appropriate building standards should therefore be developed not only to improve the thermal performances of buildings but also to reduce the aforementioned health risks in new and refurbished buildings.

Basic strategies to reduce risks of damp, condensation, and mould growth

There is no such thing to assume there is one generic solution to all damp and mould problems (English Heritage 2012). Threfore, refurbishment/retrofitting strategies should be on a case by case basis (Energy Saving Trust 2007). There are however some basic recommendations which could be considered to reduce the risk of dampness and mould growth in buildings.

It is generally accepted that moisture is the most critical pollutant in dwellings (Energy Saving Trust 2005, 2006a). Controlling moisture is an effective way to control fungi/mould (Institute of Medicine 2004) which can damage building materials (Pitkaranta *et al*. 2011). One of the major ways to reduce dampness in buildings is increasing the ventilation rate (British Standard Institute 2002b).

Studies suggest that providing enough and effective ventilation to remove excessive moisture is also enough to control other pollutants (Energy Saving Trust 2006a); however, absence of dampness does not necessarily mean acceptable IAQ. While maximum ventilation is required to control dampness, minimum ventilation is required to control CO_2 levels and provide enough Oxygen in dwellings (Energy Saving Trust 2006a). Therefore, CO_2 concentration levels and Relative Humidity (RH%) are good indicators to evaluate the effectiveness of ventilation in residential buildings.

According to BS 5250 (British Standard Institute 2002), two major ways of controlling dampness, surface condensations, and mould growth are:

a) increasing ventilation and/or reducing generated moisture to reduce vapour pressure; and
b) increasing internal temperature and/or insulation to achieve higher surface temperature (British Standard Institute 2002b).

In other words, decreasing ventilation rate will increase the risk of condensation and mould growth unless it is counterbalanced by reducing generated moisture or by increasing insulation and/or internal temperature. Mould is very likely in buildings where a steady surface RH of 80% and above is probable (British Standard Institute 2002a, 2002b and Chartered Institution of Building Services Engineers 2006).

The general aim should be to improve energy performance of the building (Energy Saving Trust 2006b, 2007) while keeping the RH% below 70% (Energy Saving Trust 2005). Other studies indicate that a lower RH (60%) would be enough for mould to develop (Crook and Burton 2010). To achieve effective ventilation strategies, local extraction will be required for rapid removal of moisture at the point of production to avoid spread of moisture to other parts of the building. Openable windows will also help for rapid purge ventialtion of moisture (Energy Saving Trust 2005).

Improving thermal performance of the building by increasing the thermal insulation is another approach which should be considered in addition to the ventilation strategies. Retrofitting strategies may include, internal/external wall insulation; roof/loft insulation, floor insulation, draft stripping, insulated doors, replacing old windows with high energy performance windows. However, the adopted specification greatly depends on the construction form/type and the main pourpose of the improvement (Energy Saving Trust 2006b, 2007).

Project's **Research Methodology (Phase 1)**

Three typical student accommodations properties managed by Mistoria Group within the North West of England were selected after several visits and discussions on 11 properties. A building survey was then completed for the selected properties to record building layout, orientation, construction method, building materials, and signs and extent of mould and dampness. A checklist was developed to facilitate this survey. This information will be used for the computer models.

Data loggers and sensors were installed in the selected buildings to measure and records four indicators of temperature, RH%, light, and CO_2 for a period of six months to identify the percentage of time when these are above acceptable levels recommended by CIBSE (Chartered Institution of Building Services Engineering) and WHO. This is done to identify the extent of any existing IAQ related issues in the case study buildings.

For the purpose of physical measurements five HOBO U12/12 data loggers and two CO_2 sensors with traffic light indicators were installed in each property to record RH%, Temperature, and CO_2 concentrations on 15 minutes intervals (Fig. 2). The traffic lights were covered to avoid disturbing the occupants particularly in the bedrooms. According to the manufacturers' data sheets, CO_2 sensors can measure a range of 400-4000ppm with an accuracy of +/- 5%. Data loggers also can measure temperature and RH ranges of -20ºC to +70ºC; and 5% to 95% RH respectively. As suggested by BSRIA (Building Services Research and Information Association 1998), sensors and data loggers were installed at a height of 1-1.5m above the floor level.

Figure 2: Hobo U12 data logger and CO_2 sensor

Gas and Electricity meter readings were also recorded to evaluate the energy consumptions of the case study buildings (CSBs). The collected data were used to evaluate the current situation of the CSBs as well as the ways forward to prevent/control dampness, condensation, and mould growth in the properties while optimising their energy performance.

Case Study Buildings

The case study buildings are typical 4-5 bed two-storey mid-terrace, end-terrace, and semi-detached houses occupied by students and are located in Salford/Manchester. All properties have one bathroom/shower on the first floor, with the kitchen and living rooms located on the ground floor. Bedrooms are positioned on both ground and first floor levels. Out of three shortlisted properties one was removed from the study due to the irregular occupancy patterns which affected the reliability of the results. Physical measurements were therefore carried out for two buildings only. Both buildings have masonry walls with energy performance certificate (EPC) rating of C and are located in residential areas surrounded by similar two-storey buildings (Fig. 3).

Figure 3: Locations of the Case Study Buildings

In both buildings heating and hot water are provided by gas-fired central heating systems controlled by radiator valves. None of the CSBs have mechanical cooling systems and ventilation is provided through openable doors and windows in addition to local extract fans in the kitchens and bathrooms. CSB1 also benefits from the hit and miss vents which help to enhance the natural ventilation. Table 1 summarises the specifications of both case study buildings.

Table 1: Characteristics of CSBs

	CSB1	CSB2
Location	Salford/Manchester	Salford/Manchester
Area (m^2)	123	96
Building Type	Semi detached	Mid-terrace
Construction type	Masonry	Masonry
Glazing type	Double glazed PVC windows	Double glazed PVC windows
Energy Performance Certificate (EPC) Rating	C (73)	C (72)
Number of storeys	2	2
Number of occupants	5	4
Number of Bathrooms	1	1
Heating System	Central heating and local radiator	Central heating and local radiator
Cooling system	No cooling system	No cooling system
Ventilation System	Natural ventilation (windows, doors and hit & miss vents) + local extract fans	Natural ventilation (windows, doors) + local extract fans

Results of the studies (Phase 1)

Physical measurements were conducted in order to study the performance of the CSBs. Collected data from the living rooms and one of two similar bedrooms are reported below.

As shown in Figures 4 and 5, IAQ and thermal comfort have been considerably better in CSB1 compared to CSB2. The relative humidity in CSB1 almost always remained in acceptable ranges of 40-60%, recommended by CIBSE (Chartered Institution of Building Services Engineers 2006), while in CSB2 the RH exceeded 60% several times revealing a high risk of condensation, damp, and mould growth in this building.

Results also revealed that the RH and outside temperature (To, based on Weather Underground data, Salford, Manchester) (Weather Underground 2014) followed the same pattern in CSB1 (especially in the bedroom). This is most probably because of high ventilation rates due to frequent opening of the windows/vents and/or high air permeability rate of the building. Reduced internal RH in CSB1 is caused by the mixture of internal warm air (with high water content) with external cold air and very low water content despite the high external RH (Hashemi and Gaze 2014). Although CO_2 concentration levels in CSB1 were considerably lower than CSB2, CO_2 levels were still higher than the maximum recommended level of 1200 ppm suggested by BS EN 15251 for existing buildings (British Standard Institute 2007).

Moreover, according to the physical measurements, the bedrooms' average daily temperatures were 19.1°C and 16.2°C in CSB1 and CSB2 respectively. This is while, according to WHO (World Health Organization 2003), an indoor air temperature of 18ºC is recommended for bedrooms and, according to Hong, Oreszczyn and Ridley (2006), average bedroom temperature in England is 18.5 ºC. Average living rooms' temperature in CSB1 and CSB2 were also 19.7 ºC and 16.7 ºC respectively. It should be noted that the average temperature in CSB1 is also higher than the average living room temperature of 19.1ºC in England (Hong *et al.* 2006).

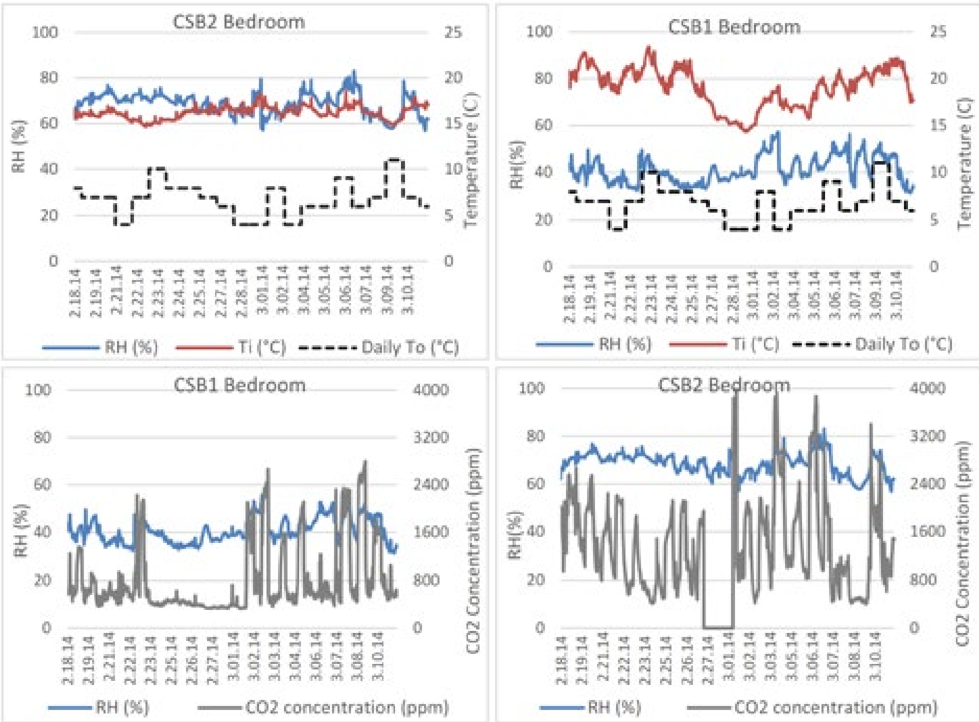

Figure 4: Temperatures and IAQ in two similar bedrooms

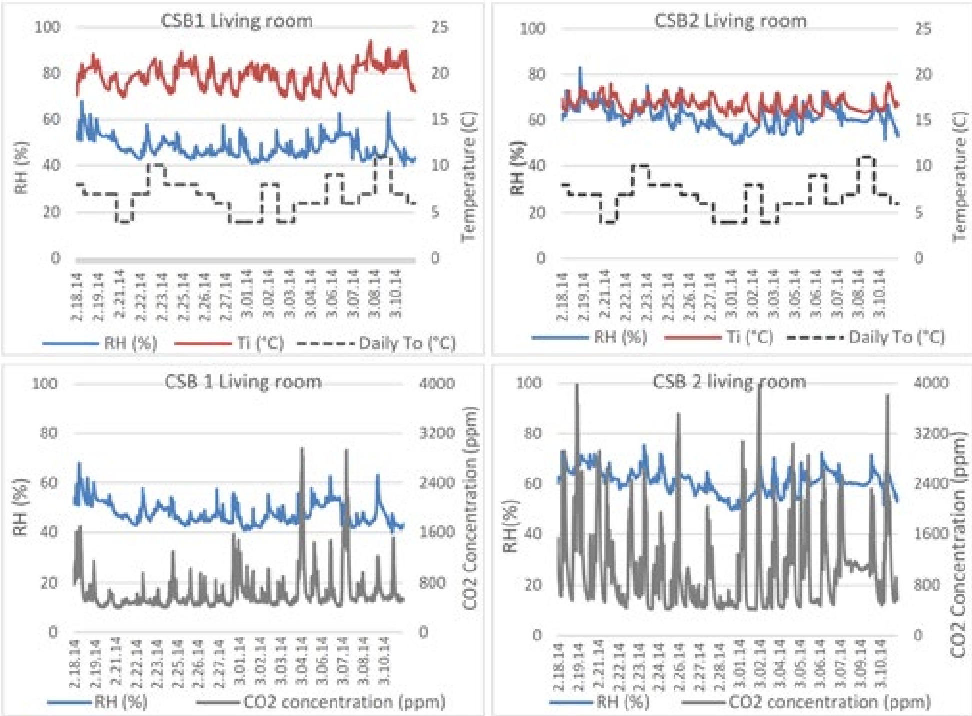

Figure 5: Temperatures and IAQ in living rooms

Meter readings showed slightly higher electricity consumption in CSB1 which could be explained by higher number of occupants (Tab. 1). However, according to recorded energy consumption, gas usage in CSB1 was around 7 times higher than in CSB2 (Fig. 6). Although CSB1 provided better IAQ and thermal comfort, energy consumption was considerably higher and remedial actions are required to solve this issue.

Occupants' behaviours and construction details appear to be the main reason for such huge differences in energy performance, IAQ, and RH% of the CSBs. According to the recordings and the observations, CSB1's occupants frequently opened the windows whereas occupants of CSB2 kept the windows closed which meant high and low energy consumptions associated with rather acceptable and poor IAQ respectively. Construction details (e.g. Hit & Miss vents) on the other hand, provided more ventilation in CSB1 while ventilation seemed to be unsatisfactory in CSB2.

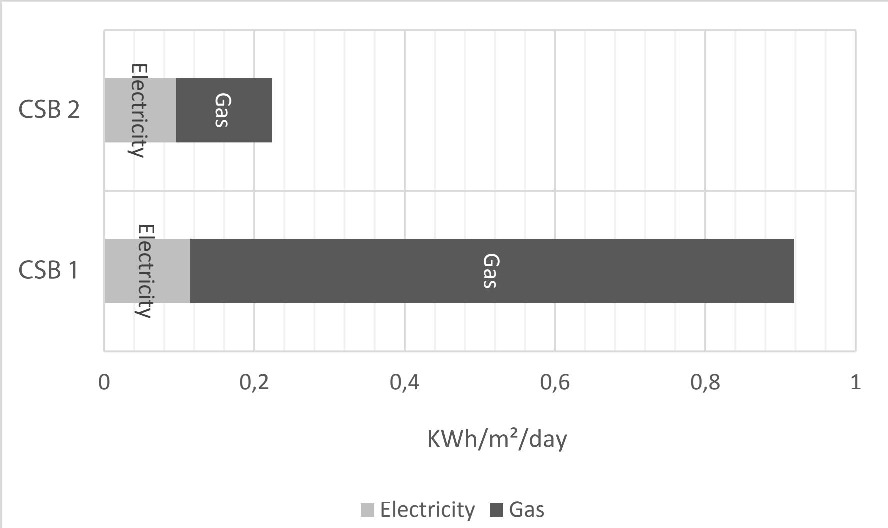

Figure 6: Average daily energy consumptions in the case study buildings

According to the findings, bedrooms may pose more critical conditions in terms of IAQ and RH levels. Better IAQ and RH levels in the living rooms in both buildings seem to be related to the life style of students and larger sizes of the living rooms. Therefore, it could be argued that design strategies should concentrate more on providing acceptable IAQ and RH as well as thermal comfort in the bedrooms.

Conclusions

This study intends to develop refurbishment strategies to prevent/control dampness, condensation, and mould growth while improving the energy performance of buildings. According to the results of Phase 1 of the studies on the case study buildings, CSB1 had better CO_2 and RH% levels with acceptable internal temperatures and very high energy consumptions. CSB2, however, had a very poor IAQ in terms of CO_2 and RH% levels with rather low internal temperatures falling below the average UK standards. This was despite the fact that both CSBs are similar in terms of construction details, EPC ratings and number of occupants.

The challenge of this research is therefore to refurbish the case study buildings to improve their energy performance without sacrificing IAQ. Although it is generally believed that improving IAQ is associated with increased energy consumption, studies show that both IAQ and energy efficiency could be improved (American Society of Heating, Refrigerating and Air Conditioning Engineers 2011) if efficient refurbishment strategies are considered. Yet, although there are some existing recommendations to improve the energy performance and IAQ of buildings, it should be borne in mind that "no one size fits all" (English Heritage 2012) and to achieve the best results, each building should be treated separately considering its unique conditions including building behaviours; construction details; orientation; location; and occupancy patterns, types and behaviours.

This paper reported on the Phase 1 of the KT research project. The following are the next stages of the study:

a) air pressure tests will be carried out to identify the air permeability rates of the case study buildings to evaluate the possible effects of air infiltrations on the

IAQ and energy performances of the buildings. One test will be carried out for each case study buildings;

b) questionnaire surveys will be carried out to study/record the occupants' lifestyles and occupancy patterns in more detail;
c) CAD models of the selected CSBs will be developed using all data from the physical measurements;
d) dynamic thermal simulations will be conducted to evaluate the effects of various construction details and ventilation rates on IAQ, dampness, condensation, and mould growth as well as on the energy performance of the buildings; and
e) triangulation of results achieved from aforementioned stages will be correlated to establish recommendations to prevent/control dampness, condensation and mould growth in the properties while optimising their energy performance.

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APPLYING PRECASTING AND MASS CUSTOMIZATION IN THE HOSPITAL ESCOLA MUNICIPAL DE SÃO CARLOS

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APPLYING PRECASTING AND MASS CUSTOMIZATION IN THE HOSPITAL ESCOLA MUNICIPAL DE SÃO CARLOS

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Abstract
This article presents an analysis of the construction of Hospital Escola Municipal de São Carlos Prof. Dr. Horácio Carlos Panepucci, and the use of precasting, mass customization approaches and traditional building systems. It aims to investigate the adaptability of a construction project designed with a closed loop precasting system, but built using an open loop system. In this study case, the construction processes are presented and collected through visits and interviews. Due to the complexity involved in the production and maintenance of hospitals, precasting can provide greater accuracy and better coordination of the construction process. Eight visits to the hospital and two interviews were conducted between 2009 and 2012. This article presents the implementation of precasting and traditional construction systems in the following stages of construction: foundations, structures, external walls, internal walls, and roofing. Ten construction systems are presented, of which eight are precast or pre-shaped and two are traditional. An important conclusion of this investigation was that the use of precasting provided greater flexibility and control of construction processes. The precasting system employed during the hospital construction can be considered as open loop, since it uses different suppliers for different building systems applied to the construction work.

Keywords: *Precasting, mass customization, construction process, open loop.*

Introduction
Hospital buildings are projects of great complexity due to stringent functional requirements and complex networks of facilities because of its kind of use that involves special needs like rooms isolation, medicinal gases installation, etc. (Figueiredo 2002). The complexity inherent to hospital spaces may be found in their design, implementation, and maintenance requirements. Given all the complexity involved in building and maintaining hospital spaces, rationalization of construction work can add more accuracy and improve coordination of its processes.

Rede Sarah hospitals illustrate the implementation of rationalized construction through the application of systematic changes to traditional construction methods. Designed by João Filgueiras Lima, those hospitals are built with precast elements produced by Rede Sarah Technology Center (CTRS). CTRS enables the employment of precasting systems at all construction stages, from the superstructure to services, thus giving rise to an organized and efficient cycle of production and maintenance for Rede Sarah hospitals throughout Brazil (Lukiantchuki 2010).

Hospital Escola Municipal de São Carlos Prof. Dr. Horácio Carlos Panepucci[1] is an example of implementation of architect João Filgueiras Lima's design language beyond Rede Sarah. The design of the aforementioned hospital was donated by the architect in 2004, and the detail design was produced by Brasil Arquitetura and Apiacás Arquitetos

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[1]Prof. Dr. Horácio Carlos Panepucci São Carlos Municipal School-Hospital.

under his supervision. The first phase of the project was completed in 2007 and the second phase is still under construction.

Its design resembles - formally and spatially - that of Rede Sarah hospitals, notwithstanding its distinct program. While Rede Sarah hospitals are intended for treatment and rehabilitation of patients' motor functions, the target of Hospital Escola is to cater to general patients and as implied by its name, to serve the Universidade Federal University of São Carlos medical school. It has a surgery center and special rooms for treatment (isolation).

CTRS did not actively participate in the construction work of Hospital Escola, following a Court of Auditors' decision that prohibited CTRS to operate outside Rede Sarah. Thus, many of the components that would be supplied by CTRS had to be either produced locally or supplied by other manufacturers.

The purpose of this article is to describe the processes employed in the construction of the Hospital Escola Municipal de São Carlos Prof. Dr. Horácio Carlos Panepucci, by characterizing both traditional and industrialized building methods. It aimed to investigate whether it is feasible to industrialize construction based in a design thinking, with building components manufactured or acquired in the construction market, without having necessarily to depend on any given manufacturer of precast components. The analysis conducted in this study explores how an architectural project initially designed to be closed loop was adjusted to an open loop model, as well as the difficulties, advantages, and disadvantages of this adaptation.

Literature Review

According to Associazione Italiana Prefabbricazione per L'Edilizia Industrializzata [2] (*apud* Bruna 1976), precasting consists in manufacturing, by means of different techniques, ready for assembly building components usually outside construction sites. Then it follows that precasting consists in industrializing parts of the construction process performed at the construction site. This type of construction rationalization usually makes use of machinery and mass production coordination methods to increase productivity and reduce waste (Fabrício 2008).

In order to qualify as a precast construction process, Martucci (1990) points to the need for compliance with certain basic requirements, particularly concerning design and production. Thus, precast components are directly related to the chosen construction system in that they substantially interfere with the work processes conducted during construction.

In addition to reducing waste, the use of precast components reduces the amount of work carried out at construction sites. This allows for more accurate assembling and better forecasting of interfaces between these elements within the subsystem to which they belong and other subsystems when necessary (Martucci 1990).

Precasting can be classified according to its specificities, which are mainly related to compatibility and assembly rules (Fabrício 2008). As to the rules of component compatibility, precasting can be divided into closed loop and open loop.

[2] ASSOCIAZIONE ITALIANA PREFABBRICAZIONE PER L'EDILIZIA INDUSTRIALIZZATA. AIP. Catalogo dei materiali e dei sistemi per l'edilizia industrializzata. In: Rivista Prefabricare-edilizia in evoluzione, 1973.

According to Oliveri (1972), closed loop precasting is associated with the idea of acquiring a "ready-made house", as we do with regard to cars and most industrialized products. From this perspective, production is based on mass industrialization of the entire building by a single manufacturer, which eliminates problems with incompatibility between components (Fabrício 2008). According to the literature, the precasting process employed by João Filgueiras Lima at Rede Sarah hospitals can be classified as closed loop to the extent that it produces all components of the building.

If, on the one hand, a closed loop implies mass production of the building as a whole, on the other hand, an open loop applies the same reasoning to its constituent parties (Oliveri 1972). One difficulty in this system is precisely that there is the need for rules of compatibility between parts, components, and subsystems in order to enable multiple combinations (Fabrício 2008).

Both open or closed loop precasting implies an industrial productive configuration of suppliers of components, resulting into a significant reduction of debris and other types of waste, better quality control, lower production costs, and higher productivity at construction sites (Martucci 1990).

Moreover, there is another concept in production engineering that can be contribute for the success of industrialized construction: mass customization. According to Duray *et al.* (2000), mass customization is a manufacturing approach that combines craft manufacturing with some methods of mass production to enable a variety of products with cost-efficient in large scaled products.

The work developed by architect João Filgueiras Lima is in line with precasting and sometimes, mass customization. Since the beginning of his career, right after his graduation, from the building of Brasília to the production of Rede Sarah hospitals (from the late 1970s to the late 2000s), he developed, in addition to design projects, a series of precast components always linked to a producing factory (Guimarães 2010).

The first Rede Sarah hospital, operated by Associação das Pioneiras Sociais (APS) in Brasília, was designed in the mid-1970s (Guimarães 2010). The Rede Sarah technology center (CTRS), the manufacturer of industrialized building components for Rede Sarah hospitals, was established in 1992. There followed the building of nine hospitals: São Luís, 1993; Salvador, 1994; Belo Horizonte, 1997; Fortaleza, 2001; Rio de Janeiro, 2002; Brasília-Lago Norte, 2003; Amapá (diagnostic and physiotherapy unit), 2005; Belém (diagnostic and physiotherapy unit), 2007; and Rio de Janeiro, 2009 (Lukiantchuki 2010).

CTRS building system has characteristics of industrial construction systems such as the employment of a module that establishes measurement units in which identical construction components are repeated thereby expediting assembly and construction work (Risselada 2010).

In the same time, specifics hospital areas have specifics details and this influences the production, i. e.: the ferrocement plates that have specific heights, depending on they will be used, and the roofing that have different curvatures depending on the hospital design (LUKIANTCHUKI *et al.* 2011). This production characteristic can be related to the concept of mass customization presented by Duray *et al.* (2000), according as the CTRS production is as the same time in large scale and customized.

According to Da Silviera, Borenstein and Fogliatto (2001) there are seven generic levels where the customization can occur: (1) design, (2) fabrication, (3) assembly, (4) custom work, (5) custom services, (6) package and distribution and (7) usage.

In spite of being prepared to meet the demands of other construction processes, even of other types of buildings, CTRS was prohibited to supply to the construction of buildings other than those of Rede Sarah by the Federal Court of Auditors (Pinho 2010). At that point, APS made the decision not to build any new projects and direct CTRS production only to the maintenance of existing hospitals, which eventually led João Filgueiras Lima to leave CTRS (Risselada 2010).

Objective

This article aims to investigate the adaptability of a construction project, which was initially designed to be produced through a closed loop precasting system, but ended up being built by means of an open loop system, with some mass customization approaches. It will also discuss the advantages and disadvantages of this adjustments. Moreover, it presents the traditional and precasting systems employed in the construction of Hospital Escola Municipal de São Carlos.

Method

This investigation was based on a case study carried out at Hospital Escola Municipal de São Carlos. Data collection included visits to the hospital, analysis of design documentos, and interviews with two architects, one being responsible for the conceptual design (João Filgueiras Lima) and the other for the development detail design and specifications (Anderson Freitas). All data were collected to shows the way that the hospital were built and to understand and relate the production approaches used.

Hospital Escola Municipal de São Carlos was visited in eight occasions: May 18th, 2009; May 10th and 17th, 2010; June 8th, 2010; March 27th, 2011; May 12th, 2011; January 24th, 2012; and March 30th, 2012. Besides the visits (direct observation) and interviews, photographs were taken during the visits. Data about the construction systems were also collected in addition to observing the coordination of the construction work. The strength of direct observation of the construction of Hospital Escola Municipal de São Carlos lay in observing the construction work in real time and understanding their choice of processes vis-à-vis the context. The main difficulty was that it was only possible to observe one area of the construction site at a time, which may have precluded the collection of information from other areas. In order to minimize this limitation, the visits were as long as possible, taking advantage of the site proximity and the receptivity of those responsible for the construction work.

Architect Anderson Freitas was interviewed on August 25th, 2010. He was involved in the project design during the second phase of construction, considering the basic specifications set out by João Filgueiras Lima, the author of the conceptual design. This data collection activity was important in that it elicited and enabled the documentation of the interviewee's memories, given that subjectivity and inaccuracy in descriptions could be minimized by direct observations at Hospital Escola.

Architect João Filgueiras Lima was interviewed on June 27th, 2011. The interview was focused on Centro de Tecnologia da Rede Sarah (CTRS). In addition to CTRS, the interviewee was responsible for the design and construction of all Rede Sarah hospitals. He is well known for his extensive work with precast components and his intensive integration of construction and factory in his work for federal, state, and local government administrations. Table 1 shows the data-collection activities during the research.

Table 1: Activities conducted to collect data. Conceived by Debora Verniz

DATE	ACTIVITY	DESCRIPTION OF ACTIVITY	PURPOSE
05/18/2009	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: foundations of second construction phase.
05/10/2010	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: sealing and roofing of second construction phase.
05/17/2010	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: sealing and roofing of second construction phase.
07/08/2010	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: sealing (windows) of second construction phase.
08/25/2010	Interview.	Interview with architect Anderson Freitas.	Investigate the architect's opinion on the use of industrialized materials and construction methods employed in the construction of Hospital Escola Municipal de São Carlos.
03/27/2011	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: sealing and roofing of second construction phase.
06/27/2011	Interview	Interview with architect João Filgueiras Lima	Get to know the architect's opinion on industrialized construction.
05/12/2011	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: sealing and roofing of second construction phase.
01/24/2012	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: finally services of second construction phase.
03/30/2012	Visit to Hospital Escola Municipal de São Carlos.	Visit and photographs taken.	Observation of construction work: finally services of second construction phase.

Results

With the exception of the conceptual design, all other drawings were done by the two aforementioned architecture offices. The drawings received João Filgueiras Lima's approval so as to ensure that his design did not suffer substantial changes[3]. Brasil Arquitetura was responsible for detail designs during the first construction phase (emergency care) and Apiacás Arquitetos for the second phase (surgical center, study center, admissions ward and services wing). Given the impossibility of CTRS participating in the construction work, the local government became responsible for the construction of the hospital. A general contractor was hired through traditional competitive bidding. The contracts for both construction phases were awarded to the

[3]According to information collected during interview with Anderson Freitas in August 2010.

same contractor, which outsourced most of the construction work. General information about the construction work is described in Table 2.

Table 2: General information

	Phase 1	Phase 2
Period	2005-2007	2009-present
Preliminary Project	João Filgueiras Lima	
Detail Design	Brasil Arquitetura	Apiacás Arquitetos
Contractor	MVG Engenharia	MVG Engenharia
Sector of Hospital	Emergency Care	Surgical Center, General Services, Study Center
Built Area	About 3,000 m^2	About 17,300 m^2
Number of Beds	31	182

Note: Conceived by Debora Verniz.

Hospital Escola is divided into five sectors as shown in Figure 1: Study Center (1); Emergency Care (2); Surgical Center (3); Admissions Ward (4); and Services Wing (5). During Phase 1, only the Emergency Care facilities were built. The remaining blocks were to be built during Phase 2.

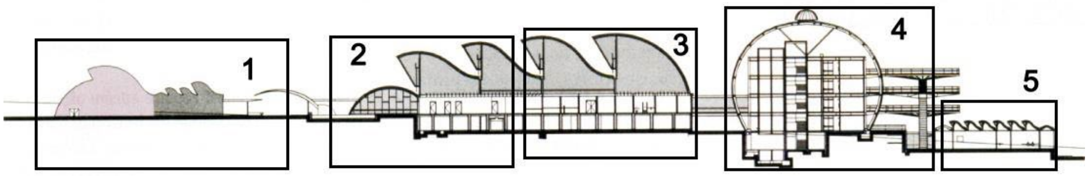

Figure 1: Hospital Escola, general schema
Note: adapted from Hospital Escola archive (2010).

Regarding the choice of construction systems, the general contractor opted for a combination of industrial and traditional building systems, the latter being fewer in number. Therefore, most of the construction work involved the use of precast components. Despite of all other hospitals designed by João Filgueiras Lima, this one could not use the CTRS' production, so there was the need to modify the specification of elements traditionally manufactured by CTRS. In the case of Hospital Escola, an effort was made to adjust the project requirements to the reality of the construction work.[4]

Foundations

During the construction of the foundations, the researchers observed the implementation of two distinct systems: precast spiked piles were used as the main type of foundation; the retaining walls were employed to prevent earth movement in the Admissions Ward basement. Omega piles were also used; however, this step was not monitored by the researchers.

Their decision to employ an industrialized system, i.e., precast piles, indicated their concern for construction quality and pace (Fig. 2). This choice eliminates some phases of the construction work since excavation and cast in place concrete would take longer. By contrast, the retaining wall (Figure 3) was built in a more traditional way.

[4]Information provided by architect Anderson Freitas during interview 08/25/2010.

Figure 2: Precast piles
Source: personal archive of Verniz (2009).

Figure 3: Retaining wall
Source: personal archive of Verniz (2009).

Structures
The structure of Hospital Escola comprises mostly made by steel components. These are manufactured by specialized factories. It is possible to find different examples of metal structures in the construction work. The Services Wing is structured with round columns and "C" profile beams (Fig. 4). The roof is also structured with metal trusses (Fig. 5).

Figure 4: Metal column and beam
Source: personal archive of Verniz (2009).

Figure 5: Roof made with metal trusses
Source: personal archive of Verniz (2009).

In the Admissions Ward, “I” profile beams and semi-circular arches with the same profile (Fig. 6) were employed to support the external walls of the building.

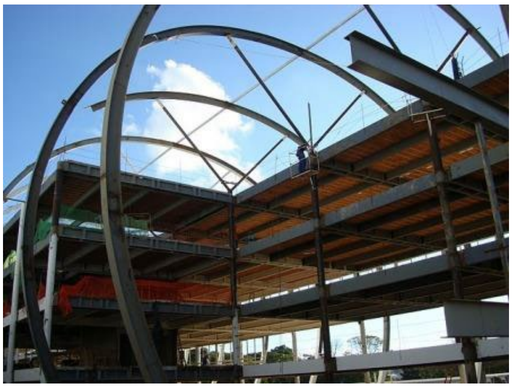

Figure 1: General view of Admissions Ward
Source: personal archive of Verniz (2009).

Concrete structural elements, i.e. slabs and columns (Fig. 7), are only found in this technical floor in the basement that connects the Emergency Care block to the Surgical Center. This floor is part of the natural ventilation system of these two sectors. These elements were produced at the construction site itself. In addition, metal molds were acquired (Fig. 8) and components were pre-shaped and stored at the construction site (Fig. 9).

Figure 7: Cast in place concrete columns and slabs
Source: personal archive of Fabricio (2005).

Figure 8: Metal molds for precast concrete elements
Source: personal archive of Fabricio (2005).

Figure 9: Production of precast concrete slabs
Source: personal archive of Fabricio (2005).

Sealing
The most significant change between Hospital Escola and the other hospitals produced by CTRS is the replacement of the ferrocement plates with concrete-block masonry and plasterboard. This replacement was necessary because there is no supplier in the market of ferrocement plates similar to those produced by CTRS. The choice of internal plasterboard walls was due to both their ease of assembly and availability of product in the market[5].

Regarding walls, the Hospital Escola projects adopted two systems, traditional and industrialized, concrete blocks of external walls and internal gypsum plasterboard partition walls.

The steel frames that give support to the gypsum plasterboard were produced especially for the construction of Hospital Escola, with longer length than those found in the market. This was necessary so that the thickness of the inner walls could be the same as that of ferrocement plates. The frames were made of 115mm wide folded galvanized steel sheets with "U" and "C" profiles (Fig. 10). By adding these measures to the plasterboard thickness (12.5mm), the internal walls thickness reaches 140mm, the minimum value specified in the design. There are other wall thicknesses (Fig. 11), which vary according to the requirements of building services (electrical, hydraulic, air conditioning, and medicinal gases).

[5]According to information provided by Anderson Freitas during interview in August 2010.

Figure 10: "U" profile galvanized steel frames
Source: personal archive of Verniz (2010).

Figure 11: Thicker internal walls for passing air-conditioning components
Source: personal archive of Verniz (2010).

The use of plasterboard promotes interfacing with other subsystems, especially building services (Fig. 12). Thus, all of these interfaces were designed (Fig. 13).

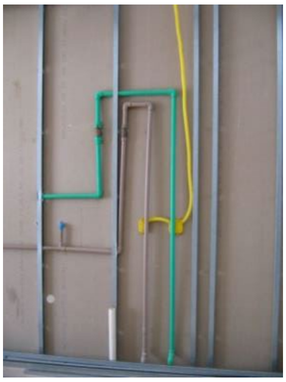

Figure 12: Hydraulic and electrical installations
Source: personal archive of Verniz (2010).

Figure 13: Opening in frame for passage of plumbing or conduits
Source: personal archive of Verniz (2010).

The concrete-block masonry (Fig. 14) confers higher stability and protection from the weather. During the visits, some construction details were observed such as binding cement to metal columns (Fig. 15).

Figure 14: Concrete-block masonry in external walls
Source: personal archive of Verniz (2010).

Figure 15: Binding of masonry to column using wire mesh
Source: personal archive of Verniz (2010).

All window frames used in Hospital Escola are made of steel (Fig. 16). In addition, the Admissions Ward will receive external walls of metallic material, creating a kind of latticework (Fig. 17), and the Surgical Center has, at some points, motorized metal fans as part of a natural ventilation system (Fig. 18).

Figure 16: Metallic window frames
Source: personal archive of Verniz (2010).

Figure 17: External walls of the Admissions Ward
Source: personal archive of Verniz (2010).

Figure 18: Metal fins of the Surgical Center
Source: personal archive of Verniz (2010).

Roofing

Visits to the construction site enabled the observation of the construction of the roofs of all blocks (Fig. 19). The roof curvature varies according to design specifications. The specificity of the sheds proposed for Hospital Escola makes for higher production complexity (Fig. 20). The metal roofing is made of galvanized steel tiles (Fig. 21).

Figure 19: Roof of Surgical Center
Source: personal archive of Verniz (2010).

Figure 20: Roof of Services Wing
Source: personal archive of Verniz (2011).

Figure 21: Detail of steel tile
Source: personal archive of Verniz (2011).

The rounded shape of the roofing (Fig. 22) is accomplished by means of metallic trusses and steel tiles, which take shape as they are fixed onto these structures. Therefore, they are not calendered. Thus, the hospital roof is industrially produced. All the Hospital Escola blocks have the same rounded roof specifications, featuring a sandwich system: tiling, acoustic protection, air layer, and roofing (Fig. 23).

Tiles and roof have the same specification; they only differ in plate thickness: the former is 0.8mm and the latter is 0.43mm of pre-painted steel, fixed onto the structure by means of epoxy glue. Soundproofing is achieved by applying a geotextile between the tiles′ layers. For thermal comfort and corrosion protection they are painted in white.

Figure 22: Curved shape of roofing
Source: personal archive of Verniz (2010).

Figure 23: Detail of metallic roofing
Source: personal archive of Verniz (2010).

Analysis of Data

Preference for using precast and pre-shaped building systems can be seen in Table 3. Of the ten construction systems shown, six are considered precast, two pre-shaped, and two traditional.

Table 3: Classification of different building systems employed at the construction works

Phase	Building System	Precast	Pre-shaped	Traditional
Foundations	Driven piles		✓	
Foundations	Retaining wall			✓
Structure	Metal structure	✓		
Structure	Solid columns and slabs		✓	
Sealing	Plasterboard	✓		
Sealing	Ceramic Block Masonry			✓
Sealing	Metal frames	✓		
Sealing	External walls (Latticework)	✓		
Sealing	Metal fins	✓		
Roofing	Galvanized steel roof	✓		

The construction work employs precast and pre-shaped building systems available in the market: pre-shaped piles, metallic structure, and drywalls. In comparison to traditional building systems, the use of these systems promotes swiftness and control of construction processes, ensuring that design specifications be met in a more efficient manner.

The use of precasting draws on practices not employed at traditional construction works, helps to reach more rational production process. An example is the prediction of interfaces between different subsystems at Hospital Escola, e.g. drywalls and building services, or the placement of porcelain floor tiles before building drywalls, which prevented waste of material.

Another advantage to employing precast or pre-shaped components in the construction work of Hospital Escola is a more strict control of the required design specifications, especially those related to mechanical properties. Thus, the use of precast piles and metal structures provided greater flexibility and control and ensured that the concrete properties were consistent with the design specifications.

Solid slabs and columns were pre-shaped in situ. To this end, metal molds were used, which reduced waste, optimized tasks, and conferred greater swiftness to construction work. The effort to produce pre-shaped elements at the construction site indicated effective control of the means of production.

In Anderson Freitas's opinion, adapting design specifications to the market reality was much more painful than difficult in that beyond its detail design, the preliminary design of Hospital Escola was laden with symbolic weight expressed through João Filgueiras Lima's work repertoire. The strict control of production and construction processes carried out at CTRS and Rede Sarah hospitals, somehow gets lost when there is a bidding process that prioritizes the lowest price.

Ferrocement plates was not produced in situ because the size of Hospital Escola did not justify it. The production of ferrocement plates requires strict control of process.

Drywall partitions were used as replacement for the ferrocement plates specified in the preliminary design project. As the thickness of the ferrocement plates was greater than that of drywalls found in the market, it was necessary to produce a 115mm-width metallic profile. This certainly was a critical point in adapting the construction work of Hospital Escola Municipal de São Carlos that the supplier had to change its whole production of steel profiles.

Conclusion

Hospital Municipal de São Carlos Prof. Dr. Horácio Carlos Panepucci was initially designed to be built with precast components manufactured by CTRS. Given the impossibility of CTRS supplying them, the choice of construction systems was made on the basis of their availability in the market.

Therefore, construction work that was to be fully pre-manufactured ended up using traditional building systems at some of its phases. In spite of that, precast construction systems were applied ostensibly, thereby promoting swiftness, rationalization, and better quality control at the construction works.

The critical point in adjusting the construction work of Hospital Escola consisted in adapting internal walls. The inability to produce reinforced mortar as specified at the beginning of the project led to the use of drywall partitions, whose metal profiles required adaptation on the part of the manufacturer.

According to classification proposed by Oliveri (1972), the precasting system employed in the construction of Hospital Escola can be considered as open loop, since it has resorted to different suppliers for different building systems applied to the construction work.

The use of precast components results in a faster construction process because the construction site became a place for assembling components according to design. This happened in several construction stages: foundation (precast piles), structure (steel structures), sealing (plasterboard, metal frames, latticework and metal fins) and roofing (galvanized steel roof).

Mass customization approaches used in the hospital's construction can be recognized in places that have specific needs. It can be seen on sealing and roofing. The variation occurs in two different ways on sealing: when the frame was produced with a different dimension that it was usually produced and in specific places when the wall thickness needs to be bigger than usual. On roofing, the customization can be seen in the different shapes on the steel roof. These shapes are different depending on its location.

These customizations are made in two different levels: fabrication and assembly. On sealing, the customization occurs in fabrication, when the factor changes the products following a pre-defined design that was specified in project. On roofing, the customization can be seen in the assembly, when the galvanized steel tiles were fixed in different steel structures, arranging standardized tiles into different shapes.

This article shows how precasting and mass customization approaches were used in the hospital's production. Despite this work shows a hospital's construction, the systems were used in it can be also used in other kinds of building. The use of precasting can also improve housing production enabling i.e. a bigger control of production process and saving time. Mass customization at all can provide the dweller's requirements adding variation in the production process.

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CONTRIBUTIONS FOR THE CUSTOMIZATION OF SOCIAL HOUSING PROJECTS BASED ON THE INTERVENTIONS UNDERTAKEN BY DWELLERS AFTER OCCUPATION

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CONTRIBUTIONS FOR THE CUSTOMIZATION OF SOCIAL HOUSING PROJECTS BASED ON THE INTERVENTIONS UNDERTAKEN BY DWELLERS AFTER OCCUPATION

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Abstract

Many social housing programs and policies in Latin America have ignored the individual needs of different households, and do not consider in their conception systematic feedback from the way housing estates are used and changed. Moreover, the use of industrialized technologies in the context of fast growing markets has encouraged the adoption of mass production ideas even further. As a result, dwellers need to do major changes in their housing unit, which can be costly, and affect the quality of the built environment. The aim of this paper is to investigate the use of information concerned with interventions undertaken by the final users of social housing projects for feeding back the development of industrialized building systems, in order to increase the possibility of customized design solutions. Three case studies were carried out, all in a construction company from Uruguay, which has developed and built social housing projects using an industrialized building system. Those case studies were carried out in projects with different degrees of user participation in the design stage. Data collection involved interviews with a sample of dwellers, direct observation of housing estates, and analysis of technical documents.

Keywords: *Mass customization, industrialization, building systems, design, interventions.*

Introduction

Nowadays, the demand for diversification of new products has significantly transformed homes, which is expressed by the different needs of residential spaces (Portillo 2010). Growing competition and highly demanding customers is a reality in the house-building market, being important for companies to adopt new strategies in order to better understand the demands of the market, focusing on customer requirements (Pine II 1994 and Lampel and Mintzberg 1996). In fact, customer involvement can be considered as a new source of skills, so that products are no longer just an artefact that customers experience, but something that customers themselves become co-creators of (Kotler 1972). In this context, mass customisation has emerged as a strategy aimed to satisfy customers through personalized products and high efficiency. In several industrial sectors, mass customisation has been widely used as a strategy to deal effectively with diversity, and distinctive efforts are being made in different countries to adopt this strategy in the housing production sector (Naim and Barlow 2003 and Noguchi and Hernandez-Velasco 2005). Barlow (1999) pointed out that, since the 1960s, innovation in the construction industry has focused on the development of specific materials and components rather than on increasing productivity of the construction sector as a whole. The creation of a mass market of customised housing associated with the use of new technologies will probably generate a scale economy and increase productivity, adding value for customers (Barlow 1999). The importance of offering more flexible spaces does not have to do only with improving and adjusting domestic activities, but also with creating spaces that can be adapted to changes in the family structure, favouring the permanence of families in their homes (Tillman 2008, Brandão 2006 and Miron 2008). This paper presents the results of a study aimed at understanding customers' interventions and needs through capturing users' requirements in the cycle of use, and at finding opportunities to increase product customisation. The development of the study was based on a case study at a company that provides social housing in Uruguay through using prefabrication. The aim of this paper is to investigate the use of information concerned with interventions undertaken by the final users of social housing projects for feeding back the development of industrialized building systems, in order to increase the possibility of customized design solutions. Three case studies were undertaken in social housing projects built by a construction company from Uruguay, which has been using an industrialized building system.

Product customisation

The term "Mass Customisation" is used when "[…] a large number of customers can be reached as in the mass markets of the industrial economy, and simultaneously they can be treated individually, as in the customised markets of the pre-industrial economy […]" (Davis 1989). Pine II (1993) popularised this concept and defines Mass Customisation as "[…] the provision of a large variety of goods and services at reasonable prices, adopting production processes and new information technologies to achieve an economy of scope, allowing to provide each customer the product that they want […]". According to Jiao *et al.* (1998), MC is a systemic concept that involves every aspect of product development, and should not be understood only as the implementation of technological flexibility, but rather as an approach involving the full development cycle of the product, from design through to the integration of the customer and the delivery of the product. Hence, mass customisation as a strategy is a concept that encompasses the dynamics and the trade-off between three processes: product design, production system design and supply chain design (Guruswamy *et al.* 2004)

Product design

In order to achieve customisation, the design of the product depends on its architecture and on assigning the functional elements of its physical construction (Ulrich 1995). Jiao, Ma and Tseng (2003) use the term design for mass customisation (DFMC) motivated by the degree of importance that design has in the product development process, and their goal is to consider simultaneously achieving an economy of scale and scope. The emphasis is on shifting the practice from designing individual products to designing families of products. That is, according to Muffato (1999), a series of elements of the product and their interfaces with different final products. In order to achieve this distinctive product, it is necessary to have a platform of products to characterise the needs of the customer, and, consequently, satisfy those needs through the configuration and modification of modules and components (Jiao, Ma and Tseng 2003).

These modular structures can be used in combination or separately, and the combination is made through interfaces. Jiao, Ma and Tseng (2003) emphasizeed that using the standardisation of components in order to produce a variety of products allows different degrees of modularity, which is something that can be found in some industrial sectors.

Supply chain management

Flexibility-oriented production is not enough to respond to the demand for variety Womack, Jones and Ross (1990). The configuration of a supply chain is essential to be able to offer products that can satisfy customers' requirements (Hoekstra and Romme; 1992[1], *apud* Barlow and Ozaki 2003). One of the key strategies is postponement,

[1]HOEKSTRA, S. and ROMME, J., 1992, Integral Logistics Structures: developing customer-oriented goods flow, McGraw-Hill, Londres.

meaning that companies delay production, assembly or design until the customer's orders are received, increasing the capacity of the product to satisfy the specific requirements of the customer (Piller, Moeslein and Stotko 2004). Another strategy to meet the demand for variety through the supply chain is to decrease the supplier's reaction time through the concept of outsourcing, i.e. the development of a value chain with capacity to produce specific components more speedily and increase the degree of flexibility of the product (Mullens, Hoekstra and Nahmens 2005).

Production system design

In a MC environment, production system design play a key role, since it is easy to obtain a variety of products through flexible production systems. Increasing production flexibility implies the ability to focus on the customer's needs, responding to competition pressures and, consequently, meeting the demands of customers (Slack 1987). According to Slack (1987), there are two types of flexibility that occur simultaneously: range flexibility and response flexibility. Range flexibility is the system's capacity to admit different configurations for manufacturing various products, while response flexibility is how easily in terms of time and costs the processes admit different configurations (Salck 1987).

Communication with customers

After acknowledging the benefits of Mass Customisation, companies are faced with the challenge of developing mechanisms to enable customers to communicate their individual preferences to the companies (Fogliatto and Silvera 2008). Compared with mass production, mass customisation is characterized by high intensity of information exchange (Piller, Moeslein and Stotko 2004). According to those authors, every transaction implies that the information and coordination regarding the product specified by the customer is based on direct communication between customer and supplier.

Mass customisation in housebuilding

According to Nahmens (2007), mass customisation in the context of housebuilding requires changes of varying difficulty, "[…] ranging from changes in the core concept through to dimensional changes, or changes in features or finishes […]". A study of the industrialized housebuilding sector in Japan conducted by Barlow and Ozaki (2003) found examples of customisation strategies identified by Lampel and Mintzberg (1996). According to Barlow and Ozaki (2003), Japanese companies adopt different mass customisation strategies, based on their different supply chain configurations, which enables them to achieve the customised delivery of their products, which are tailored from the moment an order enters the chain. For example, Toyota Home produces a final range of assembled modules, which can be found by customers anywhere in Japan. In that case, the aim is to postpone delivery to the site as much as possible. Sekisui Heim uses standardized customisation, in which houses are assembled to order at factories to create individual modules (Fig. 1). Sekisui homes uses tailored customisation, contrasting with the previous ones: it uses standardised and sub-assembly components, which are then used to configure the customer's requirements on site. They offer a high level of customisation, design and specification choices, while, at the same time, delivering high-quality housing at short delivery times. Barlow and Ozaki (2003) state that the Sekisui Heim model is the closest one to the classic perception of MC as a system with similar characteristics to those of PC manufacturing .

Figure 1: Sekisui HEIM assembly line
Source: Sekisui Chemical Co.

Reseach method

Embedded case study was the research strategy adopted in this investigation. The company involved in this research work has focused its operations in residential projects of one- or two-floor houses. It has developed an industrialized construction system that consists of heavy prefabricated components, manufactured in the factory or on site (Fig. 2). This investigation involved three projects built in two different forms of housing provision: a Cooperative system (COOP), and a project carried out for private owners (PP).

Figure 2: Housing projects

This company was selected due to the fact that it has used an industrialized building system (Fig. 3) in several projects, and, at the same time, has produced house-building projects with some degree of customization. Moreover, the company was willing to participate in this investigation, since this study was considered as an opportunity for improving its production system and product design.

Figure 3: Prefabricated system

This investigation started by understanding the company's product development process (PDP). Data were collected in interviews carried out with the company's director and technical staff. Also a survey was carried out with a sample of dwellers from the three projects. That survey included the family profile, socio-economic situation, degree of participation in the PDP, satisfaction with the final product, and changes in the housing units made or desired by users. Moreover, direct observation of the interventions carried out by the users was made, as well as the analysis of aerial photographies.

The comparative analysis of the two housing types of funding was useful because the degree of user participation in design was different for each of them. Data analysis was mostly focused on generating feedback for improving the PDP, as well as product design. Correlation analysis was undertaken for the type of project, housing typology, family structure, and time of occupancy of the units.

Analisys of interventions and comparison between projects

The results regarding family configurations show differences between projects, with a greater diversity of family profiles in the COOP units. Significant differences were found in the comparison between the COOP and the PP, with a larger percentage of nuclear families with children in the former, and the absence of extended families in the latter. There is also more variation in the number of residents in the COOP units, distributed in two and three bedroom units. Although in the PP the number of residents ranged between 2 and 4 in the two- and three bedroom units, respectively. The rate of permanence of the families that were involved in the project since the beginning in the COOP units is, on average, 58.57%. In the PP, there is a higher rate of permanence: 83.3%, of the families that purchased housing units still live in their units.

In the COOP projects, the predevelopment stages last for a very long time, so the user requirements tend to change much since the time of purchase. The decision to acquire a unit with two or three bedrooms is determined by the first need of a small family, which may grow during the process. By contrast, the HUs have not been designed for customisation, forcing users to live in inadequate spaces, or to implement costly product changes.

The majority of the families built one or more rooms in the back of the unit, with a higher percentage in the COOP, with an average of 74.85%, and an average of 58.33% in the PP. The perimeter fences built in the back of the units are interventions made by the users of both projects, aimed at improving the security and privacy of their houses. In simultaneous or subsequent stages, extensions or roofed sections associated with the perimeter fence system were incorporated. These interventions in the external spaces are characterised mostly by a barbecuing hut (a multiple use space), which is included in the cultural requirements of these families and accounts for most of the alterations in the projects studied. These are followed by garages and sheds that share the same function, as alternative spaces with multiple uses and, in some cases, as a working space for the families. The area within the setback lines of the lots has markedly different occupation rates, ranging from 7 to 70 m^2 in the COOP and from 20 to 64 m^2 in the PP. The number of stages for making the interventions were also different: in the COOPs the interventions were made at different stages during occupation, with 58,82% of the COOP units making interventions in only one stage, compared with 80% of the PP units. Regardless of the number of stages of intervention, the final result is similar in both cases, with intervention rates of 85% at the COOP and 83.33% at the PP. The interventions are characterised by lack of planning, absence of architectural or engineering technical support, and by the fact that they often remain unfinished. That produces high rates of occupation of the lot, sometimes with the house occupying the total area of the lot, and consequent loss of the outdoor area originally planned. The different ways of intervening in these spaces are determined by the size and distribution of the buildings. However, there is a pattern of occupation in the back of the lot, associated with subsequent fencing on the back and on the side boundaries of the housing units. This distribution of occupation varies according to the configuration of the building. In units where the building occupies a larger area, the lateral setbacks present lower occupation rates. In units with a smaller setback line, the need for those spaces produces occupation of the lateral setbacks with inadequate dimensions.

The additional bedroom does not show a significant relationship between the types of projects studied during the period analysed. In the PP there are families with 3 to 4 residents and in units with 2 and 3 bedrooms, respectively, who added one bedroom, and in the COOPs there are families with 2 to 5 residents in 2 and 3-bedroom units, respectively. In both projects the occupancy rate is low, 1.55 residents/bedroom in the COOPs and 1.23 in the PP, considering one bedroom for every 2 residents. That may be a determinant of the low rate of interventions for adding bedrooms to the units: in the COOPs 24% built an extra bedroom, where only 31.3% of the 2-bedroom units built an extra bedroom, and in the PP only 16.6% built this type of extension.

With regards to the perception of space, 70% of COOP users and 92% of PP users think that one room in their house should be larger. The rooms that they wish were larger vary according to the project. In the COOPs the majority would like to have a larger kitchen and bedroom, while in the PPs, users prioritize the kitchen and the bathroom. It can be interpreted that in the PP the rate of occupancy is rather low, which does not affect the perception of a bigger bedroom.

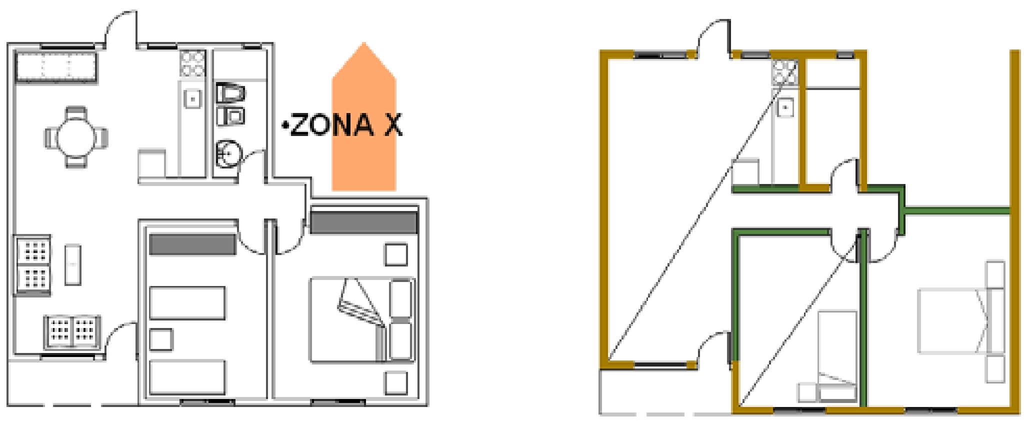
The equipment incorporated in the units includes a high percentage of air conditioning units, with 38.1% at COOP I and 40% in COOP II, and 41,67% the PP. There was also the incorporation of wood burning stoves, with 47,62% in COOP I, 52% in COOP II, and 50% in the PP. These data are very similar in spite of the income differences between the housing projects' users.

At the PP there is a higher level of satisfaction, particularly regarding the appearance of the houses, which is evident in the better finishes of the units. When asked about their level of satisfaction with the possibility of making alterations in the house, the satisfaction levels are similar in the two cases, and the interventions that users consider most important are extensions in the setbacks of their units.

Opportunities for customisation through changes in the conception of the product
According to the analysis of the company's product development process, the relationships with customers are conducted in a traditional way, in which a design with very few typological design alternatives is defined by the company's technical staff or proposed by external designers (IAT - Technical Assistance Institute) in case of COOPs.

The diversity of family profiles require different configurations of use that can be attractive at the moment of purchase of the unit, as well as its subsequent transformations during the phase of use. The market conditions revealed in the study show a demand for product variety in terms of typology and flexibility of use. In addition, the users' perception of the spaces indicates that they would like their housing units to have bigger spaces. In order to offer product flexibility, one of the proposals that emerged from a collaborative effort with the company's team was the division between a support unit (SU) and a flexible unit (FU), based on the concepts of open building (Nogushi and Hernández-Velasco 2005 and Lawrence 2003).

Based on that idea, a study was undertaken on the development of some structural elements of the prefabricated constructive system (Fig. 4) for the 2-bedroom unit. The result was the definition of a module of the house that could be configured at the initial stages of product launch by the user, making it possible to customize the housing units as close as possible to the delivery of the unit, as well as customisation during use.



(a) 2 bedroom-plan full conception

(b) Typology with definition of support through the structural component

Figure 4: Definition of the structural component in the 2-bedroom plan typology, COOP projects

The definition of the structural component limits two sectors to be customised by the user, one outside and another one inside the unit, allowing a possible improvement in the configuration of the unit based to the user's requirements. According to Jiao, Ma and Tseng (2003), in the initial stages of the process, the incorporation of changes into the product development design process should focus on designing families of products instead of single solutions. This proposition allows an offer of typologies that contemplate the processes of transformation of the HUs along its life cycle.

Incorporating customisation after the delivery of the product

The incorporation of customisation in after delivery represents an opportunity to adopt a strategy focused on meeting the demand for product variety imposed by the different family configurations identified in these markets. The prefabrication technology allows the definition of the structural component as a standard unit (SU), and increases the flexibility of use of the product based on the management of a flexible unit (FU). In this case, the introduction of the FU through the concept of outsourcing can increase the level of flexibility of the product (Mullens, Hoekstra and Nahmens 2005). This FU could be customisation oriented from the product launch through to its use through the integration of other light, rationalized construction systems, which allow maintaining or shortening lead times with the introduction of assemble-to-order or make-to-stock production (Hoekstra and Romme 1992 *apud* Barlow and Ozaki 2003).

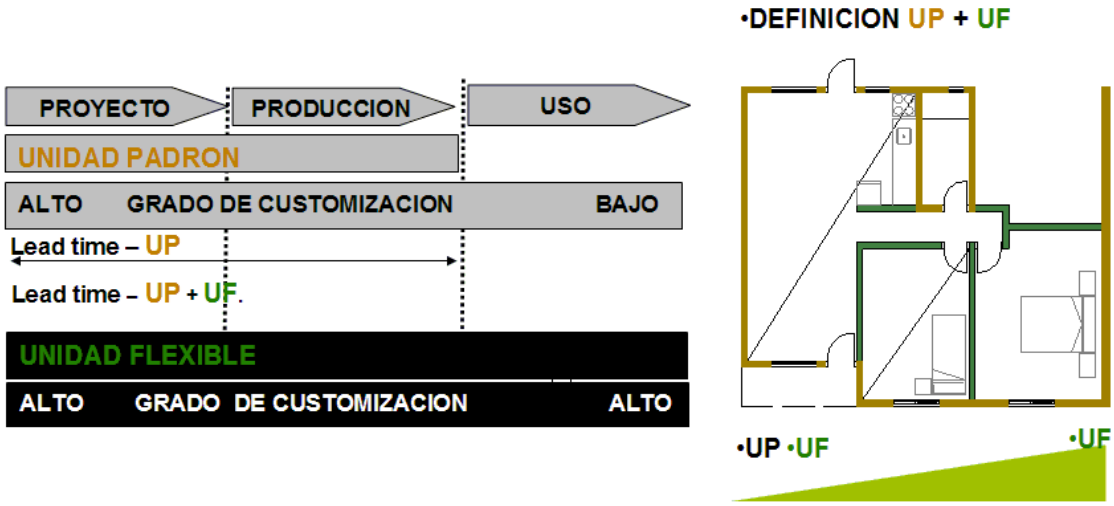


Figure 5: Propuesta Unidad Padrón + Unidad Flexible

Communication with the customer to offer a platform of choices

Based on the analysis of the demand through the interventions made and the housing profiles, the company can configure a platform of choices where customers can choose different product configurations. According to Fogliatto and Silveira (2008), recognizing these markets implies developing mechanisms that allow customers to incorporate their individual preferences. According to Silveira, Borenstein and Fogliatto (2001), Lietchy *et al*. (2001) one of the steps to create this interface with the customer is to define a catalogue of options to be offered to the customer. This step is characterised by rapidly accessing the different configurations of the product and its components, where the customer can enter his/her needs in the different stages of the PDP. Through a typological analysis and the separation of the conception of the product into SU+FU, it is possible to offer a menu of options that the user can evaluate, in which the spatial configuration of the unit most convenient for the family can be determined at the purchasing phase.

The concept of housing product includes both the habitable unit and the outdoor space around it

According to Brandão (2006), it is important to predict the possibility of expansion of the units for users who wish to add new spaces. The product design in both housing projects was characterised by a failure to conceive the HU along with the immediate surrounding private space as a product. That leads to interventions without planning, which consequently generate a loss of value for the unit as a whole. The product architecture should integrate the housing unit: the house plus its immediate surroundings, so that the interventions are properly planned and easy to implement, adding more value to the product. Data analysis indicated the need to consider an extended housing product, integrated with its immediate external space. This external space is a place where quick interventions can take place, creating a buffer zone, which can be used in several different ways according to the needs of each family. It is often used as a barbecue hut, garage or shed, including a workspace. The perimeter fence defines a space of intervention in the product, usable as a support for future extensions. This is an essential component for planning the interventions. The definition of the support fence could be configured as a prefabricated element with structural capacity, with the design predicting an interface capable of connecting to the roofs used in this kind of intervention and infrastructure connections. This new system can incorporate an extension of the product offered by the company in order to facilitate the customisation of those spaces and ensure controlled planning of the spaces. For the company, it is a component that would enable it to increase its participation in the product, increasing the scope of the project.

Integration of suppliers to tackle product customisation

In order to offer future flexibility of use, the electrical and plumbing systems should follow the same concept, designed as a standard unit that is capable of being easily extended due to interfaces predicted in design. In fact, Jiao, Ma and Tseng (2003), emphasize the design strategy of customizing products by changing the conception to a configuration in which a product platform is delivered, and components can be later incorporated during the product use stage. For instance, in the case of building services, some possible changes could be predicted, based on projects already delivered, such as air conditioning and wood burning stoves, and the product that is initially delivered has been design for introducing those changes later. Of courtse, such decisions should be made, taking into considerations product design, production system design and supply chain management (Guruswamy 2004),

The analysis of the interventions detected a lack of prediction of the set of components that could increase users' comfort and satisfaction. By constrast, a high percentage of users have already incorporated those elements or intend to do it (air conditioning, wood burning stoves, security grids, visual barriers) which points to the development of new options in the product's design stages.

Conclusions

The analysis of the changes introduced or desired by users of house-building projects has borought interesting insights about the limitations of the existing products of the company investigated. Based on that analysis, several changes have been proposed, including offering new house typologies, design of new components, and changes in design and production strategies, with the aim of customizing housing units. The proposed changes focused on expanding families of products capable of fulfilling users' requirements through the capacity of a prefabricated system to incorporate mass customisation strategies. This allowed the conceptual development of a housing product capable of offering a high level of flexibility of use and the proposition of changes in its conception. These proposals emerged from a combination of the rationalized system with structural capacity to produce components and light rationalized systems that can be easily changed after occupation.

The analysis of the technology development process led to the identification of production strategies that are key factors to achieve feasible MC levels, such as modularity and flexibility of reaction. These strategies are currently focused on reducing costs to achieve an economy of scale, without taking into account customers' preferences and, hence, without any effort to make a strategic differentiation in the company's business, aimed at adding value to the product and becoming more competitive. Another aspect of the relevant interventions observed was the occupation of the outdoor spaces of the units, reaching rates of approximately 85% in both projects. Users consider this type of intervention extremely important, and they express a high level of satisfaction with regards to being able to intervene, incorporating their needs. The understanding, through multiple evidences, of the reasons for the interventions allowed the identification of the factors that have an impact in the use of housing units and the development of possibilities of products that can be designed based on that information. Attention to those requirements can help control the process of planning and implementing changes, ranging from the urban scale, concerned with the impact the interventions in the units have on their immediate surroundings, to the social, creating adaptability capacities for the product, infrastructure, predicting safety and privacy aspects.

Through the analysis of the technology development process some possible strategies for introducing mass customization ideas were identified, including modularity and design flexibility. The introduction of customisation as a strategy in the product development process allows customers to have different degrees of participation in that process so that their preferences can be incorporated, leading to changes in the conception of the product design.

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ANALYSIS OF HOUSING PRODUCTION IN JAPAN AND BRAZIL, AND TECHNOLOGICAL STAGNATION OF THE SECTOR

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ABSTRACT

In Japan and elsewhere, the production of single-family homes has migrated from traditional on-site construction to the manufacturing environment. However, Brazil's production system is still based on artisan fabrication, which is highly dependent on available manpower. This article makes a critical analysis of the construction sector in this country, comparing the characteristics of housing production in Brazil and Japan, and examining the characteristics of the house-building industry in these two countries. This analysis is based on data collected at large-scale construction sites in Brazil and data garnered in a literature review on Japanese house-building companies. Our findings point unequivocally to the technological stagnation of housing production in Brazil, and to the negative consequences for the consumer in terms of production speed and quality. This analysis is important because it highlights the inertia of production techniques in Brazil in detriment to innovative opportunities in this country, which could contribute to improve working conditions, reduce waste, and improve the quality of end products.

Keywords: *industrialized housing production, construction, comparison, Japan.*

Introduction

Housing production in industrialized nations, especially in Japan, has veered away from the traditional practices employed in countries such as Brazil. Several factors prevent changes in the techniques and technologies employed in this subsector of the Construction Industry (CI) in Brazil, such as labor unions, the social role of the CI, government incentives, and the construction culture. These factors, allied to the intrinsic characteristics of the CI, contribute to the technological stagnation of this subsector in Brazil, keeping it highly dependent on the intensive use of manpower, which leads to failures and delays.

By contrast, in countries where there is a greater level of interaction between industry and research and development (R&D) activities, such as Japan and the USA, the development of the homebuilding subsector is underpinned by continual improvements in the quality of the final product, by competitiveness and innovation, and by the industrialization of construction activities.

Thus, in a national context of high housing demand, this article compares the production characteristics of single-family homes in Brazil and Japan, based on factors considered important in large-scale homebuilding projects, such as production speed, volume, and quality of delivered products. This comparison between Brazil and Japan is justified because the latter has been recognized as a leading innovative country that has very successfully introduced high performance industrialization in different sectors. One of the main findings here is that there is a clear technical and technological stagnation in Brazil, which insists on favoring handcrafted construction practices, while the world is shifting towards automation and waste reduction.

Research objectives and method

This paper aims to promote a discussion about the inertia prevailing in technical and technological issues in Brazil's homebuilding industry, based on a critical analysis of the practices adopted in this country, comparing them to those employed in other countries such as Japan, considering several production factors. The research method consists of comparing qualitative data collected from construction sites in Brazil, and data presented in journal articles about housing production in Japan. The qualitative data were collected at four low-income housing construction sites of different companies, where construction quality problems were observed and a diagnosis was made on the share of value adding activities.

Home Construction in Brazil

In Brazil, there is a strong focus on the social role of the CI. This role is known to be a government initiative, and the private sector ends up assimilating the State's short-term solutions, which are aimed at absorbing a given share of the country's workforce that is not sufficiently trained or qualified to work in other sectors that require such prerequisites.

In theory, this may be a positive point for businesses, since it enables the construction sector to hire workers at significantly lower wages. In this regard, therefore, it is a case of questioning the advantages this practice represents for the CI, from the technological, technical, economic, quality and sustainability standpoints, and the historical context into which it fits.

Just as in the early days of automobile production, buildings were also constructed using artisan procedures to carry out construction site activities. According to Holanda and Barros (2004), during the period of 1500 to 1808 (Brazil's colonization period), building construction depended on the knowledge and expertise of master builders, usually Portuguese workers devoid of scientific knowledge, who guided construction work that required intense physical effort. The authors state that during this period, science was not usually applied to the construction of buildings. Vargas (1994) reports that construction plans were simply "scribbled" and houses were built by these master builders, by military officers, or by priests trained in architectural practices.

The aforementioned construction characteristics are clearly identified as handcrafted production activities. Hence, this indicates the strong dependence of these processes on workers who mastered construction techniques, and the fact that they were carried out independently of scientific knowledge. Holanda and Barros (2004) state that this situation began to change after the introduction of the first technology courses, which were brought to Brazil by the Portuguese court in 1808. However, technical mastery was still limited to professionals educated by the new training centers located in urban centers such as São Paulo and Rio de Janeiro.

With the arrival of science education, increasing construction of power plants and railways (that drove the economy of the times), and the growth and densification of urban centers, the period of 1850 to 1930 was marked by the emergence of the Brazilian CI. Thus, the first national construction companies involved specifically in this activity were established during those years (Holanda and Barros 2004). The authors state that it was during this period that the first professional construction workers emerged, with European immigrants gaining greater prominence due to their mastery of construction techniques and their artistic skills.

Like most workers up to the late 19th century, these early workers were organized in trade guilds with apprentices and masters whose empirical knowledge was transmitted to artisan beginners (Holanda and Barros 2004). At that time, buildings were constructed to perform their function (despite the precarious use of science), although there was much concern with the art underlying what was being built. According to Holanda and Barros (2004), the years between 1850 and 1930 can be considered the golden period from the standpoint of execution, particularly of walls, with great emphasis on the technical and artisanal experience of workers.

Several technological product and process developments emerged in Brazil during the following years. For instance, in the 1950s, during the presidential term of Juscelino Kubitschek de Oliveira (JK) between 1956 and 1961, the country recorded a remarkable development based on the Target Plan, which opened up Brazil's economy to foreign capital, leading to the establishment of new manufacturing industries. In short, investments and new industries resulted in the introduction of new techniques and technologies that improved products and labor conditions, thus increasing production volumes and quality, generating greater profits for companies.

Despite the investments and advances of the JK government in the 50s, the Brazilian CI continued to produce residential buildings that, in essence, were built in the same way as in the preceding centuries. It must be pointed out that many other industries participating directly in the construction supply chain underwent technological developments that were not consistent with the characteristics of traditional construction sites. For example, manufacturers of waterproofing materials dealt with highly complex polymeric materials that required precise scientific knowledge and technological control of production. Another example is steel rebar, whose manufacture follows strict quality control and dimensional accuracy, which are factors that also require control over technology.

In this regard, according to Farah (1992), one of the main problems of Brazil's CI is that construction methods have not kept up with the technological development of the area. According to Oliveira (1997), in construction sites there is a clear distinction between "know-how" and "scientific knowledge." The rationalization of construction processes has not been a major concern in Brazil, since labor is plentiful and relatively cheap, thus mitigating the expenses resulting from archaic and uncontrolled processes (Oliveira 1997). Since this is a very conservative industry, the traditional practices of the CI ended up simply disregarding the theories and technologies that have emerged through scientific development and that support its activities.

Governments, in turn, instead of fostering innovation and changes in the CI in favor of technology and quality, promote funding programs that have encouraged the maintenance of all the aforementioned construction characteristics. The Federal Government program called My Home My Life (*Programa Minha Casa Minha Vida* (PMCMV) is the most recent example of incentives that encourage the technological inertia of the housing construction subsector in the country. The easy funding offered by this program to some builders and buyers, the lack of production control, and the incipient quality of the delivered housing units has, in some cases, resulted in the poor quality of construction processes and of housing units, providing opportunities for estate speculation in detriment to the efficiency and effectiveness of processes. Figures 1 to 3 illustrate several construction processes of large-scale projects of the PMCMV.

(a) (b)

Figure 1: Construction safety railing embedded in structural masonry, and poor fixation of safety elements

(a) (b)

Figure 2: Poor quality slab and joint EPS filler without thickness control in structural masonry walls

(a) (b)

Figure 3: Excessive waste of structural blocks in the slab, and traditional labor-intensive construction site

The purpose of this paper is to point out that the Brazilian house-building subsector insists on using building systems that prioritize the dependence on labor, in detriment to available innovation possibilities. Obviously, the private sector has introduced some innovations involving different technologies, such as prefabricated systems and more advanced production techniques, aiming to work towards the idea of industrialization. Even so, some construction sites that can be considered innovative have similar problems to the ones that are usually identified at traditional sites, i.e., errors, faults and waste, as illustrated in Figure 4.

(a) (b)

Figure 4: Cuts in structural struts of the light steel frame and inappropriate storage of structural elements of the same system

In essence, the errors depicted in those figures may be attributed to a lack of knowledge of the technology being used. Brazil's CI seems to ignore recent R&D developments, since, as the renowned architect Buckminster Fuller stated, each house is seen as the prototype of a design that would never work, and in addition, the house is treated as an isolated art belonging to the Middle Ages, because it is based on the "methodical ignorance" of its activities (Gann 1996). Therefore, in Brazil, the CI is often seen as a sector with social obligations, which tends to limit the technology associated with it products.

Unlike Brazil, in the first world countries one sees a close relationship between R&D and practices employed in the industry. In those countries, the homebuilding subsector in these countries can actually be considered an industry, since its practices are very closely tied to the concept of industrialization. A reference in this context is Japan, which uses several practices that can be considered innovative in Brazil, including prefabricated construction systems.

Housing Production in Japan

Linner and Bock (2012) state that in Japan, the concept of prefabrication is strongly tied to engineering and architecture. The high levels of automation and large-scale production in Japan can be attributed mainly to cultural factors, which are the outcome of a process of learning and development (Linner and Bock 2012). A noteworthy fact is that Japanese industries, including the housing construction sector, employ improvement and development initiatives known in the West by the term Kaizen. In a brief practical analysis, Imai (2012) emphasizes that the Kaizen philosophy assumes that procedural activities (which may even be activities related to daily life) should focus on constant efforts towards improvement, without ever accepting stagnation. However, the author also points out that improvements resulting from the application of a given Kaizen are characterized by being small and incremental, with results that have strong long-term impacts.

Thus, unlike Brazil, Japan promotes innovations and exchanges of experiences with different industrial sectors, which also applies to homebuilding. In this regard, Fruin (1992) reports that Japanese firms are involved in a dynamic and interactive learning system in which companies continually adapt and change in response to lessons learned from past experiences. In fact, part of the homebuilding subsector in Japan can really be considered an industry. As a reference in this context, Japan uses several solutions that can be considered innovative in Brazil.

For example, when it comes to product technologies, Japan uses mostly construction systems that facilitate assembly activities or that are exclusively for this purpose. This gives Japanese companies greater control over production, since workers handle prefabricated elements instead of raw material to be processed. A complete assembly activity of a product is divided into elements of productive work, which are smaller work units that add value to the product (Askin and Standridge 1993). Thus, the use of building technologies such as Light Steel Frames and Wood Frames is common, and companies develop their own solutions and construction details, thus often becoming marketing components of the company. Obviously, when a company eliminates flow activities, this enables it (at least in theory) to potentiate its profits, i.e., its profits are based on production efficiency.

Unlike the idea that a product's value is based on the amount of labor that went into manufacturing it, this concept aims at increasing the company's profit by adding value for customers (internal and final). This goal is achieved through a philosophy based on practices of continuous improvement, competitiveness, innovation and industrialization of construction activities. In fact, Toyota (even in the real estate market) successfully applied and developed this concept in its production processes, and STP today is a model adapted and implemented in various sectors of industry.

The notion of added value may be one of the major drivers of the success of Japanese industry. The mere fact of looking for value in production activities requires industrialists and managers to improve their processes in order to eliminate activities that do not add value. This reasoning, inherent to the manufacturing industry, led the Japanese to innovate by seeking value in housing production activities, and resulted in some companies shifting from traditional housing construction activities to the manufacturing environment. Gann (1996), for instance, reports that the process of buying real estate in Japan is usually separated from housing production activities. The author states that this prevents companies that produce housing from profiting through real estate speculation, while ensuring the development and application of efficient production techniques. Furthermore, to ensure customer satisfaction, manufacturing companies are structured to ensure customization based on predetermined design options offered to customers, and the definition of the design and confirmation of sale usually takes about three months (Gann 1996).

Another striking and decisive factor of Japanese success is investments in R&D, which allows large corporate conglomerates to operate in sectors that are often not part of their area of operations. Gann (1996) considers that large companies in Japan and other first world countries have R&D divisions that employ hundreds of scientists, technologists, ergonomists, engineers and architects, and that these professionals are organized in a vertically integrated structure that encompasses all the stages of the product's life cycle, and this is also reflected in the production of housing. Examples of this are the Japanese multinationals Panasonic and Toyota, which belong to sectors very different from the CI, but also started operating in the real estate market. Such companies, using the same working methods employed in other sectors, seek to shift the construction of a model of the single-family home into a factory and even to attempt to mechanize some activities.

Companies that sell industrialized housing units usually offer predetermined models that allow the owner to customize the product according to the options the factory offers. In this regard, Linner and Bock (2012) show that Japanese industry can deliver homes with high levels of customization, equipped with the latest technology and a wide variety of services. Interestingly, the authors also state that these products have maintenance models that ensure the house is functional for at least 30 years, and some companies offer up to 60 years of services.

This ability to customize is noteworthy because houses are manufactured on assembly lines, many of whose activities are standardized and fully automated, resulting in a production rate far exceeding that of Brazil. In this regard, it should be noted that the housing production system in Japan adopts management methods that are used in the manufacturing industry, e.g., the Takt Time concept, which is defined by the ratio of market demand to the time available for production, thus providing the pace the factory needs in order to meet the demand (Alvarez and Antunes Jr. 2001).

This means that housing output follows the pace dictated by demand. This is also obviously the case in Brazil, but in Japan, Takt Time is associated with the concept of Cycle Time, which is the time spent between the consecutive outputs of two products on the same line and represents the maximum amount of work processed at each workstation. From the operational standpoint, this makes production management easier since production must follow a predetermined pace, and represents a productive and economic advantage over traditional construction methods, as shown in Table1.

Table 1: Peak housing unit production of some of the main Japanese manufacturers

Company	Sekisui House	Toyota Housing	Daiwa House
Housing Units Produced (year)	78,275 (1994)	5,024 (2006)	44,500 (2007)

Source: Sekisui Housing (2014a), Toyota Housing Corp. (2014b) and Daiwa House (2014).

Table 1 lists production data of three major Japanese companies. Toyota stands out among them because it originally belonged to the automotive sector, reinforcing the idea of versatility and R&D. This table shows the high production rate of Sekisui, for example (the largest company in this sector in Japan (Gann 1996 and Linner and Bock 2012). In a brief analysis to illustrate the facts, excluding non-productive days and adopting a time of 365 days, Sekisui produced an astounding 214.45 houses per day in 1994 (a number that is even higher if one considers holidays and other non-productive days).

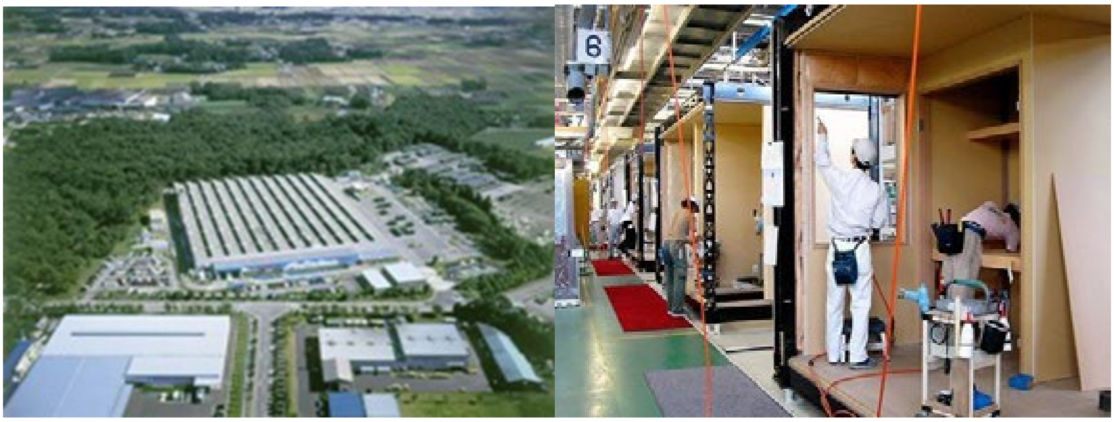
The numbers in Table 1 provide evidence of the Japanese concern regarding R&D investments and continuous process improvements. One of the best examples of investment in R&D has to do with the design process. Linner and Bock (2012) report that Japanese firms usually seek to invest in designs for housing production, known in the manufacturing industry as Design for Manufacturing (DFM), in addition to actual product designs. This type of design is very common in the manufacturing industry, but can be considered an innovation when the end product is a house. In addition to DFM, the assembly line production of houses also has designs exclusively for assembly activities, called Design for Assembly (DFA), which are also linked directly to R&D because they define construction methods, tools, parts and other factors.

A concise presentation is given below of two outstanding Japanese manufacturers, Sekisui and Toyota, which have distinct realities in the country but represent innovation and the need for ongoing improvements to face the competitiveness of the market.

Toyota Housing Corporation

Toyota Housing (2014) started operating in the real estate market in 1975, when it launched a complete line of single-family homes built according to a variety of construction techniques. Toyota's real estate activities were handled by Toyota Motor Corporation until 2003, after which the company decided to divide its operations, transferring certain activities such as planning and marketing to the new company, Toyota Housing Corporation (THC). In 2010, all the activities of the corporation's real estate division were transferred to THC, which has three factories today: Kasugai Housing Works, Tochigi Housing Works and Yamanashi Housing Works.

Unlike Toyota Motors, Toyota Housing is not the market or production leader in Japan. Despite its proven management and innovation capabilities, the company lags behind some of its competitors in terms of production volume (housing units). According to Gann (1996), Toyota transfers and shares workers between the automotive and residential divisions to promote information flow and possible improvements. Figures 5 and 6 depict some of the facilities of Toyota Housing.



(a) (b)

Figure 5: General overview of Tochigi Housing Works and workmen working on one of Toyota Housing's assembly lines
Source: Toyota Housing (2014) and Seattle Times (2014).

Figure 6: Completed module that will be part of a Toyota housing unit
Source: Seattle Times (2014).

Sekisui House

Sekisui (2014b) reported that it started its activities in 1960 with the market launch of its Model A. Gann (1996) states that the company controls the entire process (from design to final assembly on the ground), offering a high degree of customization of houses for the final customer. Sekisui is the leader in the Japanese market and has specific models for production management that ensure speed and quality as well as final consumer satisfaction by means of such customizations (Figures 7 and 8).

Interestingly, during the development of new products and even in the market of existing ones, Sekisui invites customers to participate in its R&D centers so that they can participate in tests of new components and evaluate items such as accessibility and use.

Figure 7: One of the Sekisui factories, and the basic assembly sequence of a module on the assembly line
Source: Sekisui (2014b).

Figure 8: A Sekisui housing unit
Source: Sekisui (2014b).

Final remarks

Notwithstanding cultural and market differences, the need to produce housing is a universal demand required for human wellbeing. In fact, this, *per se*, should suffice for the development and implementation of continuous improvements in the sector, aimed at achieving advances that benefit humankind.

However, in Brazil, one often finds resistance to change when it comes to building houses. As we have seen, the country invests in outmoded construction techniques that are clearly dependent on labor availability and experience, instead of facilitating

and encouraging R&D practices to break paradigms and enable it to participate in and contribute to the world's evolution.
This hampers the homebuilding subsector in Brazil from the standpoint of technology, because one sees that its activities are technologically stagnant due to the subsector's social role in absorbing labor.

Thus, the country invests relatively little in R&D for house construction, despite the housing deficit of more than six million homes. In terms of technology applied to homebuilding, therefore, Japan and Brazil's scenarios are totally heterogeneous. Japan seeks to use technologies that allow for the standardization and automation of activities in an environment potentiated by incentives for R&D.

Japan' s housing production rates are astounding for the Brazilian professional. Control and management concepts that are incipient in Brazil (at least in a few companies), such as applications of pull system techniques and tools, are routinely employed in Japanese industries, enabling them to achieve better results in a real housing manufacturing environment rather than in on-site construction.

Therefore, we believe that, given its high housing demand, Brazil should promote incentives for businessmen to implement innovative technological development processes. A greater proximity between academia and industry is imperative so that innovation can become concrete and affordable for the consumer. Moreover, such practices can ensure that industry profits and customer satisfaction are mutually sustainable. Brazil's insistence on centuries-old building practices, and the resulting technological stagnation of the sector, are therefore expected to prevent the country from meeting its demand for housing.

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EXPLORING THE POTENTIAL FOR URBAN FOOD PRODUCTION ON SYDNEY'S ROOFTOPS

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Abstract
There are environmental, economic and social benefits of retrofitting rooftops on city buildings for food production. Environmental benefits include lower carbon food miles, potential reductions in building related operational carbon emissions, reductions in the urban heat island, increases in bio-diversity and reductions in storm-water run-off. Economically, the benefits are reduced roof maintenance costs, lower running costs and direct access to fresh food. Thirdly the social or community gains are the creation of spaces where people can engage in growing food. Psychological and therapeutic gains accrue when people engage with natural environments. However there are barriers which include perceptions of greater risk of building leaks, high costs of installation and maintenance, and access and security issues. Although the technology to design and install food production on rooftops exists, the uptake and the demand have not been high to date. Overall, the gains are not deemed sufficient and in Sydney Australia, the existing numbers of food producing rooftops are testimony to this observation. This research reports on three rooftops set up in 2013 in Sydney which are producing food. The social, economic and environmental aspects and physical aspects of the installation are described in this paper.

Keywords: *Green roofs, Sydney, urban food production, case studies.*

Introduction
As millions face starvation globally and the proliferation of food waste becomes endemic, a recent report released by the Institution of Mechanical Engineers estimated "that 30-50% (or 1.2-2 billion tonnes) of all food produced is lost before reaching a human stomach" (Fox 2013). Some reasons for this amount of wastage are poor engineering and agricultural practices, inadequate transport and storage infrastructure. Urban rooftop farming has the potential to ameliorate some of these problems by shortening the food supply chain. One advantage of growing food close to consumers is reduced carbon miles. Currently, fresh food consumed in cities is transported great distances. It is estimated that the cost of transport of a $1 supermarket lettuce is around 40 cents (Midmore 2011). Rooftop agriculture has the potential to create healthier communities in alimentary and psychological ways. Urban rooftop agriculture could provide access to fresh, healthy, nutritious produce due to reduced time spent in transit and storage.

In addition there is evidence that city dwellers and workers are increasingly detached from nature, and that this contributes to rising stress and dissatisfaction with contemporary society (Shepard 1982). It is posited that "humans have a profound need for regular contact with the natural environment for continued well-being" (Kellert and Wilson 1993). In summary "Rooftop gardening means taking up an inspiring, ecological and productive activity, and developing new links with the food chain, the seasons, the environment and the community" (Germain 2008).

A complementary social benefit of rooftop farming may be community volunteer programmes where citizens and workers engage in food production. An example is the Eagle Street Rooftop Farm in Brooklyn New York (Rooftop Farms 2013) which runs a small community supported agriculture program and an onsite farm market which supplies local restaurants. Trained interns, urban farming apprentices and host volunteers provide the labour during growing seasons. In partnership with Growing Chefs the farm holds educational and volunteer programs to bring city-dwellers closer to their food source (Growing Chefs 2013). Given that there are many successful examples of urban agriculture in North America, Cuba, Canada and Germany, it is surprising that Sydney has so few examples of rooftop urban food production and to date, no empirical studies as to its viability.

Some barriers to rooftop food production include perceptions of greater risks of building leaks, high costs of installation and maintenance, and access and security issues. Property practitioners and built environment professionals have little direct experience of urban agriculture and; as a result, are sceptical and risk averse. There are questions about financial viability of such enterprises in Australia, even though viable, successful rooftop farms exist in cities such as New York where climatic conditions preclude food production during winter months.

Sydney (2013) is located in a temperate climatic zone with rainfall spread throughout the year. Annual meteorological data for 2012, showed 1213.6mm of rainfall, a mean maximum temperature of 22.7°C and a mean minimum of 14.4°C (Australian Bureau of Meteorology 2013). Sydney's annual average of sunshine is almost seven hours a day (City of Sydney 2013). Sydney's rainfall averages 11 wet days per month, with over 40% falling between March and June. With a population of 4,391,674 for Greater Sydney in the 2011 census (Australian Bureau of Statistics 2014), Sydney is growing at a rate of 1.7% per annum with two-thirds of New South Wales population living in the city. Furthermore Sydney has the highest density in Australia with 8800 people per square kilometre in Sydney's east and 7900 people per square kilometre in Sydney City's west. By comparison to other global cities Sydney's density is high, Mexico City has 8400 people per square kilometre, London 5100 people per square kilometre, Paris is lower still at 3550 people per square kilometre and Los Angeles has a population density of 2750 people per square kilometre. With increasing urban density and a growing population the disconnection to the natural environment is set to increase. Furthermore the demand for food is also increasing. One part of the solution may be urban farming on rooftops.

Research Aim

There is a growing body of research into the benefits or otherwise of specifying new or retrofitting green roofs to existing buildings for food production. However much of the empirical research has been undertaken in cities outside of Australia, in Europe and the northern hemisphere which has quite different climatic conditions. This research evaluates three different approaches to rooftop food production in Sydney. The objective is to use an empirical study to identify the gaps in knowledge for the city and to establish a research agenda to close the knowledge gaps. All research has limitations and in this case, given that the beds are raised and/or have limited direct contact with the roof structure and covering there are limited impacts on the thermal performance of the building. Where garden beds have direct contact the roof structure there will be an impact on thermal performance. There are social and economic impacts of urban food production which are part of this study but are excluded from the scope of this paper and are reported elsewhere.

Rooftop garden bed designs

Some of the options available for rooftop agriculture include portable containers, raised beds and vertical garden units. The issues to consider are access, portability, cost and the types of vegetables and plants to be grown. Containers come in various forms, are typically smaller than raised beds, and are easily portable. By using containers that would otherwise go to landfill, rooftop gardeners can recycle on garden plots of varying shapes and sizes. Milk crates with hessian sacks, recycled plastic wading pools, buckets, packing crates and recycled wooden pallets are examples. Container gardening allows growers to take their project with them should they be required to relocate and this can be useful when renting property. The factors to consider when creating a container bed are drainage and root depth. The most important aspect to consider when using recycled containers is toxicity and all treated and painted timbers should be avoided as well as plastics that contain solvents, PVC and high density polyethylene (HDPE).

The wicking bed derives its name from the cloth that is placed between the soil and a water reservoir inside the garden container that works much like a wick in an oil lamp. By giving the plants access to water at their root zone, when and where they need it, it reduces the potential for plants to become water stressed. Furthermore less water is wasted as evapotranspiration and the gardener does not need to water the plants as frequently. A simple way of building a self-watering garden bed or sub–irrigated garden is to use a plastic pond which is positioned directly onto the waterproof membrane of the roof. A hose is attached to an overflow outlet and the excess water is channelled to a drain. This type of garden bed has a very minimal impact on the surface of the rooftop. The weight is reduced by using agricultural pipe below the growing medium, separated by a layer of geo-textile fabric.

Another option is to elevate or raise the garden beds, and having a working height of 1100 mm from roof level is more comfortable than traditional gardening methods. This is a good solution for those who have mobility issues and furthermore, there is less direct contact with the roof membrane which is reassuring to some owners and property managers. The drainage can be channelled by hose from the garden bed outlet to stormwater pipe outlets which should ameliorate concerns about potential roof leaks or staining on tiles. Raised garden beds can be heavy and create point loads on the roof and therefore careful thought is required with regards to the design and construction of the trestle. There are proprietary garden beds such as those made from recycled UV stabilised plastic which are lightweight and easy to transport to the roof top, as well as kit form corrugated zincalume which are relatively lightweight and portable. Other options include timber framed beds manufactured in-situ.

There is a range of vertical garden beds produced and sold in hardware stores. Transportation to and accessibility of the roof top has to be taken into account with this option. Some systems may be good for growing herbs and flowers, but if gardeners are intending to use a spare north facing wall to grow food, which generally requires seasonal replanting, the ease of removal and planting out of new vegetables and the root zone depth required need to be considered when choosing a vertical system. The majority of vegetables grown by urban farmers are seasonal, and the plants will need replacing quite often as the seasons change and they either get picked or die off. A planting system that has inadequate sized apertures can be difficult to plant out. Some vertical planter systems accommodate small garden pots, and though convenient; it does limit planting to those with shallow root systems. There are vertical garden systems which have deep troughs that can be used to grow some very large vegetables and herbs. Due to the shallow depth of the growing mediums in most vertical gardens, they require more frequent watering and run the risk of water stress. The installation of a drip irrigation system on a 24 hour timer can provide reliable watering.

Each garden has different advantages and disadvantages. With each; accessibility, transportation and the load bearing capacity of the roof structure has to be considered. Orientation and access to sunlight, the availability of water and a power supply should also be scrutinised. Finally, cost and any issues regarding the comfort for the gardeners are decision factors as the working height of the bed affects gardeners comfort.

Research methodology

This research uses empirical evidence derived from growing plants and vegetables on three different rooftops at the University of Technology, Sydney (UTS), in New South Wales Australia in 2013 and 2014 (Melbourne 2013). Three different types of rooftop garden beds are described in three illustrative case studies below.

The research is qualitative, sharing the three basic assumptions identified by Patton (1980) of being naturalistic, holistic and inductive. Naturalism involves seeing the phenomenon in its natural occurring state, in this case by visiting the three sites to observe what has taken place. The holistic aspect involves looking at the whole problem to develop a more complete understanding of the influencing factors and variables with regards to three different approaches to rooftop food production in Sydney. The inductive approach is derived from the literature review whereby a picture of the problems and issues emerge as the researcher becomes more familiar with the topic area. The literature review identified which areas needed to be addressed.

An advantage of case study research is that it is a flexible and adaptable method which can be adapted during the research (Robson 1993). With this research three different types of beds are evaluated on three different roofs and so it is not possible to make exact comparison on outputs. However that is not to say that the conclusions which may be drawn from the study are not valid.

A limitation of the case study technique is that the researcher does not sample widely enough and that studies may represent the peripheries and not the average (Robson 1993). However, Yin (1989) observes that case study is concerned with analytical and not statistical generalisation. Care was taken to ensure conclusions drawn are noted as being analytically general rather than statistically representative in any way. The criticism of case study as a 'soft option' was rejected as the method requires preparation, knowledge of procedures (in this case food production on Sydney rooftops) and analytical skills (Robson 1993). It is soft in the sense that no hard and fast rules exist for the researcher to follow.

The means of data collection was through observation and direct experience which was deemed most suitable because it allowed the researcher to collect identical data from each site (Moser and Kalton 1979). Records were kept on bio-diversity, watering, weather, bed costs, planting, dates, fertilisers used and crop yields.

Case studies

The first task was to find suitable roofs on the University campus. After a number of visits to rooftops it was found that there were issues such as accessibility, where one had a series of narrow steps out onto the rooftop. Another had a telecommunications mast which precluded any other activity on the roof. A third roof was discounted as it was heavily overshadowed and poorly orientated to the suns path. The property managers were also a significant factor and finally the team met one who was also a gardener. This staff member was helpful and knowledgeable and took the team to several potential roofs before a joint decision was arrived at with the Gumal roof described below. The Science Faculty are involved in this research and had test beds on their roof and permission was given to position another bed on their roof. Finally the researchers' home faculty have a roof space directly outside the staff kitchen and the DAB Faculty Manager gave permission to site the V garden beds here.

Science Roof

This roof is located at 7th floor level on the corner of Harris Street and Thomas Street in Sydney. The roof faces north-west. The roof construction comprises reinforced concrete with an impervious covering. The roof is protected with walled structures approximately three metres high to three sides and a glazed screen to the Thomas Street elevation. The garden bed chosen for this site was a plastic wicking bed.

The bed was a pond purchased at a cost of $280. It has a 320 litre capacity and the dimensions are 1500 mm x 750 mm x 300 mm high. The reservoir in the bed is created by laying 100 mm agricultural drainage pipe across the bottom of the pond. A short section of tube is positioned vertically from the bottom of the pond up to the top (in a place where the overflow is visible). This is the filler tube and a section of agricultural pipe is used. A hole, to accommodate a 30 mm threaded tank outlet, is drilled into the pond shell at the height presented by the top of the agricultural pipe, here 100 mm from the base. The outlet has a washer to eliminate leaks. The overflow outlet was located as close as possible to the rooftop drain to minimise the trip hazard created by a hose. A layer of geotextile fabric was placed on top of the agricultural pipe and poked down slightly between random sections of the agricultural pipe to prevent the soil and roots from entering the reservoir and to allow the capillary or wicking action to irrigate the garden bed. Figure 1 shows the bed immediately following planting in December 2013.

The bed was filled with a mixture of soil and compost to a depth of approximately 200 mm. It was top dressed with a compressed pelletised organic seaweed fertiliser (Seamungus). The bed was filled with water through the vertical filler tube until it overflowed from the outlet. It was topped up over the two days while the soil conditioned and after this initial phase it was topped up with 30 - 40 litres of water every five to six days. The bed was planted with a mix of eggplant, zucchini, basil, carrots, beetroot, lettuce, chilli, capsicum, silverbeet, celery, rocket, mizuna and marigolds. After planting, the bed was mulched with lucerne hay and fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied typically once a month. The bed was planted out in December 2013 which is summer in Sydney Australia. The total cost of the bed was $412 plus labour.

Figures 1: Wicking Bed on Science Roof

Gumal Student Housing
This roof is located at 9th floor level on Broadway in Sydney. The roof faces south east. The roof construction is reinforced concrete with an impervious tiled covering. The roof is designed for access and has a concrete perimeter wall approximately 1200 mm high 600mm wide and 800 mm deep which is planted out. There is lift access to level 9. It is exposed and open to the wind and sun. The garden bed chosen for this site was a recycled plastic raised bed supported on a timber frame trestle. The UV resistant recycled plastic was extremely light, easily assembled and its dimensions were 3300 mm long x 1200 mm wide x 300 mm deep. See Figures 2 and 3.

A 3600 x 1200 mm trestle was constructed from 90 x 45 mm treated pine frames, braced with galvanised strapping tied together using a 90 x 45 mm treated pine rail top and bottom. The frames were prefabricated off site to minimise the noise impact during construction, and for easier transportation. Two sheets of ply 1800 x 1200 mm formed the top of the trestle and supported the plastic framework for the bed.

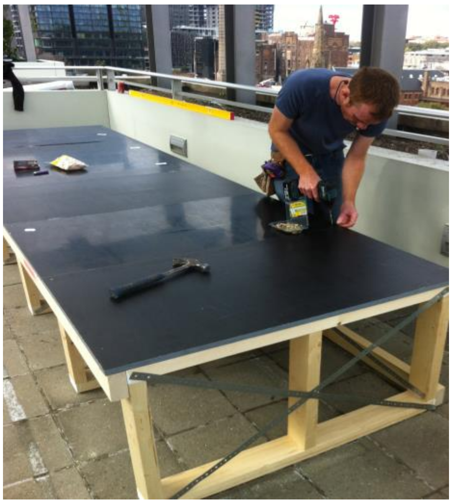

Figure 2: Gumal under construction

Figure 3: Gumal bed planted out

A layer of food grade rubber waterproofing membrane, ethylene propylene diene monomer (M-class) rubber (or EPDM) was placed over the timber trestle as weather protection. The plastic pod was positioned on the membrane and a bead of food grade silicone sealed the base of the garden bed and held it in place. At one end a floor drain was installed and sealed with silicone, and using a spirit level and some small plastic wedges, the end of the trestle furthest from the floor drain was raised slightly to facilitate drainage. A layer of 20 mm drainage cell sheeting was placed across the floor of the bed with a layer of geo-textile fabric laid over the drainage cells to keep the soil and plant roots from blocking the drain. A layer of fine gravel 20 mm deep was laid onto the geo-textile fabric, followed by another layer of geo-textile fabric. The bed was divided into two sections for different growing media; one was filled with an organic composted cow poo and garden soil mixture and the other a lightweight engineered substrate with a mixture of coir bark, perlite P400, Canadian peat, 0-8mm composted pine bark, all trace elements, Calcium Nitrate, coarse granular Dolomite, Gypsum, Superphosphate, Zeolite 1-3mm and Magrilime. Both beds were top dressed with a compressed pelletised organic seaweed fertiliser (Seamungus), and mulched with lucerne hay. Both were fertilised topically fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was applied topically once a month.

The beds were planted out with eggplant, zucchini, basil, carrots, beetroot, lettuce, chilli, capsicum, silverbeet, celery, rocket, mizuna and marigolds. These beds were planted out in November 2013 and the costs for the beds was $1350.62 plus labour.

Vertical Gardens

This roof is located at 5th floor level on Harris Street in Sydney. The roof faces North West. The roof construction comprises reinforced concrete with an impervious tiled covering. The roof is designed for access and has a concrete parapet wall approximately 1200 mm high and 200 mm deep to one side. Two sides are flanked by buildings which rise to a height of 7 floors and 20 floors. The remaining edge has a metal framed glazed fence and over looks an internal courtyard at fourth floor level. The roof is enclosed on all sides by tall buildings. In summer months, when the sun is high there are around six hours of direct sunlight on the roof, however in winter months there is minimal direct sun. Furthermore the buildings do encourage very high wind levels at times. There is lift access to level 5 however there are steps out onto the roof terrace area which made transportation less easy. The garden beds used on this site were supplied by V Gardens in Sydney. The beds have a timber frame and a large base bed with a series of metal framed horizontal trays to a height of 1600 mm. The horizontal trays are approximately 150 mm deep. One bed has a self-watering system on a 12 volt timer which utilises a submersible 12 volt pump and drippers. It is powered by a battery which is recharged by photovoltaic cells and the sun. The reservoir at the base of the garden houses the submersible pump and acts as a wicking bed for the lowest garden. The second bed is identical in design apart from the irrigation system and wicking bed. See Figure 4.

These beds were planted with a variety of herbs including basil, mint and oregano and vegetables such as lettuce, eggplants, silverbeet, and capsicums. Larger root vegetables such as carrots and beetroots were grown in the base bed. The beds were planted out in November 2013.

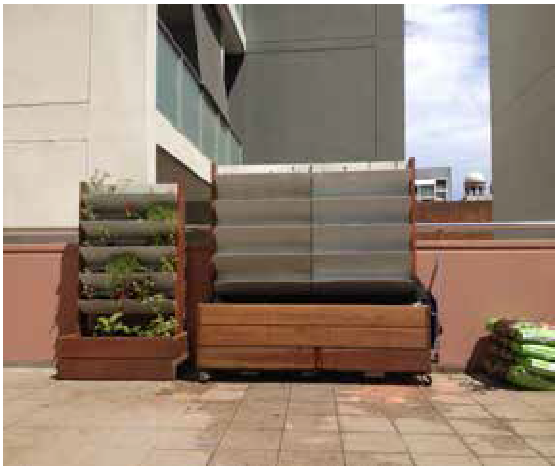

Figure 4: V Gardens on DAB Level 5 roof

Results and interpretation

Social

There has been considerable interaction and interest from staff within the faculties where the beds are sited around the university. This interest is focussed on what has been planted, and whether anyone can join in to water the plants and harvest the food. Without prompting, staff in the DAB put up a wall calendar with a pen in the staff kitchen to record whether the plants had been watered. When watered, the staff member or person simply ticks the date and others know when the plants have been watered. It is a simple system and few plants died despite a record breaking hot, dry Sydney summer. People ask and talk about the plants regularly and will often describe the meals they have cooked with the plants and the flavour of the herbs and vegetables they have used. Other staff such as security guards also expressed interest in the rooftop gardens, imparting tips and guidance where they think it needed. One staff member, upon learning that the beds were an experiment to see what could be grown on Sydney rooftops, noted that 'this is why the Cubans survived and the North Koreans starved to death'. They have given advice also about the timing of the watering and care of the plants. Students approach the researchers when attending the gardens at Gumal and chat freely about the plants. One student this semester, a journalism student from Germany decided to write about the gardens for her assignment. Industrial design students have used the gardens and rooftop agriculture in their major design projects. Overall the social interactions are high and positive.

Economic

The costs of the beds varied as described above. Furthermore the amount of growing space also differed between the three roofs. The costs are reasonably affordable, although it would take many years to grow sufficient food to pay back the initial costs.

Environmental considerations

The three locations experience different weather conditions to some extent. For example the Gumal rooftop is exposed to sun and high winds, which scorched the plants on a number of hot summer days. The beds needed more watering due to accelerated evapotranspiration. The Science roof however was sheltered from wind on three sides as described, and the plants received more shade during the hottest months resulting in less leaf burn and water stress. High winds were experienced in the DAB roof area and although the V Garden's construction, with the weight centred at the base meant that neither structure was affected by the winds, some of the larger vegetables were badly battered on these occasions. The DAB roof is surrounded by high buildings on all four sides and consequently during autumn and winter periods less direct sun is experienced on the roof and this will effect production rate. However in the summer the plants here have more respite from the effects of intense heat and direct sunlight.

In terms of thermal performance, the installation of rooftop gardens should inevitably result in some reductions in cooling loads. Due to the inherent thermal properties of shading, the temperature under the raised bed was significantly cooler and this provided a reduction in the temperature of the roof covering. With the wicking bed and its direct surface contact, higher levels of thermal performance would be expected. No data was recorded on temperatures in the rooms directly below the beds though this might be worth exploring in the future. Given the absorptive properties of the growing mediums, there was as was to be expected, a noticeable diminution in the amount of water entering the rainwater drainage systems of each of the roofs as a result of the installation of the garden beds. The Gumal beds had plastic tanks sited below the drainage outlet and this allowed the researchers to ascertain the approximate amounts of pluvial runoff from the beds compared to rainfall recorded in a rain gauge. The science roof beds drained onto the roof and into an open drainage channel. No silting of the drains occurred on any of the roofs as the geotextile fabric ensured only water passed through the textile.

With regards to attracting bio-diversity, as soon as all three roofs were planted insects appeared. Native and European bees were spotted on all sites. On the Gumal roof a group of cockatoos visited the site on the first day and uprooted the majority of the plants. Protective screens of wire mesh were fixed temporarily to deter the birds. Both yellow and orange lady beetles encamped within just a few weeks and within all the beds worms are seen on a regular basis. No actual tests have been conducted on air quality around the beds but it should be the case that the air should have higher levels of oxygen and lower carbon dioxide as the plants photosynthesise.

Physical and location

Access to all three roofs varied. Gumal, because it was always intended for public access had amenable conditions from the basement car park through to the rooftop. There are convenient water and power sources on this roof too. The recycled plastic garden beds were delivered in a long tube which was lightweight and could fit in the passenger lift. The prefabricated trestle frames and the pine sheet were heavy and cumbersome but these also could fit in the lift, as did the substrates and membranes. The 3600 mm rails had to be carried up the fire stairs. Once assembled these beds were very heavy and not easily relocated.

With the science roof access was via a goods lift from the car park to level 7. However due to the sensitivity and security concerns of the science labs, special access had to be negotiated for the researchers and no public access was possible. With the DAB roof top there is lift access to the floor but the space planning and configuration of offices meant there was a circuitous route to get the V Garden to the roof top. Fortunately the units are not too heavy for two people to carry. The DAB roof does not have a water or power supply and therefore water has to be transported from the adjoining staff kitchen to the gardens. Although a solar powered pump on the larger bed with the wicking bed provides irrigation to that bed, it does require topping up with water on a regular basis.

Table 1 provides a summarises of the performance of the three bed types.

Table 1: Summarises the three bed types and their performance in respect of the categories described above

	Bed 1 – Science roof wicking bed	Bed 2 – Gumal raised bed	Bed 3 – V Garden
Transportability and assembly.	Very easy.	Difficult. Some carpentry skills required.	Units easily transported with 2 people and a trolley but location presented a challenge.
Ease of working.	Low to ground.	Easy.	Very easy.
Costs / metre square of growing area.	Medium.	Very High.	High.
Ease of watering	Easy.	Manual, every other day in summer.	Easy.
Plant growth	Very good.	Varied.	Good.
Water usage	Low.	Medium to high.	Medium.
Exposure to wind	Low.	High.	high
Exposure to excessive summer sun/heat	Medium.	High.	Medium.
Bio-diversity attracted to bed	Very Good.	Very good.	Good.

Conclusions and further study

This research reports on three rooftops set up in 2013 in Sydney which are producing food. The social, economic and environmental aspects and physical aspects of the installation are described in this paper.

Despite varying conditions on all three rooftops, production over the summer period in 2014 was good. There were different challenges with all three roofs with the physical environment and environmental conditions. The social impacts were overwhelmingly positive in all respects. Economically there is variation in the costs of the beds and amount of skill and labour required for installation and set-up, however there are options to suit most budgets.

This project did not test any of the plants grown for the presence of heavy metals and this work is currently underway and will be reportedly in a following paper. Further funding is being sought to measure and ascertain the impact on thermal performance on buildings of the rooftop beds.

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COMMUNITY AWARENESS OF GREEN ROOFS IN SYDNEY

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COMMUNITY AWARENESS OF GREEN ROOFS IN SYDNEY

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Abstract
There are environmental, economic and social benefits of installing green roofs on city buildings. The environmental benefits are lower building related operational carbon emissions, reductions in the urban heat island, increases in bio-diversity and reductions in storm-water run-off. Economically, the benefits are reduced roof maintenance costs, lower running costs, higher capital and rental values for commercial buildings. Finally the social or community gains are the creation of aesthetically pleasing spaces, landmarks and cultural capital as well as provision of recreational spaces. Furthermore social, psychological and therapeutic gains accrue when the roof is visible to people and is used for social interaction and leisure activities. The perceived drawbacks are perceived greater risk of building leaks, high costs of installation and maintenance, and access and security issues. Whilst the technology to design and install green roofs has existed for hundreds of years the uptake and the demand for green roofs has been affected by poor understanding and a lack of data. Overall, the environmental social and economic gains are not perceived sufficient to create significant demand to set up green roofs. In Sydney Australia, the existing number of green roofs is testimony to this observation. With the aim of addressing the barriers to the uptake of green roofs; it is essential to understand the way in which the key stakeholders; here the community, perceive the technology. With this knowledge it is then feasible to develop an agenda to mitigate any erroneous perceptions that exists. This research reports on a survey with the Sydney community to determine their perceptions of green roofs. Adopting a qualitative methodology using questionnaire surveys, this paper aims to evaluate community perceptions and views in the City of Sydney with regards to green roofs. The findings with regards to social, economic and environmental sustainability will inform the City of Sydney's policymaking and support of green roofs in the city.

Keywords: *Green roofs, Sydney, community, community engagement.*

Introduction
There is increased and increasing densification of our urban settlements globally (Brand, 2011). In some cities, in developing countries the pace of urbanisation is so rapid, that it puts pressure on existing infrastructure such as sewer systems, transportation networks and provisions of open space for residents (Brand 2011). Developed countries also face pressure in increasing urban density; Australia for example is one of the most urbanised societies globally with 89% of its population residing in cities, and 40% living in just two cities (Australian Bureau of Meteorology 2014 and Department of Infrastructure and Regional Development 2013). In Sydney the amount of green space is less than 22 metres per resident and the urban canopy covers only 15% of the city area (Greening our City 2013). This lack of urban green space leads to a number of unwanted outcomes which include, increasing the urban heat island effect, reductions in urban bio-diversity and increases in pluvial run-off and flash flooding (Lamond, Wilkinson and Rose 2014).

In addition there is less recreational space for residents to enjoy and relax in (Skinner 2006). This lack of recreational space leads to disconnection with nature which can be detrimental to human psychological and physical health as well as a lack of understanding of and empathy with wider global environmental issues facing mankind (Castleton 2010).

Roofs can represent up to 32% of the horizontal surface of urban settlements (Frazer 2005), and herein lies potential to create green spaces in places not typically used such as horizontal gardens on rooftops. These green roofs could provide much needed recreational space for urban dwellers. What are community views and perceptions towards the adoption of green roofs? This paper explores community perceptions towards this technology in Sydney Australia using a qualitative approach and questionnaire survey.

In 2014 the City of Sydney adopted the first green roofs and walls policy for Australia, which sets out a commitment to increase the number of high quality green roofs and walls in the City (Sydney 2014). The policy includes a 3-year implementation plan to ensure the policy is understood, properly adopted and integrated. There are 59 green roofs in Sydney currently (Sydney 2014), 62.7% of which have no public access.

There is a growing body of research extolling the benefits or otherwise of specifying new or retrofitting green roofs. However much of the empirical research has been undertaken in cities outside of Australia, particularly in the northern hemisphere which has quite different climatic conditions. This research addresses the question; *what is the community awareness and perceptions of green roofs and green in the Sydney CBD*? The objective is to identify the gaps in knowledge for the city and to establish a research agenda to close the knowledge gaps.

Green Roof Attributes

There are numerous environmental, economic and social benefits of installing green roofs on city buildings (Wilkinson and Reed 2009). Often these benefits co-exist regardless of the primary goal of the designer, so for example a roof which is intended to improve thermal performance by providing an additional layer of insulation will also attract some biodiversity (Williams, Raynor and Raynor 2010). The environmental benefits include lowering building related operational carbon emissions through improved thermal performance, which includes cooling in summer and heating in winter (Castleton 2010). If sufficient green roofs were specified it is posited that they would reduce the urban heat island, whereby city centres are a few degrees hotter than outer suburban and rural areas due to trapping of solar energy by urban surfaces. In this instance the green roofs can reduce sensible heat flux through evapotranspiration (Santamouris 2012). The increase in planting in cities will attract insects and birds. This increase in faunal biodiversity in turn will help pollinate the flora, which absorbs carbon dioxide and emits oxygen thereby increasing air quality (Castleton 2010:62). Getter and Rowe (2009) calculated that if the city of Detroit (USA) greened 15,000 hectares of rooftop, over 55,000 tonnes of carbon could be sequestered. It is possible that wide scale retrofit of existing buildings with green roofs could help to deliver zero carbon goals. Finally green roofs can absorb rainfall, improve the quality of stormwater runoff and reduce the quantity of runoff into sewer systems (Mentens 2006 and Hilten 2008). It is considered that if specified widely, the installation of mass green roof technology could mitigate pluvial flooding in some cities and research is currently underway to model this potential (Wilkinson, Ghosh and Page 2013).

Economically, the benefits of green roofs are reduced roof maintenance costs, lower running costs and higher capital and rental values for commercial buildings (Wilkinson, Ghosh and Page 2013). The membrane, which is the waterproof component of the roof is protected in green roofs by the substrate and planting. The life of the membrane is extended by estimates of as much as 100%, therefore a bituminous felt roof may last for 50 years in the northern hemisphere compared to 25 years without a green roof (Kohler 2008). Lower building operating costs are achieved because the improved thermal performance of the roof results in lower energy consumption. In hot climates green roof technology can reduce the heat load by absorbing heat and reducing the amount of heat entering the building (Castleton 2010), though it is acknowledged that white roofs or cool roofs are the most cost effective way of reducing heat load through rooftops (Hes *et al*. 2012). Fuerst and McAllister (2011a, 2011b) conducted a study in Europe and the US which found that sustainable commercial buildings had higher capital values as well as higher rental values. Newell, Macfarlane and Kok (2013) replicated the study in Australia and made similar conclusions about the positive effect of sustainability features on commercial property.

The social or community gains are the creation of aesthetically pleasing spaces, landmarks and cultural capital as well as provision of recreational spaces. Furthermore social, psychological and therapeutic gains accrue when the roof is visible to people and is used for social interaction and leisure activities. The perceived drawbacks are perceived greater risk of building leaks, high costs of installation and maintenance, and access and security issues. Access to recreation space, including green rooftops, has the potential to create healthier communities psychologically (Wilkinson, Ghosh and Page 2013). Green roofs provide access to outside space where city dwellers and workers are increasingly detached from nature. Kellert and Wilson (1993) stated that people have a deep need for 'regular contact with the natural environment for continued wellbeing' and detachment contributes to rising anxiety and frustration (Shepard 1982). Having access to outside space on roofs and/or engaging in rooftop gardening involves taking up an inspiring, 'ecological and productive activity, and developing new links with the food chain, the seasons, the environment and the community' (Germain 2008). A further social benefit of rooftop agriculture may be community programmes where residents engage in food production, for example Eagle Street Rooftop Farm in Brooklyn New York (Rooftop Farms 2013).

Green roofs in Sydney

Sydney is located in a temperate climatic zone with rainfall spread throughout the year. Annual meteorological data for 2012, showed 1213.6mm of rainfall, a mean maximum temperature of 22.7°C and a mean minimum of 14.4°C(Australian Bureau of Meteorology 2013).Sydney's annual average of sunshine is almost seven hours a day (Sydney 2012). Sydney's rainfall averages 11 wet days per month, with over 40% falling between March and June. Generally these climatic conditions are favourable for growing plants and vegetables. To date most empirical data about the performance of green roofs comes from examples in Europe and North America (Wilkinson, Ghosh and Page 2013). Furthermore some European and Canadian jurisdictions have mandated green roofs in their development plans to require developers to specify green roofs. As a result the number and area of green roofs in these cities far outweighs current provision in Sydney and there is a need to ascertain what the community awareness and perceptions of green roofs are.

Methodology

This was a qualitative research study adopting the characteristics of an inductive, holistic and naturalistic approach as advocated by Silverman (1997), seeking to establish the opinions of the research population (Naoum 2003:38-43). Time, finance and physical distance precluded the use of interview data collection and therefore a combination of online and face to face questionnaire surveys was adopted as a means of collecting information. The questionnaire was designed using best practice methods (Moser and Kalton 2002 and Robson 2011) and comprised seven sections. Survey items were generated through a combination of direct consultation with research panels, and expert advice, both from the City of Sydney project team and other independent parties involved in building development in the City of Sydney Local Government Authority (LGA) (Dept of Infrastructure and Regional Development 2013). The survey had to be brief enough to facilitate rapid completion but detailed enough to cover the key concepts. The survey included respondents awareness, need evaluation/environmental priority assessment, perception of environmental benefits, level of support of green roof concepts, price sensitivity, funding options/alternatives, demographic and background items and finally an opportunity to make an open ended commentary. This paper reports on demographic data and awareness and perceptions only. The questionnaire was designed to provide descriptive, bi-variate and inferential statistical data for analysis using SPSS software.

Two survey methods were used to collect data; a self-completion online survey and a face to face survey executed as a street intercept survey of random respondents. Street intercept surveys occurred at locations around the City of Sydney LGA. The online survey was accessible from the City of Sydney website and was promoted on the website, in email newsgroups, and a large number of emails were also sent as invitations to improve participation in the survey via a URL link. The street intercept survey aimed to ensure suitable participation from City of Sydney residents rather than just those working or visiting the CBD, or those accessing the web link. This survey ensured that a suitable number of responses were not through self-selection which is the case with all online/email surveys. A team of at least two interviewers attended each location and randomly approached people in the street. Interviewers were trained on the survey and the concept of green roofs so that they could execute the survey effectively. Interviewers were assigned different locations around the city and different survey sessions covering different days, day parts (morning, early afternoon and late afternoon). The main locations that were used for the survey were Glebe, Newtown, Central Sydney CBD, Surry Hills and Woollomoloo (Fig. 1).

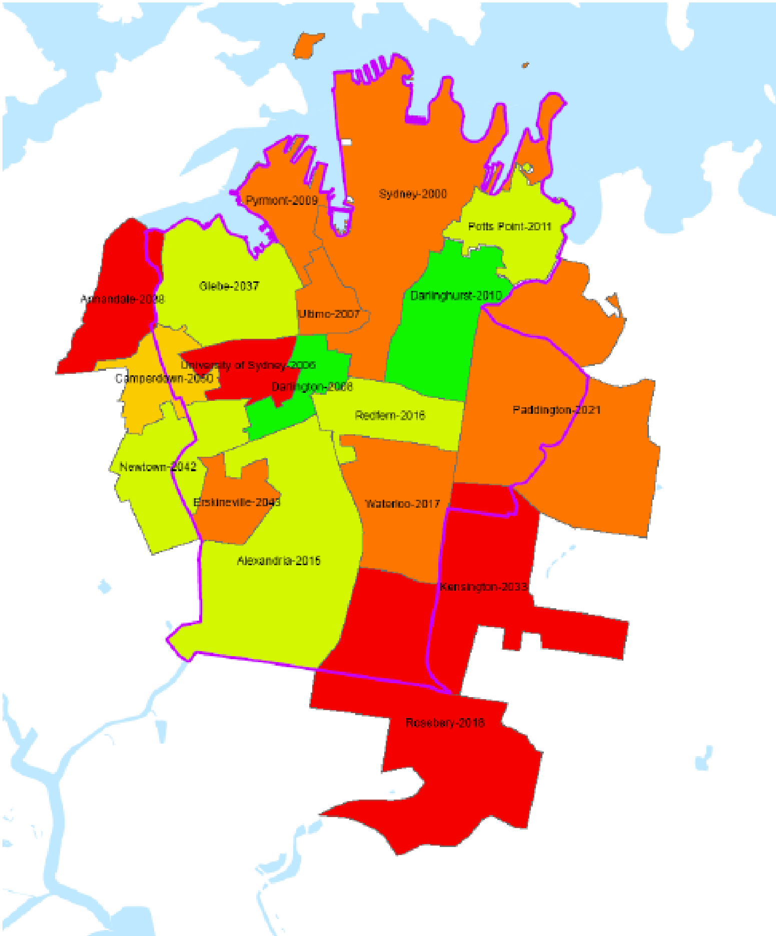

Figure 1: City of Sydney Local Government Area (LGA)

Results and interpretation

416 surveys were completed, see Table 1 for a break-down of characteristics. 193 respondents (46.40%) were male and 218 or 53.60% were female; a reasonably even distribution of gender. In terms of residency, 244 respondents (58.65%) were City of Sydney residents and 172 or 41.35% were non-residents.

The total maximum error margin (at the 95% confidence interval) based on this sample is approximately ±5%. This means that we can be confident 95% of the time that the proportional survey results are within 5% of the true population value for results. This makes the assumption that the sample is representative of the target groups and that the distribution on items is approximately normal. The error margin can be considered in several ways when assessing the sample, as a total or as subgroups of data, depending on the level of analysis in question. As subgroups have smaller samples the error margins are larger. Table 1 shows the ranges of error margins. Significance testing takes into account error margins depending on the contrast being examined.

Table 1: Sample Characteristics

Sample Grouping	Sample Range	Approx. Max Error Margin
Total Sample	416	±5%
Gender	193M/218F	±7%
Age Groups	n=20, up to n=132 (26-35 yo)	±22% to ±8.5%
Residential Location	244 COS Residents, 172 Non- Residents	±6.3% to ±7.5%

The sample is reasonably close to the expected fifty per cent split between males and females. Generally, females, particularly older females are more responsive to surveys in most market research methods and it is commonly found that they are slightly overrepresented in data sets unless quotas are enforced. The face to face component had the effect of correcting the online sample which was slightly pro male. This final difference of ±3% is not sufficiently large to justify weighting of data by gender. The age profile is distributed around a median age group of 36-45 years, with the most populous age group being aged 26-35 (see Fig. 2).When the age profile in the sample is compared to the full City of Sydney LGA, from the 2011 census, the profiles are similar, with some under representation in the sample survey of those under 35, and over-representation of those over 35 years of age. Overall it is a reasonably similar age curve. The sample is likely to be more representative of a 'CBD working age population' than LGA residents per se.

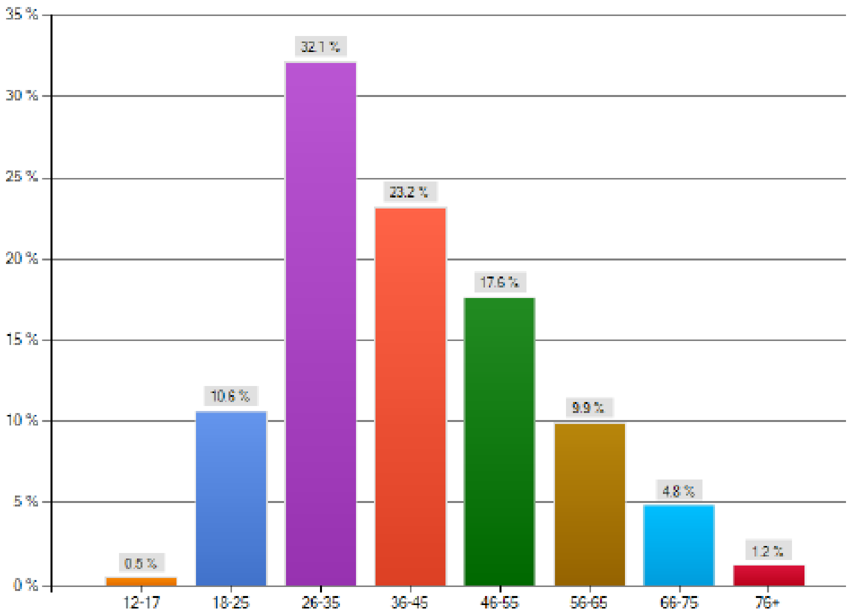

Figure 2: Age profile of survey respondents

The income levels of the sample is shown in Figure 3 and reveal that respondents are well paid compared to the median City of Sydney resident. For example the proportion of City of Sydney LGA residents earning greater than $80,000 per annum is around 23%, however in this sample it is almost half the respondents. As surveys were conducted during working hours it is more likely respondents were employed than unemployed. Furthermore the respondents had high levels of education which is positively correlated with income levels. In the sample 79% were degree educated compared to 33% in the LGA.

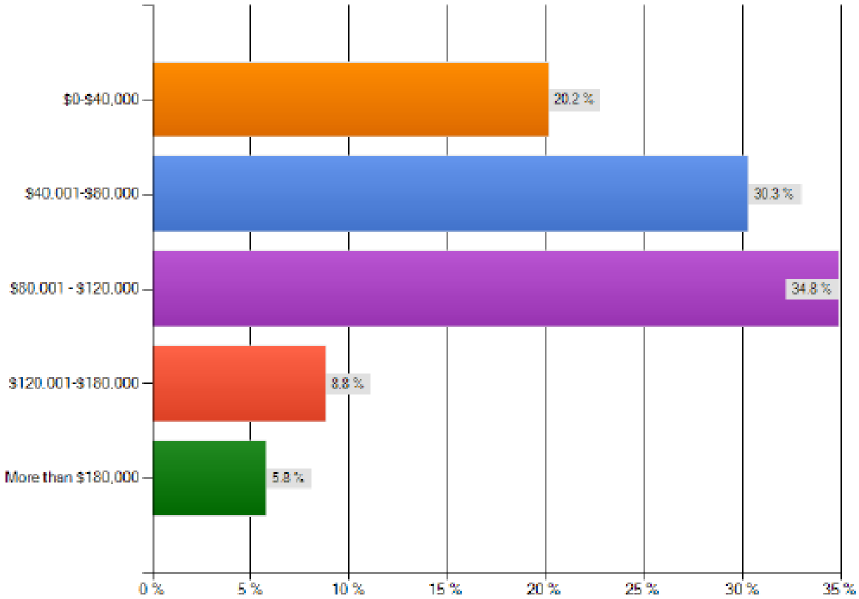

Figure 3: Income levels of survey respondents

Awareness

Three visual representations of green roofs were shown to respondents so that they could unambiguously see the concept being assessed. They were then asked which of five statements best described their understanding of green roofs. Responses are set out in Table 2. Overall self-reported familiarity is high. Those either working in the area or having a strong understanding were more likely to be male than female. There is limited knowledge and awareness in around a third of the sample (33.8%) who expressed either no knowledge (10.4%) or having 'seen something' (23.4%) about green roofs. Finally 28.7% described having a general knowledge and interest in green roofs.

Table 2: Green Roof Awareness

Best description of respondents' understanding	Proportion of responses
No awareness prior to survey	10.4%
Seen or read something about green roofs	23.4%
General understanding	28.7%
Strong interest in the concept	31.2%
Working in an area involving green roofs	6.3%

Where gender is concerned women expressed less understanding of green roofs than males, although only marginally, where 61.8% of males stated either a general understanding or a strong interest in GR compared to 58.2% of females. In terms of age, the oldest and youngest age groups displayed least awareness. Those aged 46 years plus ranked highest followed by the 26-35 years old age group. The lowest understanding of GR on age was found in the 18-25 year old age group. Interestingly those surveyed in the intercept surveys expressed lower levels of understanding than those who completed the surveys online. Perhaps people feel less able to give an impression of knowledge when speaking directly to another human or it is more likely that those who completed the online survey were motivated to do so by their interest in green roof and so there is some degree of self-selection bias in the sample.

Perceptions of green roofs

The respondents were asked to rate a number of sustainability attributes of green roofs by assigning priority ratings to areas where green roofs could deliver benefits. The attributes they were asked to rate were:

a) increasing habitat and bio-diversity;
b) improving air quality;
c) reducing building energy costs;
d) improving views and city landscapes;
e) reducing urban heat island;
f) providing space for recreation and leisure;
g) managing stormwater run-off;
h) acting as noise buffers; and
i) reducing glare between buildings.

Figure 4 shows the results where items at the top of the bars and coloured purple show the higher priority ratings.

The items with the highest priority were increasing habitat and bio-diversity (72.3%), improving air quality (71.6%), reducing building energy costs (69.3%) and improving views and city landscapes (68.1%). If sustainability is considered to comprise three components of environmental, economic and social sustainability (Elkington 1997), this data reveals that the first two items are environmental. The third attribute is economic and the fourth is environmental/social. In the mid-range of priorities reducing the urban heat island and, providing more recreational space; an environmental and a social attribute respectively. The lowest priorities were managing stormwater runoff (56%), acting as noise buffers (45.4%) and reducing glare between buildings (33.6%). Stormwater runoff and noise are environmental attributes, whereas reducing glare is a comfort issue and therefore classed as environmental / social.

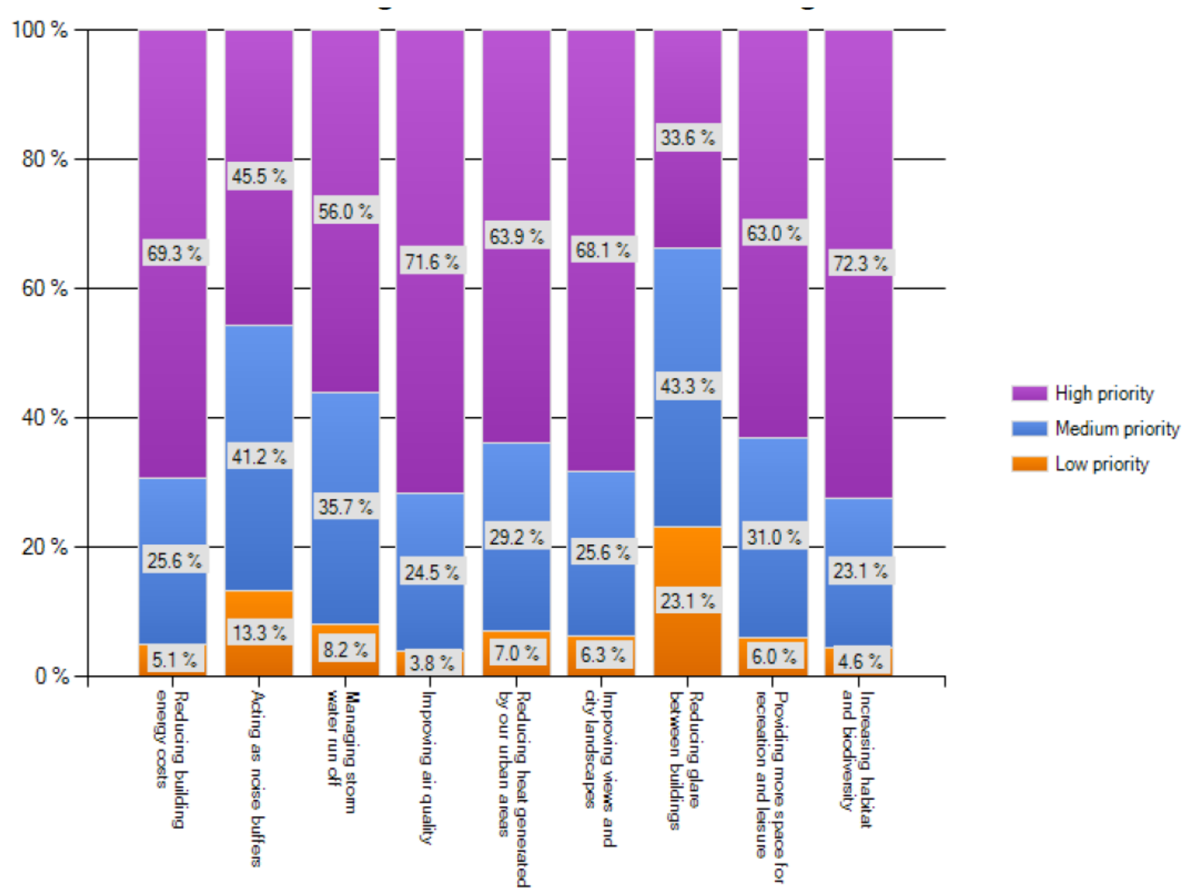

Figure 4: Sustainability ratings of survey respondents

When gender difference was examined at the 0.5 significance level females assigned higher priority to reducing building energy costs, acting as noise buffers, air quality and, increasing habitat and bio-diversity. Across all attributes females rated environmental attributes more highly than males (see Figure 5).

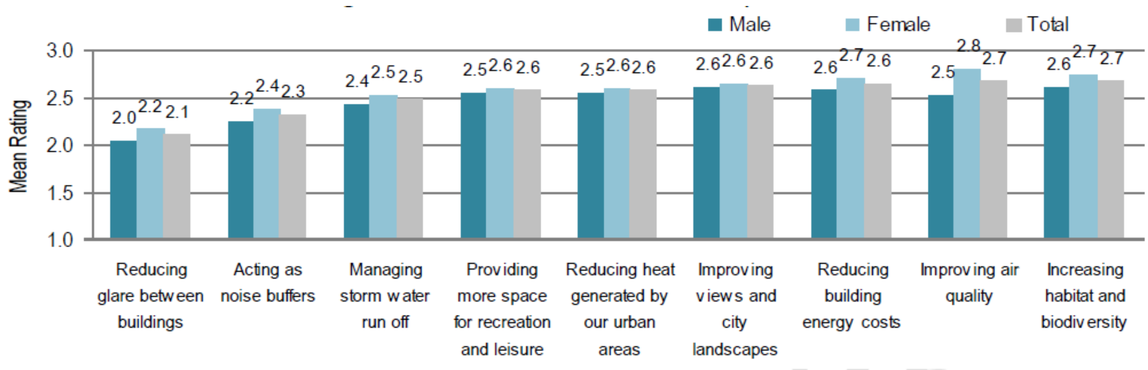

Figure 5: Sustainability priorities and gender

Where age is considered two attributes 'acting as a noise buffer' and 'reducing glare' became more important to older respondents. Equally when respondents' residential location was evaluated the City of Sydney residents in the sample were more concerned about noise and glare issues than non-residents. With urban densification, and an aging population, increasing noise and glare issues may become more prominent. Interestingly the workers in the sample, who are non-residents, were more concerned about improving views and city landscapes. Visitors to the city were more concerned with air quality and travellers more concerned about habitat and biodiversity. Visitors are those paying a short visit to the city, whereas travellers tend to have extended stays and often work in the city during their stay. These results reveal the interests and concerns of respondents vary depending on the type and extent of their relationship to the city.

Perceptions of social and functional benefits

The survey asked respondents about the importance of green roofs for direct human use such as exercise, growing food, a space to catch up with friends, a peaceful relaxing space to enjoy and a place in which to get some fresh air in. The results showed considerable variation depending on the functional use being considered. Figure 6 shows the results in categories of very important, important, moderately important, slightly important and not important. The highest importance was attributed to getting some fresh air (where 88% stated either very important or important). This was followed by a space for 'peace and quiet' (81%). Growing food rated at 61%, followed by social space to catch up with friends (53%) and a place to exercise (45%). Interestingly these respondents were more interested in personal environmental benefits over social engagement. The gender analysis showed significant differences in this item. Females rated social aspects such as exercise, a space to catch up with friends and grow food higher than males. When age was considered all age groups valued fresh air and peace and quiet highly.

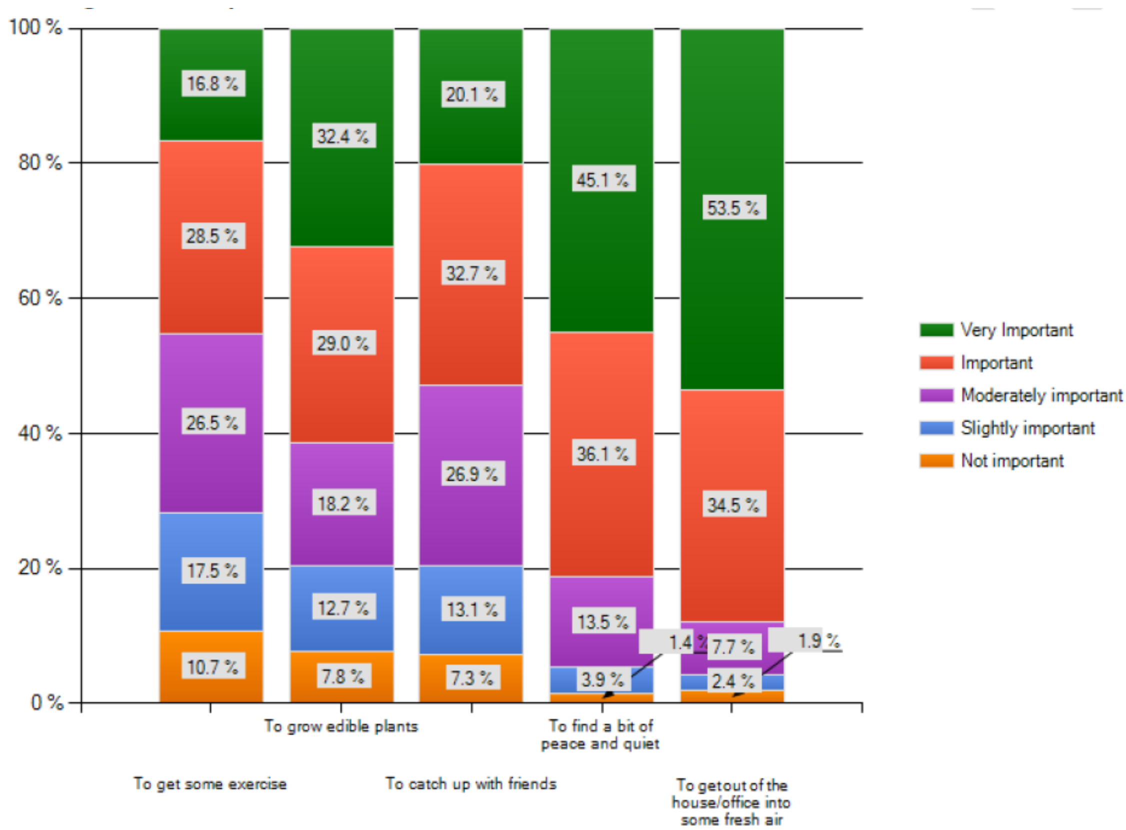

Figure 6: Importance of social/functional benefits of green roofs

General attitudes to development of green roofs
Respondents were asked to state their levels of agreement with six statements related to the development of green roofs. The statements were:

a) as long as they meet current building standards I think GR projects should be allowed to develop on their own merit;
b) encouraging new building techniques that minimise environmental impacts should be a priority for the City of Sydney;
c) if we don't build more greenery into the CBD, Sydney will fall behind other global cities as an attractive place to live;
d) we are better off investing in normal suburban parks than green roof projects;
e) it is well worth encouraging greater use of building materials with even a small environmental advantage; and
f) the benefits of having greenery around us outweigh a small additional cost.

For statement one the highest score was 37.7% agreeing followed by 30.3% agreeing strongly. Statement two scored highest on strongly agree (64.7%), followed by agree (30.8%). Statement three scored highest on strongly agree (38.6%) followed by agree (33.2%). With statement four, the highest score was disagree (41.7%) with the notion that the City were better off investing in parks than green roofs. Statement five rated 'agree' the highest, with 48.7% followed by strongly agree (33.7%) and; finally statement six with 55% stating they strongly agreed that the benefits of greenery outweighed a small additional cost. Therefore support was strong across all aspects.

Females consistently ranked all aspects higher than males. Overall the strongest rating was that the City should prioritise building techniques that minimise environmental impacts, followed by acknowledgement that the benefits of greenery outweigh a small additional cost, which is very positive. The lowest ranked item was the statement that conventional street level parks should have priority over green roof spaces. This result shows a strong community commitment to green roofs at the expense of investment in conventional parks.

Conclusions
This paper addresses the question *what is the community awareness and perceptions of green roofs and green in the Sydney CBD*? The literature review identified benefits relating to green roofs with which the survey sought to determine the level of awareness in a sample of residents, workers and visitors in the City of Sydney. The sample was generally representative of the population in terms of gender and age, but was better paid and educated compared to the median for the area. There were marginal differences of awareness of green roofs based on gender. On the basis of age there was least awareness in the old and young.

Improvements to habitat and bio-diversity and air quality were perceived as the most important environmental sustainability attributes of green roofs. Given that Sydney has only 4% of its native flora remaining, the other 96% having been destroyed since the arrival of Europeans just over 200 years earlier, this is an interesting outcome. Some differences were found with respect to age, where older respondents considered attributes such as noise buffering and glare reduction as more important than other age groups. Furthermore differences as to the importance of particular attributes were found between residents and non-residents.

Of the social and functional attributes, access to fresh air, peace and quiet and growing food were most important. With these attributes there was consistency among the age groups but significant differences based on gender.

Finally the general statements showed overall the strongest community view was that the City should prioritise building techniques that minimise environmental impacts, followed by the view that the benefits of greenery outweigh a small additional cost. In this respect, wide scale retrofit of existing buildings with green roofs could support delivery of zero carbon goals. The lowest ranked perception was that street level parks should have priority over green roof spaces and shows a strong community commitment to green roofs.

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RETROFITTING HOUSING WITH LIGHTWEIGHT GREEN ROOF TECHNOLOGY IN SYDNEY - AUSTRALIA AND RIO DE JANEIRO - BRAZIL

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Abstract
The built environment contributes around half of all greenhouse gas emissions and 87% of residential buildings the UK will have in 2050 are already built (Kelly 2008), there is a need to adopt sustainable retrofit for existing residential buildings. Furthermore these statistics are broadly similar across many countries. The question is; what are viable solutions? One answer may be to retrofit with green roofs as there are environmental, economic and social benefits. Environmental benefits include potential reductions in operational carbon emissions, reductions in the urban heat island, increases in bio-diversity, housing temperature attenuation and reductions in stormwater run-off. Economically, benefits are reduced roof maintenance costs and lower running costs. The social gain is the creation of spaces where people have greater access to nature. However there are barriers to the adoption of retrofitted green roofs; which include perceptions of structural adequacy, risk of water damage, high installation and maintenance cost, as well as access and security issues. In some locations the intent will be to reduce cooling loads, whereas others will desire thermal insulation, or will seek reduction in stormwater run-off. The ability to meet the demands will depend on budget and physical characteristics. Many Australian and Brazilian residential buildings have profiled metal sheet roofing which is a lightweight material with poor thermal performance During summer periods Sydney as well as Rio de Janeiro temperatures can reach 45 degrees Celsius and rainfall patterns are variable and changing. This research reports on an experiment on two small scale profiled metal sheet roofs in both cities which aimed to assess thermal performance. One roof was planted to compare performance to an unplanted roof. The findings are that considerable variation in temperature were found in both countries indicating that green roof retrofit could lower cooling energy demand considerably.

Keywords: *Green roof retrofit, Sydney, thermal performance, residential buildings, housing, case studies.*

Introduction
There is a consensus amongst climate scientists that global weather patterns are changing with some regions getting hotter and drier whilst others will become wetter (Australian Bureau of Meteorology 2014). One of the highest contributors to human induced climate change is the built environment, which adds around half of all greenhouse gas emissions into the atmosphere. Within the built environment the biggest land use type contributing to green-house gas emission is the residential sector (Maslin *et al.* 2007). Whilst efforts are being made globally to improve sustainability in buildings through operational and embodied energy efficient design, it remains the case that most of the stock that will exist by 2050 is already built. In the UK it is estimated that 87% of residential buildings the UK will have in 2050 are already built (Kelly 2008). Furthermore many cities are experiencing rapid urban expansion and or densification which contribute to the phenomena known as the urban heat island effect whereby city centres are

sometimes up to five degrees warmer than outer suburbs (Lamond, Wilkinson and Rose 2014). In addition, within some cities urban heat canyons are created whereby heat is trapped between buildings which during excessively hot days can contribute to negative human health impacts and even fatalities (Oke 2006 and Harlan *et al.* 2006). In the recent past, high temperatures have been observed worldwide. The city of Rio de Janeiro experienced historical records of high temperatures on February 2014 (Climatempo 2014). In a four to five day period of plus 45 degree days in January 2014 in Melbourne Australia more than twice the average rate of mortality was experienced. These deaths were attributed to the excessive heat conditions which were exacerbated in the CBD (ABC 2014); furthermore with predicted climate change impacts and an ageing population these statistics look likely to increase. On this basis the focus for climate change mitigation is through the adaptation and sustainable retrofit for existing buildings. Furthermore these statistics are broadly similar across many countries. The question is; *what are viable solutions in terms of retrofitting our existing residential buildings?*

If the aim is to reduce building related green-house gas emissions; for some regions the goal will be to keep buildings cool and therefore reduce cooling loads, whilst for other areas the problem will one of retaining heat and reducing heat loss through leaky buildings. Whereas in other regions the problem will be one of accommodating increased frequency of intense rainfall (Lamond, Wilkinson and Rose 2014). One answer, which may suit a number of regions to some degree, may be to retrofit buildings with green roofs as there are environmental, economic and social benefits.

The environmental benefits include potential reductions in operational carbon emissions, reductions in the urban heat island, increases in bio-diversity, housing temperature attenuation and reductions in stormwater run-off (Castleton 2010, Wilkinson and Reed 2009 and Sydney 2012). Air quality is improved as plants remove carbon dioxide and harmful pollutants from the atmosphere. In addition green roofs provide a habitat for insects and birds and reptiles to shelter and find food sources and water (Williams, Raynor and Raynor 2010).

Thermally the mass of the green roof improves the insulating qualities of the building by reducing heat transmission through the roof. Much heat loss occurs through the roof as heat rises and then escapes through inadequately insulated and leaky roof structures. Some authors have evaluated the role of green roofs cooling and warming potential in energy savings, and the potential for retrofit, based either on modelling or experimental data. It is a common consensus that, in non-insulated buildings (common feature in Rio de Janeiro and Sydney), the addition of green roofs can improve the insulation properties and reduce annual energy consumption. According to Castleton (2010) over the past 10 years, several studies have shown that green roofs can offer benefits in winter heating reduction as well as summer cooling. Nichaou *et al*. (2001) showed an annual energy saving potential of green roofs on non-insulated buildings for heating and for cooling, of 45-46% and 22-45%, respectively. Wong *et al.* (2003) found for a non-insulated case covered by an extensive green roof of turf, an annual energy saving of 10.5% when compared with a non-greened exposed roof. However, it is important to emphasize that the aforementioned energy saving is applied to adjacent environments to the rooftops. Alcazar and Bass (2005) state that due to the tall nature of the buildings, roofs comprise around 16% of the total building envelope, and the largest reductions in energy consumption were seen in rooms directly below the green roof. There was no energy savings for more than three floors down.

Where stormwater or pluvial flooding is an issue green roofs can reduce the run off rate and also filter or cleanse the water passing through the roof covering (Lamond, Wilkinson and Rose 2014). There are numerous environmental benefits from the installation of green roofs in urban settlements which are suitable whether the problem is one of excess stormwater or a need to enhance thermal performance. It is the case that the specification of white roofs, roofs that are painted white or reflective colours is the most cost effective means of reducing heating load in buildings however the bio-diversity and air quality benefits are absent with this option (Hes *et al.* 2012). Thus the decision to retrofit a green roof has multiple variables and should not be evaluated on one variable alone but the multiple benefits that are delivered (Wilkinson, Ghosh and Page 2013).

Economically, the benefits to occupiers and owners are reduced roof maintenance costs and lower running costs (Castleton 2010). There are erroneous perceptions however, among the practitioner community that green roofs lead to higher maintenance costs (Wilkinson, Ghosh and Page, 2013) which is resulting in less specification of green roof technology in buildings. Whether the aim is heat retention or reducing the cooling load green roofs can deliver lower operating costs (Castleton 2010).

The third aspect, the social gain is the creation of spaces where people have greater access to nature. The bio-philia effect describes the phenomenon whereby humans experience positive feelings as a result of the connection to the natural environment (Kellert and Wilson 1993). Unfortunately for many, living in cities; access to the natural environment is limited and diminishing (Sydney 2012). In Sydney, for example, it is estimated that there are less than 22 metres squared per resident and that around 15.5% of the city is covered by urban canopy (Sydney 2012). The city wishes to increase this level of urban greenery for the health and well-being of the community (Sydney 2012). There are initiatives which seek to increase the amount of urban greenery in Sydney by 20% before 2020 (202020 Vision 2014) and the specification of green roofs would be a way of contributing to the delivery of this target. On the contrary, the amount of green spaces in Rio de Janeiro has decreased significantly, mostly due to the lack of space and population growth. Furthermore no plans have been adopted yet to deal with this problem.

However there are barriers to the adoption of retrofitted green roofs; which include perceptions of structural adequacy, risk of water damage, high installation and maintenance cost, as well as access and security issues.

In some locations the intent will be to reduce cooling loads, whereas others will desire thermal insulation, or will seek reduction in stormwater run-off. The ability to meet the demands will depend on budget and physical characteristics. Although the technology to design and retrofit green roofs exists, the uptake and the demand have not been high. Overall, the gains have not been deemed sufficient and in both cities, the existing numbers of residential green roofs confirm this observation. Many Australian and Brazilian residential buildings have profiled metal sheet roofing which is a lightweight material with poor thermal performance; heat transfer is very high. Many buildings have little or no insulation to offset the high heat gains. During summer periods Sydney, as well as Rio de Janeiro, temperatures can reach 45 degrees Celsius and rainfall patterns are variable and changing; affected by La Nina and Il Nino weather cycles. This research reports on an experiment on two small scale profiled metal sheet roofs in both cities to assess thermal performance. In each city, one roof was left as a control whilst the second roof was planted with succulent plants in trays. Data was collected using thermal data loggers over a summer and autumn season. The paper discusses the findings and the potential for retrofitting residential stock with lightweight trays planted with succulents.

In 2014 the City of Sydney adopted the first green roofs and walls policy for Australia, which sets out a commitment to increase the number of high quality green roofs and walls in the City (Sydney 2014). The policy includes a 3-year implementation plan to ensure the policy is understood, properly adopted and integrated. There are 59 green roofs in Sydney currently which serve a variety of purposes including enhancing thermal performance (Sydney 2014).

Research Methodology

The methodology adopted is predicated on the development of simple technologies to mitigate the problems created by increasing urban densification which exacerbates the urban heat island which in turn leads to uncomfortably high internal housing temperatures. There are many technologies and approaches available to execute this research; but in this case the researchers aimed to use adaptive techniques that minimised initial costs and maintenance costs; in other words technologies which would be affordable and easy to implement. For this reason, this project used lightweight removable modules of vegetation (rectangular containers) of low thickness. This modular system enables planting, cultivation and maintenance off site to be undertaken.

The researchers sought to evaluate the performance of a green roof retrofit system which could be widely used in metropolitan areas. At this point in time there is a dearth of empirical evidence on the performance of green roofs in Australia, with most data coming from the US or Europe where climatic conditions are very different. Similar conditions exist for South America in terms of empirical data on green roof performance. Previous studies have shown significant variations based on temperatures, evaporation rates and wind conditions which affect the performance of green roofs.

Two sets of experiments were performed in Australia (Sydney) and in Brazil (Rio de Janeiro). The Australian site is located at the University of Technology, Sydney in Ultimo Sydney and the Brazilian location is on the roof of an existing building at the Oswaldo Cruz Foundation (Fiocruz).

Succulent plants were preferred due their higher drought resistance qualities and a lower risk of fire. Furthermore these species can develop easily in shallow soils, and thus, structural reinforcement of existing roofs is unnecessary. Additionally, due to the modular characteristics of the planting containers, the modules can be applied directly onto the roof covering be it profiled metal sheeting or tiles.

Rectangular plastic containers were selected according to the availability at the different sites (Rio de Janeiro – 400 x 500 mm and Sydney – 190 x 330 mm) where the experiments were performed, as shown in
Figure **1**.

Figure 1: Rectangular plastic containers used in the temperature experiments - left hand side - Brazilian module, provided by Cidade Jardim Institute; right hand side - Australian module

It is important to highlight that both containers have a water storage system which meets two main objectives. Firstly it provides water to the soil through evaporation, enhancing the plants survival even during extended period of no rain. Secondly, it can attenuate temperature fluctuation due to the water layer between the soil and the roof.

The soil is separated from the drainage system by a permeable fabric (Geotextile) which allows the passage of water but prevents the soil from leaking into the water chamber. For the plant species used in this research a soil with good drainage and low organic load is required. A composition of two parts of sand to one part of loam is employed.

The evaluation of the green roofs cooling potential is performed by the comparison between two housing prototypes with vegetated and non-vegetated roofs. Due to financial limitations it was not possible to use full scale housing for the experiment. Therefore small scale structures are used to demonstrate the thermal performance of a non-green, traditional roof and a green roof. The experimental set-up comprises covering the roof of the one of the prototypes with planted soil containers. Different types of housing prototypes are considered in this research. As shown in Figure 2, the Rio de Janeiro tests were carried out using small brick houses covered with metal sheeting, whereas in Sydney, metallic sheds were employed. In Australian housing profiled metal sheet roofs are typically specified and for this reason the metal sheds were selected.

A simultaneous comparison between the records of temperature inside the vegetated and non-vegetated structures was made use of data loggers that allows a continuous temperature records during long periods of time. The temperature measurements were carried out using Extech TH10 Temperature USB Data logger, using a time sampling of 30 minutes. The Rio de Janeiro tests were performed over 194 days, from October 17th 2012 to April 29th 2013, whereas Sydney trial tests comprised a 97 day period from December 11th 2013 to March 18th 2014.

The data loggers were positioned in different heights inside each of the prototypes, according to the experimental site. In Rio de Janeiro and Sydney they were placed 250 and 50 mm respectively, below the top of the structure. All the temperature differences observed are attributed only to the influence of heat incidence on the structures, given that the perimeter conditions between the vegetated and un-vegetated prototypes are identical.

Figure 2: Housing thermal experiments. Left hand side – Rio de Janeiro; Right hand side – Sydney

Results and discussion

The results with regards to the green roof cooling potential for the two experimental sites (Rio de Janeiro and Sydney) are depicted in figures 3 to 5 below. Besides some basic differences in the structures (that is blockwork in Rio de Janeiro and metal sheeting in Sydney), the tendency in temperature attenuation is evident. From the measurements performed in Rio de Janeiro and in Sydney it was observed that green roofs are able to attenuate daily variations of temperature.

Rio de Janeiro results

Figure **3** presents a comparison between the non-green and green roofs internal temperatures, during the 194 day data collection period, which comprises the whole Brazilian Summer period, and also part of Spring and Autumn. Some of this work was partially reported in Feitosa (2012).

During the period of investigation the non-green roof presented maximum, minimum and average temperatures equal to 41.1ºC, 20.1ºC and 28.8ºC respectively. Correspondingly the values observed in the green roof case were 39.3ºC, 20.3ºC and 27.7ºC.

Based on daily variations of temperature, the maximum values observed during daytime for non-green and green roofs varied from 23.9ºC to 41.4ºC and 23.2 to 39.3ºC, respectively. The minimum values which occurred during the night time, varied from 20.1ºC to 31.8ºC for the non-green roof and 20.3ºC to 31.8ºC for the green roof. It is important to highlight that the green roof cooling potential is not directly related to the differences observed between those limits presented, due to the existing time lag between the non-green and green roof temperature peaks.

Comparing the simultaneous temperature differences between green and non-green roofs it was observed that these values vary from -1.5ºC to 5.6ºC. The temperature differences were dependent on the temperature background. That is to say that previous temperature register are able to influence present ones, considering that green roofs tend to attenuate thermal exchanges. If for example a warm day increases the inner temperature, this internal heat will influence the following temperature register. Positive values mean higher non-green roof temperature, whereas negative values depict the opposite. The lowest positive temperature differences between non-green and green roofs (≤2ºC) were observed when the internal non-green roof temperatures were below 30ºC. The highest positive temperature differences (≥5ºC) were registered at the end of the summer period, when during the previous night-time period the green roofs temperature were cooler than the non-green roof. However, higher green roof nocturne temperatures contribute to weaker following day-time temperature differences (<5ºC). The delay observed between the temperature peaks of non-green and green roofs results in slightly warmer green roof temperatures (negative differences) during the night-time and early morning periods, which contributes to weaken the temperature differences in the following day.

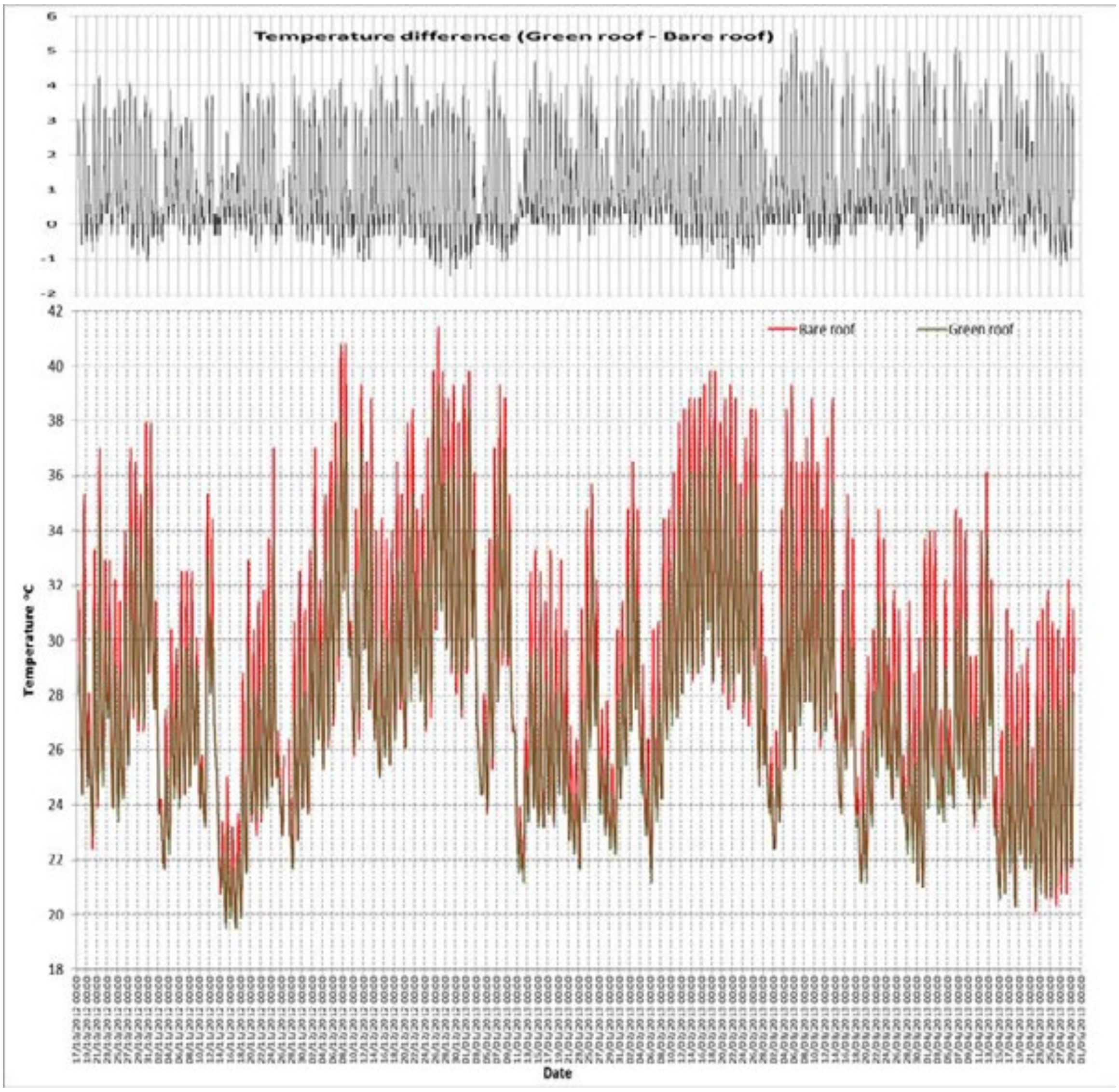

Figure 3: Comparison between non-green (bare) and green roofs inner temperature – experiments performed in Rio de Janeiro, Brazil

Sydney results

Despite of the shorter period, when compared to Rio de Janeiro experiments, it was also observed that a significant green roof cooling potential occurs. However, according to the characteristics of the site where the experiments were undertaken, it can be observed a particular pattern in temperature registers. As shown in

Figure 4, it is observed a sudden reduction in temperature for non-green and green roofs occurs around 3pm due to the shadows caused by adjacent buildings. From this same figure it can be seen that a slower response to temperature variation for green roofs, which is consistent with their insulating properties.

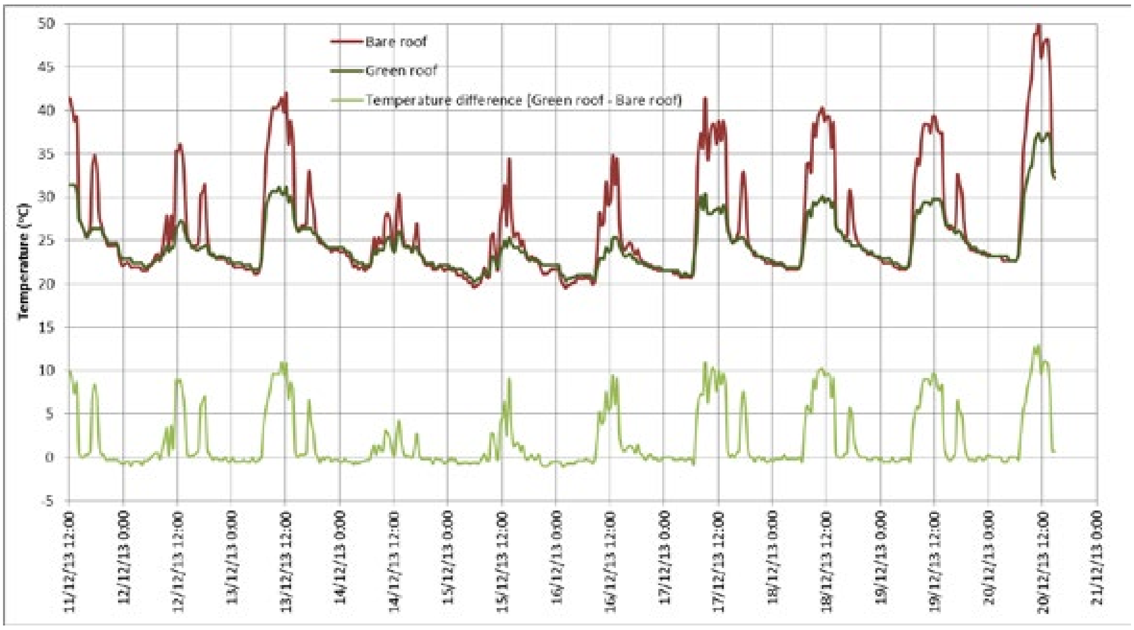

Figure 4: Influence of shadows caused by nearby buildings in temperature

Figure 5 presents a comparison between non-green and green roof inner temperatures, over 97 days, during the summer period. The Sydney non-green roofs presented maximum, minimal and average temperatures equal to 50.3ºC, 17.2ºC and 25.2ºC, respectively. Correspondingly, the values observed in green roof case were 37.4ºC, 17.6ºC and 23.9ºC. The Sydney experiments showed a similar profile to the observed experiments in Rio de Janeiro, where the highest positive differences also occurred around noon in the warmest days.

The temperature differences between green and non-green roofs varied from -1.6ºC to 14.8ºC. The lowest positive temperature differences between the non-green and green roofs (≤4ºC) were observed for the non-green roofs inner temperature under 30ºC. The highest positive differences (≥10ºC) occurred basically to non-green roof temperature peaks higher than 42ºC. Negative differences were evident practically along all night time periods, corroborating additionally the green roof efficiency in attenuate high and relatively low temperatures.

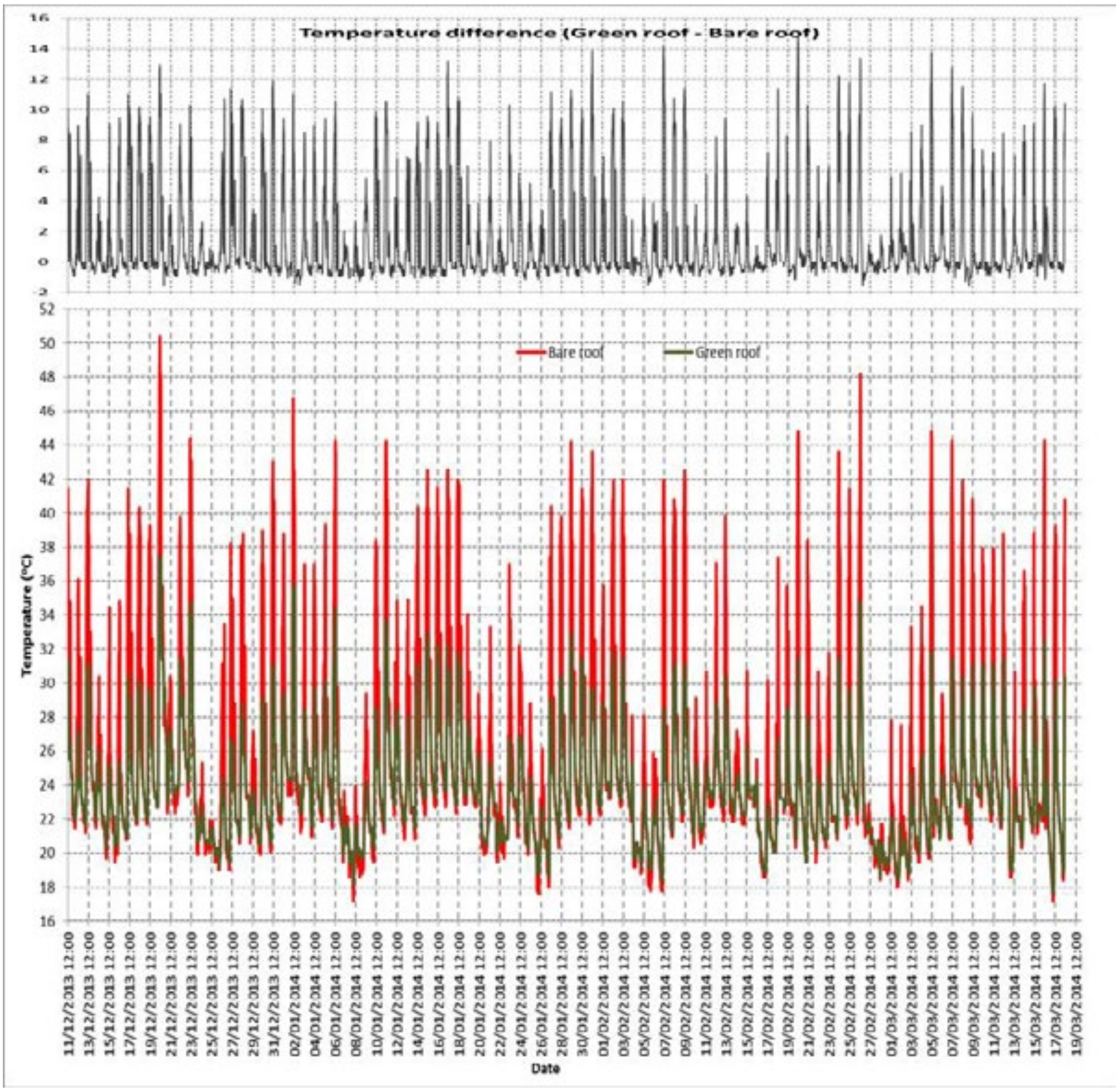

Figure 5: Comparison between non-green and green roofs inner temperature – experiments performed in Sydney, Australia

Evaluation of Rio de Janeiro and Sydney results

This work does not solely intend to perform a comparison between Sydney and Rio de Janeiro experiments, but it aims to evaluate the green roofs potential to attenuate housing temperature under different aspects.

Table 1 depicts for Sydney and Rio de Janeiro sites, non-green and green roofs maximum, minimum and average temperatures, as well as, their higher and lower differences.

It was observed a green roof cooling potential in Sydney greater than the observed potential in Rio de Janeiro, which was most likely due to the existing differences in both experiments. This may be attributed basically to positioning of the temperature data loggers. In Sydney they are located about 50 mm below the roof, whereas in Rio de Janeiro they are 250 mm below the roof. To evaluate this influence, a new pair of data loggers has been purchased to be placed in both Sydney sheds, in order to provide a future temperate comparison in a lower position.

Table 1: Experimental temperature comparison between Sydney and Rio de Janeiro

Temperatures (ºC)	Rio de Janeiro			Sydney		
	Bare roof	Green roof	Simultaneous temperature difference	Bare roof	Green roof	Simultaneous temperature difference
Maximum	41.4	39.3	5.6	50.3	37.4	14.8
Minimum	20.1	20.3	-1.5	17.2	17.6	-1.6
Average	28.8	27.7	-	25.2	23.9	-

Source: Authors.

It is believed that the new temperature measurements in a lower position in both sheds will provide temperature differences closer to the observed in Rio de Janeiro. Additionally, it is also important to consider that, besides the positioning of the data loggers, the differences observed between Sydney and Rio de Janeiro may lie on the setup characteristics of both experiments sites, such as:

a) neighbourhood shading condition existing in Sydney and non-existing in Rio de Janeiro; and
b) different roof side conditions, which comprises brick walls in Rio de Janeiro and metal sheeting in Sydney.

Besides, the differences adopted in both methodologies showed the green roofs' relevance in temperature attenuation.

Another aspect to consider is related to the water existence and/or its levels in the storage systems. Due to the high specific heat, water is supposed to provide inertia against temperature fluctuations. However, in the studies performed so far, these water levels were not monitored, and its influence remains unknown in the present work. This evaluation is intended to be object of further research to be carried out in Rio de Janeiro.

Additionally, it should be pointed that only temperature, and not solar radiation levels, was collected in the two studies presented. Thus, it is posited that the temperature attenuation provided by the green roofs must be directly related to high solar radiation levels and that during cloudy days this effect tends to be less pronounced.

Conclusions

Both experimental setups in Rio de Janeiro and Sydney showed the potential for green roofs as a means of cooling buildings, reducing carbon emissions and helping towards zero carbon targets. However, the experiments carried out in Sydney presented a potentially better green roof performance in housing temperature attenuation, which may be partly attributed to the closer positioning of the data loggers in relation to the roof. Additionally, the water levels in the water retention systems may have a relevant role with regards tothe heat exchange through the roof, which can support the role of the water layer as part of the green roofs insulation properties. To evaluate this issue further research is necessary.

Even though there are no registers of low temperatures (that is <16ºC) in this dataset, the negative differences observed (green roofs temperature higher than non-green roof) may indicate the potential for green roofs to attenuate extremes of temperature, due to their insulation properties. It is probable that different substrates would provide different results and this should be investigated,

The temperature differences showed a relationship to the temperature background. The delay between temperature peaks of non-green and green roofs results in slightly warmer green roof temperatures (negative differences) during the night-time and in the early morning periods, which contribute to weaken the temperature differences during the following day.

Considerable differences of temperature between city centre and suburban urban areas have been reported in the literature. Green roofs promote thermal comfort improvement, attenuating heat exchanges between the internal and external environments of buildings. Additionally, as these results show; it is expected that attenuation of the urban heat island effect in large cities can be achieved, if green roofs are adopted for new build and retrofitted for existing buildings on a large scale. The research has demonstrated that roof structures planted with succulent plants are viable and could provide a low cost, drought tolerant, lightweight option to reduce heat gain and heat loss through roof structures in some regions of NSW and Australia.

However, as far as thermal effect is concerned, the adoption of green roofs in urban centres is a partial solution, due to the contribution of the building facades in the overall heating. Thus, a combination of green walls and green roofs could be an optimum solution to this problem. Furthermore, with regard to energy saving issues, considering that buildings comprise the most part of big cities, the use of green roofs would only bring effect to top floors, which reinforce the combination of these systems (green roof and green walls) in the urban environments.

Further experiments with structures which more closely emulate typical Australian housing specification in terms of wall construction would be very useful. One of the limitations of the research is that the walls of the shed are profile metal sheeting which is not typically specified in housing. In the Rio de Janeiro experiments, brick walls comprise a common type of solution adopted in the majority of housing. However, additional procedures, such as green walls, should be evaluated in order to mitigate the existing thermal exchanges through the walls.

This research is ongoing and data is being collected for a full calendar year. Through this data it may be possible to estimate the level of economic savings and greenhouse gas emission reductions that may be achieved through green roof retrofit with succulent plants in New South Wales. Further iterations will see insulation introduced to the structures in Sydney to determine and compare the thermal performance of the structures. Data is also to be collected on the nature and extent of the attraction of bio-diversity to the Sydney roofs to determine the likely impact of an increase in green roof provision over time. In the Rio de Janeiro case, it is intended to evaluate the role of water in the green roof retention system, in the prototype covered with the vegetated system. Additionally, a future project to be submitted for approval, would be for the evaluation of the effect in energy savings before and after the adoption of green roof and green walls system in an existing house. It is possible that the widespread retrofit of green roofs may, with reductions to cooling demand, help towards zero carbon goals in the built environment.

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DESIGN AND TECHNOLOGY FOR INCLUSIVE HOUSING: PRO-FESSIONAL RESIDENCY EXPERIENCE

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DESIGN AND TECHNOLOGY FOR INCLUSIVE HOUSING: PRO-FESSIONAL RESIDENCY EXPERIENCE

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Abstract
Adequate housing has been a chronic issue in major Brazilian cities. The main problematic aspects of the past century include accelerated urban growth processes, insufficient income for most of the population, restricted access to urbanized land and ineffective, selective and incoherent public policies. The result is an extensive and increasing informal self-built urban occupation. Generally, no technical assistance is provided to improve these settlements. Although important initiatives have been achieved with the City Statute approval – a new Brazilian legal-urban order to provide land and housing access, continued institutional actions are required to provide broad partnerships. Towards this end, this paper presents a university extension project that made the Professional Residency in Architecture, Urbanism and Engineering turned possible at the Federal University of Bahia, designed by the Architecture School in partnership with Polytechnic School. Similar to what already occurs in the Medical Residency as a graduate program, this new professional residency is a specialization course in Technical Assistance for Housing and City Rights, which includes university classes, workshops, seminars, field work and design activities. Based on the initial results, analysis is focused on methodological aspects of the participatory processes in obtaining low-cost technologies and design, geared towards inclusive housing and sustainability. This recent project finally puts Brazilian Federal Law 11,888 (BRASIL 2008) – Free and Public Technical Assistance for Social Housing – into practice with the potential to expand as a program on the national level and to attract international exchanges for improving technologies. This interface among teaching, research and extension aims to empower professionals and citizens to promote urban insertion and social inclusion projects, learning with the city in a broad and continuous dialogue that sets new commitments for city rights.

Keywords: *Technical assistance, university extension, professional residence, inclusive housing, sustainable design and technology.*

Introduction
New technologies referring to environmental sustainability in housing today considers mostly the new products and services offered to formal homebuilders, although they are still barely able to adopt recently emerging innovations such asmass custom design approach to the delivery of sustainable affordable homes. Even less has been accomplished when considering the huge demands for improving the informal housing urban condition that is widely found in less socially developed countries.

In the Brazilian contemporary urban context, there has been a constant political struggle for governmental interventions to address the basic needs of poor communities, such as adequate housing, basic sanitation and energy distribution. One of the main advancement of the social movements for urban reform has finally resulted in the approval of Federal Law 10,257 (Brasil 2001) – known as the City Statute, which can guide for better sustainable urban environment considering design and technology for inclusive housing.

Much has been achieved since then: innovative laws, inclusive policies, and participatory instruments in addition to our resources. Brazil is nowadays the 7th biggest economy in the world, a powerful emerging country in the face of a profound world economic crisis. However, have not been able to effectively apply these achievements towered the democratic construction of cities, nor have we recognized the win-win situation of promising social investments for the inclusion in and the betterment of cities.

Within this context, architects, city planners and engineers, professions with the function of planning and creating spaces, with the scope of the complex interdisciplinary task of imagining and creating better and more inclusive cities, feel powerless to implement the invention and use of better technologies. At the present moment, strengthened by the collective will that creeps in by the definition of other priorities, these professionals should be able to act together with communities and city managers in better initiatives for necessary changes.

Contributing to this, the Federal University of Bahia, via the School of Architecture, together with the graduate program in Architecture and Urban Planning and the Lab-Habitar- Laboratory for Housing and City-, in partnership with the Polytechnic School, launched the proposition of the Residency in Architecture, Urbanism, and Engineering (AU+E/UFBA). As a specialization course, similar to that of the medical school, it enables the Technical Assistance for Housing and the Right to the City[1], with the enrollment of its first class in the first academic semester of 2013. This project, directed collectively in the last years, finally puts Federal Law 11,888 (BRASIL 2008) into practice, for Public Technical and Free Assistance for Social Interest Housing. This project brings the perspective to become a continued activity, and to amplifyin a national network. For this to happen, it is fundamental the support of public interest institutions, university extension, research programs, municipalities and social movements for inclusive housing, as a base of sustenance, enrichment, and replication.

About the complex, urban, Brazilian reality

Adequate housinghas been a chronic issue in great Brazilian cities since the beginning of the 20th century, in both quantitative and qualitative dimensions. At the heart of the issue: an accelerate d process of urban growth, insufficient income for the majority of the population, restricted access to urbanized land and ineffective, inefficient, selective, and discontinued public policies.

The results in big Brazilian cities are expressed by the highly segregated, exclusive, deficient, and increasingly dysfunctional and unfeasible urban spaces, creating great obstacles for adequate urban planning, in favor of less unequal and sustainable cities. All of these aspects are underneath the extensive process of informal occupation in the production of space, without collective urban parameters, covering to precarious construction, problems with infrastructure, accessibility, and sanitation, land regulation, in addition to other accumulated and growing demands, that affects the city environment. In this process, undertaken mostly by self-build expansion, technical assistance plays a fundamental role.

Currently, almost half of the Brazilian population is concentrated in large urban areas, or approximately 87 million inhabitants in the 35 metropolitan regions and half of these in the 10 major metropolises. While the 2010 Census indicates a broad urbanization of

[1]The proposal was elaborated as a *latosensu*graduate program by Professor Angela Gordilho Souza, as coordinator of LabHabitar/PPGAU-FAUFBA, in March of 2011. It was approved as a specialization course (Universidade Federal da Bahia 2011), first installed at the beginning of the 2013.

Brazilian territory, mainlyin the Midwest and Northern regions, metropolises continue to cover a significant portion of the Brazilian population. Concomitantly, there is a tendency towards growth in medium-sized cities, primarily in integrated municipalities of metropolitan regions, while maintaining the same problems that are historically documented in large cities (Instituto Brasileiro de Geografia e Estatística 2011).

Meanwhile, metropolises have the primary concern of housing deficiency, estimated at 5.6 million residences, in contrast to a similar index of housing vacancies. According to recent data from the Urban Development Ministry, while the housing deficit has presented a tendency towards decline in recent years, with significant increase of new residences, in relative terms it represents 9.7% of the stock of homes in the country, and it is concentrated in the population which makes an income of under US$984 (R$2.324) - 96.6% (Ministério das Cidades 2011).

The qualitative deficit, which reflects the absence of city content, is also significant. Above all, it is found in the informal occupation of favelas, shanty towns, and slums in big cities, defined by the absence of adequate infrastructure, highly elevated population density, scarcity of free spaces, among other necessary urban attributes for quality housing. It constitutes an even more grave reality, due to the complexity of necessary interventions, such as in Salvador-Bahia, the third largest major population capital in the country, where the index of the informality of urban occupancy has reached more than half of the existing residences, according to recent research data incorporated in its Municipal Housing Plan, 2008-2025 (Salvador 2008 and Gordilho-Souza, 2008).

As has already been observed, these processes have triggered, since the 1960s, movements for social changes that, among other demands, call for urban reform, putting architects at the fore, culminating in the National Seminar of Housing and Urban Reform - a historic reference for urban and housing topics in Brazil -, executed by the Brazilian Architects Institute (IAB) in 1963 at Hotel Quintandinha in Petrópolis, Rio de Janeiro. These movements were hindered during the long period of military authoritarianism and reborn in the 80s with the social movement for housing. As a result of this process, the introduction of the chapter on urban policies in the Constitution of 1988 expressed in articles 182 and 183 towered socialrightfor housing and the obligation of municipal master plan. These constitutional obligation and rights were regulated by Federal Law 10,257 (BRASIL 2001), pushed by a civil social movement initiative, known as the City Statute (BRASIL 2001 and BASSUL, 2002).

Inspired in these urban reform movements and by the principles of the right to the city, advocated by Henri Lefebvre (1968), the City Statute comes to ease the anxieties of civil society in the creation of instruments in the struggle for more inclusive cities and for the broad access to urban rights. In this concept, the right for adequate housing must include not only the housing unit, but also its integration in the urban environment.

In this sense, since 2003, with the creation of the Urban Development Ministry, new urban policies were put into place - housing, sanitation, mobility, urban programs - (Brasil 2003). A new National Social Interest Housing System (SNHIS) was formed, with the creation of the National Fund of Social Housing (FNHIS) and its Managing Fund Council. This new policy gave a great impulse of direct financing for states and municipalities, in addition to credit programs run directly for housing associations and self-management (Brasil 2010). There is therefore the occupation of an institutional vacuum bringing back the federal government that was out of the discussion of urban politics and the fate of cities and introduces clear institutional or regulatory new frameworks for urban sector policies (Maricato 2007).

These new possibilities include institutional modernization programs, investments in urban and housing improvements, land regularization and the production of new housing units. As such, master housing plans become mandatory for municipalities of more than 50,000 inhabitants, adding to the concept that "to produce housing is to produce cities", (Brasil 2010). Central urban area rehabilitation policies were also defined, with the intention of transforming empty or under-utilized buildings and inadequatehomes, in housing, as a strategy of urban space expansion for all (Rolnik and Botler 2007). In this context, new national programs were also launched, such as Brazil's Growth Acceleration Program (PAC), in 2006, and the "My House My Life" Program (PMCMV), in 2009, involving large sums of resources and a strong subsidy for social interest housing.

More recently, there has been a strong induction and the accelerated production of housing units, with a predominance of investments in the real estate market, intensified by the PMCMV investments, as a social mass housing program. While this program has achieved high quantitative results (in merely three years, a million new houses were produced in Brazil, with the anticipation of two million more by 2014), critiques on this production have been severe, especially about urban insertion, urbanized land and appropriate design and technology (Ministério das Cidades 2010, Maricato 2011 and Ferreira 2012). Additionally, interventions in the qualification of the large number of vacant real estate properties existing in urban central areas and informally occupied peripheries are not prioritized, giving privilege to open space distant from urban centers. In this process, there is also a lot of subcontracting of services and administrative discontinuity in relation to the public management implantation of developed housing plans (Gordilho-Souza 2014). Under the technological prima, the improvements carried by mass custom design would be welcome in such production (Zemch Network 2014)

These new federal funds, in addition to affecting the metropolitan regions, also reach medium-sized and small cities, that in the past decade have displayed higher indices of population growth, incentivized by various factors such as: decentralization of economic activities, the founding of new universities, the allocation of permanent professional positions, an increase in the cost of living in large cities, the income increase of the "C" class, compensatory policies, such associal family aid (bolsa família), in addition to cheaper urban land.

With the recent income increase it comes a greater consumption of construction materials, contributing to increase industrial products and real estate dynamics in these areas. These are processes that demand the broad and continued action of public policies and professional capacitation and innovation in this field, including the needs of small municipalities that, due to technical deficiencies, cannot enable the elaboration of urban and housing improvement plans and projects (Gordilho-Souza 2011).

A promising initiative is the large provision of professional technical assistance for low-income populations, strengthening the role of municipalities and states for co-operative management. It can bring more adequate form of operating, especially in the regulation of Special Social Interest Zones (ZEIS), for the urbanization construction improvement at these informally occupied areas. Specialized technical assistance in this field is also necessary in the support of communities initiatives provided by local housing entities, neighborhood associations and non-governmental public interest organizations that demand the elaboration of self-management social projects to access available programs, such as Credit Assistance (Crédito Solidário), PMCMV Entities, land regulation, agricultural villages, and so on.(Gordilho-Souza 2011).

Through university extension projects, several undergraduate programs have promoted active, community-based learning with participatory projects for communities concerning self-regulated housing improvements, low-cost construction technology, environmental education, etc. Usually, these are short-term, intermittent projects or are limited to pilot experiences which do not provide sufficient professional preparation.

Moreover, few pay attention to the issue of appropriate technology, which refers to the choice and definition of sustainable technological solutions to local problems, considering the available materials and work force. This kind of strategic choice can be started by working together with the community to develop innovative skills, project quality, and technical assistance. It may ensure projects that address real needs at the local level. The importance of knowledge exchange and appropriate technologies is paramount, in addition to awareness and division of responsibility for the process maintenance itself. As such, rights and duties go hand in hand.

The issue of insufficient technical capacity is also related to the lack of educational public policies that could promote innovative projects to enroll young people. On the other hand, university students might influence them to perform actions and improvements in their own communities, which would, in turn, prepare these professionals for entry into job market in this field, with appropriate skills.

Nevertheless, the accumulated social demands and the present moment of strong investments in the production of social interest housing in this country demand a great number of professionals capable in this field, as a mean of urban improvement and increasing the rights guarantees by the City Statute that can result in strengthening of citizenship.

Finally, it is important to mention the Federal Law 11,888 (Brasil 2008) that provides the legal support for technical assistance activities in Architecture, Urban Planning and Engineering, that brings various possibilities, including professionals enrolled in academic residency and university extension programs by means of universities public offices (Brasil 2008). In terms of technical, free public assistance in thisfield, its content enables initiatives such as the one to be presented in this paper, aiming to contribute to the collective construction of better, fairer, and more democratic cities.

Institutional advances designing the AU+E/UFBA Residency

The Architecture, Urbanism and Engineering Residency project was designed to implement professional skills, via the *lato sensu* graduate program, integrating, improving capacity, field service urban educational activities, researches and developing projects, inspired at what already occurs in the Medical Residency[2]. It involves the Specialization in Technical Assistance for Housing and the Right to the City, based on a multidisciplinary approach, in addition to join undergraduate and graduate professors and students, public institutions, and the communities involved in the projects.

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[2] The Medical Residency in Brazil has existed since the 1940s as a way to guarantee the recently-graduated medical student the opportunity to have practical work experience within health institutions, under the guidance of qualified medical professionals. Instituted by Decree n^{o} 80.281, of 9/5/1977, the same decree that created the National Commission of Medical Residency (CNRM), it works as a model of graduate program for doctors in the form of a specialization course. In ministerial order n^{o} 9, from 6/28/2013 (Ministry of Education and Ministry of Health), the value of the scholarship reserved for the doctor-resident, in return for service training of 60 weekly hours, was set at a value of U$1258,94 (R$ 2.976,26). Nearly 27,000 spaced are offered in 53 specialties throughout the country (Residência Médica 2013).

The proposal was developed in 2011 by the Architecture School in partnership with the Polytechnic School of the Federal University of Bahia (UFBA), originally presented by LabHabitar to the Graduate Program of Architecture and Urban Planning and ultimately approved by the university's Dean of Extension (Gordilho-Souza 2011 and Universidade Federal da Bahia 2011). The first edition was effectively implemented in 2013, operating in the recently funded Architecture Extension Center (Núcleo de Extensão de Arquitetura).

Its primary objective is to systematically enable free and public technical assistance in Architecture, Urbanism and Engineering for underserved communities and needy municipalities by means of integrated teaching-research-extension graduate-level activities for professional training associated with undergraduate students and the implementation of projects in this field, contributing to better housing quality, social and citizenship development.

Being designed as a multi-participatory project, it is able to integrate University - Community - Public Management. By putting the referenced Law of Technical Assistance into practice, this initiative represents a new experience in the university environment, getting together education of skilled professionals in the field, based in communityrelationships. It simultaneously includes training, service delivery and the development of a participatory social interest project for underserved communities.

In the definition of the course methodology, the following conjectures exist:

a) housing concept, including not only the housing unit but also integrating it into the housing environment and its urban insertion (infrastructure, sanitation, open, public spaces, in addition to physical security and environmental preservation);
b) priority performance in small and medium-sized cities in need of professional aid in the indicated fields, in addition to peripheral neighborhoods of large cities and rural settlements that demand this kind of technical assistance; and
c) the specialization in this field assumes participatory action, in permanent communication with the involved communities, in the definitions of the projects.

In its first edition, 2013/2014, there were 23 professional residents and 46 professors involved. The residents' backgrounds were mostly related to the main field proposed, including 18 architects, three urban planners, two engineers, one geographer, and one social assistant professional. Among them, 23 had recently graduated and 4 were urban public officers. Among the 23 residents, 17 were from Salvador, one was from another city in the state of Bahia, three others were from other states in Brazil and two were from Italy. The 46 professors all have experience in the field, most of them had completed the graduate course at UFBA, and had either an MA or PhD that reflects their education in the field in addition to their multi-disciplinary skills.

In this experimental edition of the program, most of the 23 professional residents are working in communities located in Salvador, reducing transportation costs, since there are no scholarships yet available. Only two projects are out of Salvador: one in João Pessoa, Paraiba, as part of a partnership between UFBA and UFPB, and another, in a partnership with the municipality of Ruy Barbosa, Bahia. There is already some support from the PRONEXT-MEC/UFBA - Ministério das Cidades.

For the selection of candidates, necessary application include previous acceptance of a résumé and his/her potential for the project to be developed, under the guidance of a tutor professor, attending to the demand of a public institution or an emergent community in the municipality in which the resident will work.

The development and finalization of the course should occur in a minimum of fourteen months and a maximum of sixteen months, resulting in 40 academic credits (408 hours - 24 credits, of which 340 are classroom hours and 68 are for the development of the final, guided research project) and 16 fieldwork credits (minimum of 960 residency hours), distributed in three periods:

1st Period - Disciplines, seminars, and the definition of the project to be developed: total of four months, dedicated to theoretic-conceptual and technical training with five thematic themes:

1. Space production, urban policies and the right to the city;
2. Urbanization, infrastructure, and environmental projects;
3. Architecture project, urban planning and engineering for technical assistance;
4. Methodologies and techniques for participatory projects; and
5. Seminars and workshops for residency area definition.

2nd Period - Residency for the development of social and fieldwork with the community: minimum of eight and maximum of ten months, for collecting data, studies, technical assistance, workshops, and other practical extension activities, with the participation of public managers and the involved communities.

3rd Period–Review of results and presentation of the final project: two months.

The final project should be presented as a proposal, developed in a participatory manner, with an analysis of the project subject, including a Term of Reference with dimensions and specifications for future implementation, with due annotation of the resident-professional's technical responsibility. Depending on the level of complexity and the resident's field of study, the project will be finalized in the form of a preliminary study, or executive project, defined in agreement with the guidance professor, after the academic semester's end, which will be donated to the community.

This program has the perspective of getting institutional foment and cooperation, able for a large exchanging, with the possibility of project guidance in other Brazilian states, with the participation of advising professors from the university of the residents' states of origin,as already settled with the Federal University of Paraiba. A goal is the possibility of program replication, in other universities, consolidating an interactive network of project databases and diverse experiences.

Methodological and technical approaches

When discussing participatory process methodologies, value should be ascribed to human beings in the process of collective decision-making, as communities are composed of the people who already live and wish to continue living in their respective locations. In other words, the technician who proposes a project must be aware of his/her own attitude towards the local people, as the improvement proposition will be enjoyed in the daily life of everyone who lives in the community. From this point of view, conscious decisions can be made using methodologies that consider the value of people's memory of the place, their sense of belonging, and employing the collective practice of listening and dialoguing, as well as utilizing methodologies to awaken people to be purposeful and think together to come up with creative and sustainable solutions.

As mentioned before, the professional activities in community residency includes several phases. The necessary interdisciplinary dimension is emphasized, with the intention of promoting knowledge regarding pluralistic, inclusive and adequate housing. This project's execution articulates the three spheres of academic life: teaching, research and extension, and proposes a direct relationship between theory and practice, involving real situations in a participatory way.

Regarding the first phase of the residency, workshops were developed and several meetings with leaders and visits to previously identified areas were conducted. These activities were vital to inspire community discussions and promote the participatory process approach. It was also during visits and contact with local residents of the selected areas that the professional residents identified the communities' demands and their areas of expertise.

At the end of this first stage, the residents began to develop a work plan with reference to the content provided by the course, focusing on specifics themes, for their respective projects related to the chosen community. In order to provide integrated solutions, defined by multidisciplinary teams, they were required to identify a broad and effective diagnosis for their chosen problem. This way of approaching demonstrates effectiveness in developing suitable solutions and in promoting significant techinicalimprovements.

The specific issues of infrastructure, environment and sustainable urbanization were addressed through their various environmental and infrastructural aspects, focusing on appropriate technologies and projects that could realistically be incorporated by the communities. Many solutions to issues regarding water supply systems and solid and liquid waste were discussed and considered, including the use of energy sources, urban mobility, and answers involving the physical environment, support and the influence of the landscapes' physical constraints.

The subjects were initially addressed theoretically and conceptually, enhanced with the most diverse examples of related initiatives and projects throughout Brazil and the outside world, in order to establish a critical insight into the processes of choice- whether for architecture or urban design or a specific area of work. As the main methodological characteristic that defines inclusive housing, it is important to understand not only the solution proposed and implemented, but to also know its compatibility with the presented realities, with the social and cultural diversity of each studied community. During class discussions, questions that were not directly related to the theme provided were raised, reinforcing the importance of multidisciplinary processes in choosing appropriate technology for each project.

In the discipline of architectural design, urban planning and engineering for technical assistance, issues concerning the built environment, regarding to vacant and occupied areas, the projects' quality, different types of housing, collective infrastructure, public and private areas, and landscape were considered. As such, the prevailing topics on urban sustainability were discussed. Focusing on design methodologies, case studies of rehabilitation, improvements and housing production were analyzed, using computational technologies in design and planning.

The challenges for professional residency consolidation

By promoting the insertion of the university in communities to define projects that involve public management, this action incentivizes the involvement of government bodies - at the federal, state, and municipal level -, non-governmental entities and community associations in the development of these projects through a plural and interactive learning process.

One of the great challenges put forth for consolidation is the provision of scholarships and additional support costs, due to its large territorial field needs, including small cities in different municipalities in addition to the metropolitan peripheries. This aspect includes more distant communities what demands a long term residency for technical assistance.

Necessary exploratory practices on adequate technology are required, in the continued, collective learning and mutual training exercises, as a means of interacting with multidisciplinary knowledge and that of the habitants. This experimental condition also entails the direction to improve design and technology for inclusive housing, based on research practices, and technical innovation, high demand for sustainability, and network projects.

While the promotion of these technical assistance initiatives seeks to incentivize professional internalization, it also demands effective support from its representative institutions, from applicant municipalities and public bodies involved in this area of development.

Overcoming these challenges would mean bringing the possibility of the replication of this project to the national scale, with specific funding in order to create better conditions and possibilities for cooperation and the exchange of experiences. It strengthens the social insertion of the public university and the perspective of innovative technology in the areas of social interest.

May these initiatives strengthen the achievement of better and fairer cities!

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TEACHING THERMAL COMFORT AT THE SCHOOL OF ARCHITECTURE OF THE UFMG: PROJECT PRACTICE

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TEACHING THERMAL COMFORT AT THE SCHOOL OF ARCHITECTURE OF THE UFMG: PROJECT PRACTICE

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Abstract

Achieving passive thermal comfort is an important subject in architect´s education in tropical countries. This topic has been included in the regular architecture curricula in Brazil since 1994, leading colleges to establish laboratories to support the practical activities. This paper describes the experience of teaching thermal comfort for undergraduate students in the School of Architecture at the Federal University of Minas Gerais, Brazil. Besides theoretical knowledge about natural ventilation, solar geometry and heat transfer in buildings, the course deals with a house designed or renovated by the students in a previous semester. Students start analysing the design using climate data and recommendations from the Brazilian technical standard for thermal performance of buildings (NBR-15220), so as to establish a reference about the house performance in a certain climatic zone. The project is then fully tested for ventilation by applying three methods: (a) mock-ups in a qualitative wind tunnel; (b) internal air fluxes through a simplified CFD and (c) dimensioning of openings through empirical numerical models. After that, the students will study the solar orientation of the house and learn how to control solar radiation inside rooms also applying three methods: (a) mock-ups in a *heliodon* or a sundial; (b) digital mock-ups in electronic *heliodon* and (c) graphical analysis through sunpath diagrams. Once the project is reviewed for ventilation and solar geometry, students go further analysing the thermal performance of the house envelope by applying the standard recommendations for its climatic zone. Thus students have to research about construction materials and components in order to present adequate alternatives to the existing envelope. The results are presented and discussed in seminars giving the students the chance to improve their ability to share information about solutionsdeveloped.

Keywords: *project processes, thermal comfort, undergraduate teaching, laboratorial practices, technical standard application.*

Introduction

Thermal comfort is defined as “that condition of mind which expresses satisfaction with the thermal environmentand is assessed by su bjective evaluation” (American Society of Heating, Refrigerating and Air Conditioning Engineers 2010). In tropical regions, such as in most of Brazilian territory, buildings generally are not air-conditioned; therefore achieving thermal comfort by passive processes is an important task for architects. Moreover, it is a topic directly related to the current need for energy efficiency in buildings (Macaró 1985 and Lamberts, Dutra and Pereira 2004).

Thermal comfort is included in the group of “environmental comfort” professional level courses inmost Architecture and Urbanismdegrees in Brazil. This group also includes natural and artificial lighting and building acoustics. The scale approach of these studies in most colleges of the country is the building and its surroundings. Although of major importance, this group of courses was only included as mandatory subjects in the regular curriculum in 1994 (Ministério da Educação e do Desporto 1994). One of the positive effects of the curricular regulation was to establish laboratories to support experimental and practical activities related to the theoretical knowledge presented in classes.

The Thermal Comfort course in the School of Architecture of the Federal University of Minas Gerais (EAUFMG) emphasizes the passive strategies, namely:

a) climate analysis for architectural recommendations. The procedure uses thermal comfort indexes for different regions in Brazil, as suggested by Assis (2001) and Frota and Schiffer (2001). Mahoney Tables are also applied (United Nations 1971). Discussions are conducted about the procedure adopted by the Brazilian technical standard for thermal performance of buildings (Associação Brasileira de Normas Técnicas 2003);
b) natural ventilationtypes and dimensioning (Mascaró 1985 and Frota and Schiffer 2001), using ventilation rates as recommended by Mesquita, Fagundes and Nefussi. (1977);
c) sunlighting control (Bittencourt 2000 and Frota and Schiffer 2001); and
d) thermal performance of the construction materials (Frota and Schiffer 2001 and Associação Brasileira de Normas Técnicas 2003).

The undergraduate program in Architecture and Urbanism at the EAUFMG lasts five years on a semiannual basis. The Thermal Comfort course is the first of the “environmental comfort” studies and is offeredduring the third semester. The course has 37.5 hours of lessons for classes of 25 to 30 students. Extra-class, practical activities are developed in groups of fivetosixstudents. Each group deals with analyzing a project or renovation of a house designedin the previous semester by one of the students. The group will have to analyze the house project according to the information given in classes and design improvements on it.

At this point of the program students still have a limited view of architecture and design since the previous project courses focused on space dimensioning and rooms layout. Therefore the approach of the Thermal Comfort course has to be adapted to the initial experience of these students. This paper intends to show the practical activities using their house projectsto apply theoretical knowledge seen during lessons.

In order to show and discuss practical activitiesconducted during the course one of the studies of a house project will be presented as example (Fig. 1 and Fig. 2). The project was originally designed by student Lara Secchin and is located in Nova Lima, a city near Belo Horizonte, which is the capital of the state of Minas Gerais in Southeastern Brazil. The house has two pavements. The living and dining rooms, kitchen, laundry area and garage are on the ground floor. Bedrooms are on the second floor. The main façade is oriented to the southwest. Since there are no side setbacks, all the openings had to be designed in the front and rear façades. Internal courtyards were then designed in order to provide light and ventilation to the rooms.

Site Analysis

Site analysis comprises two aspects: (a) to identify the kind of local climate, the climate-based needs for human thermal comfort and therefore the expected performance of buildings in this climate and (b) to identify in the land use and building codes of the county the requirements for the envelope thermal performance and the openings dimensioning for room ventilation and sunlighting.

Initially students are introduced to the Brazilian standard on thermal performance of buildings (Associação Brasileira de Normas Técnicas 2003) which focuses on social dwellings. This standard presents the national bioclimatic zoning, based on Givoni´s Bioclimatic Diagram (Givoni 1992) adapted to Brazil and on Mahoney Tables (United Nations 1971). This standard assigns to each zone recommendations to passive thermal comfort and criteria for thermal performance of materials and/or construction components. Students can use computer software ZBBR (acronym as to Brazilian Bioclimatic Zoning (Laboratório de Eficiência Energética em Edificações 2014) inserting the site geographic coordinates or search for the place in its database and get recommendations for climate sensitive design and envelope thermal performance. Figure 3 shows the software screen for the city of Belo Horizonte.

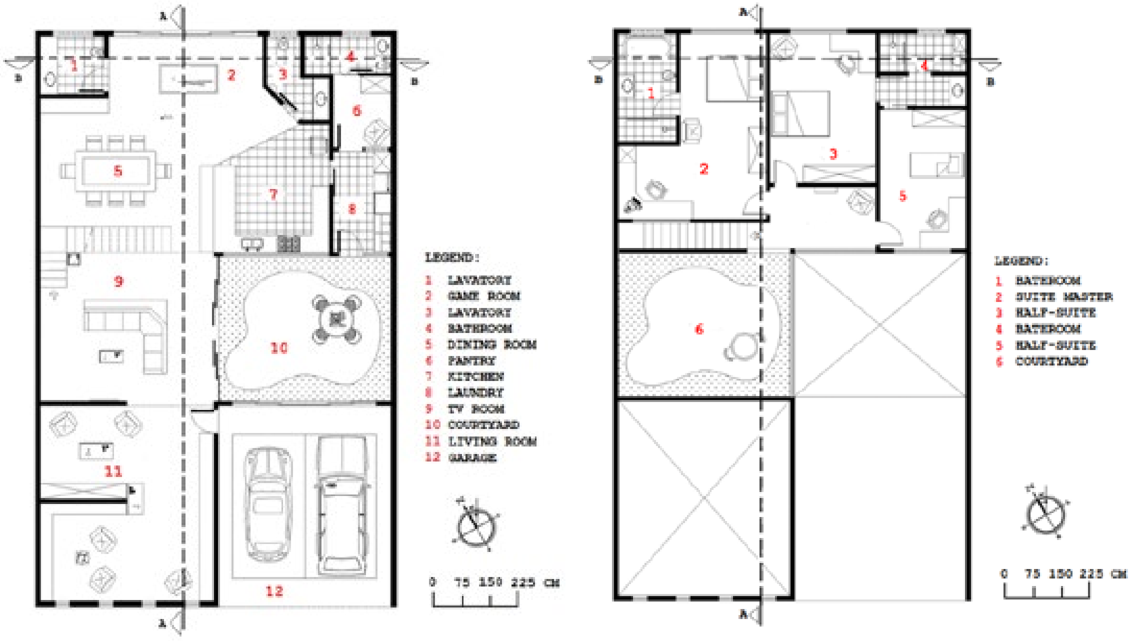

Figure1: Plan views of the house project. At left the 1st pavement and at right the 2nd one
Source: modified from the Report of Secchin *et al.* (2013).

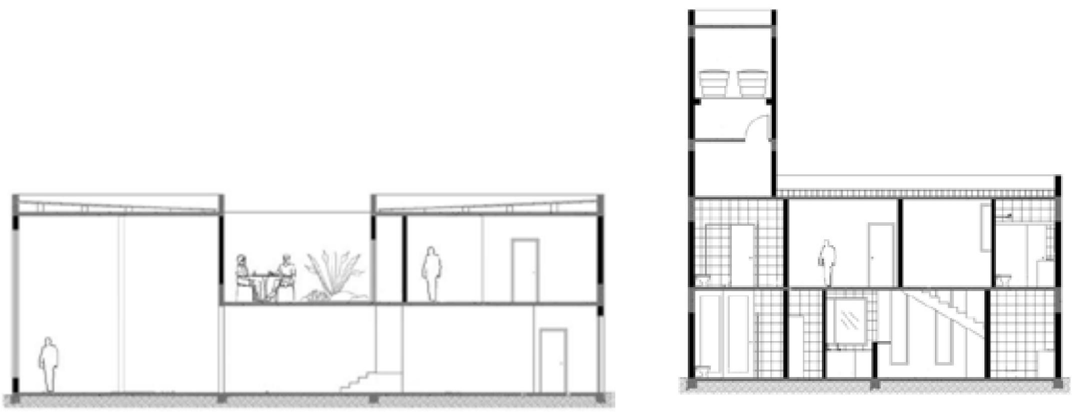

Figure2: Section views of the house project. At left section AA and at right section BB
Source: modified from the Secchin *et al.* (2013).

Students also have to search for legal requirements in the county codes for land use and building as, for instance, the rules for building location and setbacks, room ventilation and lighting, and thermal performance of building materials. Consulting the maps of land use and local block division students can find out the solar and wind orientation of the projected building. Gathering the two sources of information studentswilldevelop a framework of recommendations in order to compare it to the original achievements of their projectand identify what they need to improve or correct.

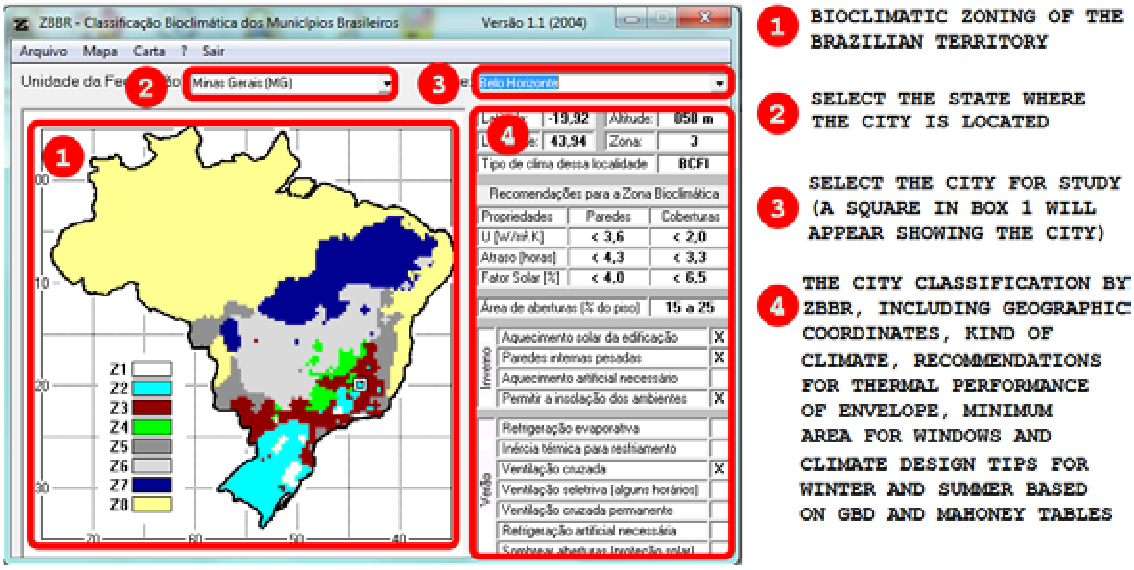

Figure3: Interface of ZBBR software with results identified
Source: ZBBR image, modified by Marianna Teixeira.

Ventilation Analysis and Openings Dimensioning
Once having ventilation recommendations from NBR-15220 (Associação Brasileira de Normas Técnicas 2003) and the local building code, students start studying the wind resources in theirbuilding lot by means of practical activities. First of all, each group will do a survey, observing the local wind speed and orientation around the lot and/or its block. For doing so, they use the Beaufort Scale for land and a compass. Afterwards the group will build a 1:100 or 1:200-scale mock-up of their house project and its surroundings in order to test the model at the Laboratory of Environmental Comfort (LABCON). The lab has a qualitative wind tunnel which provides students the visualization of aerodynamic effects of wind on local buildings once known the prevailing wind directions inthe project site (figure 4).

Through this practical test students can identify the wind effects according to Gandemer (1979) and the house façades in positive and negative pressures due to the local wind effects. They will need this information for the next step of the work, when they will analyze, locate and dimension the openings for adequate ventilation in the rooms.Figure 5 shows a mock-up built for this kind of test and in figure 6 we have a test in progress. In the example presented the students could identify some effects as reported in their analysis:

*It is noticeablethat the red strips are moving around and over the house studied. The **Wake Effect** may be perceived in a moderate scale, since the gaps between the constructions – as shown in the mock-up – are enough to decrease any uncomfortable effect generated in the lot.In the garage area, the **Corner Effect** is noticeable since there is turbulence in the red strips on thiscorner of the house. This effect is considered as very uncomfortable, especially to pedestrians when the wind gets a higher speed.The **Cluster Effect**is also noticeable in the internal courtyard of the residence, although its occurrence is very moderate, being almost null. It rarely would cause discomfort for the inhabitants. (Secchin et al. 2013, free translated).*

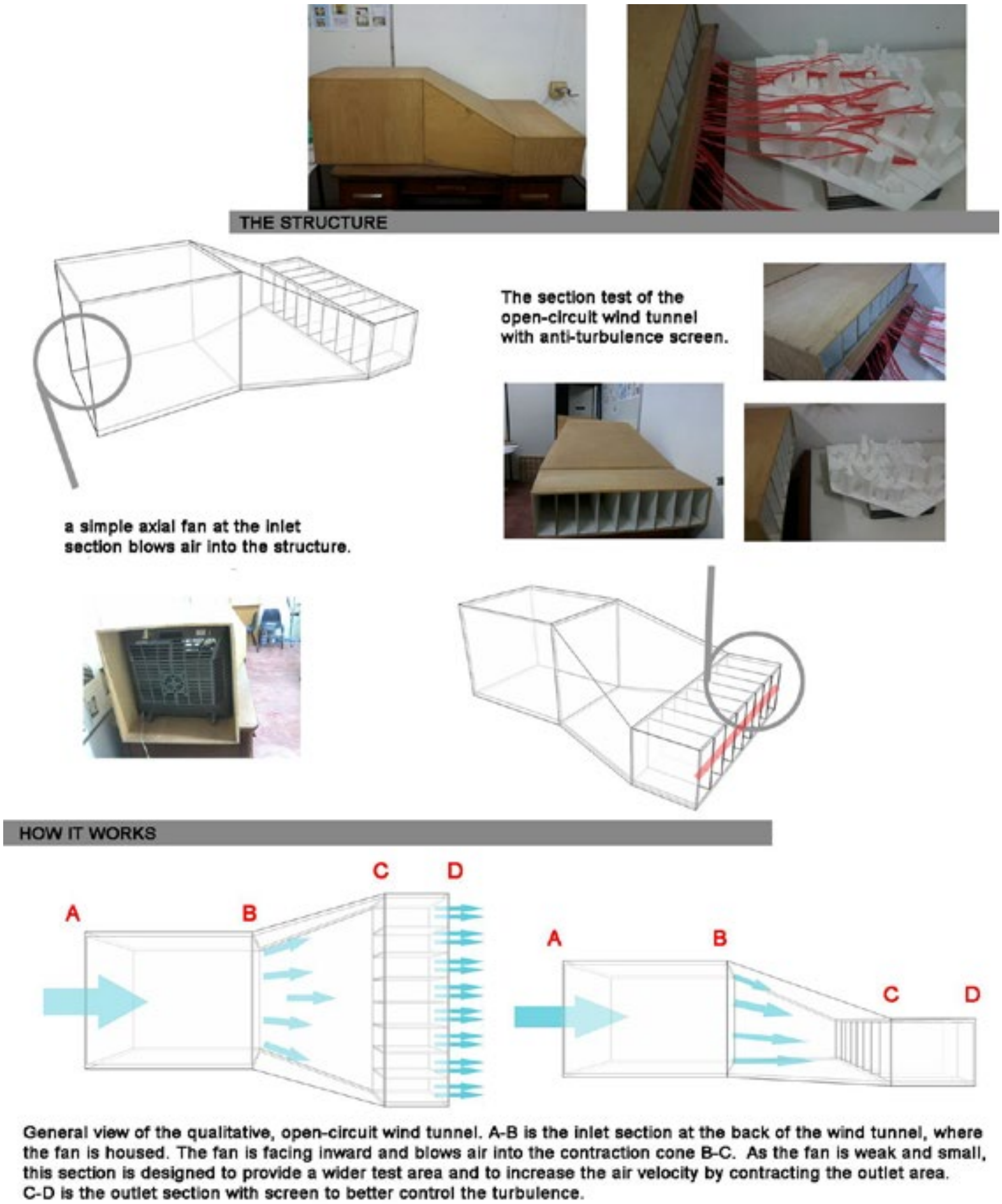

Figure 4: Explanatory diagram about the operation of the qualitative wind tunnel at LABCON Source: diagram drawn by Marianna Teixeira based on experiments and information gatheredin LABCON website (Laboratório de Conforto Ambiental e Eficiência Energética em Edificações 2014).

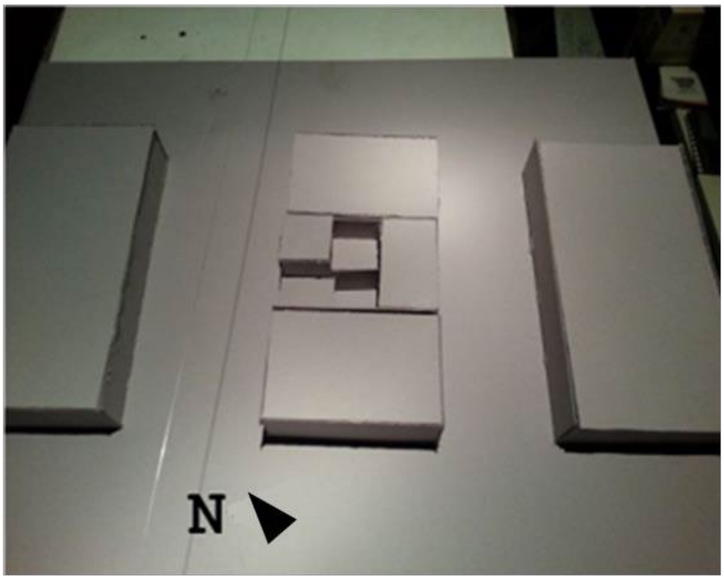

Figure 5: Mock-up view and orientation
Source: Secchin *et al.* (2013).

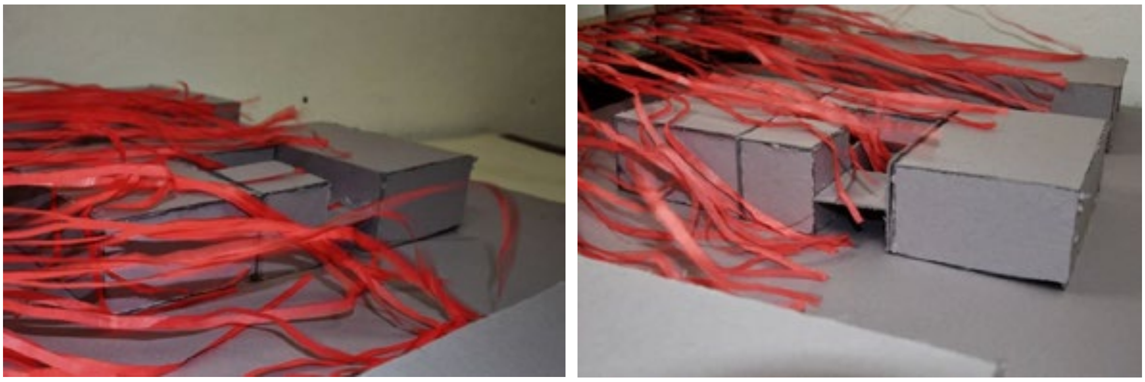

Figure 6: Views of the experiment in the wind tunnel in order to observe wind effects
Source: Secchin *et al.* (2013).

The study of the internal airflow and openings dimensions beginsby simulating the house plan or section view in the free CFD software called Fluxovento© (Carvalho and Martha 2005). This software is simple enough to be properly used by students since they do not have information about fluid dynamics in the program. Figure 7 shows an example of airflow modeled on a house plan view. The plan or section view must be conveniently oriented in the software grid since the wind always comes from the left side of the software window. This will be done according to the results of the previous wind tunnel test.

Frequently students will notice that some part of their house project is not well ventilated and then they will have to calculate and/or locate new openings. NBR-15220 (Associação Brasileira de Normas Técnicas 2003) does not deal with openings dimensioning and on the other hand Brazilian building codes are poor on guidance about room´s ventilation. Thus, empirical models from literature are used for such calculations.

For cross-ventilation concepts two dimensioning models are used: a model forcasement or sliding windows, based on the Irminger and Nokkentued work (Toledo 1967[1] *apud* Frota and Schiffer 2001) and a model for awning windows developed by Van Straaten (1967[2] *apud* Mascaró 1985).

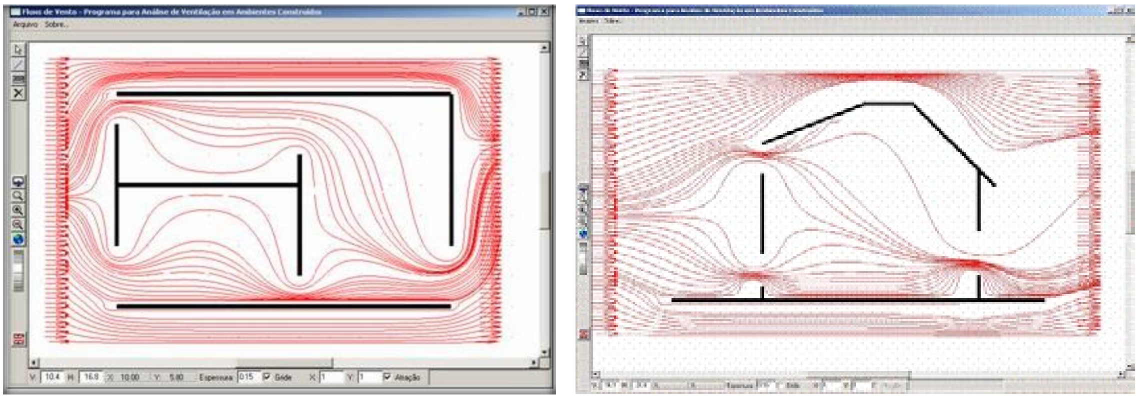

Figure7: General interface of software Fluxovento© - at left the airflowmodeled on a plan view and at right the airflow on a section view
Source: Carvalho and Martha (2005).

For stack-ventilation concepts the model used is presented by Frota and Schiffer (2001) and for combined effects of cross and stack ventilation the Jorgensen model is used (Mesquita, Fagundes and Nefussi 1977). These authors also present lists of ventilation rates for various types of rooms which can be considered as ventilation rates for thermal comfort and then applied for calculation of the term of airflowin those models. The terms of wind speed and orientation were surveyed before; coefficients of pressure are provided by the models according to the gaps among buildings and the local density of the built-up surroundings. So the only unknown variable will be the area of the windows. The students choose the proper equations for the ventilation concept of their house and calculate the new areas for windows. Then they will test the dimensioning by modeling these new areas again in Fluxovento© and compare the results with the original house windows. Figure 8 shows one of such studies where one can notice the improvement of the air circulation through the rooms.

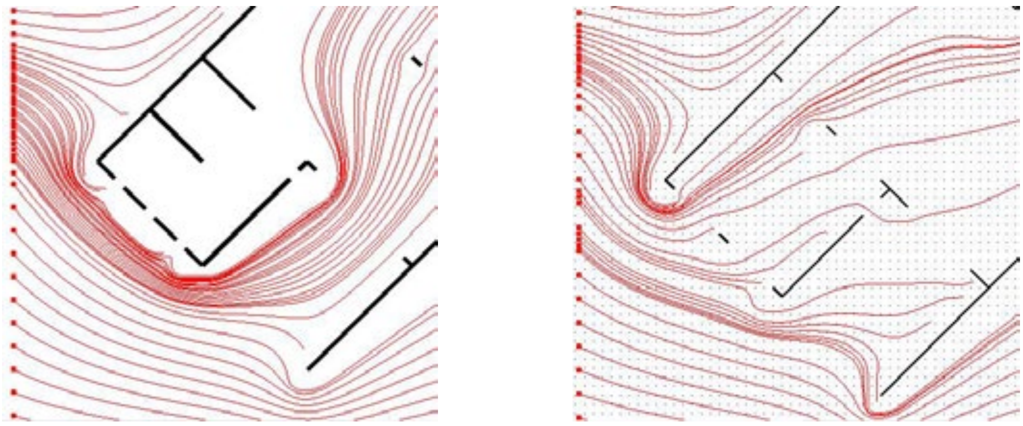

Figure 8: Comparison between airflow in rooms before (left) and after (right) correcting the openings dimensions
Source: Secchin *et al.* (2013).

[1] TOLEDO, E., 1967, Ventilação Natural dos Edifícios, LNEC, Lisboa.
[2] VAN STRAATEN, J.F., 1967, Thermal Performance of Buildings, Elsevier, London.

Sunlight Analysis and Control

NBR-15220 (Associação Brasileira de Normas Técnicas 2003) recommends sunlight control in certain bioclimatic zones mainly during the summer season. To enable students to do that solar geometry must be well understood. Students are presented to the graphical methods in solar geometry through the approaches of Frota and Schiffer (2001) and Bittencourt (2000). The practices in solar geometry will also include mock-up tests and computer simulation of the digital model of the house project. So students can try different methods and mature their spatial vision.

This stage of work begins with the correction of magnetic north or grid north of the land use map to true north which is the reference for sundials, sun path diagrams and computer softwares that simulate the local sun path. Using the Brazilian map of magnetic declination (Observatório Nacional 2012) the students learn how to correct both magnetic or grid north to geographic north no matter the age of the map. Doing so the same mock-up used to ventilation analysis is now ready to be tested in the sun path simulator called *heliodon* at LABCON (Fig. 9).

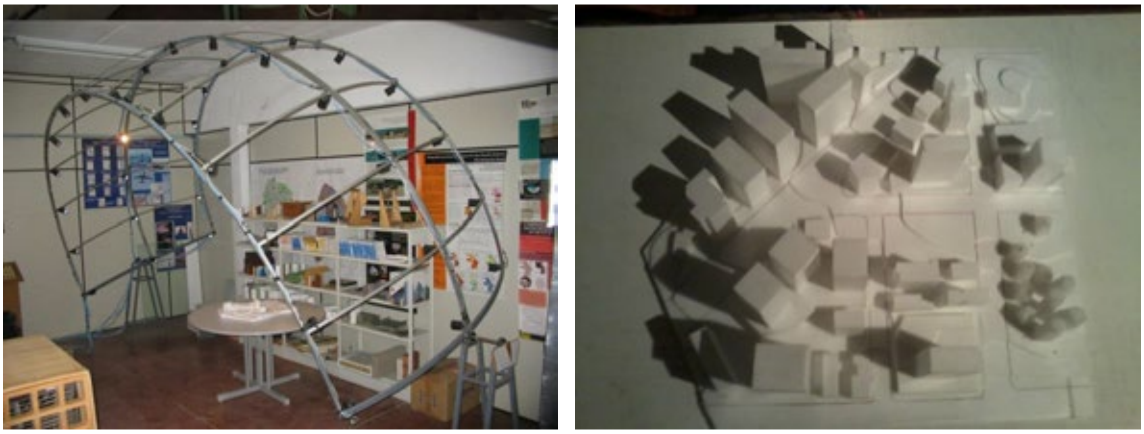

Figure 9: At the left side the *heliodon* with its three arcs representing the trajectories of the sun in the solstices and equinoxes – each lamp represents a specific hour – at the right side an urban mock-up being tested
Source: Laboratório de Conforto Ambiental e Eficiência Energética em Edificações (2014).

During the tests students can see how the house envelope is being hit by the sunlight and the shadows produced by the building and its surroundings in some representative periods of the year. The following Figures 10 to 12 show these studies for different days and times. Analysing the results the group can identify the façades that receive most of the sunlight during the year and whose openings have to be protected. They also observe that the roofs can be widely sunny throughout the year in the low and mid latitudes of Brazil requiring materials of good thermal insulation.

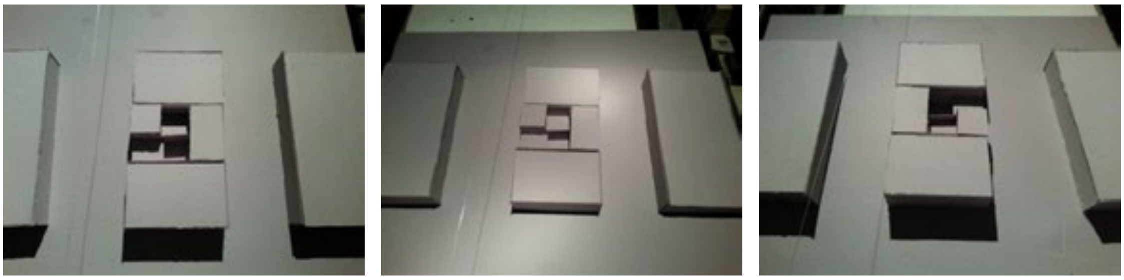

Figure 10: The house project simulation in *heliodon* in the summer solstice, respectively at 9am, 12am and 3pm
Source: Secchin *et al.* (2013).

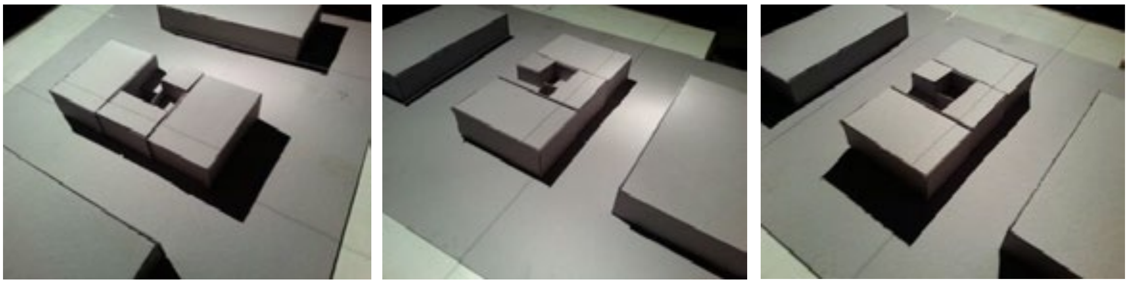

Figure 11: The house project simulation in *heliodon* in the equinox, respectively at 9am, 12am and 3pm
Source: Secchin *et al.* (2013).

Figure 12:The house project simulation in heliodon in the winter solstice, respectively at 9am, 12am and 3pm
Source: Secchin *et al.* (2013).

The next step is to choose one window that will need a shading device (*brise-soleil*) and design it applying the sun path diagram method and the computer simulation method to check the results. In order to find the area of the sun path to be masked, the solar radiation level considered as critical is from 400 W/m^2. So students can overlay the solar radiation diagram (Olgyay and Olgyay 1963) oriented to the studied façade on the local sunpath diagram and draw the area to be masked. Then using the solar angles protractor they can extract the angles for the device project. Figure 13 shows the result of this procedure for the north façade of that house.

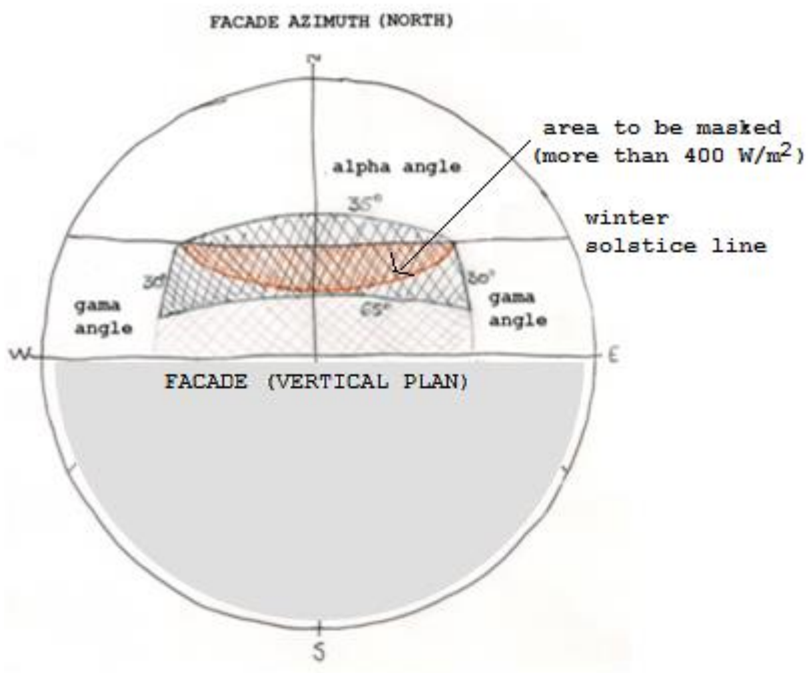

Figure 13: Sketch of the sun path mask, masking the critical radiation zone (in red) and the angle values for the shading device design
Source: modified from the Secchin *et al.* (2013).

The group will then propose a shading device corresponding to that mask (Fig. 14) and test it using the solar path simulator included in free software SketchUp©.

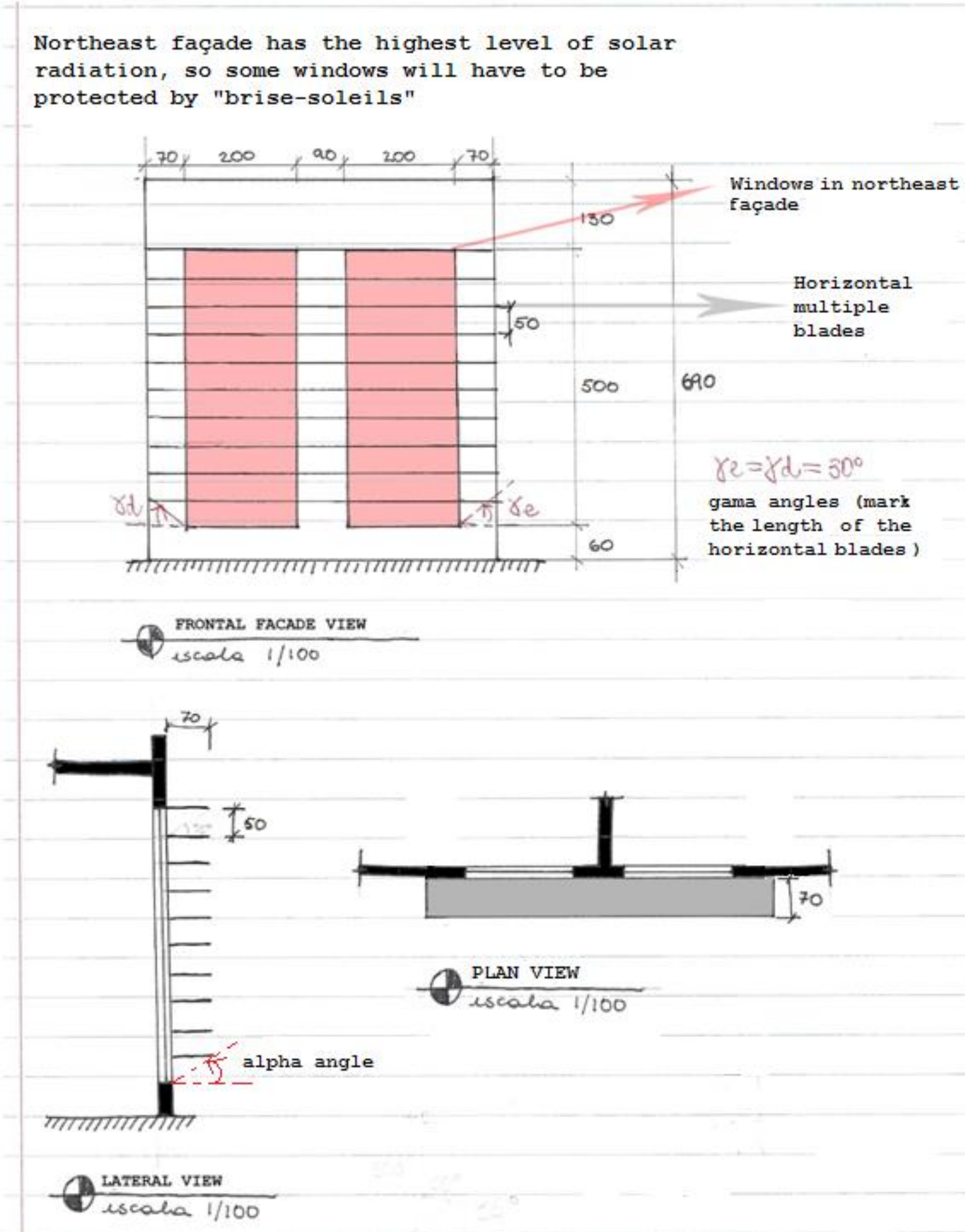

Figure 14: Sketch of the shading device (*brise-soleil*) developed from the previous mask
Source: Secchin *et al.* (2013), modified by Marianna Teixeira.

Figure 15 shows SketchUp© resources to model a project and to simulate the incidence of sunlight both on façades and on internal rooms. The software can reproduce the local sun path once setting the local universal time coordinates (UTC), the time and date for simulation in the Shadow menu.

Figure 15: SketchUp© screens showing the virtual heliodon in the software at the left side and studies of external and internal solar incidence on a house project
Source: Folha Azero (2008).

By modeling the shadow device on the studied façade and windows students will observe whether it is efficient in protecting the windows from excessive solar radiation. Figures 16 to 18 show the results for the solstices and equinox in some hours of these days.

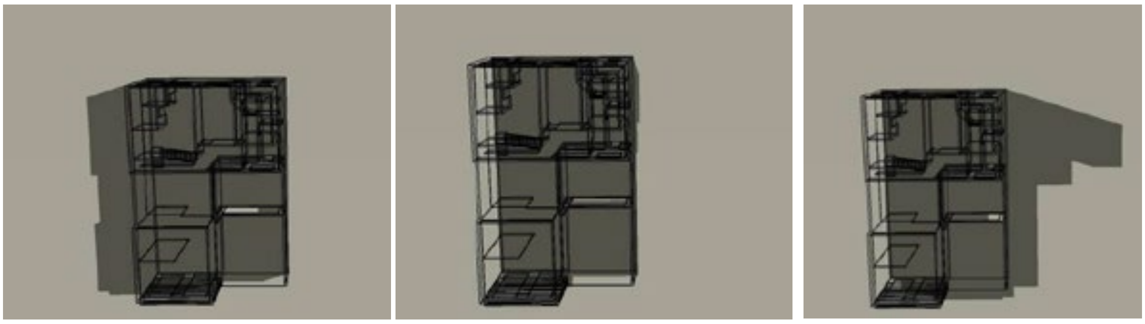

Figure 16: Summer solstice respectively at 9am, 12am and 3pm
Source: Secchin *et al.* (2013).

Figure 17: Equinox respectively at 9am, 12am and 3pm
Source: Secchin *et al.* (2013).

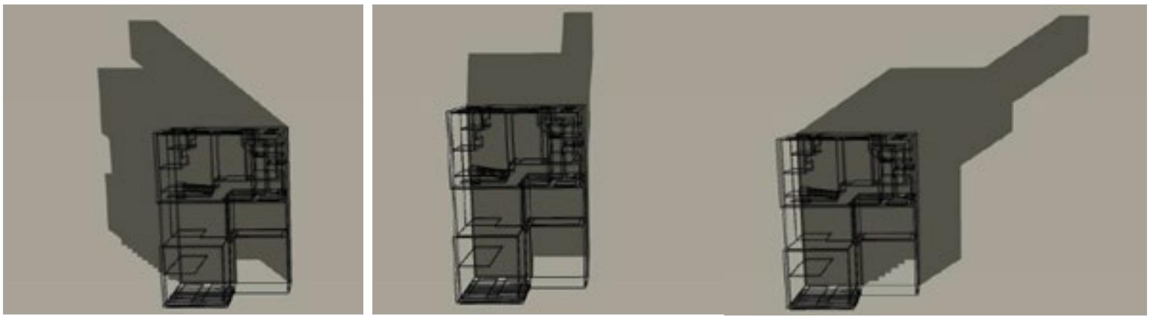

Figure 18: Winter solstice respectively at 9am, 12am and 3pm
Source: Secchin *et al.* (2013).

Thermal Performance of the Envelope

Having achieved good conditions of ventilation and solar protection, in this last step the students will analyze if the envelope materials specified in the original project match NBR-15220 requirements for the local bioclimaticzone. Table 1 shows these requirements in italics bold characters for bioclimatic zone 3 where the project example is located.

Table 1: Construction terms specifications and limits for thermal performance

External Seals		Thermal Transmittance¹ U (W/m².K)	Thermal Delay² φ (hours)	Factor Solar Heat ³ FSo (%)
Walls	Light	U ≤ 3,00	φ ≤ 4,3	FSo ≤ 5,0
	Light and reflective	***U ≤ 3,60***	***φ ≤ 4,3***	***FSo ≤ 4,0***
	Heavy	U ≤ 2,20	φ ≥ 6,5	FSo ≤ 3,5
Roof	***Light and Isolated***	***U ≤ 2,00***	***φ ≤ 3,3***	***FSo ≤ 6,5***
	Light and reflective	U ≤ 2,30	φ ≥ 3,3	FSo ≤ 6,5
	Heavy	U ≤ 2,00	φ ≥ 6,5	FSo ≤ 6,5

Source: Associação Brasileira de Normas Técnicas (2003).
¹Thermal Transmittance: the inverse of the Thermal Resistance (R-Value), which is the sum of all thermal resistances correspondent to each material layer of a construction component, including its superficial resistances.
²Thermal Delay: the time span between attaining peak temperatures at outside and inside surfaces of a constructive componentsubmitted to a periodical heat transmissionsituation.
³Factor of Solar Heat: the ratio between thetransmitted radiation through a component (opaque or translucent) and total radiation incident on theoutside surface of the component. In this table the factor for opaque seals is considered.

In order to calculate all these variables, students have to consult the thermal properties of the materials used in the components of each kind of seal. These properties are thermal conductivity and specific heat. The external colors used in the house project are also considered as they are related with the absortance coefficient used to determine the factors of solar heat. NBR-15220 (Associação Brasileira de Normas Técnicas 2003) provides all the equations and procedures for the calculations.

Students are then asked to propose new seals for the house project that achieve better thermal performance than the original project. Thus they will have to research about construction materials and components applying what they learnt in a previous semester course about construction technologies.

Seminar: Presentation of the Synthesis of the Project

Each group presents the results of the practical activities in a seminar at the end of the course. The students have to present a comprehensive synthesis of the work and detail each step performed justifying their decisions according to the theoretical aspects. The seminar is one of the procedures for assessing the student´s performance in the course, specifically when working in groups. The other procedures are individual tests.

The seminar is thought as an important moment for sharing experiences and practice of the skills to present and debate ideas. They will needsuch skills throughout the program and after graduation in their professional career.

Final Remarks

Considering the short duration of the course of Thermal Comfort in the program of Architecture and Urbanism at EAUFMG, the development of project practices as extra-class activities was found as the means for students apply the information given in lectures.

Analyzing the students answers from the University´ system of evaluation of courses in the last three semesters (94 answers), we calculate that 98.96% of the students found the course contents relevant and 89.16% considered that the course objectives were achieved. 62.37% of the students found their learning as “good” or “very good” and 61.22% of them conducted extra-class studies. The courseware was thought as “good” or “very good” by 61.29% of the students; the bibliography used in the course was “good” or “very good” for 73.40% of them. At last 76.34% of the students considered the procedures for assessing their performance in the course as “good” or “very good”.

We think thepractical activities process can only be successful if there is a personal supervision of the group works. Thiswas achieved in our experienceby means of the engagement of ajunior student with a scholarship from the University undergraduate training program on teaching (PMG). This student assists all the groups during their practical activities helping them to better apply the theory, procedures and calculations required as well as training them in the usage of LABCON facilities.

Acknowledgements

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DESIGN METHODOLOGY FOR SUSTAINABLE BUILDINGS: A CASE STUDY

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DESIGN METHODOLOGY FOR SUSTAINABLE BUILDINGS: A CASE STUDY

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Abstract
This paper presents a case study in which a design methodology on a building scale, with the objective of realizing sustainable nearly zero energy buildings, is implemented. From one side, it includes the principles of bio-climatic design controlled with the aid of computer models and, on the other, it uses the criteria of the LEED certification system for the design of sustainable buildings. These principles and criteria are applied in the decision making process, by using an integrated methodology. The criteria taken into consideration become input data as important as the other data, which come from the analysis of the climate data and the users' requirements. For what concerns the criteria to be applied for the realization of sustainability, the credits of the certification system are applied from the beginning of the design phase. The case study concerns the process of planning a mountain dew located in the alpine area in the North-East of Italy. In this case study the sustainability criteria taken into consideration are those of the LEED environmental certification system. The application of the LEED protocol criteria directed the research in terms of formal choices, technological and building products' choices. This paper suggests that such an approach should become an ordinary procedure, independently on the certification system applied. In synthesis, the study proposes a new design method that introduces sustainability criteria in current procedure.

Keywords: *Sustainability, bioclimatic design, environmental certification, certification systems.*

Introduction
The design methodology that has been tested and then discussed in this paper develops from the need of creating a working method that becomes an ordinary procedure for the planner of 2020. The proposed design methodology is applicable in a building scale; it concerns the principles of the bio-climatic design (monitored by the aid of computerised models) (Caini 2010) and the sustainability criteria stated in the LEED certification system (GBC Italia 2011).

The LEED system was chosen because such method has been widely used in Italy and because the client of interest of the case study requested it. The bio-climatic design methodology (Caini and Paparella 2012a) has the purpose of optimally exploiting the outside environment's characteristics in order to build a comfortable setting. The aim is to pursue the following objectives: minimizing environmental impact, optimally exploiting the already existent climatic resources in order to reduce the energy consumption of non-renewable resources.

However, the sole application of the bio-climatic design methodology does not deal with all the aspects that arise from the analysis and application of the criteria of an environmental certification system. The environmental certification systems (Garau, Jorio and Paparella 2009) tackle the problem of the relationship between the building and the environment under many different points of view. Whenever a building is designed and then built, the pre-existing balance between the environment's components such as land, water, air, energy, material and resources gets altered. The environmental certification systems draw attention to the criteria to be taken into consideration for the planning development and present to the planner the objective to pursue without, however, indicating a precise method to follow. Therefore, we believe that the bio-climatic design methodology and the environmental certification criteria are complementary tools which have to be integrated in the same methodological procedure in order to obtain high standards of certification and the realisation of high energy efficiency buildings. This paper reports the application of a working methodology applied in a case study in which bio-climatic design was implemented using the LEED certification system's criteria. Such experimentation creates a methodology that combines the objective of designing a building that exploits the environment's climatic resources while reaching high standards of environmental certification.

The case study

The design experimentation carried out concerned the requalification of Malga Fosse municipality of Siror, a mountain dew near Passo Rolle in Trentino Alto Adige (Fig. 1), and its outskirts.

Figure 1: View from Malga Fosse to Passo Rolle

The case study considers a building with the following peculiarities:

a) it is located inside a natural park in the alpine area of the North-East of Italy at a height of about 2000 m; and
b) the person of interest required a building capable of receiving a specific system and class environmental certification.

During the testing, aspects linked to tourism and its evolution and the building's cultural function (Sovilla 2013) as mountain dew have been taken into account.

Mountain tourism is continuously developing and there has been a shift in the characteristics of the typical tourist: families with children and elderly have replaced the excursionists.

The implementation faced the issue of trying to maintain the continuity between tradition and innovation (Selva 2013); while trying to maintain the building look like a mountain dew, the project strived to keep the efficiency and environmental certifications' standards high (Trubiano 2012).

The interested geographic area is where Passo Rolle is located; at a height of 1984mt. above sea level, it connects the Fiemme and Fassa valleys with the municipality of Siror and above all, the tourist location of San Martino di Castrozza.

This project corresponds to a very large allotment where there are two buildings:

a) Malga Fosse (Figure 2 and 3), which is now abandoned - even though not so dated (from the Sixties), it lies in a high degrading state; and
b) a newly built stable, active only during the summer season and not used in winter.

Figure 2: "Malga Fosse" full view

Figure 3: South side view

Project data

The proposal of a new public place in the area has the objective of creating a new attraction site for both summer and winter times. Therefore, it has to correspond to specific requests made by the person of interest:

a) the formal requalification of the building with the aim of creating a new attraction site;
b) the planning of a building with high environmental sustainability characteristics. For the final execution, the certification of the LEED Gold protocol is required; and
c) the consideration of the environment in which it is located (Natural Park of Paneveggio and of the Pale of S. Martino).

Basic functions such as the possibility of an overnight stay must be guaranteed, therefore it will have:

a) a bar, a restaurant, a stocked pantry and hygienic services for guests and the personnel;
b) 6 rooms with bathroom (minimal dimensions: 13.5 m^2 for double rooms and 7.5 m^2. for single rooms, 3 m^2 for bathrooms); and
c) a guardian's apartment composed by two rooms, a dining-living room and a bathroom. The total minimal dimensions are 60 m^2.

Rooms such as the kitchen, storage rooms, technical compartments and rooms for the personnel can be located in the basement provided that they are well conditioned and large enough. The building will have to be accessible by disabled people.

For what concerns the parking lot, it was requested to realise 6 to 9 parking spaces underground, which together with the outside ones will have to respect the attachment 3 of the article 59 of the LP 1/2008, which means that the parking lot should be 6 m^2 for each tourist's bed added to the double of the net surface of the restaurant and decreased by 1 m^2 for each bed.

The applied design methodology

The design of the case study was put in act by implementing the methodological process on the bioclimatic design already developed by the authors (Caini and Paparella 2012b). Such process updates the bioclimatic principles (Olgyay 1963) and it uses physical-technical modelling tools in a dynamic regime (Ljubomir 2012) in order to follow the methodological bioclimatic principles and the LEED system certification' criteria. Such methodological process proposes itself as a real integrated planning process.

The proposed bioclimatic design methodology is divided into the following steps.

Step one:

a) analysis of the structural invariants of anthropic value (historical analysis and possible archaeological analysis);
b) analysis of the infrastructural invariants (road networks, specialized knots and specialized territorial endowments); and
c) analysis of the structural invariants of natural value (hydrologic analysis and geomorphologic).

Step two: analysis of the physical characteristics of the territory based on the variety of the climatic data of the last 5 years, recorded by the meteorological station closest to the project area.

The necessary data are: Speed of the wind (m/s), Direction of the wind (degrees), Air temperature at dry bulb (°C), Relative humidity (%), direct solar radiation and Diffused solar radiation.

Step three: analysis and systematization of the climatic data, in order to get the standard climatic year.

Especially for the wind climatic datum, it is necessary to determine the monthly averages, the standard day for each month and to carry out the synthesis of the direction and intensity parameters in the overheated period.

Step four: representation of the systematized climatic data inside the bioclimatic diagram. From this operation the planner can understand to what extent the climatic conditions of the location are inside the comfort area. In the periods of the year in which these revert inside the comfort area, it is necessary to set out planning strategies that are able to guarantee the comfort.

Step five: individualization of the climatic requirements and their representation, and Integration of the diagram with the availability of the on site climatic elements.

Step six: based on the already carried out analyses, development of the first planning idea with application of the appropriate strategies.

Step seven: analysis and control of the planning choices through the aid of modelling simulators.

Step eight: revision of the project according to the achievement of the objectives with an iterative method.

Let's examine the steps to follow for the application of LEED protocol and how they modify the design. In the examined case study all the main parts of the protocol have been analysed (*Site Sustainability, Water Management, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality*), except for *Innovation in Design* and *Regional Priority* as these categories do not directly affect the design, but are two consequences of the LEED rating obtained and of the measured results. Obviously the satisfaction of a credit does not necessarily imply an important intervention in the design of the building; then a credit that has not produced any influence in the design phase does not mean it has not been exceeded.

From the analysis it was possible to fill tables that relate the analysis of LEED credits and the related design choices.

Table 1 lists all the LEED credits for Sustainable Site (SS) and its influences (if there are any) in the design phase with the explanation of the choices made regarding the project.

Table 1 underlines that for the credit “Alternative transports: bicycle racksand changing rooms", the corresponding requisite in the case study taken into consideration (commercial building) was achieved by:

a) the furnishing of safe bicycle racks and/or deposits to a distance inferior to 200 ms. from the building’s entrance for at least 5% of all the building’s consumers (measured during peak periods); and
b) the furnishing of locker rooms with showers, inside the building or to a distance inferior to 200 m from the building’s entrance, in measure equal to the 0,5% of the full time equivalent occupants (FTE: Full Time Equivalent).

In the case study, the credit "Heat island effect: shells" deprived of any green coverageis translated in the requirementof using coverage materialsthat have aSolar Index Reflection, SRI, for a minimum of 75% of the roof surface calculated with values obtainedby the interpolation between white and black limit values.

In the case study, the SRI value was calculated to be 72 because of the choice of an aluminum plate as element of external coverage.

Table1: Influence of individual LEED credits on the project with respect to credits of the Site Sustainability

CREDIT	TITLE	AIM	PROJECT
SS Prerequisite1	Prevention of pollution from construction activities	Limit the production of waste.	-
SS Credit 1	Site Selection	Appropriate choice of the project site.	-
SS Credit 2		Building density and proximity to services.	
SS Credit 3		Recovery and redevelopment of contaminated sites	
SS Credit 4.1	Alternative Transports: access to public transport	To minimize pollution due to the use of private transport.	-
SS Credit 4.2	Alternative transports: bicycle racksand changing rooms	To minimize pollution due to the use of private transport	Realization of a locker room for the employees on the ground floor
SS Credit 4.3	AlternativeTransports: low emission vehicles and alternative fuel	To minimize pollution due to the use of private transport.	Presence of some charging stations in the basement
SS Credit 4.4	Alternative Transportation: capacity of the parking area	Guarantee a minimum number of parking spaces in the area.	In addition to carrying 6 underground car park, it was decided to take no action on the dirt yard to the west of the refuge to ensure the possibility of parking.
SS Credit 5.1	Site Development: protect and restore habitat	Pay particular attention to the habitat, trying not to destroy it.	-
SS Credit 5.2	Site Development: maximization of open spaces	Promote the presence of areas devoted to green space	The intervention was carried out exclusively in the dirt without removing the existing greenspace.
SS Credit 6.1	Rainwater: controlling the amount	Controlling the flow of wastewater into the ground and polluting substances.	-
SS Credit 6.2		Rain water: Quality Control	
SS Credit 7.1	Heat island effect: external surfaces	Minimize the heat island effect.	Paved surfaces outside the building have not been realized
SS Credit 7.2	Heat island effect: shells	Minimize the heat island effect	Careful choice of finishing materials to cover with an adequate SRI index
SS Credit 8	Light Pollution Reduction	Avoid or minimize light pollution in the timetable night.	There is no light devices

Tables related to the following matters have been designed:

a) Water Management (WM) and its influences (if they had) in the design phase with the explanation of the choices made regarding the project;
b) Energy and Atmosphere (EA) and its influences (if they had) in the design phase with the explanation of the choices made regarding the project;
c) Materials and Resources(MR) and its influences (if they had) in the design phase with the explanation of the choices made regarding the project; and
d) Indoor Environmental Quality (IEQ) and their influences (if they had) in the design phase with the explanation of the choices made regarding the project.

For example, for the inherent credits “Water Management” it is observed that to satisfy the credit "reduction of the use of the water", the project proposes sanitary with a low water consumption.

For the credit "Innovative technologies for the waste waters" it proposes a path for meteoric waters, with relative reservoir and a possible re-use, all favored by the inclination of the roof.

For the inherent credits “Energy and Atmosphere” it is observed that in order to satisfy the credit regarding the optimization of energy performances, production systems from renewable sources on site must be used in order to compensate the energy consumptions of the building.

This involves the evaluation of the building’s performances pointing out the energy production from renewable sources as percentage of the annual requirement of primary energy of the building and the results obtained by the energy consumption analyses.
Using the data emerged by the simulation in a dynamic system for the calculation of the supposed consumption, the choice has reverted on a bio-fuel boiler supported by a thermal solar plant.

The biological fuel is constituted by virgin wood, therefore the whole energy requirement for the heating and the sanitary warm water is entirely satisfied by renewable energy sources. The whole electric requirement is satisfied by the energy produced by the photovoltaic plant.

The only energy contribution produced by fossil fuels is related to the derisive quantity of gas deriving from cooking. In conclusion it can be affirmed that the percentage of renewable energy used is almost 100%.

For the inherent credits“Materials and Resources” for instance for the credit Materialsextracted, processed and producedinlimited distance(regional materials)for the attainment of the objective the choice has reverted on raw materials coming from the neighbouring areas, minimizing transport pollution(wood and concrete), with an ornamental use of the stone.

For the inherent credits “Indoor Environmental Quality” for the monitoring of the indoor air the assemblage of CO^2 control sensors is expected.
As it regards the control of the chemical and polluting sources indoor, finalized to avoid the entry of harmful substances inside the building it is anticipated an anti-dirt barrier along the floor of the atrium, realized in a synthetic material.

To consider the credits of the protocol LEED together with the other data, and to constantly refer to these within the methodological process of the bioclimatic planning, brings to the end of a first phase of application that individualize the possible relapses present in the project.

The necessity to reach an high score to get an high standard environmental certification, inevitably pushes to redefine the design choices up to the attainment of the maximum score obtainable.

The two area of interest of the study converge toward the objective of realizing a sustainable building in its wider meaning, this justifies an integration of the two processes in a single methodological one. For more clarification, the method is schematically presented in Figure 4.

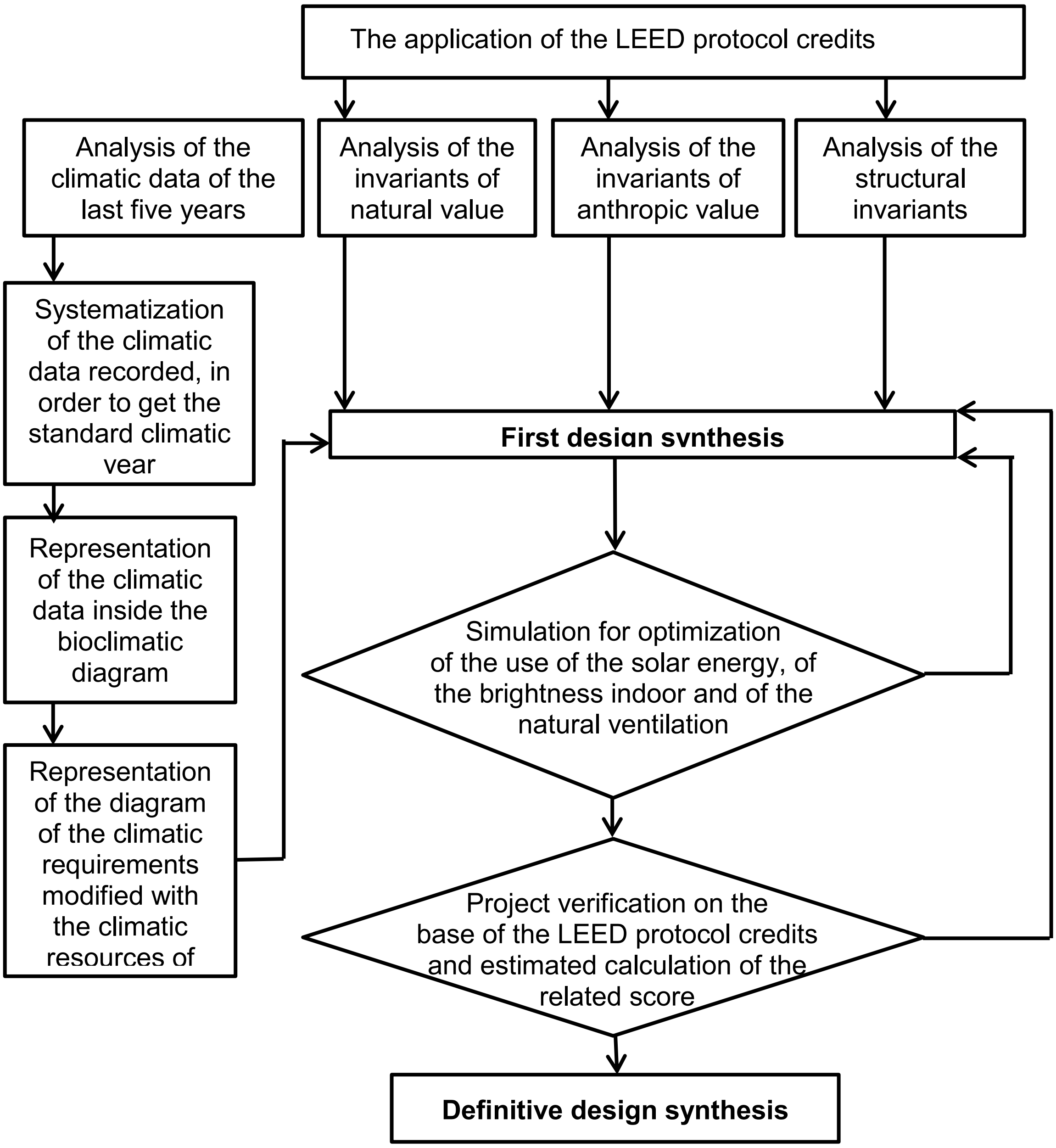

Figure 4: Flow chart of the methodology for a bioclimatic design integrated with the credits of the LEED certification system

The application of the method to the case study

As an example it showed the design reasoning followed with regard to the alternative transportation credit: low-emission and alternative fuel vehicles, the aim is to reduce the environmental impact and pollution generated by road traffic.

With regard to the mentioned credit several options for obtaining credit are analyzed. Solutions are analyzed to which the preferential parking, the ability to supply or that of a car-sharing service for both occupants and visitors. In this case we have chosen to exploit the alternative fuel vehicles considering their increasing spread in a future perspective. An attempt was therefore operate by trying to satisfy the following option.

To install the alternative fuel refueling stations for 3 % of the full capacity of the site's parking area (charging stations for electric vehicles and systems for liquid or gaseous refueling).

Due to the demand for the tender notice to carry out a minimum of six underground parking spaces, it was decided to exploit the latter to fulfill the credit requirements. Given the continuing spread of electric or better hybrid cars, able to exploit both electricity and fossil fuels, it is now necessary to make increasingly available on the territory of charging stations in order to allow the effective use of this new means of transport, that would otherwise be strictly confined to the area near to the point of charging base (probably the owner's house). So here in the underground car park are arranged two charging stations as well as a preferential parking for alternative fuel vehicles (see Figure 5).

Figure 5: Arrangement of charging station in the basement

When it relates to the minimum standards required by the LEED credit alternative fuel stations must cover at least 3% of the total capacity of the parking lot. Quantifying the number of parking spaces in the immediate areas not immediate as well as the six underground parking, there is any outdoor area, especially around the western entrance of the lot that will be used as space for parking as it is far from now.

Considering the presence of two charging stations, so that at the limits imposed by the credits could represent the 3% of the total parking spaces, it means that the maximum occupancy of the parking lot of the new Malga Fosse can get to 66, number that exceeds the capacity in the studied lot.

The installation of a charging station is possible only because the project foresees the installation of a photovoltaic plant that guarantees an high production of electric energy to the esteemed requirements.

The synergy and the complementarity of the two areas of study are demonstrated: the environmental certification and the bioclimatic planning.

Similarly for the other credits were performed reasoned paths similar to the just played one.

The design experimentation on the case study under consideration is illustrated in Figure 6, 7, 8 and 9.

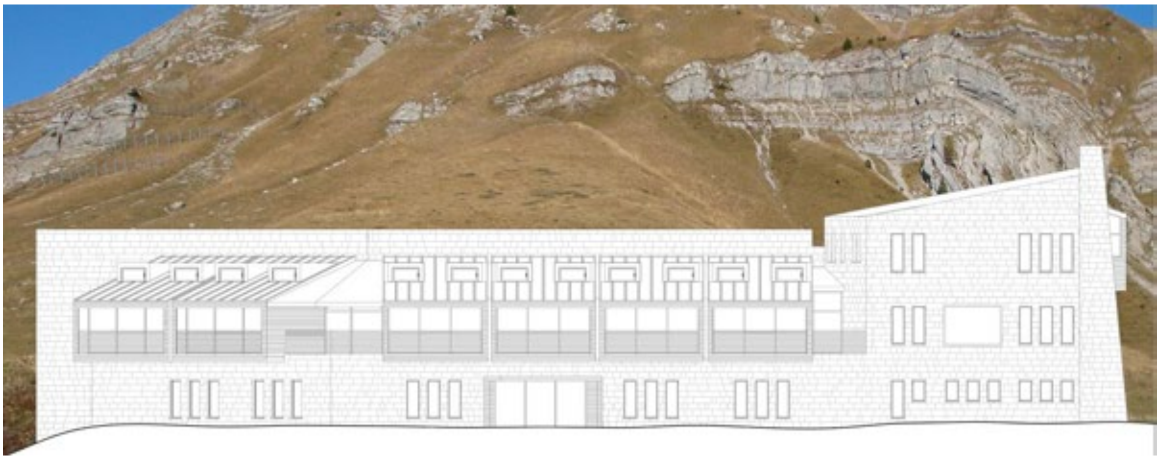

Figure 6: South front

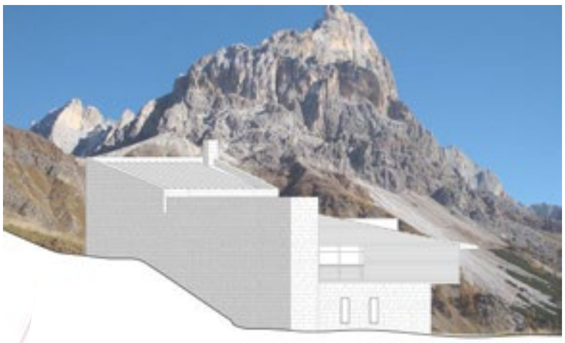

Figure 7: North-West front

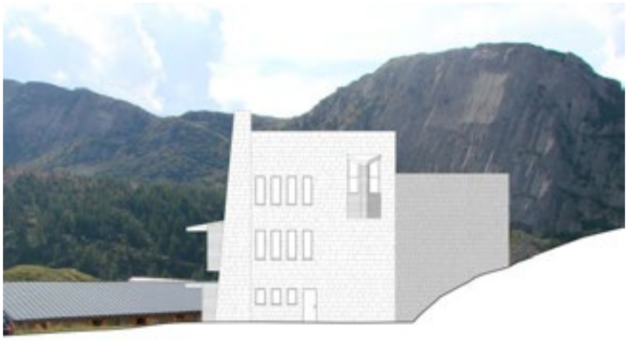

Figure 8: East front

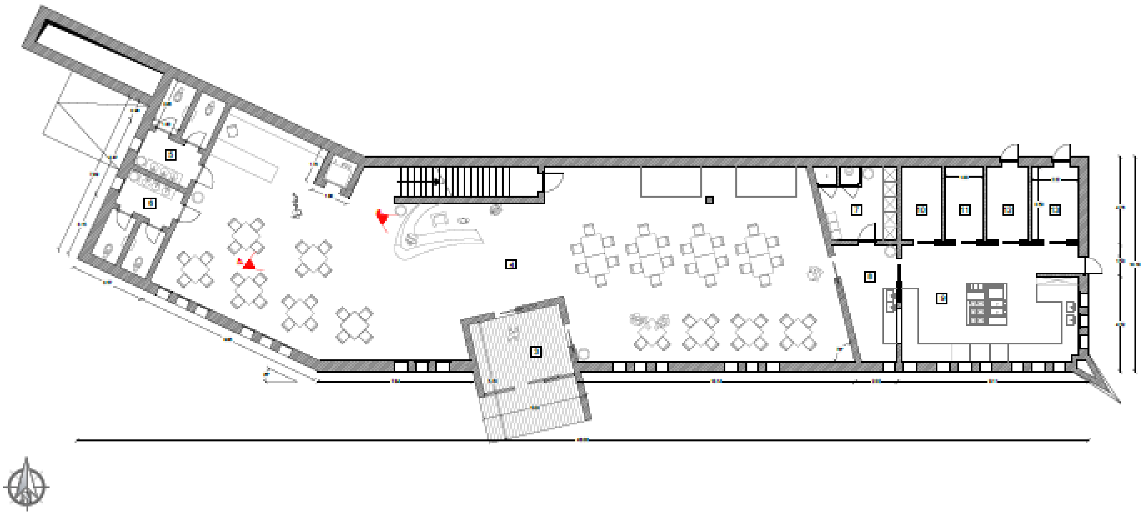

Figure 9: Ground Floor Plan

From the energy efficiency point of view, by using the bioclimatic design methodology, the consumption of the building is reduced (Fig. 10) and corresponds to 103 kWh/m^2 per year.

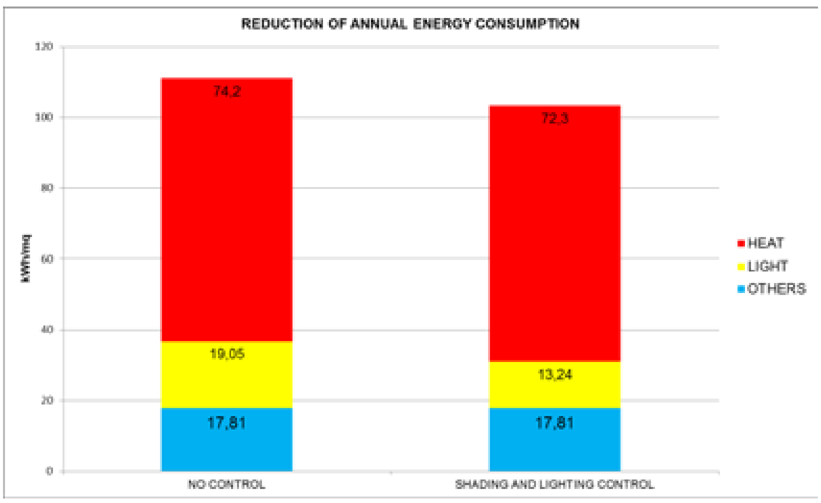

Figure 10: Reduction of annual energy consumption (kWh/mq)

As a result of the design experimentation performed according to the prescribed design methodology, has finally gone through the verification in terms of score obtainable according to the LEED system.

The analysis of individual credits shows that the project can achieve an estimated score of 89 points, configurable as maximum attainable standards of certification, corresponding to the LEED Platinum. In such way the tender notice's requirements of obtaining the LEED Gold are met.

The level of certification obtained together with the resulting performance in terms of energy consumption shows that the method is effective.

As proposed in the initial part of the paper, the obtained results proved the bioclimatic design methodology and the LEED certification system to be efficient when used complementarily.

It is believed that the proposed design methodology needs to be experimented under other environmental certification systems. This would allow verifying and comparing the obtained results for what concerns the energy consumption reduction level and the attainable environmental certification level.

Conclusions

The proposed method combines the energy efficiency and the environmental sustainability allowing to reach high standard environmental certification and reduction in energy consumption. This result is possible because even if the building is located in an area with severe weather conditions, the method integrates the requirements of LEED specifications with those of bioclimatic design.

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ENERGY SIMULATION STUDY FOR REDESIGNING OF FLEXIBLE TERRACED SOCIAL HOUSING

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ENERGY SIMULATION STUDY FOR REDESIGNING OF FLEXIBLE TERRACED SOCIAL HOUSING

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Abstract
The case study house chosen forms the basis of this paper which is a pilot energy efficient social housing project completed by the Accent Group Ltd in 2005. The main aim of this study is to inform the redesign of a flexible energy efficient house. The housing designed for social tenants, and built by, the Accent Group using modern methods of construction, and sustainable materials based on extensive research from the adaptable and grow home principles of Avi Friedman. The first pilot scheme was designed in collaboration with the Building Energy Analysis Unit at the University of Sheffield together with the Goddard Wybor Practise, and was a successful housing development as environmentally friendly and low energy designs for the UK climate. The paper presents redesigning of a flexible terraced house and its performance evaluation using building simulation. The aim was to plan a row of terraced houses that can not only utilise a flexible design concept but also reduce energy consumption with a passive design and a particular attention to materials' selection. In addition, building simulation work has been carried out with the use of DesignBuilder software for both thermal and energy performance evaluation. The study examines the annual energy performance and comfort conditions in the designed house to be situated in the North East of England, UK. The terraced house design is considered as a flexible home that can adjust the tenants' different needs with the purpose of achieving a sustainable building under different aspects such as low energy, low carbon, use of renewables and low impact materials, with flexibility by design.

Keywords: *Flexible housing; sustainable design, energy efficiency; Social Housing; building simulation, mass customisation.*

Introduction
Climate change is one of the biggest issues the world is facing today and the UK government is at the forefront to deal with this challenge. The domestic sector accounts for 27% of the UK's carbon emissions making it necessary to pay attention on the way homes are designed and constructed (Department of Energy and Climate Change 2012). Attention should also be paid on making the existing housing stock energy efficient, as most of them will continue to be in existence for another 50 years, if not longer. According to the UK House of Commons Environment Committee, around 200,000 dwellings would need to be built each year in England up to 2016 between 1991 and 2016, as there is a need for 4.4 million houses to be added to the housing stock (Golland and Blake 2004).

Adaptability and flexibility are quality characteristics of space while the need for change is universal phenomenon. There is a great need of studying flexibility of our living space with the potential of spatial changing in long period of time rather than only thinking of the need of space for the present use. We need to surpass the phrase of "forms follow function". Furthermore, this type of accommodation will accommodate various function demands within a limited space. Besides its pragmatic benefits, flexible housing has ecological potential, especially for saving energy and resources. The refurbishment, obsolescence, and demolition of adaptable designs require less material, energy and labour, and therefore, it is sustainable by design as there are less waste and lower costs.

In past decades, architectural practise has faced a lot of challenges. Although our living conditions changed in different contexts considering social, technological, economic, environmental, and political aspects, our housing types, responding to our patterns of living evolution, still largely based on early twentieth century models (Forster 2006). The speed of modernisation which had started from the 18th century is changing our living and the industrial revolution made it so difficult for the buildings to function without any adaptability or flexibility due to changes in our lifestyle. By migration of many people from the villages to cities and creating metropolis, the social disorder due to the poor quality of living emerged and expanded through the technology (Leupen, Heijine and Zwol 2004).

In this paper, a cases study of a pilot energy efficient social housing (Fig. 1) has been chosen with the main aim to inform the redesign of a flexible energy efficient house. The housing designed for social tenants, and built by the Accent Group in 2005 using modern methods of construction (MMC), and sustainable materials based on extensive research from the adaptable and grow home principles of Avi Friedman (Friedman 2002). The first pilot scheme was designed in collaboration with the Building Energy Analysis Unit (BEAU) at the University of Sheffield (Altan 2006) together with architects, the Goddard Wybor Practise. The project was a successful housing development as environmentally friendly and low energy designs for the UK climate.

Figure 1: A row of terrace houses – energy efficient social housing in north east of England

The paper presents redesigning of a terraced house (Muthesius 1982) and its performance evaluation using building simulation. The aim is to plan a row of terraced houses that can utilise a flexible design concept as well as building performance evaluation for optimising energy demand. Moreover, the terraced house design is considered as a flexible home that can adjust the tenants' different needs with the purpose of achieving a sustainable building under different aspects such as low energy, low carbon, use of renewables and low impact materials, with flexibility by design.

Approach and Methodology

In this study, a pilot project of social housing development based on the 'Accent Home' concept- a row of terraced houses, has been redesigned with flexibility and adaptability to meet the needs of different tenants including a single family in the future (Fig. 2).

Figure 2: Redesign of a social housing development

The following layouts (Fig. 3) and the longitudinal section (Fig. 4) help to understand the way in which the housing unit can grow over its lifespan. Starting from a configuration with one unit, i.e. first and second floor units (Fig. 3, centre and right), it is possible to divide the same housing unit into two or even three separate units (Fig. 4, left to right).

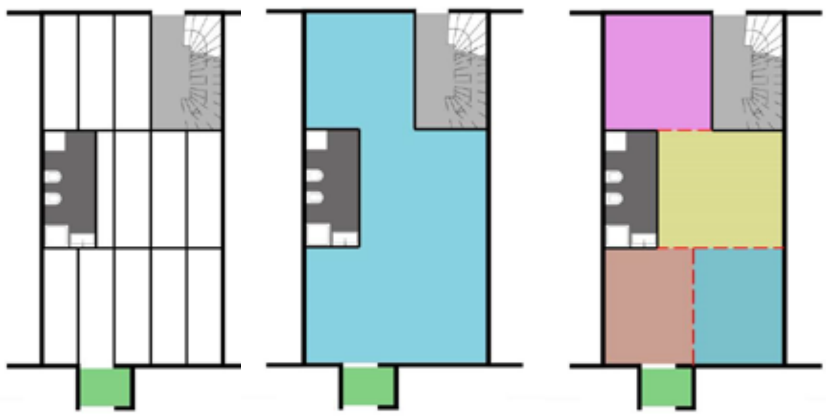
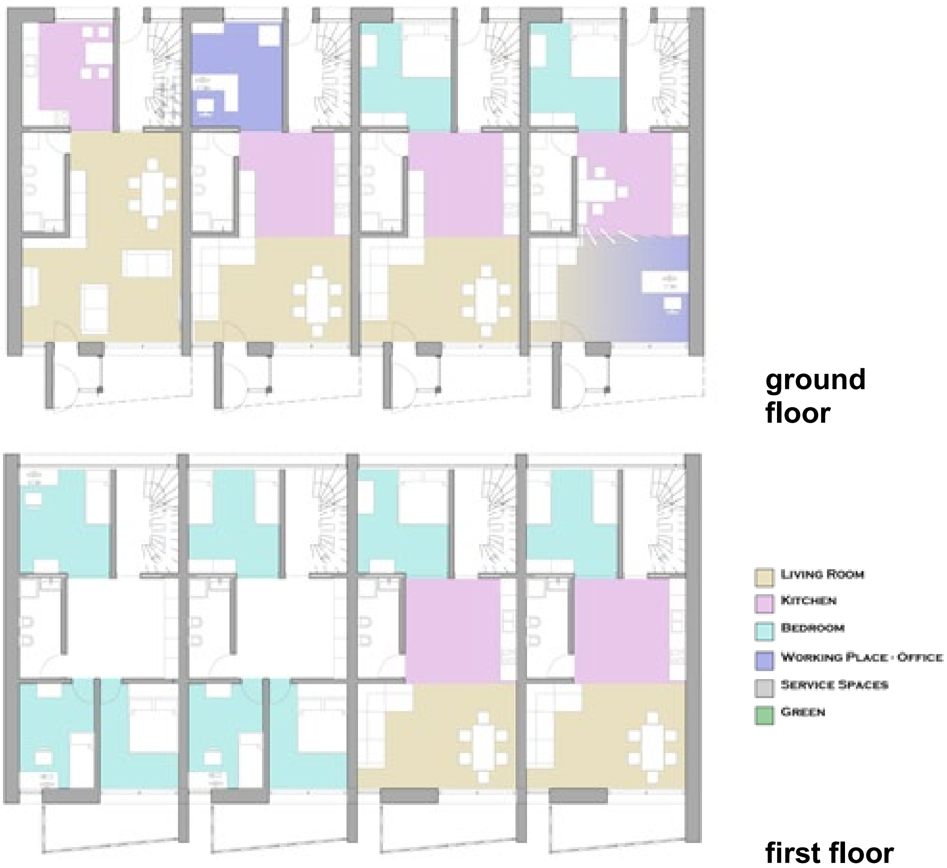


Figure 3: Configuration layouts (left to right) of unit(s)

Figure 4: A longitudinal section with growing units

The housing unit(s) with the main entry and the staircase can be provided with two independent entry doors. One on the south facade and connected directly with the main street, and the second one on the north side, which can be also used as a service door or an independent door to arrive at the housing unit of the first and second floors (Fig. 5). The internal space resulting from the division is a long and dynamic space of 48m^2 that can meet the needs of different tenants. In addition, different zones can be converted by tenants through sliding walls or sliding wall for daily changing or through more or less flexible kind of wall.

In the following, the full layouts of the housing units' floor plans are presented (Fig. 5).



second floor

Figure 5: The housing units' floor plans

Energy performance evaluation is usually beneficial at the early stages of design however in this particular case, in redesigning of social housing, it is still an important factor that has to be considered in order to make the necessary provisions for achieving the best practice standards, i.e. low energy, low carbon (Energy Saving Trust 2004, 2010) for sustainable future housing. Hence, in the recent years applications of low and zero carbon technologies, and adoption of the renewable energy sources in domestic buildings rapidly increased. On the one hand, it is equally important to design flexible houses in order to create provisions for the needs of future lifestyles while also reducing the use of energy demand by maximising the advantages of passive design and the use of low impact materials. This approach is nowadays essential and the benefit of passive design could allow indoor comfort with a few renewable technologies. Passive design is not a supplement to architectural design, but it is rather part of the design process itself with integrated approach to architectural and sustainable building design (Brophy and Lewis 2011, Keeler and Burke 2009 and Yudelson 2009).

In the study, DesignBuilder software has been used for conducting building simulation work (DesignBuilder 2013). The software package has integration with EnergyPlus, the US Department of Energy's (DOE) 3rd generation dynamic building energy simulation engine for modelling building, heating, cooling, lighting, ventilating and other energy flows. This integration within DesignBuilder allowed the user to carry out complete simulations without having to leave the interface, which is an excellent feature for the use of practising architects.

The following table is showing the necessary input information for building simulation analysis (Tab. 1).

Table 1: Building simulation input data for HVAC, DHW, activity and construction

Compact HVAC	
HVAC systems is defined parametrically and modelled within EnergyPlus using Compact HVAC descriptions with a CAV (constant air volume)	
Natural Ventilation	
Natural Ventilation and infiltration air flow rates is calculated based on opening and crack, sizes, buoyancy, wind pressure and the activity schedules	
Mechanical Ventilation	
Mechanical ventilation utilised in the flexible housing design has an ac/h (air change per hour) rate of 0.4 as required by the PassivHaus standard with an outside air definition method set for zone	
Fans	
Night cycle control	Cycle on control zone
Fan placement	Blow through
Part-load power coefficients	Variable speed motor
Fan type	Intake
Pressure rise (pa)	1000.0
Total efficiency (%)	85.0
Fan motor in air (%)	100.0
Outside air definition method	Minimum fresh air (Per area)
Outside air mixing	Recirculation
Outside air control minimum flow type	Proportional
Heat Recovery	
Heat recovery type	Sensible
Sensible Heat Recovery Effectiveness	0.800
Heating setpoint temperature	15.00
Domestic Hot Water (DHW)	
Type	Dedicated DHW boiler
DHW CoP	0.85
Fuel	Biomass
Water Temperatures	
Delivery temperature (°C)	65.00
Mains supply temperature (°C)	10.00
Activity	
Compact schedule has been used for occupancy, metabolic activity, openings of windows and doors, lighting, and the schedules are based on data published in the UK's National Calculation Methodology (NCM)* * The NCM for the EU's Energy Performance of Buildings Directive (EPBD) is defined by the Department for Communities and Local Government (DCLG) (BRE 2013).	
Construction	
DesignBuilder uses construction components to model the conduction of heat through walls, roofs, ground and other opaque parts of the building envelope. Using the construction data the physical properties of each elements have been defined of the building (e.g. external wall, party wall, interior wall, roof, floors and ground floor). The same is for windows and doors that can be selected from a well-provided library. Since this project is a row of 4 identical blocks, with the exception of internal changes depending of utilisation and flexibility design.	

Analysis and Results

In this section, the analysis based on simulation studies has been presented. For the simulations, the following table shows several details of the selected housing unit (Tab. 2). As part of the analysis, a series of simulations has been carried out using DesignBuilder software considering the above input data. One of the concerns was the overheating potential due to the type of construction used and in the case of PassivHaus standard adopted (Passivhaus Institut 2010 and Uffelen 2012), i.e. super insulation, high airtightness and large levels of glazed south facade of the house design. Therefore, the study evaluated the internal comfort during one of the warmest weeks of the year in order to avoid likely overheating over summer periods.

Table 2: Selected housing unit information

Dimensions	Metres (m)
Width	6.4
Depth	9.0
Floor Height	2.4
Type of Unit	Mid-terraced House
Number of Floors	Ground + 2
Number of Bedrooms	4
Floor Area	170 m^2
Climate Data	Leeds/Bradford (UK)

The following graphs are the results of an hourly internal comfort and temperature distribution for the living room on ground floor from 29 June to 5 July (Fig. 6 and 7).

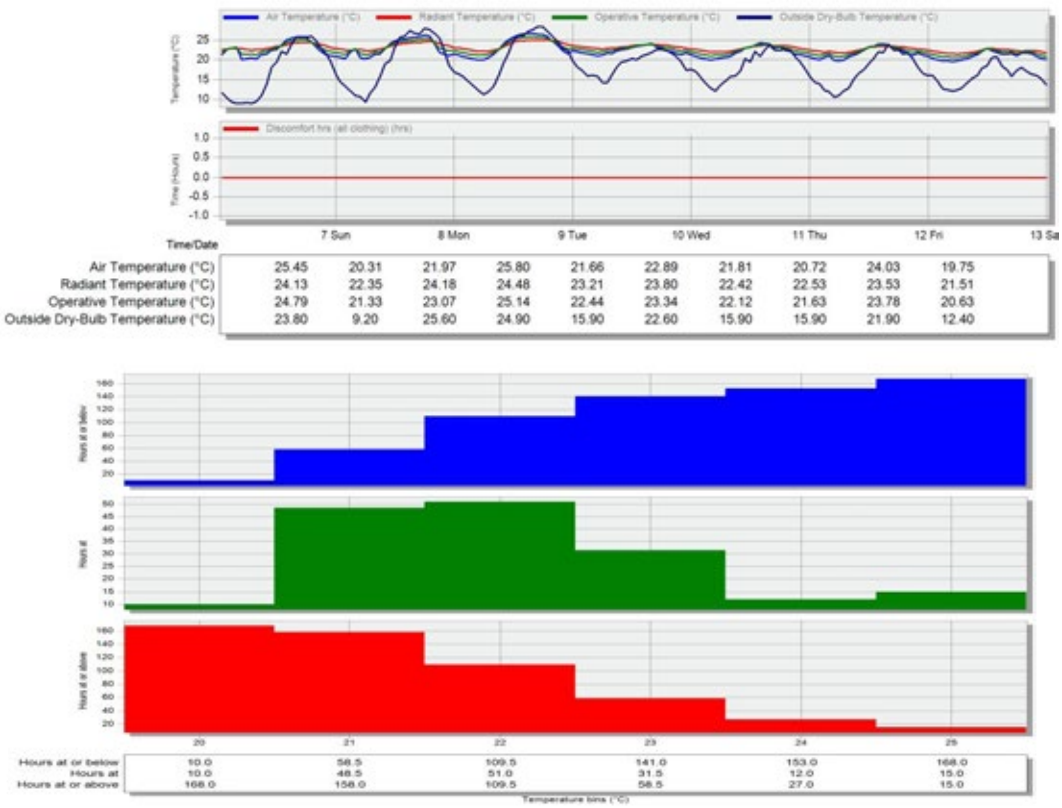


Figure 6: Typical summer week showing temperature and discomfort hours

Again, same evaluation has been carried out for a typical winter week and the results have shown that the average temperature profile stays constant around 20°C due to heat recovery, insulation and solar gains (Fig. 7). In a PassivHaus designed house there is no use of any heating system but a system that contains mechanical ventilation with heat recovery (MVHR) (Tab. 1).

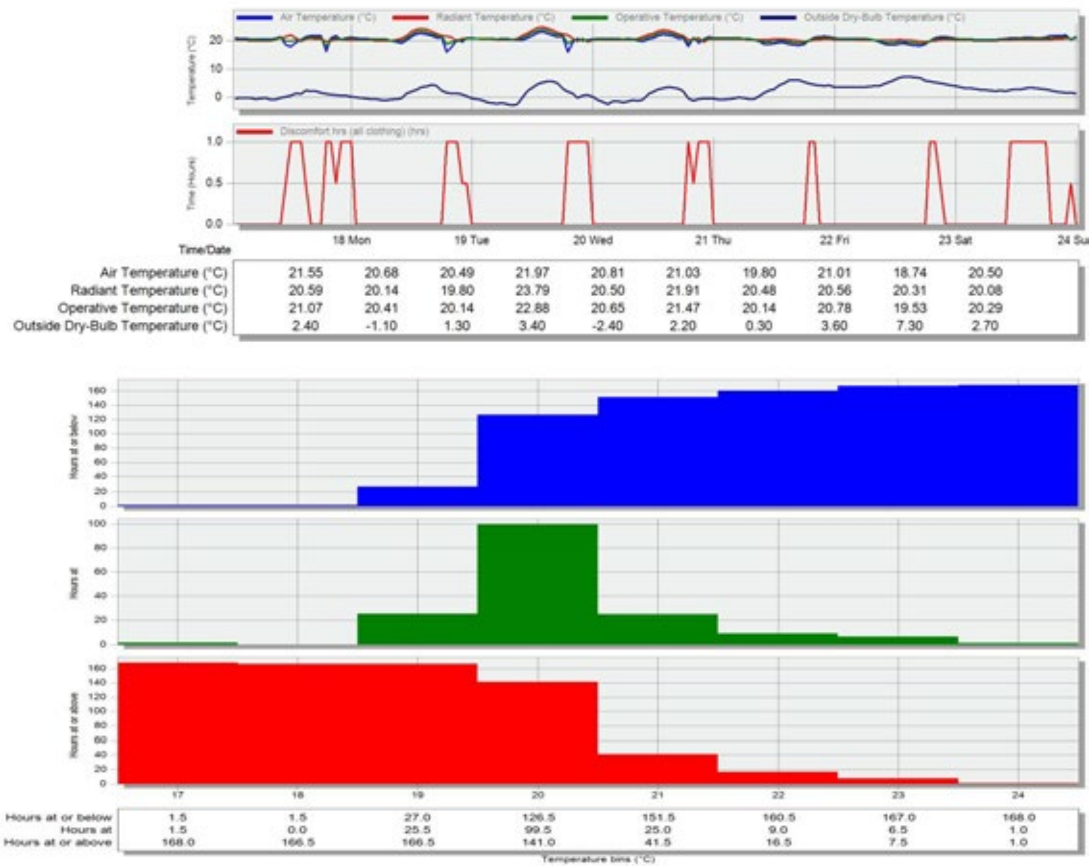


Figure 7: Typical winter week showing temperature and discomfort hours

The following presents the total fuel breakdown listing different energy consumption for the redesigned flexible housing unit (Fig. 8).

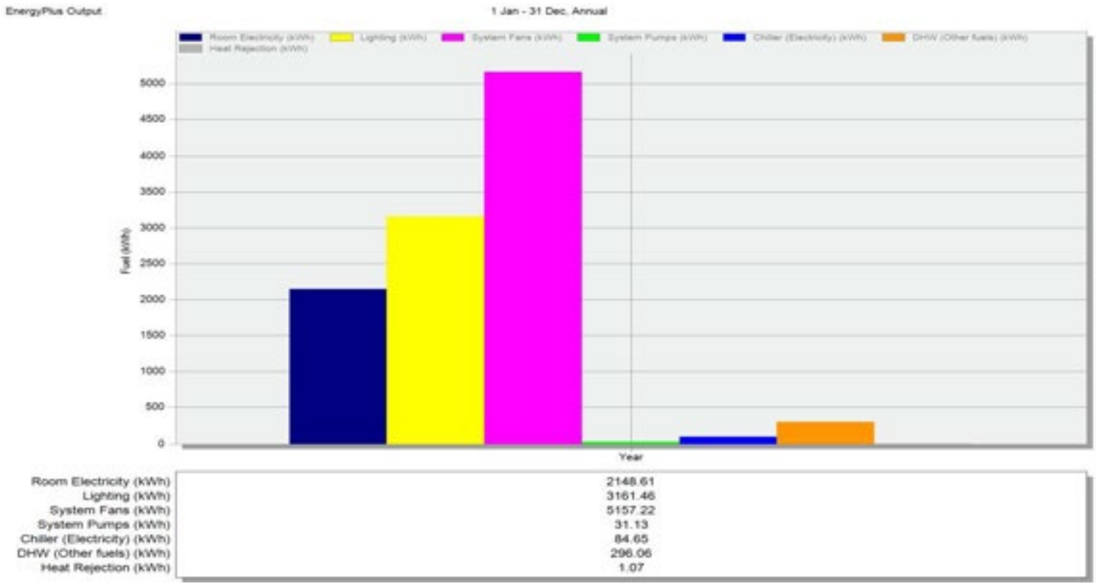


Figure 8: Fuel breakdown

As the housing unit chosen has the floor area of 170 m^2, to obtain the annual energy consumption and the associated carbon dioxide emissions (CO_2), further calculations has been made to present the necessary values (Tab. 3).

Table 3: Annual energy consumption and carbon emissions

Total Energy Demand	Carbon Dioxide (CO_2)
10880 kWh/year	7493 kg/year
64 kWh/m^2	**44** kg/m^2

In order to demonstrate the benefits of simulation study findings for retrofit, it is important to compare against the measured consumption figures. In this case, the following table presents the average measured energy consumption and the associated carbon dioxide emissions obtained from years of on-site monitoring between 2007 and 2009 (Tab. 4). As the existing housing unit floor area is 128 m^2, the calculations are based on this value.

Table 4: Measured energy consumption and carbon emissions

Total Energy Demand	Carbon Dioxide (CO_2)
13358 kWh/year *	6833 kg/year *
~104 kWh/m^2	**~244** kg/m^2

* The measured data is based on an average usage during years 2007 to 2009.
Note: Floor area for the same unit is 128 m^2.

As can be seen from both tables above (Tab. 3 and 4), the simulated housing unit, i.e. the retrofitted housing unit, has shown much better performance in terms of both the energy demand required and again the carbon emissions related. This however should be validated through real-time measurements in the retrofitted units, particularly for checking against the accuracy of simulation studies.

Discussion and Conclusions

The redesign of a terraced home has been a worthy challenge in terms of both adopting flexibility and adaptability in form as well as achieving the best practice energy efficiency standards. In this way, it was also useful to utilise building simulation and performance evaluation as means to help aid the building design considering various important factors such as PassivHaus standard, concerns of overheating, etc. Moreover, in real life situations, the occupant (i.e. the user) could still make a big difference in the way the energy is being used at home even though the design could be a high performance case, however it is once more fundamental to get the design specification right and tested throughout the design process, which has been demonstrated in this study. Therefore, without undermining the energy conscious user/behaviour to save energy at home, further studies should be undertaken and related to the people variable, i.e. their behaviour and attention for environment and energy, as a full follow-up.

This is a reminder for all practicing architects to utilise the available building simulation platforms to aid their designs or redesigns at the early stages of design of throughout their design process. Once more, integrated building design is not a myth but a way of today's building design practice, and all professionals should work closely in full collaboration, such as architecture and engineering, to help solving challenges of building science.

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GOOD PRACTICE FOR FUTURE SUSTAINABLE HOUSING

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GOOD PRACTICE FOR FUTURE SUSTAINABLE HOUSING

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Abstract

An average Scottish home emits about 3 tonnes of carbon dioxide (CO_2) annually which is higher than the UK's average figure of around 2.75 tonnes CO_2 emissions. As a result, the Scottish Government has set a target for new build housing, which can secure the zero carbon emissions by 2016/17. Nonetheless, to realise the net zero emissions in housing operation, much attention should be paid to the energy efficiency measures in existing housing where the energy usage of households accounts for a significant portion of the total energy consumption and CO_2 emissions. The challenge is still remaining and the major question is how average households could make a difference in their lifestyle in the light of their energy usage pattern and behaviour to live in housing under good standard indoor conditions without having to compromise too much with the increasing utility bills and carbon emissions. The paper presents a case study of an affordable house located in Prestwick, Scotland. The aim is to clarify users' current living conditions at home and to prepare for a future home concept that encompasses not only flexibility in occupants' dynamic lifestyle, but also sustainability by design. The reduction of energy consumption in the selected household had been achieved by implementing 'good practice' of the occupants' energy conscious behaviour accompanied by the installation of energy efficient domestic appliances. Moreover, the study provides grounds and an opportunity to investigate some of the key and common issues so as to identify elements of the good practice within home environments as well as successful measures taken with end-user behaviour and associated energy usage patterns.

Keywords: *Energy efficiency, Scottish Post-Council Home, occupant behaviour, building monitoring, energy consumption, mass customisation.*

Introduction

Energy usage of households in the UK accounts for a significant portion of total energy consumption and carbon emissions. In 2010, 27% of the UK's end-user greenhouse gas (GHG) emissions originated from the residential sector (Fig. 1) where the majority came from space and water heating totalling up to 67% (Department of Energy and Climate Change 2012). Therefore, encouraging consumers to reduce and change their patterns of energy use at home could make a significant contribution to reducing greenhouse gas (GHG) emissions, as required by the Climate Change Act 2008 (Committee on Climate Change 2012). As part of Great Britain and being placed at the northern part of the island, Scottish homes today are highly energy consumers emitting on average 3 tonnes of carbon dioxide (CO_2) per household annually and the amount exceeds the UK's average of 2.75 tonnes of CO_2.

A study by Wilson and Dowlatabadi (2007) has shown evidence that the behaviours of individuals can deviate significantly from a standard pattern in which people objectively weigh up the costs and benefits of investing time and money into 'greening' their homes and being more energy efficient. The study also indicated that social, cognitive and behavioural factors are important in explaining why many people have not yet introduced changes that could help them to enjoy cosier homes and lower energy bills (Wilson and Dowlatabadi 2007). The UK government has been looking at ways to encourage the uptake of some of the most effective energy efficiency measures through programmes, such as the Green Deal (a new initiative which will enable individuals to undertake energy efficiency measures in their homes with no upfront cost), and the investigation have shown that it is crucial to have an understanding of how people behave and use energy in their homes, and again why they do not act already, in order to identify and both overcome the barriers and facilitate the prompts to becoming more energy efficient at home (Cabinet Office Behavioural Insights Team 2011).

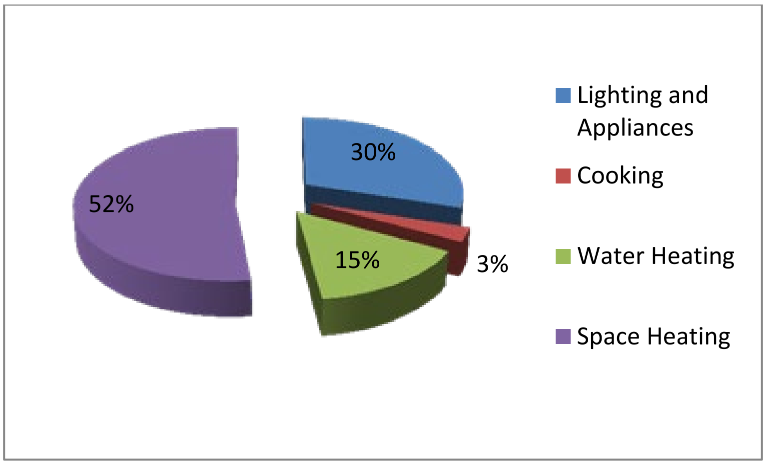

Figure 1: UK residential CO_2 emissions by use (Department of Energy and Climate Change 2012)

With the increasing utility prices and the associated carbon emissions, 26% of the households are actually facing severe fuel poverty also because of their 'hard-to-treat' dwellings and the related conditions with indoor environments (Scottish Governnment Social Research 2008, Scottish House Condition Survey 2013, Oreszczyn and Pretlove 2000 and Refaee and Altan 2013). Main factors for energy consumption in households are usually driven not only by the occupants' lifestyle and behaviour, but also the standards of building fabric and envelope, installed building services and appliances in order to maintain comfort and activities within. Energy consumption of households usually depends on environmental and human factors, and the occupants' presence and behaviour have a significant impact on energy demand due to services like space heating, ventilation, lighting and other appliances (Page *et al.* 2008[1] and Cadima 2009). An occupant present in a room generates pollutants like CO_2, odour, heat, which can directly change the indoor environmental conditions and as a result, the occupant is likely to adjust their comfort either by opening windows or running services to accommodate comfort based on their subjective needs, which in turn result in energy usage within the home environment. The indoor environment is a complex system including factors like thermal, visual, and acoustic conditions. The influence of these factors on human beings has been studied extensively and thus guidelines for design and measurements have been also established (Olesen and Seelen 1993). Therefore, it is an important task to efficiently manage and minimise energy usage in housing through good practice in order to meet reductions in both energy consumption and carbon dioxide emission toward targets such as 80% overall cuts in carbon emissions by 2080 for the UK, compared with 1990 levels (Department of Energy and Climate Change 2012).

[1]PAGE, J., ROBINSON, D., MOREL, N., and SCARTEZZINI, J.-L., 2008, 'A Generalised Stochastic Model for the Simulation of Occupant Presence', Energy and Buildings, 40(2), pp. 83-98.

In the past, a number of UK government initiatives, including the ‘Warm Front’ scheme (Gilbertson *et al*. 2006), have gone some way to meeting emission reduction targets through interventions such as cavity wall and loft insulation. Today however, it is acknowledged that there are barriers which cannot accommodate such standard energy efficiency measures, e.g. ‘hard-to-treat’ homes defined by the Energy Saving Trust (2004), where the issue should be tackled differently such as through energy use behaviour. In this context, energy conscious behaviour (or also known as energy use behaviour) can help significantly reduce energy use in households. From previous studies, it is known that user behaviour can influence efficiency gains via the day-to-day actions of occupants, e.g. whether they undertake energy conserving actions around the home, as well as to appropriately adopt and use energy efficiency interventions in an appropriate way (Mullaly 1999 and Janda 2009).

A study completed by Yohanis (2012) has recorded that although most homes could improve their home energy efficiency through various measures such as by improved tank insulation or installing condensing boilers and more energy efficient appliances in their homes, most householders are unaware of their advantages. Again, another research carried out by Jackson (2005) indicated that although many people are concerned about the environment, this does not always translate into taking practical steps to reduce domestic energy consumption. Therefore, sustainable practice of home energy usage patterns by occupants is crucial for making a huge difference both in end-user behaviour and in reduction of energy in general which will set an example for fundamentals of the good practice within home environments.

This paper aims to showcase good practice on an affordable existing house for energy saving and sustainable home design through exploring the indoor environments and energy usage patterns. The rest of the paper is organised as follows: Section 2 presents an overview of the household energy consumption; Section 3 describes the background; Section 4 mainly focuses on investigating energy usage pattern in the existing home; Section 5 analyses indoor environment of the existing house; Section 6 discusses how the findings can inform good practice based on this investigation of energy usage pattern and indoor environment. Last but not least, Section 7 concludes and highlights this study.

Typical UK Home Energy Consumption

The UK has the oldest housing stock in the developed world with 8.5 million properties over 60 years old (Energy Saving Trust 2010). Although the most common house type in the country is a semi-detached house with almost 30% of the existing housing stock, in Scotland terrace houses are around 21% of the existing housing stock, which is again one of the highest proportion of occupied dwellings after detached homes (22%) and tenements (24%) (Scottish House Condition Survey 2013 and Scottisch Government Social Research 2008). Table 1 shows some of the typical existing dwellings' performance in the UK.

The average household electricity consumption for lighting, appliances, cooking, heating and cooling varies across the UK but this is averaged to around 4,700 kWh per annum (Energy Saving Trust 2004). Moreover, the same report states that with an increased exposed wall area, the total energy consumption and the associated CO_2 emissions are increased. In this paper, the selected case study home is an average Scottish home.

Table 1: Performance of UK typical existing dwellings (EST 2010)

House Type	Floor Area (m²)	EPC Band	Existing Total CO_2 Emissions	
			Tonnes/yr	Kg/m²/yr
Solid-walled detached	104	F	13.7	132
Period end-terrace	89	F	6.5	73
Period mid-terrace	85	E	6.7	79
1950s semi-detached	90	E	6.5	72
1960s bungalow	64	E	6.2	98
1980s detached	111	E	7.7	69
1980s mid floor flat	61	E	4.2	68
Post 2002 mid-terrace	79	C	3.4	43

NRGStyle Existing Home Profile

The NRGStyle case study home is a post-council three-bedroom house, also classified as an affordable house, located in South Ayrshire, Prestwick, Scotland (Fig. 2) where a family of four live, i.e. a couple with full-time jobs and two school-aged children. To understand the energy usage patterns of the selected households, the energy data has been collected through a monitoring using smart metering through Ewgeco technology in the existing home (Ewgeco 2012). The analysis has been conducted to demonstrate their energy conscious behaviour living in this average Scottish home (Han, Altan and Noguchi 2012). In addition, an evaluation study using on-site measurements has been carried out monitoring indoor environment conditions in the same post-war dwelling. The analysis has been conducted to also demonstrate the indoor conditions and its likely standards when compared with the accepted recommendation and guidelines (Altan *et al.* 2012).

Figure 2: NRGStyle's existing home in Prestwick, Scotland

Below are the general information regarding the existing NRGStyle home in South Ayrshire, Scotland, showing building age, dwelling-tenure, window type, ventilation method, cooker type, and number of occupants, and the occupants' ages of the NRGStyle home (Tab. 2).

Table 2: NRGStyle's existing home in Prestwick, Scotland

Description	NRGStyle's Existing Home
Type of building	End-terrace house
Home age (year)	1950s (64)
Dwelling (tenure)	Owner occupied
Window type	Fully double glazed
Ventilation	Natural (at least one window open every day)
Cooker type	Gas
No. of occupants and ages	4 (2 Adults under 60 and 2 Children over 11)

The study was carried out with the aim to bring the research outcomes of the company's existing house into the development of their new housing prototype called 'ZEMCH 109' (a net zero energy/carbon affordable housing prototype) and the retrofit application in the UK contexts (Rohatgi *et al.* 2012). As part of this further analysis, a comparison study has been completed against the energy consumption of the existing house informing the design of ZEMCH 109 which has been proposed for delivery in the near future (NRGStyle 2014).

The following two sections analyse both the energy usage pattern and the indoor environment condition for the NRGStyle home.

Energy Usage Patterns

The house owner is a couple under age 65 with full-time employment jobs. They also have two school-aged children. It is important to understand the energy consumption during working and non-working days as this will provide us energy usage patterns thinking of the lifestyle of the occupants. Han, Altan and Noguchi (2012) has already completed analysis of the energy data where the annual period was classified as 301 days into working days, public holidays i.e. weekends and bank holidays, and school holidays.

As a result of this analysis, it was easier to pick up on the energy consumption showing patterns and usage of electricity, gas and water (Tab. 3). Accordingly, the values in below table are relative values of the energy consumption which are equal to the relative values times the actual averages of daily and weekly energy usage for electricity, gas and water that are also shown. Hence, the energy usage patterns of electricity, gas and water have been analysed at different time granularities based on days and weeks respectively (Han, Altan and Noguchi 2012).

As can be seen in above table, electricity consumption in working days is much less than in public holidays according to the mean values of working days (0.87) and public holidays (1.27), and is very close to the one in school holidays with no significant difference (0.91). This means either the children were not at home or their usage of electrical appliances was low during school holidays at home.

As for gas consumption, there is no significant difference between working days or non-working days. This is mainly related to temperature of the outdoor conditions as the energy consumption in winter is usually higher than any other seasons, especially from months December to January. There is no correlation between their lifestyles and gas consumption which is mainly due to steady space heating demand over cold winter months.

Table 3: Energy usage pattern of electricity, gas and water

Energy Consumption (Actual Values)				
Average	Electricity (kWh)	Gas (kWh)	Water (Litre)	Average
Daily	19.82	56.88	790.02	Daily
Weekly	138.74	398.16	5530.1	Weekly
Electricity Consumption (Relative Values)				
Electricity	Energy Consumption	Working Days (175)	Public Holidays (93)	School Holidays (33)
Mean	1	0.87	1.27	0.91
Minimum	0.31 12 /08/2011, Fri, Week 1	0.40 28/10/ 2011, Fri, Week 12	0.51 14/04/2012, Sat, Week 36	0.32 12/08/2011, Fri, Week 1
Maximum	2.25 5/02/2012, Sun, Week 27	1.89 6/10/2011, Thur, Week 9	2.25 5/02/2012, Sun, Week 27	1.38 20/10/2011, Thur, Week 11
Gas Consumption (Relative Values)				
Gas	Energy Consumption	Working Days (175)	Public Holidays (93)	School Holidays (33)
Mean	1	0.9592	1.036	1.1148
Minimum	0.0476 31/05/2012, Thur, Week 43	0.0476 31/05/2012, Thur, Week 43	0.1675 15/10/2012, Sat, Week 10	0.0952 12 /08/2011, Tues, Week 1
Maximum	2.5857 07/12/2011, Wed, Week 18	2.5857 07/12/2011, Wed, Week 18	2.482 04/12/2012, Sun, Week 18	2.4961 05/01/2012, Thur, Week 22
Water Consumption (Relative Values)				
Water	Energy Consumption	Working Days (175)	Public Holidays (93)	School Holidays (33)
Mean	1	0.93	1.19	0.82
Minimum	0.07 09/08/2011, Tues, Week 1	0.41 28/10/ 2011, Fri, Week 12	0.11 07/08/2012, Sun, Week 1	0.07 12/08/2011, Tues, Week 1
Maximum	1.99 05/02/2012, Sun, Week 27	1.80 16/03/2012, Fri, Week 32	1.99 19/02/2012, Sun, Week 29	1.41 09/04/2012, Mon, Week 36

On the other hand, water consumption demonstrates that there is no significant difference between working days and public or school holidays according to their mean values (Tab. 3). During school holidays, the water usage is about 0.82 times of the average value equalling to almost 1, which reflects that the children were not at home.
In the following comparison graphs of electricity, gas and water consumptions (Fig. 3), energy usage patterns for both working and public holidays have been presented.

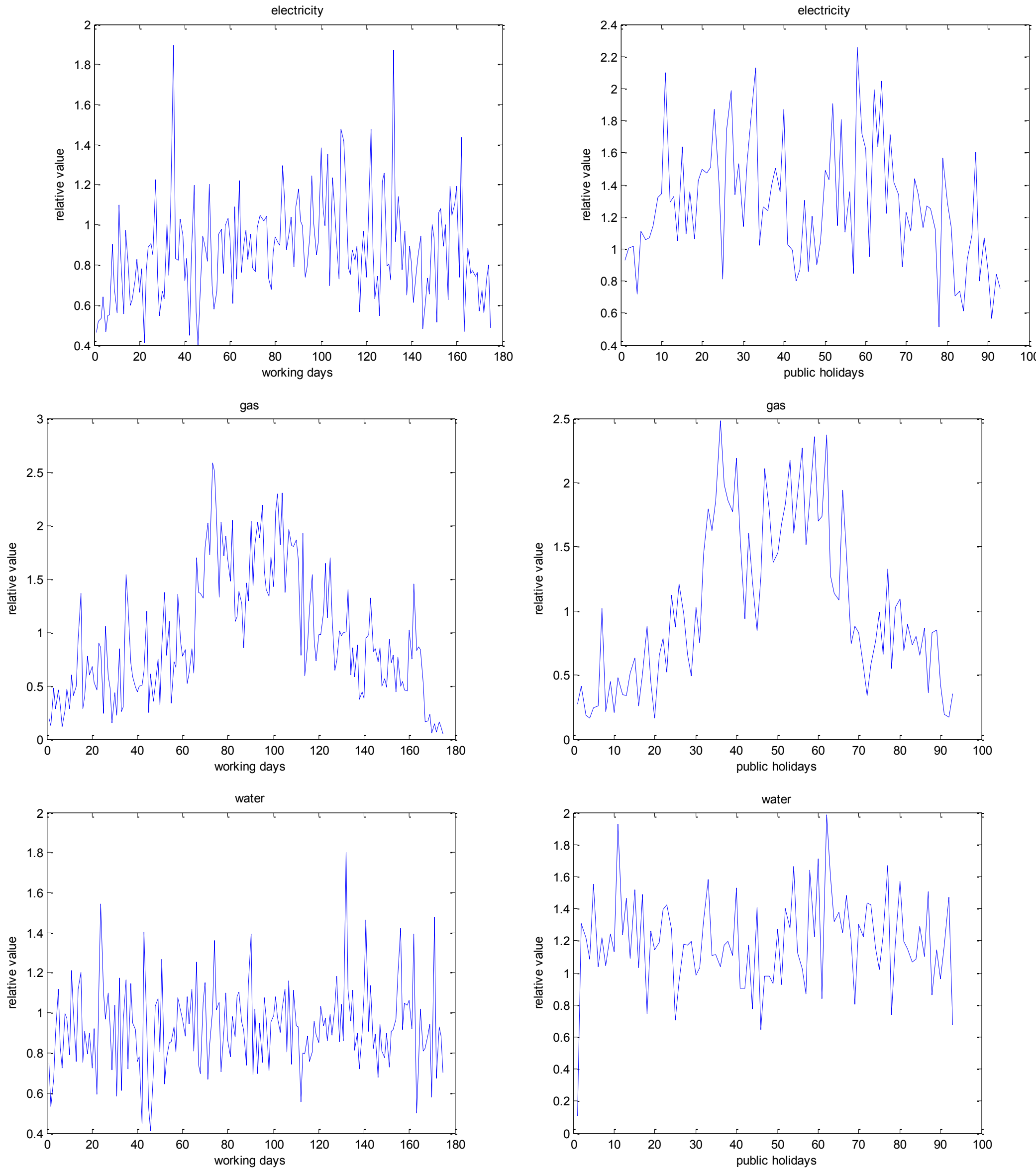

Figure 3: Electricity, gas and water usage patterns (working days vs. public holidays)

While the analysis of energy usage patterns is important for good practice, it is equally essential to look into the conditions of indoor environment of living spaces in the home to check against the recommended design guidelines.

Indoor Environment

It is important to maintain a healthy life in indoor environments that depends heavily on thermal comfort, air quality and sources of noise in residential dwellings. Altan *et al.* (2012) has already completed analysis of the indoor environment conditions in the selected case study home where the indoor air temperature, relative humidity and carbon dioxide levels were recorded through on-site physical measurements, which have been compared against the recommended standards, i.e. the UK's Chartered Institution of Building Services Engineers (CIBSE) and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), to demonstrate the indoor environmental conditions in a typical Scottish home with a standard family living.

As a result of this analysis, it was possible to draw some clear conclusions on the indoor environment conditions (Fig. 4). Accordingly, the values in below figure are daily mean levels which are compared against the standard levels of recommendation for indoor air temperature, relative humidity and carbon dioxide that are also shown (Altan *et al*. 2012). Accordingly, the daily mean indoor air temperature (°C) and the average relative humidity (%) of the living room and the two bedrooms for one week (16/12/2011 to 23/12/2011). The dashed line is the internal air temperature of 22°C recommended in living room and 18°C recommended in bedroom (Chartered Institution of Building Service Engineers 2006). The optimum level of humidity should be between 40-70% (American Society of Heating and Air0Conditioning Engineers 2012).

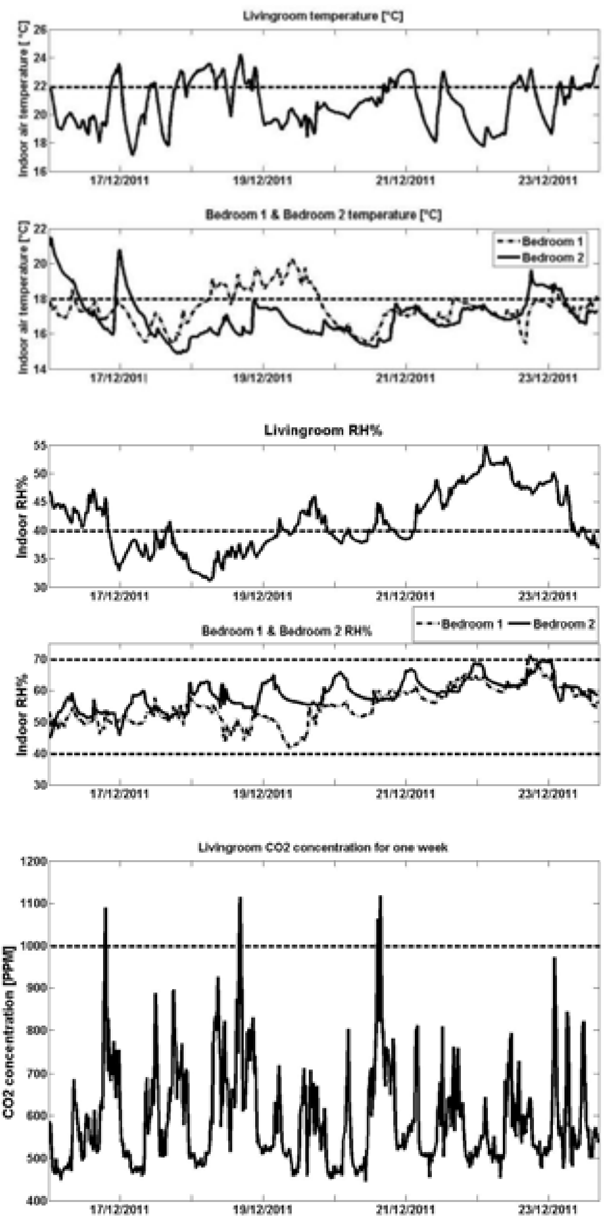

Figure 4: Daily mean indoor temperature (°C) and relative humidity (%) for the living room and two bedrooms, and level of carbon dioxide (CO_2) in the living room for one week

As can be seen in below graphs, it is clear that the living room conditions did not always agree with the CIBSE's recommendation for the range of internal temperatures (22-23°C). The two bedrooms however agreed most of the days for the standard guideline of internal temperatures (17-19°C). As with relative humidity levels for the living room and the two bedrooms, it can be seen that the levels recorded agrees with the ASHRAE's standard guidelines all the time during the same week.

As with the indoor CO_2 levels of the living room for the same week, it can be seen that the level is fluctuating under the recommended value for indoor space, which indicates the availability of fresh air indoors all times in the living room. The dashed line is the indoor CO_2 level of 1000ppm recommended for indoor space (American Society of Heating and Air-Conditioning Engineers 2012). The three peaks indicate that there is lack of ventilation during night time due to closing windows overnight time.

Discussion and Comparison - Why Good Practice

In this paper, we have performed analysis of energy usage patterns collected in a post-council Scottish home where a real-time monitoring system for electricity, gas and water consumptions has been installed as well as a short-term indoor environment conditions had been monitored. The results of analysis demonstrated that the energy usage patterns have generally positive correlation with occupants' lifestyles such as presence and behaviours. One random day (22/12/2011) has been chosen to plot indoor temperature against gas consumption. As can be seen in Figure 5, the indoor temperature of the living room is not affected by the change of gas consumption. In addition, monthly indoor air temperature and monthly gas consumption were correlated with statistically significant results (r =0.66, P =<0.05), which has shown a direct (positive) relation.

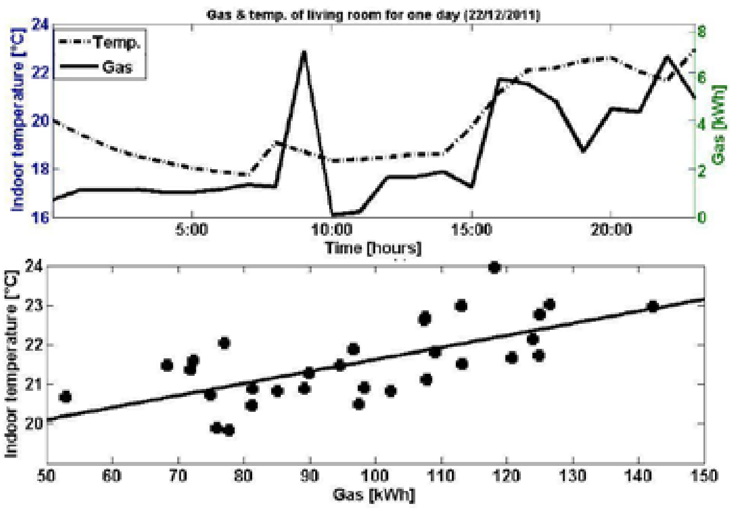

Figure 5: Indoor temperature and gas consumption of the living room for one day, and correlation of gas consumption vs. indoor temperature of one month

The study has shown the electricity and water consumptions are closely linked with occupants being present at home while gas consumption is highly related to the seasonal variations due to outdoor conditions. There are also identified peak usage patterns demonstrating occupancy with intense activities, such as in public holidays and non-working days or during evenings. In terms of the indoor environment, conditions seem to be within the recommended design standards confirming sustainable indoor environment. Moreover, the occupants have been communicated and the results of analysis have been confirmed with occupants and fed back to the family for creating an energy saving plan and promoting their energy conscious behaviours in the new design.

To verify that the NRGStyle case study home has shown good practice patterns, it is important and also helpful to compare with other existing cases such a typical UK home with a similar size dwelling to justify the results obtained and discussed in this paper (Tab. 5).

Table 4: Comparison of Energy Consumption and Carbon Dioxide Emissions

Demand	NRGStyle Home (1950s end-terrace house) 89 m^2		Typical Home* (1950s semi-detached house) 90 m^2	
Consumption	Energy Usage ($kWh/m^2/yr$)	CO_2 Emissions ($kg/m^2/yr$)	Energy Usage ($kWh/m^2/yr$)	CO_2 Emissions ($kg/m^2/yr$)
Electricity	32	15	52	21
Gas	110	21	258	33

*The performance of a typical existing dwelling (Energy Saving Trust 2010).

As can be seen in above table, it is clear that the NRGStyle home is performing way better than a typical UK house with similar size before improvements, i.e. poorly performing home where the fabric and services improvements recommended.

Conclusions

The paper presented a typical Scottish home considering the households energy usage pattern and indoor environment conditions for an affordable house located in Prestwick, Scotland. The aim was to clarify users' current living conditions at home and to prepare for a future home concept that encompasses not only flexibility in occupants' dynamic lifestyle, but also sustainability by design. The reduction of energy consumption in the selected household had been achieved by implementing 'good practice' of the occupants' energy conscious behaviour accompanied by the installation of energy efficient domestic appliances. Moreover, the study provided grounds and an opportunity to investigate some of the key and common issues so as to identify elements of the good practice within home environments as well as successful measures taken with end-user behaviour and associated energy usage patterns.

Furthermore, the future work will focus on the use of feedback mechanism and how this can be best put in use by the energy conscious occupants such as in the case of this study. The idea then can be developed and adopted in the new ZEMCH 109 design to inform the new build.

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GENERATION OF A TROPICALLY ADAPTED ENERGY PERFORMANCE CERTIFICATE FOR RESIDENTIAL BUILDINGS

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Abstract
Over the past decade, several national Green Building certification indices have emerged around the globe. The American LEEDS, the German DNGB or the British BREAM are all considered comprising measurement tools for environmental-friendly housing. Since 2009, the application of countries in the Northern "colder" hemisphere has been adapted towards tropical countries (e.g. the Singaporean Green Mark and the Malaysian Green Building Index). In contrast, for a different market niche, the Tropically Adapted Energy Performance Certificate of green and energy efficient building (TEPC) translates the United Nations' triple bottom line principle (planet, people, profit) into green building sustainability (planet), thermal comfort (people) and affordability (profit). Dwelling upon the tradition of five countries in the European Union, the TEPC initially targets affordable residential buildings. In its parenting countries, the tool has been especially developed and revamped for high and mid-class households to green buildings and help to reduce global warming on a wider scale. Hence, by its comparably simple and transparent energy audit, the 2012 created TEPC can check any kind of building upon four criteria: (a) its contribution to reduce CO_2, (b) its transmission rate shielding a building's envelope against the effects of the tropical heat, (c) gaining tropical adapted thermal comfort and (d) referring total cost of ownership to green the building further. All of the four dimensions are measured in scales between blue/green on one and red on the other extreme, potentially in compliance with individual national energy regulations. After the elaboration and prior presentations in Malaysia and Germany, this research targets at the tool's implementation for countries in the tropical belt. One tropical case study in residential areas for retrofitting (semi-detached house) seeks to prove the practicability of the approach. Final considerations are made to derive a holistic certification by an internationally accredited certification board.

Key Words: *CO_2-Emission, energy audit, passive house, Green Building Certification.*

Introduction: Beyond the Sick Building Syndrome

Over the past recent years, several high-tech developing countries have become sensitive and proactive towards green solutions for the built environment. The "Rainforest Alliance" based in New York with its green building is a globally operating body for the tropics, whereas Colombia and Singapore belong to those countries having green building councils. In Malaysia, the Green Building Index and the self-commitment of saving 40% of CO_2 emission till 2020[1], together with Germany the country is on the spearhead in the region with plans to embark on viable environmental survival strategies. Countries like these find themselves at a significant turning point to turn green ideas into practice (Byrd 2008).

The so-called developed countries in the colder hemisphere dispose at an energy potential being far more restricted. Since 1990, they have already devised a wide variety of energy regulations and according renewable technologies that might be adaptable to green buildings.

[1]Envisaged by the Prime Minister of Malaysia, Sri Najib Abdul Rahman at the COP Conference Copenhagen 12/2009.

This contribution focuses on the adaptation of the EPC deriving from the European Union and the implications for a tropical country (Luciana 2011). Occupants are not longer simply victims of the offending “sick building syndrome”. It comes up with a simple scientific colourful tool kit to measure the CO_2 -emission and sketches a case-study related staggered procedure how to save CO_2 according to the thermal comfort needs and affordability of its inhabitants. The proposed and tested toolkit starts with the question for a building how green it is.

Consider a property developer or a landlord ambitious to sell his or her green and energy efficient tropical building. The person has invested in green and enjoys both higher thermal comfort and reduced monthly electricity bills. He can claim he is a greener person, contributing with an effort to save the environment. Will the achievement be rewarded when he strives to sell the building for more as a landlord who did not? At first, let us have a look at the following conversation between a potential house buyer and the landlady about a tropically adapted energy performance certificate (TEPC) for residential housing (Fig. 1):

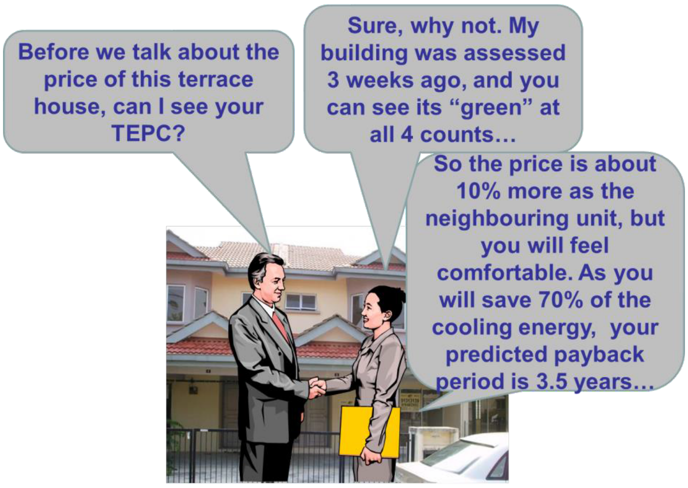

Figure 1: Negotiating the Price of a Green & Energy Efficient Building

Energy Assessment Tool for Residential Housing

The often requested idea to implement an **Energy Demand Certificate** (EDC) for new and then an **Energy Performance Certificate** (EPC) for existing residential buildings is the current practice and furthermore regulation for ANY building in so far 5 countries of the European Union: Effective 01/07/2009 every seller of real estate e.g. in Italy has to enclose the energy performance certificate as an appendix to the sales agreement (e.g. Volland *et al.* 2009). The **Tropical**-EPC does not mean to copy the origin, but implies a cautious adoption to a warm country where cooling is by far the major environmental issue for the operational costs in the modern built environment. This tool provides no status of platinum, gold or silver, but distributes school marks from A+ to G aligned with the spectral colours (Weglage *et al*. 2009) (see Figure 2).

Figure 2: Energy Performance Certificate for Buildings[2]

Following both the school marks system and the thermographic profile, any building's energy performance can be certified between RED and even more than GREEN. A building, which is fully independent or is producing its own renewable energy and even can feed in electricity into the grid, will be granted more than mark "A" or green on one of its following four parts which is energy consumption (Tuschinski 2010). The Blue A+ building is self-sustainable like all natural life on our blue planet. In their extremes, A+-buildings are power producers that hence might supply the grid under the Feed-In Tariff (FIT) (Malaysia 2012).

The practical meaning of the TEPC is not a green label solemnly shown to relatives, neighbours and friends how "green" and perhaps also energy-efficient the building is. It is there to assist the occupant or a prospective buyer to gage how to save more energy and hereby save CO_2 in the future. In addition, selling will be facilitated, and the certificate is affordable (following European standards it would be about RM 400), The tool is a substitute and distinct from more sophisticated Green Building Indices such as LEEDS – USA, BREAMS – United Kingdom, Greenstar - Australia, DGNB – Germany or GBI – Malaysia (Zalina 2012). The reason is that the EPC is SOLELY interested to evaluate a) the strength of insulation and subsequently b) the greenness of the electricity consumption in the form of energy efficiency.

Along with three further criteria shown below, the certificate derived by the TEPC will show in how far a building is able to avoid the generation of energy AND, in the BLUE case it will even produce renewable energy for others. It is clearly benchmarked against so-called ideal or real reference buildings. The following European example shows the overall energy` consumption comparing "this building" against other reference buildings with different standards (retrofitted, newly erected, 30% and 50% on the scale of the most recent German Energy Regulation 2012 (EnEV) (see Figure 3).

[2]http://www.groupon.at.

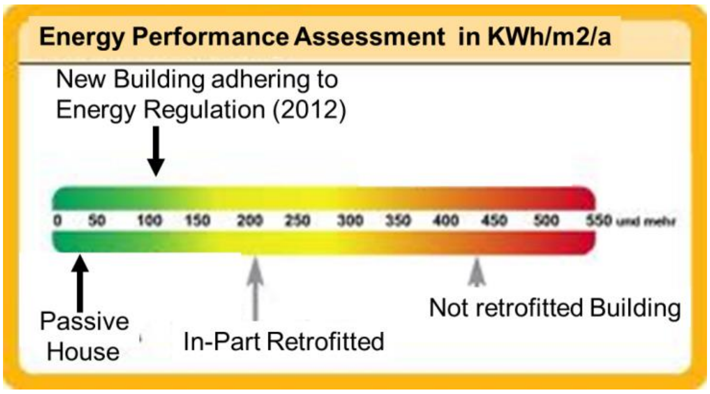

Figure 3: Scale of Energy Performance Certificate Summary and Example of a Yellow Zone Building

As this “light-yellow” building is an existing building, it falls short of only kWh (m^2a) electricity consumption if it were to comply with the official regulations for ***4. retrofitted building***. That means, only minor renovations have to be undertaken in order to bring it from its 303.66 kWh (m^2a) to the here permitted 295 kWh (m^2a). Proven methods are by replacing single to double glazing with the effect that the primary energy demand per annum will decrease below the targeted value of 295 kWh (m^2a) – if the green building consultant’s recommendation (e.g. consumption is monitored by a smart system) is implemented.

The following depiction shows the fully-fledged energy part of the performance certificate of a building near Stuttgart/Germany of a building which with 12 kWh (m^2a) p.a. power consumption and 26 kWh (m^2a) primary energy demand is already quite green. Selling this property to a new owner can anticipate the greenness of the building and help to negotiate accordingly towards a much higher market price compared to a common red building (Volland *et al*. 2009) (Fig. 4).

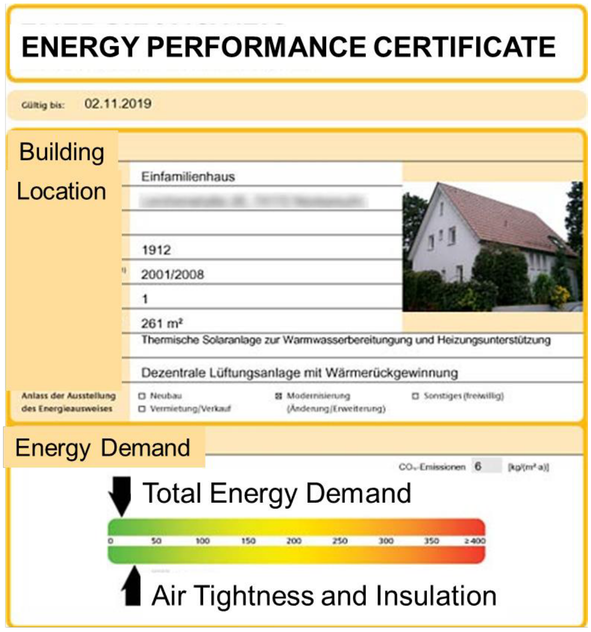

Figure 4: Energy Performance Certificate Residential Building (Germany)

Measuring the Status Quo in a Residential Building

Throughout the following pages, four core dimensions of the Tropically Adapted Energy Performance Certificate (TEPC) will be derived that come out of the Triple Bottom Green Line (chapter I): **CO_2 Emission**, **Thermal Comfort and Cost Saving** as ***output***-factors derive from the so-called magic triangle of green & energy efficient buildings, whereas **Heat Transmission** (optimum insulation, up to air-tightness) is considered an enabler or ***input*** factor. Basically, prior to details elaborated further below, as a summary all of them can be individually measured between green and red (Fig. 5).

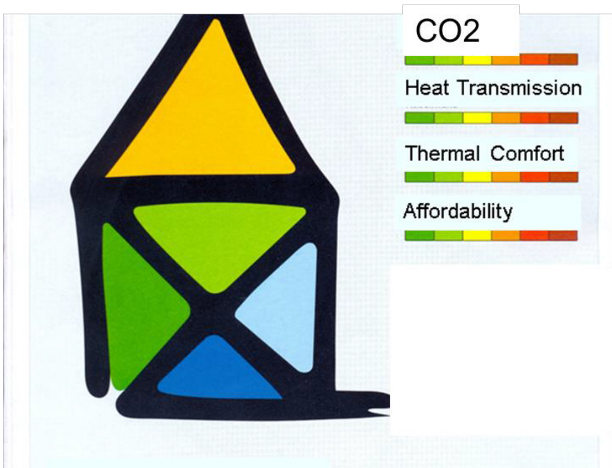

Figure 5: Four Parameters of the Tropically Adapted Energy Performance Certificate

In detail, this is the closer look into the four categories paving the way for further discussion:

Heat Transmission and Insulation Rate

Within the current measurement, it is common practice to measure heat rejection indicators like R-values, better U-values, A-values, CHI-values and so forth. Within the TEPC, these values are enablers to reduce the basic temperature. As a concerted action, the approach mobilised here is quite different. Still we are utilising materials in terms of heat reduction, but in the end there is only one relevant factor to determine the greenness or redness of a building's insulation which is the radiant "surface" temperature of all the following 9 parameters at ***peak*** values during a set of 5 typical sunny cloudy afternoons (Fig. 5).

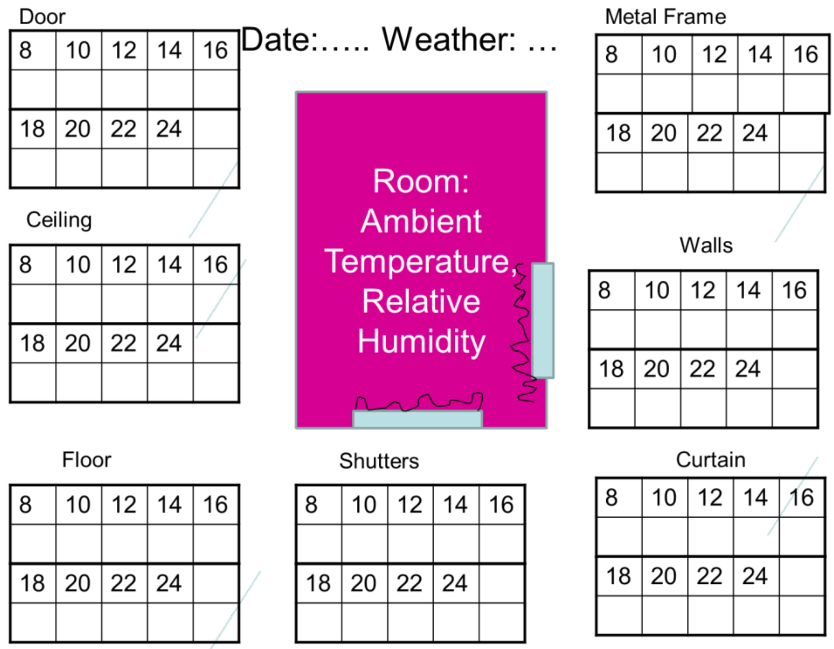

Figure 6: Ambient Temperature of a Room's 7 Surrounding Elements measured 9 times daily (always compared with Outside Temperature!)

Again, the radiant temperature (respectively the humidity) is considered an input factor which is enabling a building to create an agreeable and healthy ambient temperature inside. It is possible to calculate the ambient temperature by using the single parameters above. The precise way is a mathematical formula that probably still is looking for its creative inventor. The easier way is to trust on statistical values of one's own research as we did in case of a room in an urban high rise contrasting a rural taman building with the following rule of thumb: The average of the radiant temperature of the room's 8 surroundings minus 1 = ambient room temperature at a given time. That means if we are able to bring down the radiant average peak day temperature on a sunny/cloudy day from 30 to 29 °C, the ambient temperature will result in 28 °C which is already in range of the tropical thermal comfort zone (Sabarinah *et al.* 2007 and Wagner 2013). If the average radiant temperature is still above 29.6 °C, it would be necessary to cool the respective room further or to decrease the ambient temperature until it is in range and can be maintained. Therefore, the colour scale along with a scale from 0-100 for an overall TEPC-scoreboard.

In contrast to the A+ value of the blue European energy performance certificate, blue in a tropical sense of surface temperature would mean an *over*-delivery of too cold temperatures which are not requested by any occupant. Therefore, the scores (max. 100, min. 0) are low, similar as when the temperature exceeds 29.6°C resulting in the maximum permitted room temperature of 29.6°C. Another dimension which is not discussed here is the acceptance of higher humidity of tropical occupants. As researches have proven several decades ago, the acceptable temperature is not necessarily only restricted to the fact being a Caucasian who accepts lower, and a tropical human being who favours higher temperatures. The longer a person lives in a tropical country, the more he or she seems to be adoptable with the local standard thermal comfort (Ellis 1952). The relative humidity is not considered being part of the

TEPC, because its effects are highly controllable by our behaviour of taking showers, not eating too late and utilising ventilation.

Carbon Footprint

Within this tool, as the only emission CO_2 in relationship with the operation of gadgets is considered. Unlike the Green Building Indices referred to above, the TEPC will NOT include the carbon footprint through the generation and life cycle costs of the building. The reason is that the supply chain of an investment good like windows or walls is not operational, very sophisticated and the measurement might be also be subjectively biased and arbitrary. A building is a long-term investment with the possibility that even the initial carbon footprint will be depreciated through the course of time. In case of walls, doors and roofs, natural biodegradable and replantable local goods might be preferable compared wit those which have to be produced with lots of energy respective carbon footprint. The usage of recyclable material (like in the case of light-weight concrete or wood wool) is a plus, in case we cannot fully rely on natural material like paddy husk or palm oil fibre alone. Furthermore, locally manufactured products and services for an energy efficient green building should be chosen over those from far or from foreign counties.

If we estimate the life expectancy of our building at 70 years, the carbon footprint of its generation will be factored in to every year of its operation. In addition, by using as many natural materials as possible, even the generation carbon footprint will decrease.
Two measurements can be distinguished: CO_2/m^3/year or per occupant. In the following example, we chose "occupant" (Fig. 7).

CO2/occupant /p.a.	COLOUR	Score for overall Scoreboard
< 100	DARK GREEN	100
100- 129	GREEN	90
130-149	LIGHT GREEN	80
150-169	YELLOW	60
170-190	ORANGE	40
190-209	RED	20
>210	DARK RED	0

Figure 7: Exemplified Green-Red TEPC-Scale in terms of Carbon Footprint per occupant

The range laid out for the measurement above is based on our own survey asking students of the German-Malaysian Master of Green and Energy Efficient Building-programme to measure their daily and weekly energy consumption. A household with less than 100 kg/occupant is considered low, whereas >210 is considered quite high. This tool is applicable for houses which are already being in use, not for upcoming houses. However, existing houses can serve as a great benchmark to avoid the generation of CO_2[3]. As the Table 1 presumes with house no. 3. and 5., even the moderate use of an air condition will be the trigger for electricity costs of about

Description	Built in (Year)	Built-up m2/ Volume m3	Additional Appliances*	Costs/ KWh p.m.	CO2 per capita/ p.m.
1.Flat 5 storey	1986	96.25 m2	*	RM 35.00 160.55kwh	1 160/1= 160
2. 3 storey Terrace House	2008	67m2 Volume: 535.4 m3	*	RM 64 292 kWh	2+1 253/2.5= 121
3. 2 storey Terrace House	1997	98+88 Ground floor = 343 m3 First floor = 660 m3	Water Heater AC	154 RM 700 KWh	3? 607/3= 202
4. Taman Semi-Detached	2009	83 m²	*	RM 38 37.6 kWh	2+1 138/2.5= 101
5. Low-Cost Highrise (level 10, 25 storeys)	?	65 m2	Water Heater	RM 170 775 KWh	6+1 baby 672/6= 139

Table 1 : Case Studies Carbon Footprint per m^3 and per Occupant

Thermal Comfort

We define Thermal Comfort as the *state of mind that expresses satisfaction with the temperature, humidity and velocity of the surrounding environment* (according to the SO 7730 or, likewise, ASHRAE Standard 55). Together with a) environmental sustainability and b) long-term cost saving, c) creating and maintaining thermal comfort for occupants of buildings or other enclosures is the third of the three important objectives of TRIPLE GREEN building architecture and engineering. Thermal comfort belongs to the family of basic individual needs. Presuming it is taken for granted or has significantly improved, it enables us in a concerted effort with other physical needs to climb up further the ladder of Maslow's renowned motivational pyramid of needs. Conversely, in its absence, mainstream research holds that any thermal gain or loss above or beyond the following generic borderlines may generate a sensation of discomfort. School children in low-cost buildings who are expected to do their homework in temperatures of 32 ºC and above become victimised as they will not be in a mood to perform well.

A typical Western conception of the state of mind called thermal comfort keeps on believing that the inside temperature for offices should be 21.1° C on average with variations of +- 2.5° C (Thermal Comfort, Fundamentals volume of the ASHRAE Handbook (2008). Of course, in a cold country every °C that has not to be heated can save tremendously energy and budget. In recent years, this figure for thermal comfort has been even proposed to be altered for

[3]Average Scores during 3 times daily with "typical" sunny/cloudy weather conditions, 2 days no rain. Accuracy option for future R&D : 10 afternoons 5-8 pm with different weather conditions

European offices to 24.5° C, which means an enormous deviation from the internationally renowned ASHRAE-standard. For tropical countries, Busch (1990) carried out a pioneering field study for Thai offices in Bangkok and found that the neutral temperature or effective temperature for the air conditioned buildings and naturally ventilated buildings was 24.5ºC and 28.5ºC, respectively. A similar range of “neutral” conducive temperature was determined for a Malaysian School (Hussein, Hazrin and Rahman (2009), based on PMV regression is 25.9ºC with a comfort range between 24.4ºC and 27.4ºC. The trendy increase of temperature in offices and public cooled down areas also follows the in-part demise of the common dress code with suits and ties translatable into the 2011 policy by the Malaysian government requesting all state-owned buildings to set-point the temperature not lower than 24°C.

Abdul Rahman (1995) in his ground-breaking study found that the most comfortable indoor temperature in Malaysia (tropical region) for residential areas ranges even from 25.5-28°C narrowing down the general recommendation by World Health Organization (1990) ranging from 18-28°C. Similarly, UTM’s researchers Sabarinah Sh.Ahmad, Nor Zaini Ikrom Zakaria, Mohammad Shayouty Mustafa, Mohd Ghadaffi Shirat concluded that a 2.5°C range between 26.1°C and 28.6°C is optimum in tropical countries even for adapted people from Northern countries (2007). Others and our own findings clearly confirm that the optimum residential area temperature for most tropical occupants in their privacy at its highest comfortable end should not exceed 28.6º C. As a conclusion, “the comfort band for the Kuala Lumpur area for all building types is between 23.6° and 28.6° C with an optimum medium temperature in Malaysian households of 26.1° C” with the upper space limit (USL) set at 28.6°C. Two reasons can be sorted out. 1) the lower cost when putting the highest set-point in a tropical warm country. 2) the perception by people living in tropical regions is different from those in temperate and cold regions (Wang and Wong 2007 and Singh, Mahapatra and Atreya 2009). The perception is based on lifestyle and habits, and based on economic necessities. All of them contribute to the explanation of the following comparison:

Northern countries	19.1	21.1	23.1	ASHRAE 2008 (general)
“new approach”	22.5	24.5	26.5	Braatz and Suparoek 2008 (offices)
Malaysia (Kuala Lumpur)	23.6	26.1	28.6	e.g. Sabarinah *et al.* 2007

Table 2: Comparison of different thermal comfort definitions

Devising the tropically adapted concept of energy performance for thermal comfort with these higher temperature banding can cause a steep increment in terms of energy saving potentials by 4-7% of less CO_2 and energy cost with each degree centigrade the temperature is increased (Green Efforts Start at 24°C. In: The Star, 12/08/2011, 2). Unfortunately, even if the USL (upper space limit) - temperature is set to its highest end at 28.6°C, in a typical uninsulated concrete building - with the walls, windows, ceiling and roof as permanent heat traps - TTC cannot be achieved during a sunny/cloudy day even in kampong areas (Sanusi 2010).

We stripped off relative humidity, for simplicity reasons, and for the reason that apart from the A/C it is volatile and hard to control within green cooling. Green makes the humidity more humid, but if we would be able to adjust the rules elaborated in the chapter on green lifestyle, we would not consider the high humidity as a serious issue.

The determination for the greenest of the temperatures above is the one which is able to create thermal comfort along with minimum CO_2 emission at reasonable costs (below). Apart from the environmental issue, it can be concluded that whether blue, dark green or light green is the target of our building is a matter of individual well being. Therefore, European and Tropical Green may have a different weightage. If the temperature is between 26.8 and 28.6, the highest scores can be achieved. The weightage of European green is lower, but might receive higher scores in the Northern atmosphere. Average scores during 3 times daily with sunny/cloudy conditions, 2 days no rain[4].

Cost Considerations

The last variable is dedicated to answer the question of the last angle of the magic triangle whether or not and for whom a GEEB is affordable. This is a vital subjective question, because it is widely believed that green buildings are necessarily quite expensive and therefore a NO-GO. Therefore, those who know and would appreciate to become owners, believe they are not able to purchase a new unit or to retrofit an existing one complying with our desired thermal comfort levels above at all time:

a) however, for **new buildings** we can state that following the European principle a passive house (as the most radical version of the green and energy efficient building!) ***may not exceed 110% of the investment costs of a traditional RED building*** with cost saving from the first moment the building is in operation with pay-back periods of less than 1 – 5 years DENA (2009). In terms of the following scale for a residential building, this is still considered LIGHT GREEN (Fig. 8)

RM	**COLOUR**	**Score for Overall Scoreboard**
Cheaper than standard house	DARK GREEN	100
100 < 110%	LIGHT GREEN	90
111 < 120%	YELLOW	70
121 < 130%	Light ORANGE	50
131 < 140%	Dark ORANGE	30
140 < 150%	RED	15
> 150%	DARK RED	0

Figure 8: Exemplified Red-Green TEPC-Scale in terms of Affordability (<u>New</u> Buildings)

b) the case of an **existing standard** residential building to be retrofitted clearly again is even more a *subjective* question and answer. Whether it can be greened like in case of the reference buildings an additional investment of less than RM 5,000 with the possibility to break even after maximum 5 years might still be green or red, might mainly depend on three parameters: a) the family's income, b) the cash flow and, first and foremost, c) the readiness to invest into green. Furthermore, one caveat and prerequisite is that the building does a "smart" job, and has to be

[4]Accuracy Option: 10 afternoons 5-8 pm with different weather conditions

smarted with additional cost incurred! That means green cooling PLUS building automation can adjust the temperature according to the occupant's wishes at heat peak hours, and react flexibly to the building frame's ability to serve for already much colder temperatures compared to a standard building (elaborated above under pillar 2 - electricity).

The following scorecard is more subjective. It presumes that this mid-class household has an annual cash flow of 6,000$. Therefore, it could easily digest green retrofitting expenditures of 3,000$ and would still have another 3,000 $ for other cost positions. That would mean that 3,000$ could easily be absorbed, and up to 3,000$ are still at "green-light" status with a high consideration for investment.

On its RED end, this exemplified scale is left open on purpose, starting with an amount of RM 30,000 which might be quite hard to invest for our mid-class income example above. Of course, the 3,000$ rule needs to be adapted not only towards the financial capacities of the occupants which are usually the owners (cash flow), but also towards the size of the building
Both scales (new and retrofitting) can now be compared with the payback periods of its investments due to lower operational costs in terms of energy consumption.

Case Study
In order to illuminate the applicability of the TEPC, prior to generic research the five examples above for retrofitting have been selected. Out of these, only case no. 3 has been chosen to illuminate the operability of the TEPC for a tropical house.

Typical Terrace House Center (Kuala Lumpur Area (built 1997))
Size: Ground floor = 98 m2, First floor = 88 m2 (cooling load 558 m3), Car park area = 56 m2

Location: Suburban area (not affected by city heat stack effect) with evening temperatures at peak heat days reaching tropical thermal comfort level at sunny/cloudy conditions between 8 and 12 p.m.

Occupants: 5 Adults

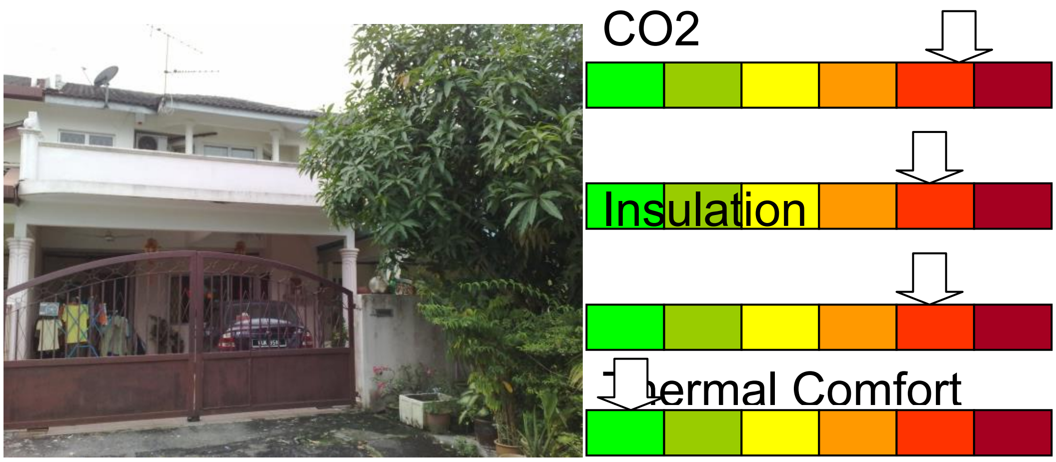

Figure 9: Case Study Typical Terrace House Center (Kuala Lumpur) Area (1997) and Applied TEPC)

The average electricity consumption p.m. is about 700 kWh = 46$ per months. The following appliances are in use (one common air condition used 8 hours usually during nighttime):

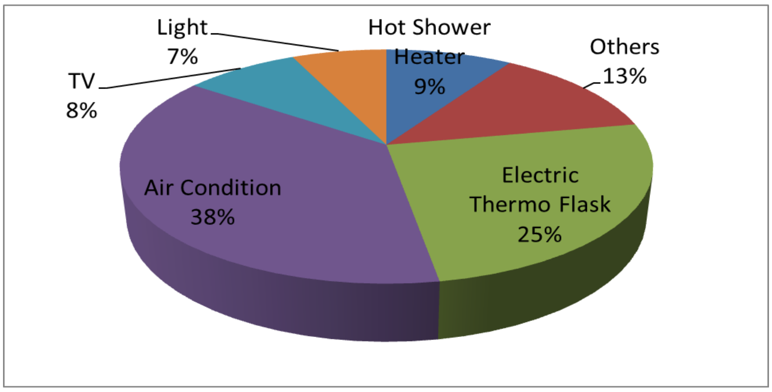

Figure 10: Energy Consumption of Terrace House KL

The TEPC will yield the following results:

1: CO2 = Due to the air condition, the electricity consumption id RED: install cross-ventilation during night time
2: Building envelopes radiant temperature average (measured at heat peak hour): 32°C = RED

3: Thermal comfort
same peak hour: 31°C = RED

23°C = BLUE (night time average temperature sleeping room at the same day with air condition unit)

29°C = ORANGE (dto, but instead of air condition stand fan)

4: Affordability = GREEN: In order to bring 2 and 3 into green, the expenses are the following priorities:

1) insulation of the roof (3,000$);
2) add on insulation shutters to all 8 windows (100$ * 8 = 800$);
3) insulate walls and doors (6,000$); and
4) air condition unit in 3 sleeping rooms to be fitted with interrupter, auto-switch into cross-ventilation mode. Lighting can be replaced with low-energy tubes) (300 $).

As the cash flow of this family with 3 adults working equals 900$ per month, this expenditure is affordable.

As a conclusion, even though this building is in RED areas in terms of CO_2 emission, insulation and thermal comfort without air condition, it has a very high potential among other case studies. As the family income is considerably high, the chances to green this building are high, if the occupant who is the landlord has created awareness, and applies the EPC to guide him or her.

Conclusion and Outlook

In order to assist tropical countries to bring down the CO_2-emission, the TEPC can play its part as it did in Europe. It can contribute for mass appreciation as it contains a clear affordable business model for landlords and even tenants. Negotiations with internationally operating bodies like the German TÜV will show in the near future whether the approach is viable for developing countries in the tropical and subtropical belt. However, these are potential impasses we have to face:

a) lack of Reliable Research Data so far, we only can rely on selected case studies rather than on a multiple of generic cases to green tropical green buildings;
b) availability of System Knowledge (playing together as a "Green Orchestra"): the TEPC has to jive with the idea looking at the building from a holistic perspective;
c) transparency of Professional Benefits (ROI) out of research. Reliable data are not yet generated to forecast the monthly saving on the part of the electricity bill due to implemented efforts to green a building further;
d) availability of Resources: a visit to green expos shows that knowledge is available. Nevertheless, the market is not quite transparent when it comes down to source green suppliers that can cater for necessary solutions;
e) no financial Incentives (market value like European energy regulations). Policy should take the first turn via staggered energy regulations to enforce green strategies via the TEPC; and
f) mindset of Owners and Tenants (Short-Term Thinking and other priorities - Demand Preference Structure DPS). Of course, the greatest challenge of all is to create a change of mindset within the population which can ony be achieved with a generic roll-out plan compiled by a committed team and spearheaded by a higjly effective business organisation.

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EFFECTS OF MANUAL AND AUTOMATIC NATURAL VENTILATION CONTROL STRATEGIES ON THERMAL COMFORT, INDOOR AIR QUALITY AND ENERGY CONSUMPTION

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EFFECTS OF MANUAL AND AUTOMATIC NATURAL VENTILATION CONTROL STRATEGIES ON THERMAL COMFORT, INDOOR AIR QUALITY AND ENERGY CONSUMPTION

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Abstract
Occupants of naturally ventilated buildings can tolerate wider ranges of temperature and Indoor Air Quality (IAQ) if they have more control over their environment. Meanwhile, due to the complexity of advanced natural ventilation (ANV) strategies, introducing some form of automatic control is essential despite the fact that they limit the occupants' control over their environment. Therefore, it is essential to understand the performance of ANV systems and occupants' behaviours in order to identify a balance between automatic and manual controls to enhance the performance of ANV systems while maintaining the occupants' comfort. The aim of the work reported in this paper is to evaluate the effects of a retrofitted ANV system with manual and automatic controls on thermal comfort, indoor air quality and energy consumption in an open-plan office building in the UK. Physical measurements were used to study the building performance in terms of thermal comfort, IAQ and energy consumption. The results revealed that occupants were much more aware about thermal comfort compared to IAQ. Therefore, relying on the occupants to control the ventilation system would considerably increase the risk of poor IAQ in buildings. Moreover, introducing automatic controls did not affect the thermal comfort conditions for those who understood and actively controlled the ANV system, while the situation improved for those occupants who were not active. Results of this study showed that introducing automated natural ventilation helped to reduce energy consumption by 8%.

***Key words**: Automatic control, manual control, advanced natural ventilation, Indoor Air Quality (IAQ), thermal comfort.*

Introduction
Interest in providing thermal comfort and acceptable Indoor Air Quality (IAQ) through natural ventilation is increasing due its lower energy consumption compared to mechanical ventilation systems. According to Allocca, Chen and Glicksman (2003) energy costs of naturally ventilated buildings are 40% less than equivalent air-conditioned buildings. Additionally based on the results of several studies, occupants of naturally ventilated buildings feel comfortable in a wider range of temperatures (De Dear and Brager 1998, Nicol and Humphreys 2002, Moujalled, Cantin and Guarracino 2008 and De Dear 2009) and have lower IAQ expectations compared to air conditioned buildings (Hummelgaard *et al*. 2007).

As natural ventilation is highly influenced by external climatic conditions such as temperature, wind velocity, and wind direction, it is necessary to introduce some form of control in order to protect occupants and buildings from undesired conditions. Control of natural ventilation can be manual, automatic or a combination of both (Martin and Fitzsimmons 2000). Results of Heieslberg (2008) and Khatami, Cook and Hudleston

(2011) showed that occupants are usually very slow to control their thermal environment and react to thermal discomfort too late. At the same time, results of studies by Griffiths and Eftekhari (2008) and Khatami, Cook and Hudleston (2011) suggested that occupants are often unaware of CO_2 levels as an indicator of IAQ and for this reason it is not recommended to rely on manual controls alone. Although providing automatic control in naturally ventilated buildings was found to be essential, results of studies by Ackerly, Baker and Brager (2011) showed that in naturally ventilated buildings, introducing automatic control may eliminate the abovementioned advantages of occupants' control in naturally ventilated buildings and according to Frontczak, Anderson and Wargocki (2012), occupants much prefer manual controls in naturally ventilated buildings. This study therefore intends to compare manual and automatic controls and their effects on the temperature, IAQ, and energy consumptions in office buildings.

For this purpose a typical office building was selected and performance of the building in terms of thermal comfort, IAQ, and energy consumption was studied before and after implementing ANV strategy. Performance of the building after intervention was studied in two different phases. In the first phase, occupants were responsible for controlling the ANV system and in the second phase automatic controls were introduced into the system.

Description of the case study building (CSB) and ANV strategies

The CSB is located on a typical UK trading estate surrounded by similar two storey retrofitted lightweight buildings and open green fields. The building orientation is 22° clock-wise from north (Fig. 1).

(a) (b)

Figure 1: Case study building

The total building floor area is 1100 m² and a densely occupied open plan office is located on the first floor while a training/meeting room, kitchen, toilets and warehouse are located on the ground floor (Figures 2a and b). No mechanical cooling is installed; however, during hot seasons personal desktop fans are used to provide air movement for occupants in the open plan office. Ventilation in the open plan office is provided by cross and single sided ventilation through 14 top hung openable windows on the north, north-east, and north-west facades each measuring 1.14m×1m. Furthermore, a mechanical supply and extract system with 0.9 l/s/m² capacity helps to ventilate the office on the first floor. However, the supply and extract system was disabled when natural ventilation systems were introduced into the building. The open plan office itself is divided into three subzones (Fig. 2b).

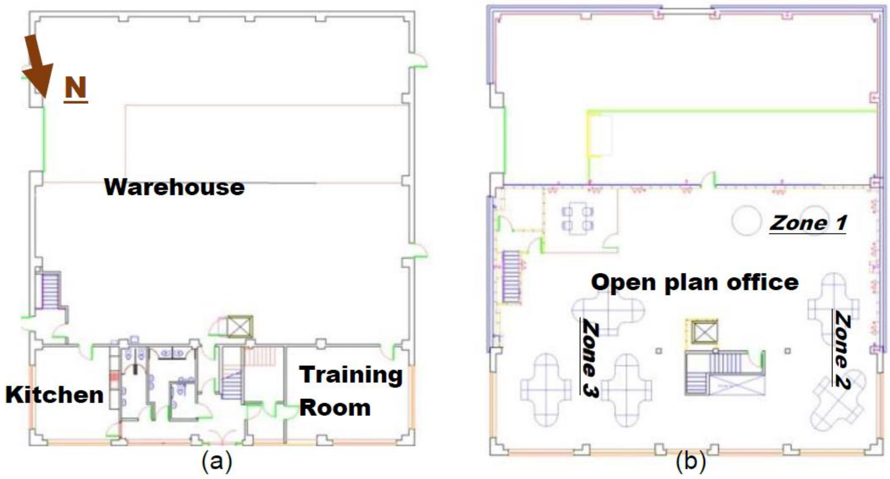


Figure 2: Plan of Case study building

Khatami, Cook and Hudleston (2011) showed that due to high internal heat gains, lightweight structure, and limited ventilation devices, ventilation was ineffective in the CSB before intervention and remedial actions were required to control overheating. For this reason, existing ventilation strategies in the CSB were enhanced by ANV strategy.

According to Lomas (2007) the stack effect is almost always reliable as an existing natural ventilation force; therefore, proposed options took advantage of stack induced ventilation as the main driving force. Implemented options (Fig. 3) included introducing a new series of openings installed on the CSB's roof. These were designed to serve as high level outlets and existing windows as low level inlets to maximize stack effect. A new series of openings were also introduced at the ceiling level by replacing some of the suspended ceiling tiles with openable vents (Fig. 3b). These ceiling vents were designed to connect the open plan office to the unheated, unoccupied roof area (loft) exhausting hot polluted air into the roof space.

Due to the important role of occupants in the success or failure of a natural ventilation strategy (Martin and Fitzsimmons 2000 and Ward, 2004), training was provided after implementing the new ANV strategy. During training, occupants were instructed on how to use the systems. They were instructed to open the ceiling tiles, roof vents, and finally the low level openings (windows), in that order. This was to take advantage of lower/milder temperature and CO_2 concentration levels of the unoccupied roof space which acted as a buffer to reduce energy consumption.

Occupants were asked to take responsibility for controlling the ANV system (e.g opening and closing the windows and roof vents) for six months after installing the ANV systems. The ANV system was then enhanced by introducing automatic controls. Control strategies contained complex algorithms based on the external temperature and occupancy patterns and were designed to monitor and control both CO_2 levels and internal temperatures. Similar to the manual controls, automatic controls activated openings in the following order: ceiling tiles, roof vents, and finally windows, to provide acceptable IAQ while minimising the energy consumption. Details of the control algorithms used are provided in Khatami *et al*. (2013) and SE Controls (2013).

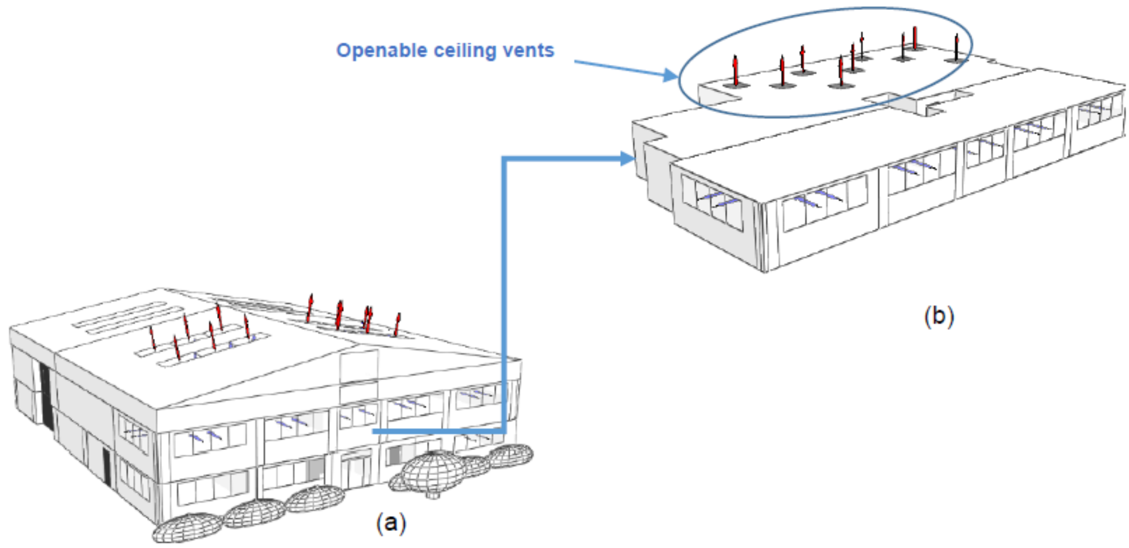


Figure 3: Principle of ANV strategy implemented in refurbishment, whole building (a), first floor open plan office (b)

Methodology

To assess the actual building performance, physical measurements were taken and thermal comfort, IAQ, and energy consumption was evaluated based on BS EN 15251: 2007, CIBSE guide A: 2006 and CIBSE guide F: 2012 methods.

To assess thermal comfort it is possible to use a heat balance or adaptive methods (Djongyang, Tchinda and Njomo 2010). It is believed that thermal comfort is affected by occupants' behavior and expectations in naturally ventilated buildings (Djongyang, Tchinda and Njomo 2010) as well as their past thermal history (De Dear and Brager, 1998). Therefore it is recommended to use an adaptive approach to assess thermal comfort in naturally ventilated buildings.

In an adaptive approach, thermal comfort is assessed based on the mean running outside temperature (T_{rm}) using equations 1 and 2. (British Standard Institute 2007 and Chartered Institution of Building Services Engineers 2006b).

$$T_{comf} = 0.33\ T_{rm} + 18.8\ (T_{rm} > 10°C) \quad (1)$$

$$T_{comf} = 0.09\ T_{rm} + 22.6\ (T_{rm} \leq 10°C) \quad (2)$$

Where:

T_{comf}= comfort temperature. According to BS EN 15251 (Chartered Institution of Building Services Engineers 2007) it is assumed that occupants feel comfortable if the indoor operative temperature is in the range of ±3ºC of the calculated comfort temperature;

T_{rm}= running mean temperature for the current day which is weighed with a higher influence of the previous daily mean external temperatures (T_{ed-1}; T_{ed-1}; …) (Nicole *et al.* 2009); and

T_{rm}= (T_{ed-1}+ 0.8 T_{ed-2} + 0.6 T_{ed-3}+ 0.5 T_{ed-4} + 0.4 T_{ed-5}+0.3 T_{ed-6}+ 0.2 T_{ed-7})/3.8.

Results of studies by Hummelgaard *et al*. (2007) showed that occupants of naturally ventilated buildings did not only have more tolerance regarding temperature but also had lower IAQ expectations. Although there are different assessment criteria for assessing thermal comfort in naturally and mechanically ventilated buildings, there is a single assessment criteria for IAQ in both naturally and mechanically ventilated buildings. To assess IAQ as suggested by BS EN 15251 (Brit2007, frequency of time when CO_2 concentration was higher than acceptable levels was reported. Acceptable ranges were specified as 1000ppm as the target value (British Standard Institute 2007) and 1200ppm as an acceptable value in existing buildings (British Standard Institute 2007). Above 1500ppm when almost all occupants report some symptoms of Sick Building Syndrome (Petty 2013).

For the purpose of physical measurements, air temperature and CO_2 concentration sensors were installed in the main zones of the open plan office. Data from air temperature sensors were used to calculate Mean Radiant Temperature (MRT). MRT was estimated by using equation 3 which was proposed by Han *et al.* (2007):

$$MRT = R^2 \times Ta - 0.01 \quad (3)$$

Where:

R^2=0.99; and

Ta= air temperature.

Using the estimated MRT and measured Ta, as suggested in CIBSE (Chartered Institution of Building Services Engineers 2006a), the operative temperature was calculated as the average of Ta and MRT. An external sensor was also installed on the north elevation of the building to estimate T_{rm} and $T_{comfort}$ in the building using equations 1, 2 and 3. As mentioned in section 19 of CIBSE guide F (2012), monthly meter readings were used to assess the energy consumption in the case study building before and after the interventions. Table 1 summarises assessment criteria which were used in this study.

Table 1: Assessment criteria for this study

Criteria	Method	Source
Thermal comfort	heating seasons= % of occupied hours Tc is not in the range of 20-24 Cooling season = % of occupied hours Tc is in in the range of calculated T_{comf} ±3 ºC	BS EN 15251: 2007
IAQ	% of occupied hours CO_2 >1000ppm % of occupied hours CO_2 >1200ppm % of occupied hours CO_2 >1500ppm	BS EN 15251: 2007 Petty,2013
Energy consumptions	Monthly meter reading	CIBSE Guide F:2012

Thermal comfort

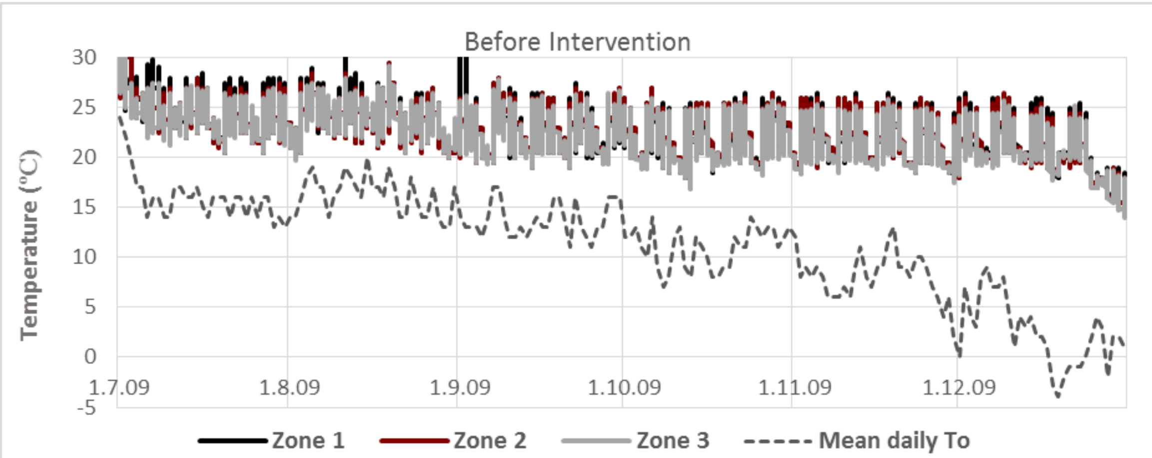
Table 2 summarises results of building performance in terms of thermal comfort when the adaptive assessment method was applied. Comparison of occupants' thermal comfort before and after intervention, overall indicated better temperature control after refurbishment as shown by the frequency of thermal discomfort in Table 2 and temperature variations during 6 months in Figure 4. This is despite summer external temperatures being slightly higher after intervention (Fig. 4).

Table 2: Effects of automatic and manual control on thermal discomfort

Criteria	Before intervention			After intervention (Manual control)			After intervention (Automatic control)		
	Zone 1	*Zone 2*	*Zone 3*	*Zone 1*	*Zone 2*	*Zone 3*	*Zone 1*	*Zone 2*	*Zone 3*
% of occupied hours Ta is not in comfortable range	18%	9.1%	6.5%	7%	7.2%	4.8%	5%	3.0%	3.1%

Table 2 shows that introducing manually controlled ANV helped to reduce the risk of thermal discomfort by a maximum of 60% (in Zone 1) and by a minimum of 21% (in Zone 2). It is while according to the results of a questionnaire before intervention, occupants of the Zone 1 were the most dissatisfied occupants while occupants of Zone 2 were the most satisfied people (Khatami, Cook and Hudleston 2011). The results showed that occupants of the Zone 1 who were the most dissatisfied occupants, responded to the new strategies more actively after intervention and better temperature controls were provided in this area. The occupants of Zone 2, who were the most satisfied, had the least intention to change their working environment. Therefore, when natural ventilation relied only on the manual controls by the occupants, they controlled natural ventilation less actively making the NV strategies less effective in Zone 2.

Comparing the results of building performance for manual and automatic controls showed that introducing automatic control was more effective in Zone 2 as it decreased the risk of thermal discomfort by 58%. This was due to the little intention of occupants of Zone 2 to control their indoor environment when natural ventilation systems relied on manual controls. Therefore, introducing automatic control was more effective in this zone. This was while introducing automatic control in the Zone 1, where occupants were more active, was less effective and the risk of thermal discomfort reduced by only 28.5%.



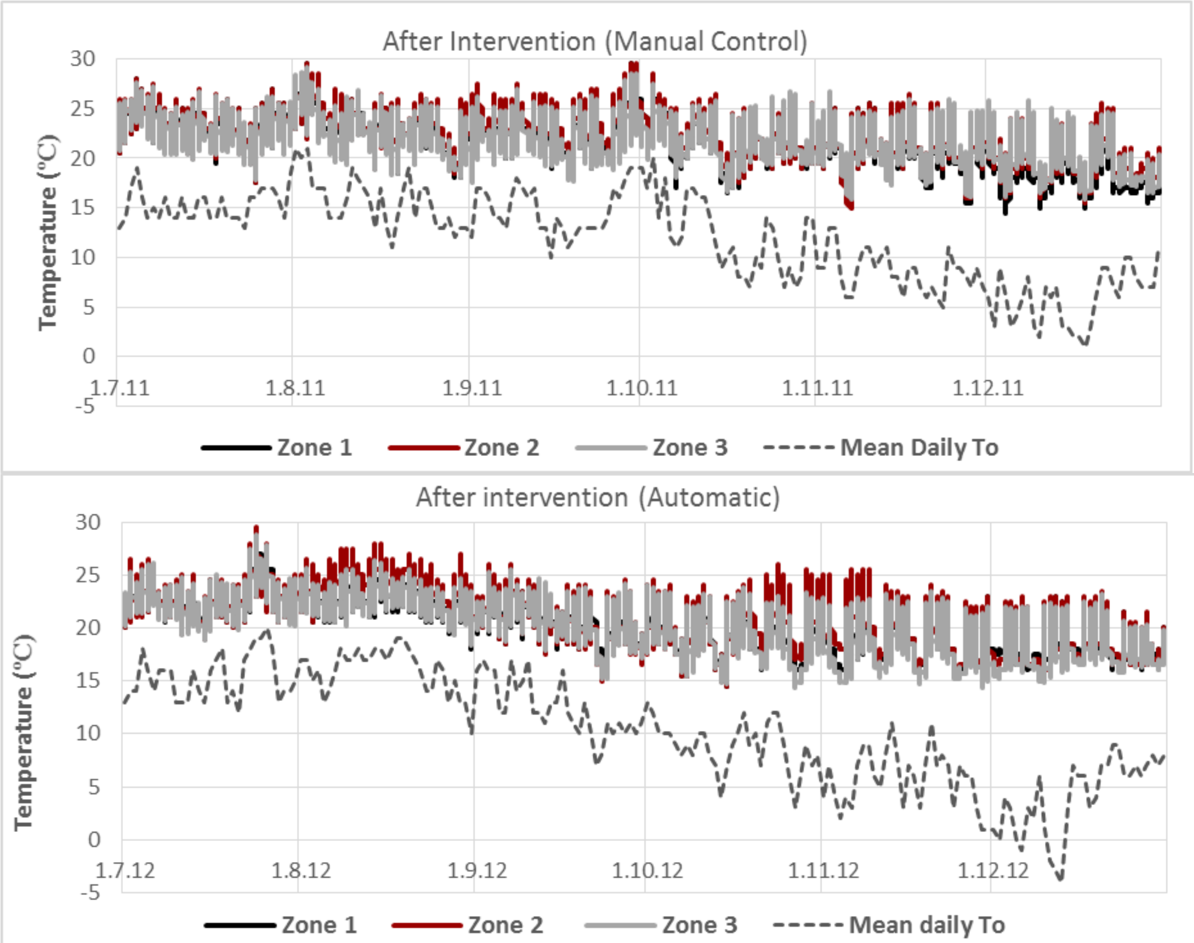


Figure 4: Internal and external temperature variation during the testing period

The results of this study revealed that when natural ventilation relied on occupants' manual control, it provided a better temperature control during hotter days (Figures 5a and b). During hot days, internal temperature at the beginning of occupied hours was usually high and occupants reacted to the internal temperatures faster and tried to control the temperature more actively resulting in more effective temperature control. It was while during milder days (Fig. 5b) occupants waited until internal temperature reached to 25ºC-26 ºC when they opened the vents. Delaying in opening the windows and high level openings led to higher internal temperature in moderate days (Figures 5a and b). Results from this section suggest that air temperature at the beginning of the working day is an important parameter to consider if occupants are responsible for control of the natural ventilation system.

Similar performances were recorded during extreme external conditions when the performance of the CSB with manual and automatic controls were compared (refer to Figures 5a and c). Both controls helped to shift the occurrence of peak temperatures from the occupied to the unoccupied periods which helped to prevent the risk of overheating. It should be noted that since the CSB has a lightweight structure, night cooling provided by automatic control was not very effective. Therefore the rapid reaction of occupants provided a similar effect to automatic control during hot days.

Although the building performance during hot days was similar, during milder summer days, introducing automatic control was more effective. As suggested by Heiselberg

(2008) and Khatami, Cook and Hudleston (2011), occupants reacted to overheating slowly and therefore introducing automatic control helped to prevent overheating and kept internal temperature within comfortable ranges (refer to Figures 5b and d).

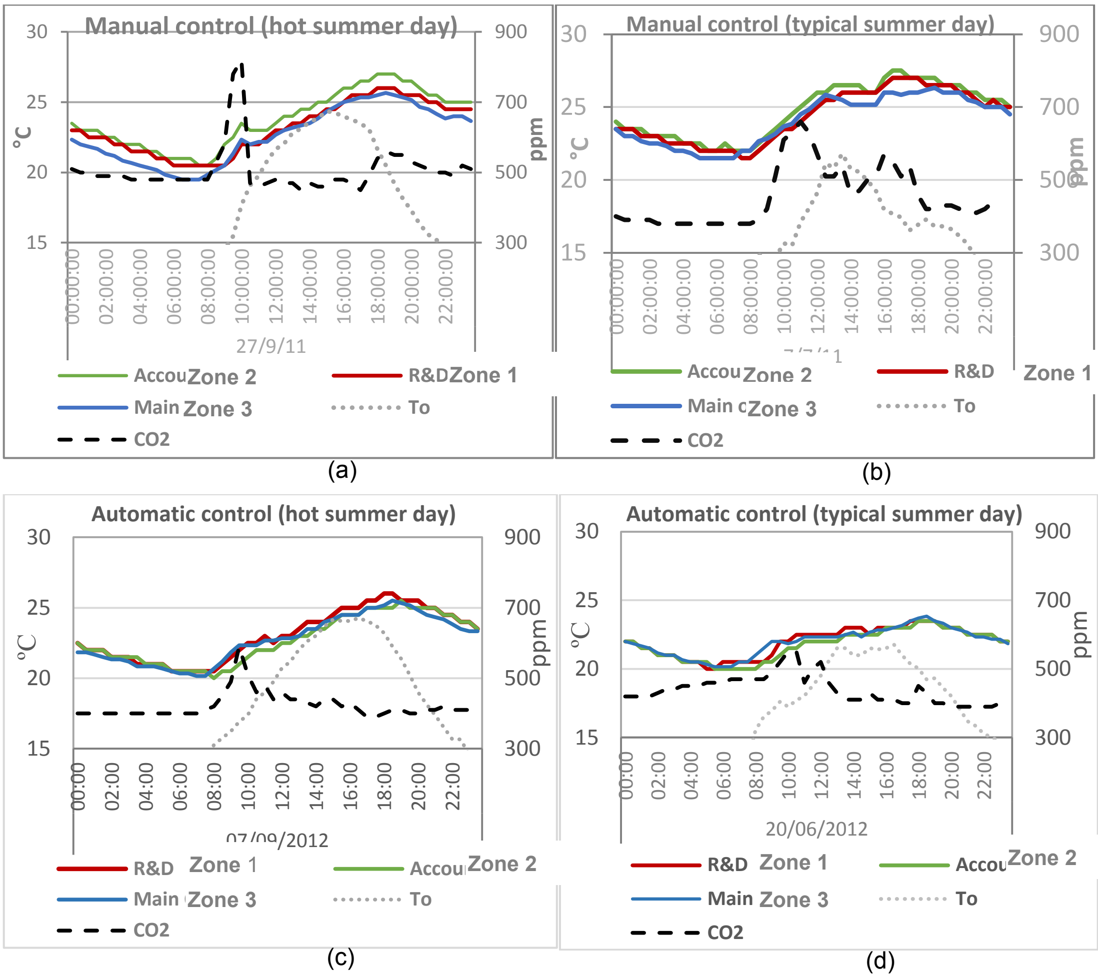


Figure 5: Effect of applying automatic control on temperature control during hot and typical summer days

CO_2 concentration and IAQ

Table 3 summarises the results of this section. Comparing the results of the building performance before intervention (when supply and extract ventilation was activated) with manual control showed considerably poorer IAQ after intervention. According to the physical measurements, the percentage of the occupied time when CO_2 concentration was higher than 1000 and 1200 ppm was significantly increased after intervention.

Table 3: IAQ before and after intervention (manual and automatic controls)

Criteria	Before intervention	After intervention (Manual control)	After intervention (Automatic control)
% of occupied hours CO2> 1000ppm	1%	15%	6.4%
% of occupied hours CO2> 1200ppm	0%	5.5%	0.8%
% of occupied hours CO2> 1500ppm	0%	%0.5	0

Although after intervention more control options were provided, occupants controlled the openings mainly based on their thermal comfort as they were less aware of IAQ conditions. For this reason, CO_2 concentration was considerably lower during hotter periods (Fig. 6).The results of this section suggested that, since there was little intention by the occupants to control windows to improve IAQ, it is rather risky to rely only on manual controls to provide acceptable IAQ.

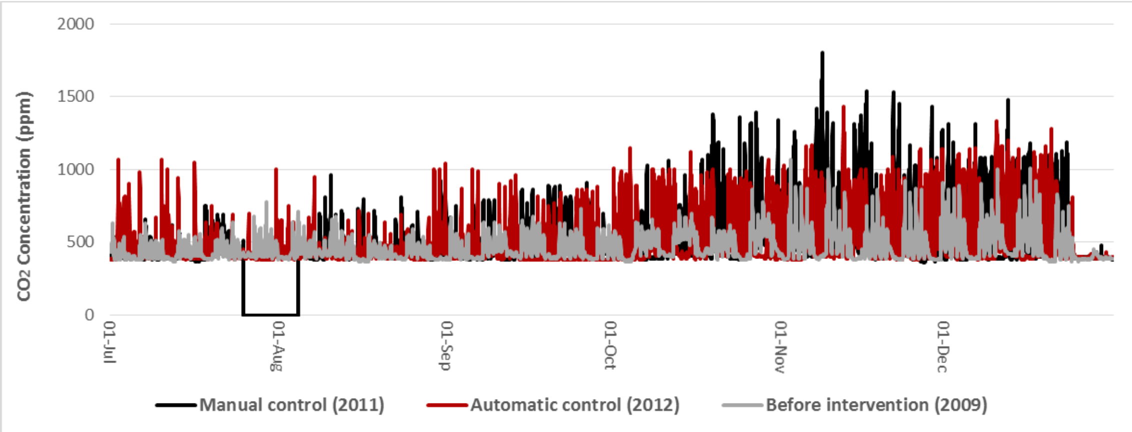


Figure 6: CO_2 concentration before and after intervention

Introducing automatic controls significantly helped to reduce the risk of poor IAQ. Automated natural ventilation controls reduced the amount of time when CO_2 concentration was higher than 1200ppm by 85%. Although when compared to the manual controls, automatic control provided better IAQ conditions, supply and extract systems proved to be more effective than both manual and automatic controls in controlling CO_2 concentration in the open plan office.

CO_2 levels during occupied hours illustrated the high dependency of CO_2 concentration to the opening positions (Fig. 5). According to the results, CO_2 concentration dropped suddenly or rose rapidly by opening or closing the openings. Therefore it could be argued that CO_2 concentration can be used as an indicator of the vents status (open/closed) in densely occupied spaces with constant occupancy patterns and large opening sizes.

Energy Consumption

The results of the study showed that introducing automatic natural ventilation into the CSB helped to reduce electricity consumption by 5%. Lower electricity consumption could have occurred as a result of disabling the supply and extract systems. Moreover, since during summertime, the ANV system controlled overheating more effectively, occupants used desk top fans less frequently (Fig. 7).

Gas consumption was also reduced by 11.5% since disabling the supply and extract system reduced the ventilation rate and associated heating demand. Furthermore, as discussed by Khatami, Cook and Hudleston (2011), before intervention there was a risk of overheating even during cold seasons and occupants needed to open windows even during winter. By applying ANV strategies, overheating was controlled more effectively and for this reason during heating seasons, occupants needed to open the windows less frequently which also helped to reduce heating demand.

Comparing energy consumption for manual and automatic natural ventilation systems showed reductions of 2% and 3% in gas and electricity consumption respectively. The results in this section suggest that both manual and automatic controls have similar effects on the energy consumption in naturally ventilated office buildings where there is no form of mechanical cooling systems.

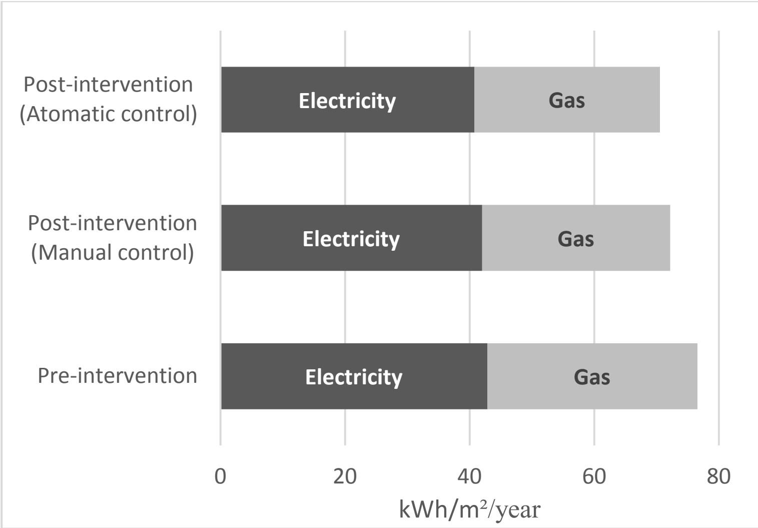


Figure 7: Monthly energy consumption before and after intervention

Conclusions

This study used monitoring to evaluate the effects of applying manual and automatic control to natural ventilation systems on thermal comfort, IAQ, and energy consumption in a typical office building in the UK.

The work has shown that manually controlled natural ventilation systems appear to perform better during hotter days as occupants react to the internal temperatures more actively in an attempt to control the internal temperatures. Manual controls may, however, be less effective during moderate summer days due to the delayed reaction of the occupants in controlling the vents (e.g. windows). Automatic control systems are therefore more effective during such days.

Based on the results of this study occupants of those areas of the CSB where thermal comfort was relatively poor before intervention (Zone 1) responded to the manual NV systems more actively. Therefore, it could be argued that the previous thermal experiences of the occupants' of a zone in buildings with manually controlled NV systems should be regarded as an additional criteria to the historic exteral temperature.

Automatic controls are more effective in spaces where occupants are less active and have little intention to change their thermal environments (e.g. opening the vents before it reaches to high temperatures). According to the results of this study, introducing automatic NV systems could reduce the risk of thermal discomfort by 60% in such areas.

Occupants seem to be much more responsive to their thermal discomfort compared to poor IAQ increasing the risk of unacceptable IAQ during colder seasons. This is because they may either avoid adjusting openings to avoid discomfort in cold weather or they are less aware of the IAQ conditions. Introducing automatic controls significantly reduced the risk of poor IAQ by 85%.

Compared to NV systems, mechanical supply and extract systems could provide better IAQ in terms of CO_2 concentration levels; however, NV systems can reduce the energy consumptions in buildings. The NV system monitored in this work reduced the gas and electricity consumptions by 11.5% and 5% respectively.

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INTELLIGENT BUILDING ENVELOPE TO OPTIMISE THE EXPLOITATION OF SOLAR RADIATION

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Abstract

A case study of a building for accommodation, located in the north-eastern Alpine area of Italy, is analyze to investigate how much the design of an envelope with integrated dynamic solar shading system results strategic for the realization of energy efficient buildings. The optimization of the ratio between opaque and transparent closure of the south facade, which acts as the collector of the contributions of solar radiation, combined with the use of automated solar shading helps to reduce energy consumption for heating in winter and greatly improve the thermal and lighting comfort indoor. The integrated dynamic simulation was conducted with the aid of tools for physical-technical modeling as Design Builder and it has allowed to quantify the important contribution to the total annual energy saving of the building through the use of intelligent solar screens. The objective is the design of a component with innovative technical features that has the ability to be integrated in an automated control system used at the larger building scale. The study highlighted a limit in the realization of the control system due to a lack in the current market of interoperable software solutions able to manage and coordinate the domotic components relating to different strategies such as, for example, the lighting and the heating system control. Indeed, they are typically supported by software not able to communicate between them. The study shows: - The need to focus and develop research in the field of product innovation, so as to provide adequate shielding for use in integrated and automated design of buildings; - The need to identify and define accurately the input data necessary for the design and proper functioning of the home automation system of screening. - The need for interoperable software solutions available.

Keywords: *Energy efficiency, shading systems, lighting control, integrated simulation, building automation system.*

Introduction

Near zero energy consumption is the target of European Union for the new buildings from 2020 (EPDB, 2010). The goal can be achieved by using different design strategies and different technologies, according to the different climate contexts. For instance in recent years in northern Europe have been developed the passive house concept that provides a high-performance building envelope in order to create a complete isolation between interior and exterior. On the other hand, results of previous studies conducted by the authors show how design strategies that start from the interaction between the outdoor environment and the indoor comfort are preferable to use in the temperate zones of the boreal hemisphere (such as the Mediterranean area) and in the temperate zones of southern hemisphere (Caini, 2010). In these climates, with alternating warm and cold seasons, the optimum is to use the maximum of solar radiation in winter time through the windowed walls to reduce heat energy consumption, conversely in summer time to use shading in front of windowed walls to reduce cooling energy consumption (Caini, 2012).

This fact puts the façade at the centre of the “energy reduction issue”. In this perspective shading systems should be considered as an integral part of fenestration system design for buildings, in order to balance day-lighting requirements, to optimise visual and thermal comfort and to reduce primary energy demand. For this reason, the impact of shading design and control on building performance is taken into account at the early design stage to optimize energy balance between the fenestration and lighting (Lee, 1995) and the need for a detailed integrated thermal and daylighting simulation is strong (Selkowitz, 1998).

First, this paper aims to optimise the exploitation of the solar radiation, adopting intelligent building envelope in the special climatic context of the case study. In fact the construction site is at 1936 m.a.s.l. of altitude, in the north-east Alpine area of Italy. Second, this paper aims to verify if the philosophy of the use of the south façade as interactive collector between the outdoor and the indoor to reduce energy consumption and to optimize comfort, that has proved valid for temperate climates with alternating warm and cold seasons, yet occurred in the same region but at high altitudes.

Integrated simulation

Analysis were carried out using Design Builder that integrates the software Energy Plus, that is a state-of-the-art software tool for checking building energy developed in the U.S. Department of Energy and Lawrence Berkeley National Laboratory (Lawrence, 2009). Design Builder calculates heating loads necessary to maintain thermal control set-points and energy consumption of primary plant equipment. The cooling loads were not taken into account because they are not significant in the climate context of the case study.

The daylighting simulation is obtained using the Radiance daylight simulation engine developed by the Lighting Systems Research group at Lawrence Berkeley Laboratory (Crone, 1992).

The daylight luminance level in a zone depends on many factors, including sky condition, sun position, photocell sensor positions, location, size, glass transmittance of windows, window shades and reflectance of interior surfaces. The reduction of electric lighting depends on daylight luminance level, luminance set-point, fraction of zone controlled and the type of lighting control.

In this work, the software DIALux is adopted to define the specific power to install and to simulate the artificial lighting system determining the best energy light solution required in accordance with the respective national and international regulations.
These programs are exploited to implement the integrated simulation of energy and daylight in an office building. The integrated simulation was conducted at every single room in the building. Only on this scale it is possible to evaluate both behaviours and requirements with regard to the thermal and the visual indoor environment defined by occupant (Nielsen, 2011).

The case study

The design theme provides for an accommodation facility for tourists, skiers and hikers (Fig. 1) situated at an altitude of 1936 m.a.s.l. within an area of considerable landscape value: the Dolomites. The area is also included in the Natural Park of Paneveggio and:

a) to the south: the view of the valley being and the tourist site of *San Martino di Castrozza*;
b) to the west: a rock formation of minor importance;

c) to the north-west: the road to get to *Passo Rolle* also with the view of some shelters;
d) to the north: the mountain *Punta Rolle* (this is the view "less" important to the north because there is a strong inclination that prevents the view of the top); and
e) to the east: the mountain *Cimon della Pala.*

Figure 1: Planimetry and rendering of the case study

The architectural concept provides for of the building oriented along the north-south axis, with the north facade totally enclosed and covered with natural local stone. The south facade has glazed openings equal to 30% of the total surface, that previous studies (Tzempelikos, 2007) show to be the best ratio, in order to maximize climate resources (solar radiation) and minimize energy consumption.

The receptive structure includes:

a) ground floor with entrance, a restaurant with 60 seats, kitchen and utility rooms;
b) first floor with bedrooms and bathrooms for 24 beds, a relax area with sauna, turkish bath,and related services (Fig. 2);
c) second floor with accommodation for the caretaker;
d) basement floor for car parking in accordance with the normative prescriptions; and
e) the roof is used for the installation of solar collectors for hot water production, and photovoltaic panels for the production of electric energy (20kwp).

Figure 2: First floor plan

The building is designed with a specific façade type and system configuration (HVAC and artificial light system) to reduce energy consumption. The model is simulated in an environment without any obstruction elements. Table 1 contains input data on construction, system configuration and internal loads for the simulation models. Heating systems is always available for all the year. The heating set-point is 20 °C and the heating operation also has one preheat hour. The heating system is composed of a boiler of 60 kW with an efficiency of 85%. Maximum natural ventilation rate through open windows is 3 Vol/h. Heating systems are simulated as active during occupancy in the entire year, therefor the system set-up would result in temperatures and air quality that always correspond to Class II requirements in the European standard (EN 15251, 2007). These values are typical and are adopted to convert thermal loads to a source energy use.

Table 1: Input values defining simulation model

CONSTRUCTIONS	
Heat transfer coefficient of exterior wall system (U-value)	0.174 W/m^{2}K
Heat transfer coefficient of roof (U-value)	0.156 W/m^{2}K
Heat transfer coefficient of horizontal inferior enclose (U-value)	0.187 W/m^{2}K
Heat transfer coefficient of glazing (U-value)	0.6 W/m^{2}K
Thermal conductivity of the screening panel	0.03 W/mK
Thickness of the screening panel	0.05 m
Visual transmittance of glazing (TL)	70%
Solar transmittance	60%
SYSTEMS AND INTERNAL LOAD	
Source of energy	Wood
Type of heating system	Radiant
CoP	0.85
Set-point temperatures - heating	20°C
Natural ventilation	3 Vol/h
Internal loads equipment	12.7 W/m^2

The study of artificial illumination is achieved using DIALux software. This software gives a detailed evaluation of the correct electric power demand to install according to the DIN 18599-4 legislation. This legislation admits a detail engineering planning (that exploits a specific software as DIALux) and other two simplified methods too (simplified utilization method and tabular method).

The possibility of using a detailed method allows defining more accurately the electric power demand that has to be installed through a 15% of power reduction compared to the other two methods mentioned above. According to the indications of the UNI 10380 legislation is defined the electrical powers to be installed to achieve the minimum request level of lux for each zone (Table 2).

Table 2: The electric power demand to install in different locals

LOCAL	ELECTRIC POWER DEMAND TO INSTALL (W/m^2)
Garage	1,95
Anti - bathroom	12,1
Restaurant	1,28
Kitchen	9,78
Pantry	6,51
Office	3,45
Dressing room	8,75
Public WC	8,8
Relax area	4,51
Bathroom of the hotel room	13,24
Hotel room	7,2
Hallway	2,64
Double room	6,29
Single room	7,1
Private toilet	6
Living room	1,09

The study of finishing materials present in a specific room is particularly important because of their characteristics and their color significantly influence the final results in terms of absorption and reflection of light. Then establishing a proper deployment of light points, always based on the use of LED light bulbs, several simulations were performed to obtain optimal results.

In this way it is possible to estimate the electrical power needed to ensure adequate lighting. All this in order to proceed to an evaluation of the effective annual consumption by using EnergyPlus.

With these data obtained from the individual simulations it is possible to estimate, during the dynamic simulation, the energy demand spent to the artificial lighting: 19.05 kWh/m^{2}year.

The lighting system is equipped with a system of continuous dimming (Fig. 4). The artificial lighting is switched on when the lighting level is less than the minimum level required. The artificial light controller will fill up the gap increasing this own power when the natural light is decreasing. The lights switch off completely when the minimum dimming point is reached. Daylight luminance is calculated for every different locals during the simulation.

(a) Room with controlled lighting to 200 lux (b) Room with controlled lighting to 350

Figure 4: Interior view

Subsequently, a study of daylight luminance level is carried out in the principal rooms.

The objective is to guarantee direct contact of the occupants in the rooms of the building more occupied with the external environment through the natural lighting of spaces and a proper visual perception of the exterior. To achieve this goal it is necessary to verify the achievement of natural illuminance value between a minimum and a maximum of 250 lux 5000 lux at least 75% of regularly occupied spaces, in clear sky conditions, September 21 at 9:00 a.m. and at 3:00 p.m. (verification according to LEED Standards).

In particular, the analysis is conducted for the restaurant, bar, hotel room, relax area and living room. The daylight simulation is carried out using the software Radiance. Of course, during this study were not taken into account artificial lighting devices. Table 3 shows the results obtained from the daylight simulation using the range of values between 0 and 5000 lux. From this analysis it appears that luminance values of the rooms on the ground floor (bar and restaurant) are very low, largely due to the shadow caused by the overhang from the hotel rooms upstairs. Must also be considered that the results are carried out on September 21 and the position of the sun is not optimal for the case study. Subsequently it was decided to perform additional checks for the ground floor rooms in a more restricted range of values between 0 and 500 lux (Table 4). The results show that the standard luminance are met in the most frequented areas of the case study with the exception of the bar area on the ground floor.

Table 3: The daylight simulation of restaurant, hotel room and relax area (range of values: 0-5000 lux)

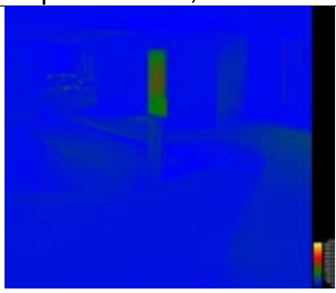
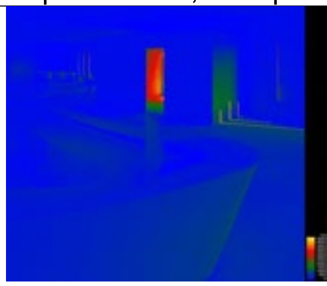
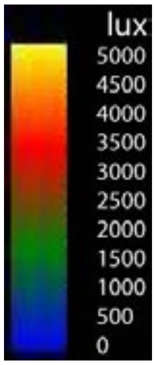
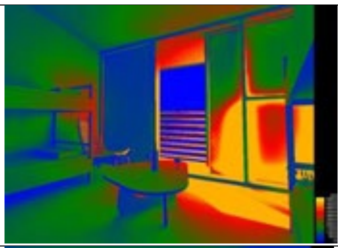
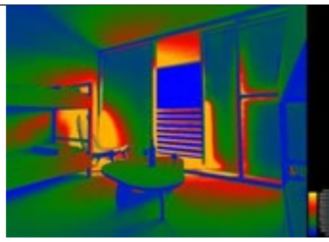
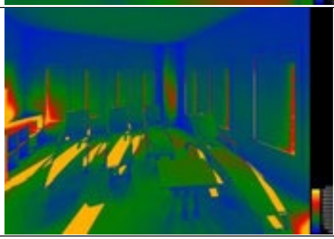
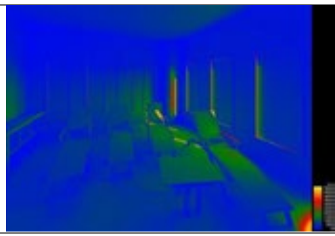
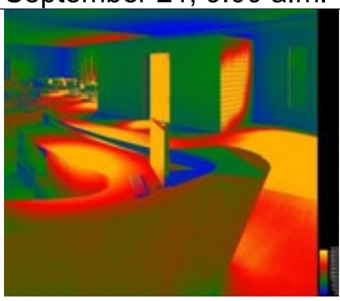
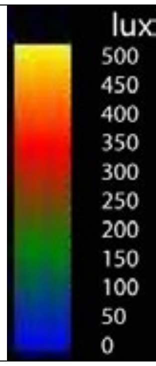
	September 21, 9:00 a.m.	September 21, 3:00 p.m.	Colour codes
Restaurant			
Bedroom			
Relax area			

Table 4: The daylight simulation of restaurant (range of values: 0-500 lux)

	September 21, 9:00 a.m.	September 21, 3:00 p.m.	Colour codes
Restaurant			

Results

The analysis has been implemented to quantify the possible energetic saving through a building automation system using a continuous control of the artificial lighting and an automated shading system device. The analysis is done using at first no control on artificial light and screens. The control system has been defined to maximize the winter sun penetration and solar radiation. Shading control strategy is defined in accord with the outdoor conditions (Fig. 5 and Fig. 6).

As already mentioned, in this case there is an artificial lighting control that is switched on when the lighting level is less than the minimum level required. The artificial light controller will fill up the gap increasing this own power when the natural light is decreasing. The lights switch off completely when the minimum dimming point is reached. Using this type of control a significant reduction of energy consumption for artificial lighting for all months is remarkable (Fig. 7).

An ulterior energetic consumption reduction is achieved by adopting automated shading panels with defined properties positioned outside of the windows. The mobile screens have a thickness of 5 cm and they are composed of an insulating panel with aluminum coating. The technical characteristics of the screening panel are defined after a series of analyses to reach the best results in terms of thermal and visual comfort. Shading is on if when the sun is setting and the free solar gains and natural light are no longer sufficient to ensure the comfort inside. The activation of shielding varies from month to month, day to day. When the sensor detects a value of solar radiation insufficient then the home automation system activates automatic panels which are positioned in front of the window and becoming outer insulating layer. The choice of this control type determines that the moment of activation of the system of screening panels happens later in a summer day than a winter day. The activation time of the screening panels varies from day to day and it is around the 15 p.m. during winter period and the 17 p.m. during summer period. The energy consumption for heating is less precisely in the winter period in which the external conditions are critical (Fig. 8). It is essential the contribution of mobile screenings in order to satisfy the requirements of indoor comfort, reduce energy consumption for heating, decrease heat loss through the window openings (Fig. 9) and heating systems can be installed with less power. It follows that through the use of dynamic solar shading devices and the lightning control the energy consumption of the building is reduced by approximately 7% (Fig. 10), from 111 kWh/m^2 to 103 kWh/m^2.

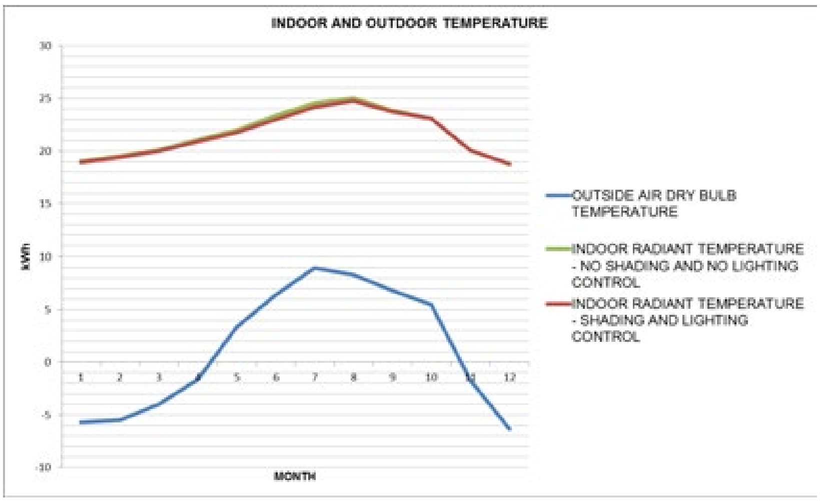


Figure 5: Indoor and outdoor temperature

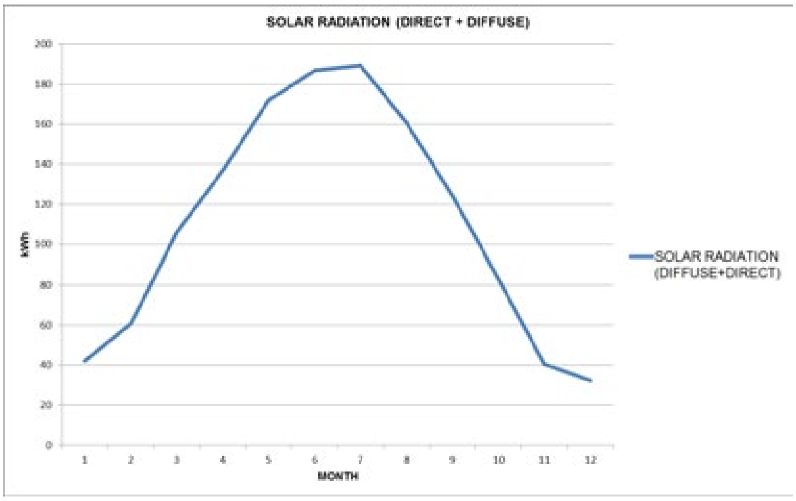


Figure 6: Solar radiation direct and diffuse

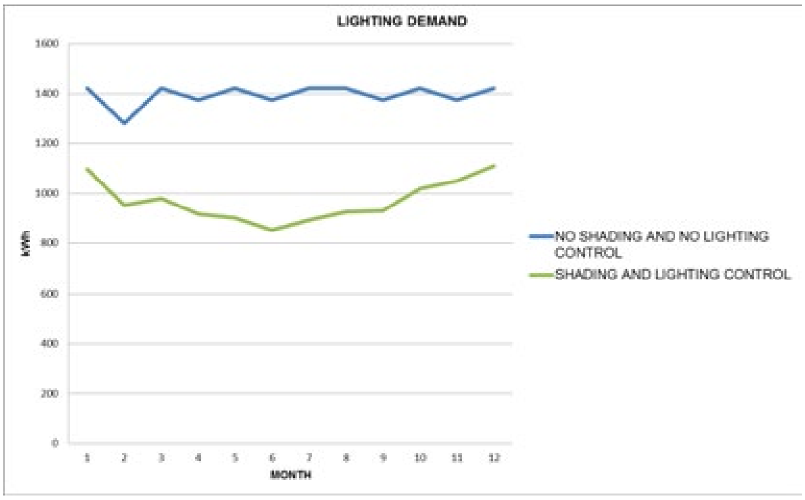


Figure 7: Lighting demand

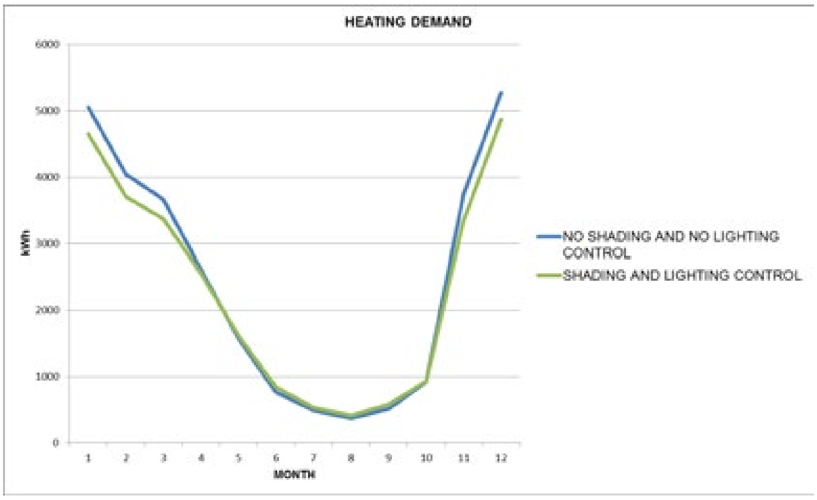


Figure 8: Heating demand

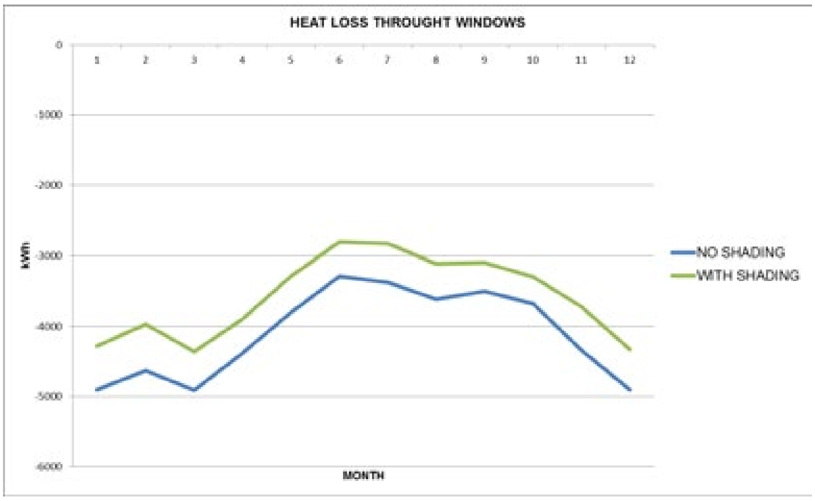


Figure 9: Heat loss through windows

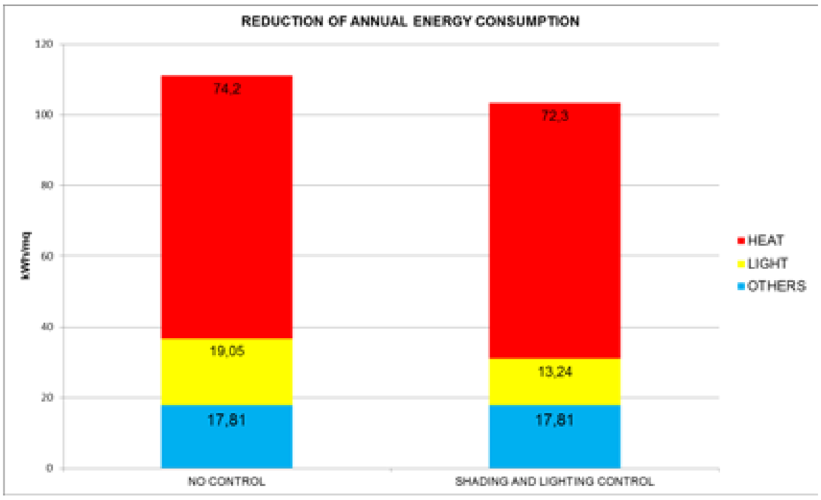


Figure 10: Reduction of annual energy consumption (kWh/mq)

Conclusion

The results show how in the Alpine area of Italy, the optimization of the indoor comfort and the reduction of energy consumption of buildings, are highly depending on the performance of suitable dynamic shading system.

The work shows that is still confirmed valid the design philosophy that provides the maximum use of solar radiation on the site in order to reduce energy consumption for heating and for lighting. It is possible to reach this goal through the use of automated shading system.

Through simulations the global energy saving achieved by using a home automation system to control artificial light and solar screening panels is 7.71 kWh/m^2 in a year amounts to about 7% (Fig. 10).

Specifically the reduction in consumption in a year of lighting is equal to 5.81 kWh/m^2 and of heating is equal to 1.9 kWh/m^2.

In these climate contexts the automated screening panels must contribute to improving the insulation capacity of the building and must be designed in a single system shielding-window in order to achieve optimal performance. The screening system is external and it must ensure air tightness. In this way the dispersion of heat towards the outside through the windows is reduced and is greatly hampered when the screening panels are positioned in front of the window. Indeed, the screening panels insulated are able to contain the heat dispersions improving the performance of the building envelope.

The study shows that:

a) future research should be directed to the development of technological design of the shading system to be adopted in these climatic contexts so as to realize a high performance window-shielding system; and
b) future research should be directed to the development of a software that can make operating ad hoc a CPU to be installed in the building, such as to govern in a coordinated and unified the various home automation systems specified in the project: the system shielding system, the control lighting with automatic dimming of artificial light and the control system of the comfort managing the heating system and air exchange.

The lack of a standard protocol between the manufacturers of the various components of smart technology on the market, it reduces the efficiency of automation and its valuable contribution to the reduction of energy consumption in buildings.

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NEAR ZERO ENERGY SYSTEMS: NATURAL PERFORMANCE BUILDINGS DESIGN

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NEAR ZERO ENERGY SYSTEMS: NATURAL PERFORMANCE BUILDINGS DESIGN

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Abstract

The current approach to energy efficiency and environmental sustainability for the design of new building needs a radical change. In the last few years, the increasing comfort demand has led to an incremental request of thermo-hygrometric properties, which are necessary for living spaces. These systems modify internal environment climate in adaptation to the external conditions. This paper introduces an innovative design strategy, which is based on the spontaneous building behavior rather than an excessive use of air-conditioning systems. In mild climate areas, the use of climatization systems can be minimized and the focus is on building surface design. The real design innovation aspires to develop new “building envelope solutions” for interpreting signals coming from the outside environment. A spontaneous building behavior can be designed taking into consideration the outside climatic conditions and corresponding building performance during the different seasons. In this way, air conditioning systems are used in external critical conditions. Building thermal performance can be improved through the design of the building envelope. New design techniques lead to modulate the natural building envelope behavior and to evaluate environmental reactivity as a primary measure of control of the living space conditions. This methodological approach requires the measurement of standard performance in order to improve it. Hence, it is possible to use iterative measurements and numerical models. In this manner, the building performance can be assessed, enhancing construction solutions and satisfying comfort conditions in the design of the building envelope. Comfort evaluation is carried out on the basis of mankind physiological and behavioral adaptive characteristics.

Keywords: *Natural building performance, building envelope design, near zero climatization systems, design strategy.*

The method question

“You Only Know What You Measure”
William Thomson, Lord Kelvin (1824-1907)

Kelvin's quote is better known as "If you cannot measure something, you cannot improve it", even if the translation is not literal.

Nevertheless, the translation gained a meaning to the detriment of knowledge, key moment for any cultural building experience. Sometimes the knowledge requires in-depth analysis that cannot be separated from numerical evaluations. These lead to science.

The purpose of this report is to find a strategy that prefers the spontaneous building behavior rather than an excessive use of air conditioning systems. It is shown that where the climate is milder, it is possible to minimize the use of systems thanks to a proper surface design. The real innovation is to precisely check building performance.

"Prestazione" derives from latin "praestatio - onis" meaning "guarantee." The achievement of optimal features is defined by the English word "performance", which means "to fulfill, perform".

The methodology is "parameterize" the performance to improve it. The cognitive process requires to measure each wall performance for reaching quality. The corrective action outlines a particular design approach. Its purpose is to develop a dynamic process that, with successive measurements, improves constructive solution making it efficient.

Every possible solution becomes a variable searching performing solution.

This is an experimentation, which is neither practical nor theoretical. Numerical models offer the possibility to measure the building performance in respect of Kelvin's logic, because if you cannot measure it you cannot improve it and if you do not measure, you do not know really.

This cognitive and experimental approach takes another step toward the project, as an effective action. It exceeds the prediction laboratory threshold because this could not be enough for simulating real conditions.

The legacy of the past

The relationship between design and climate, in wider terms "environment", which characterized largely past construction, has gradually disappeared during nineteenth century, especially with the advent of heating and air conditioning systems. Indeed, today, these are the main elements for government of internal conditions.

It is necessary to know the traditional architectural styles that came in succession over the centuries, in order to revive the built-nature alliance, and in order to take advantage of the climatization strategies based on the use of natural resources.

In particular, vernacular architecture is surprising thanks to the successful synthesis of climate-shape-material. It is a poor and wise building with environmental materials, which developed many construction and architectural perceivable and responsive methods. These are consistent with the place and the environment in which they are. They aim to determine the spontaneous air conditioning in confined spaces.

In *De Architectura*, Vitruvius writed about the importance of the climatic context, the sun path and the wind flow for building design:

> *[…] the buildings will be located if you will be taking into account the orientation and sun inclination under which you want to build, because the buildings are constructed differently in Egypt or in Spain, in the kingdom of Pontus or in Rome, depending on the location of countries, and on the proximity or distance to the sun path. The sky face is oriented differently according to the different places, and the relationship between these places, the zodiac and the sun path is variable. So you should design the buildings according to the diversity of countries and climates. (Vitruvio 1997).*

Throughout history, when the shortage of energy resources and technological instruments limited control on the environment, construction methods have been developed. These methods have determined the selection of more efficient architectural solutions that are suited to local climates. It is easy to find examples in the traditional architecture (extreme examples of architecture are the Eskimo igloo, the Indian house of straw and mud (Fig. 1 and Fig. 2).

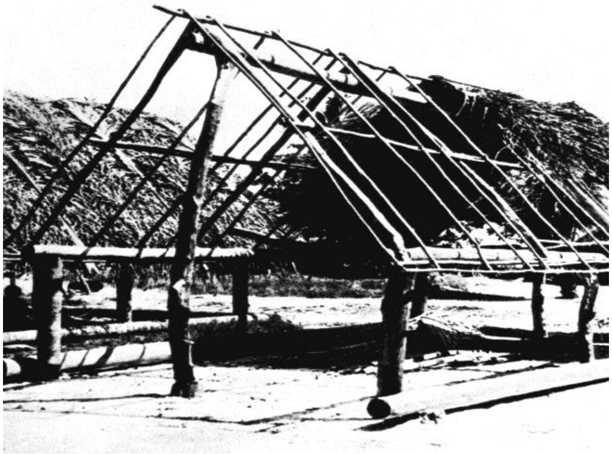

Figure 1: Cave dwelling in Melanesia in wood and straw

Figure 2: Reconstruction of a proto-historic hut, late Bronze Age, with roof in wooden structure covered by small canes closely tied together (Open air Museum Alberto Manzi in Pitigliano - GR)

Traditional architectures in Italy are “trullo” (Fig. 3) and “dammuso”. The trullo is a widespread type in the plateau of Murge (Puglia) and in some areas of Molise. It combines protection strategies and use of the mass with radiative cooling and ventilation strategies.

Figure 3: The trullo of Puglia and inside of Molise trullo

The trullo was originally an agricultural and seasonal construction. The structure consists of a dry masonry with a great thickness (1-2 meters), and of a pseudo-dome. This is lighter and it has a thickness, which is decreasing towards the cusp. It is closed in keystone with pinnacle. The door is the unique opening. As a result, the inner light is limited. The ventilation openings is limited to the chimney that allows cross ventilation during the night expelling hot air and beckoning fresh air from the slots in the bottom of the door.

Dammuso is another architectural type, similar to trullo. It is a spontaneous architecture of the island Pantelleria, characterized by strong winds throughout the year.

Dammuso has simple shapes and is oriented exposing minor surface to the strong wind. The basic typological element is represented by one population cell which can join to other compact aggregations.

The interiors have barrel-vaulted intrados and different curving extrados. The openings are the door and small windows called "stone eyes" which allow, although in small measure, the lighting and ventilation.

The high thickness of the wall ensures the delay of heat flows, which are mainly regulated by the cover. The extrados makes heating dissipation possible thanks to the radiation with the night sky. Barrel vaulted intrados contributes to the inner convective flows. In addition, the artifact implements direct thermal exchanges with the ground because it is directly placed on it.

This analysis shows that spontaneous architecture developed millennial experiences. They highlight the potential for developing architectural and urban building systems which are perceivable and responsive of the place and of the environment. This guarantees a spontaneous air conditioning in confined spaces.

The inertial daily ability is added to sequential one that can counteract the prolonged heat waves. Current building systems are not characterized by similar inertial masses and the replication of these urban structures would not give the same favorable results to the spontaneous air conditioning.

So the redefinition of a proper relationship between buildings and the environment should recover this constructive logic and support a new culture based on the science and technology domain. As a consequence, it gives the new standards and building systems in relation to the environment and the climate.

In the last years, the air-conditioning systems advent has reduced the attention on the volumes and envelope design, which has lost its primary function as a mediator between internal and external climate, leading to independence from climate. As a consequence, it is strategic to work for ensuring the project summarizes its original function. It has to constitute the key moment to establish the architectural and technical conditions necessary to comfortable internal conditions, taking advantage of technological and disciplinary advances currently available.

New building systems should have very low energy requirements, sensitive to a specific climate, and they should manage the indoor climate for long periods with almost automatic reactions to external environmental stimuli.

These reactivities are concentrated, but not exclusively, on building behavior and in its architectural and technological connotations (Croce 2007).

Requirement, performance and adaptivity

The real innovation is to rule the spontaneous building behavior and its responsiveness to the environment for controlling the internal conditions, during the seasons, with few systems.

This is possible with a proper and an *in-depth analysis of the thermal situation* (more generally of the environment), and with the design of the building volume and the *choice of building envelope solutions* that can modulate external signals. Finally, after contextual conditions are examined, it is possible to use analytical modeling for the prediction of spontaneous building behavior in free floating (free floating is an environmental condition defined by the behavior of the building, without the systems participation).

The objective is to reduce the use of traditional heating and air conditioning systems, the use of non-renewable energy and CO_2 emissions. Nevertheless, it is necessary that the internal conditions are comfortable. It is evident that psychophysiology appears a necessary basis for a proper design. Michael Humphrey and Fergus Nicol in 1992 developed an approach called "adaptive", which provides that man is able, within certain limits, to respond to environmental changes (Humphrey and Nicol 2012). This is possible with physiological and behavioral reactivity, with interventions and adjustments to the building system, opening or closing a window, lowering a curtain or wearing a sweater or temporally moving an activity.

The man's reaction takes place through physiological adaptabilities (thermo-hygric regulation of body), which change as a function of environmental conditions, and through conscious or unconscious adaptation, generated by psychological conditions. In fact, the individual has expectations because he uses to live in a given environment. This expectation, in air-conditioned spaces, leads to accept non-natural situations where the user cannot influence. In this manner, the use of air conditioning becomes raised with significant influence on the increase of energy consumption. The individual influence, in the first activity, is limited and conditioned by acclimatization but it becomes important in the second adaptivity form.

When it is possible to take advantage of the individual adaptivity, performance targets are less stringent than those set forth above, because remaining acceptable (without reducing the current expectations of quality), are based on the natural imperfect constancy of environmental conditions that is found precisely in the natural world.

In 2000, ASHRAE started a research study for the revision of the ASHRAE 1955-1992. The purpose was to develop a new standard that was specifically applicable to naturally ventilated spaces: the results (Standard 55 Thermal Environmental Conditions for Human occupancy, 2010) have shown that in these environments, a variable percentage between 80% and 90% of subjects tolerates less stringent temperatures and temperature ranges (Fig. 4 and Fig. 5). The new standard is perfectly applicable to this study.

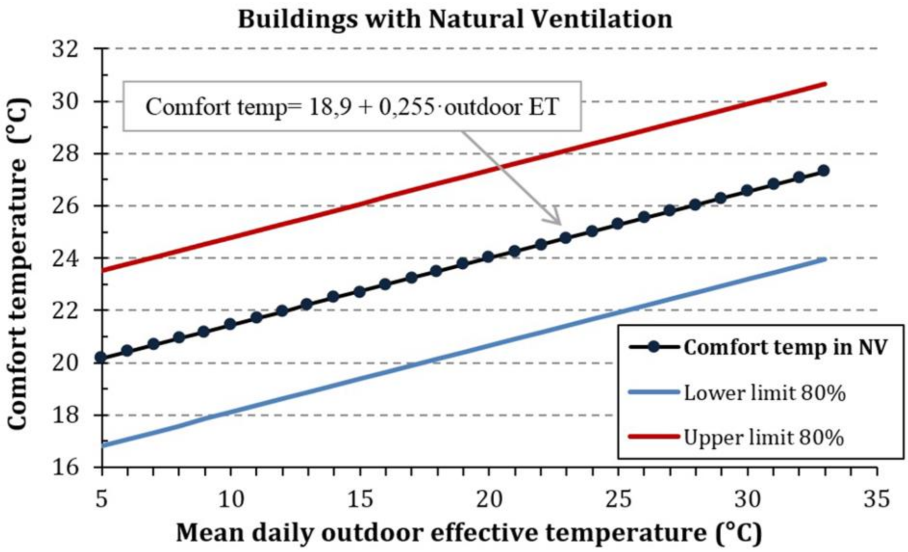

Figure 4: Optimal comfort zone for 80% of subjects in naturally ventilated and then with adaptive behavior to vary the effective temperature outdoor

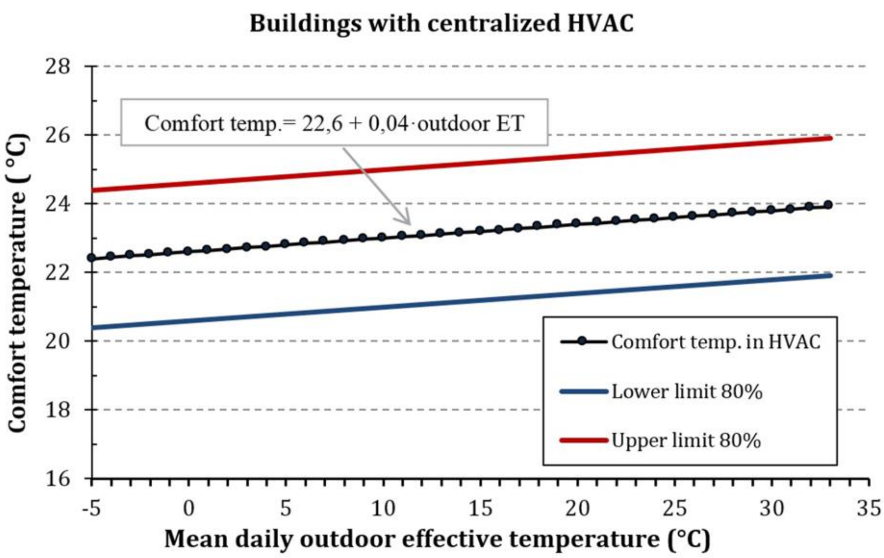

Figure 5: Optimal comfort zone for 80% of the subjects in a conditioned environment to vary the effective temperature outdoor

The analysis of the forces and the control of internal environmental conditions
Italian climate consists of multiple climatic zones: alpine areas, Apennine areas, areas of pre-Alps, lakes, level grounds, marine areas. They have different latitude, sun exposure, clouds, wind, presence of breezes, vegetation, orography, presence of aquifer, urbanization etc... There are sites where summer conditions prevail, other where winter climates prevail and there are sites with very hot summer and cold winter.

It is necessary to know and use local potentiality for using non-renewable sources. For each site, it is necessary to analyze which are the critical issues (negative force) and the potentialities (positive force) for controlling the internal environmental conditions.

In the following diagram, forces are inserted. They influence spontaneous climate of the building (Fig. 6).

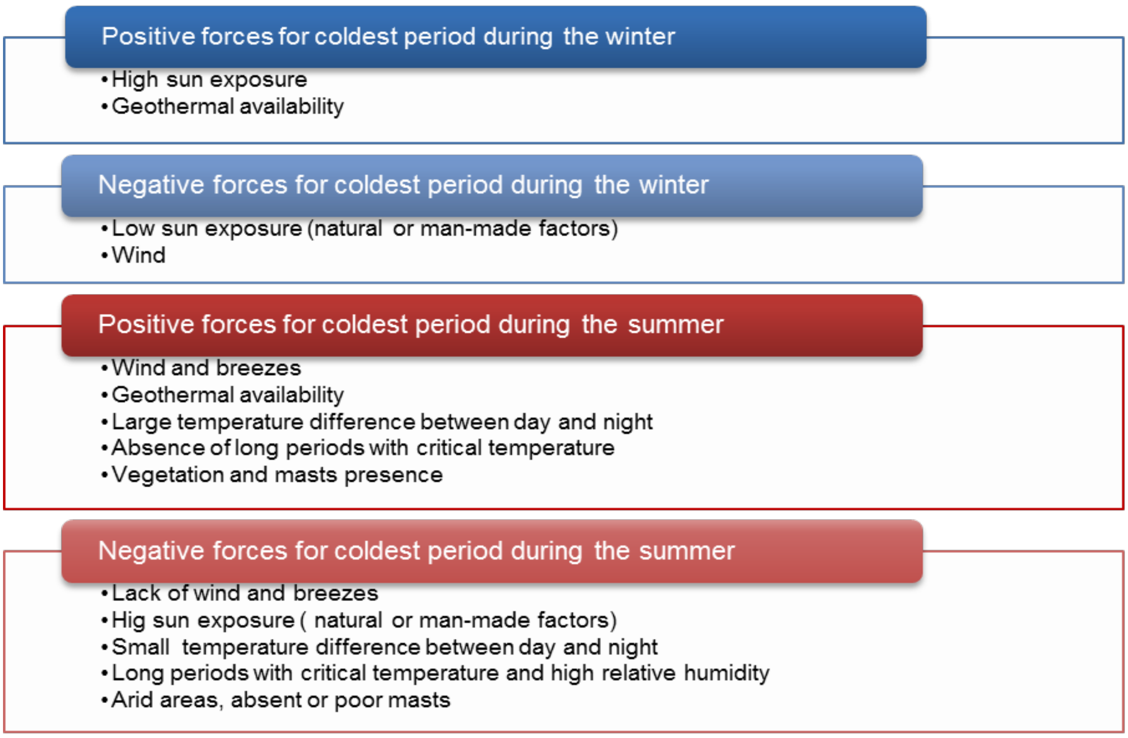

Figure 6: The analysis of the forces

Site orography can generate various microclimates also if there are relatively close sites, for example for presence or lack of breezes and masts.

It is necessary to deepen the knowledge of the context data during seasons. It is crucial for evaluating the performance of the internal environmental conditions, compared to the variability of external environmental stimuli.

Building envelope design
In relation to specific microclimatic conditions, the design purpose is to conceive envelope solutions for modulating external signals. Consequently, various technical elements of envelope emit them again, transforming, strengthening and reducing them. The purpose is to introduce new signals in the environment for obtaining the performance targets.

Therefore, it is necessary to make a design centered on government of building dispersing surfaces, rather than aimed to the control of air temperature.

The envelope becomes a signal generator. The control of envelope depends on the perceived environmental quality.

It is evident the design potential in new envelope development respecting environmental quality and sustainability. The lack of potentiality comprehension and the reproduction of stereotypes often leads to use systems. It is appropriate to distinguish static and dynamic modulations.

The static modulation (in existing buildings) refers to not-variable behaviors of the singular components, which are independent from quality level and environmental stimulation. It is possible to say that the modulation is managed by the design "once and for all" (thermal insulation, etc.).

Dynamic modulation means instead the possibility to vary the behavior of a specific envelope solution when there is a specific environmental condition (solar screening furniture, envelope openable portions that activate natural ventilation, etc.). This is achieved through variable daily or seasonally configurations.

In general, we can distinguish two types of surfaces. Their modulation define the achievement of a given operating temperature:

a) opaque elements; and
b) transparent elements.

The most popular strategy for reducing energy winter consumption is to increase the closing thermal resistance, insulating the opaque parts or using high thermal inertia. As a result, the transparent closures have to govern the thermal flows.

In summer conditions, in analogy to winter conditions, it is still necessary operate on modulation of opaque or transparent closures for achieving optimal environmental conditions. The difference between winter and summer regime is that transparent winter open closure (including screening systems) handles the heat flows through the solar factor, but also the heat flux for mass transfer in natural ventilation.

In fact, glass transparency, for the energy transfer, is an advantage during the winter season and a disadvantage in the summer. So the focus of the technological development and new materials is particularly directed toward the improvement of glass performance. This should be different in relation to climate change and different glass orientation.

Obviously, glass surfaces with high thermal insulation are necessary where the winter is colder. Solar control glass surfaces with possible dazzle protection are suitable where climate is warm. For temperate climates, depending on the season or time, both requirements could be satisfied with appropriate innovative dynamics solutions. Generally, for South exposure glass should maximize winter solar gain, while for other orientation, glasses should improve thermal insulation.

Conclusion, predictive analysis and numerical model experimentation
It is possible to use model experimentation for predicting building spontaneous behavior in relation to varying contextual situations.

The analysis allows to improve the spontaneous building behavior in free floating during design phase.

In this paper, the building has been designed favoring a natural behavior. It is possible thanks to the volumes and surfaces design in relation to the environment. Therefore, the first step was to comprehensively evaluate the bioclimatic aspects that characterize the site in order to identify problems and potential.

The model is a detached house in a rural context, in Grazzanise, Caserta (Italy).

The municipality is located in the heart of the lower valley of Volturno, on the river edges. It has an altitude of 12 m s.l.m. and it belongs to the climatic C zone, recording a mild climate and a high relative humidity during the months of April and May, reaching 94%.

The temperatures during winter are not very cold. Indeed, the average is around 9°C and only in January and the minimum is -3°C. During the summer, the average temperature is around 23°C, with the maximum 35 °C in August. The climatic profile shows that there are not very hot months but only hot months (July and August) and comfort conditions in May, June, September and October. The remaining months are very cold or at least cold.

The collected data are summarized graphically in the environmental emergencies map, in which there is solar path, the prevailing winds, the green areas and farmland, the views, the infrastructures and the neighboring buildings. This representation identifies and summarizes potential issues in relation to the site. Then it is possible to make design decisions more accurate. During the design phase, in effect, there was attention to the orientation and building shape, to the envelope and to the choice of passive systems for using solar energy (Fig. 7).

Figure 7: The project model

The building is designed maximizing solar energy during the cold months, and checking it during the warm months. Indeed, it was oriented along the east-west axis that allows southern facade (70% openings) collects solar radiation. The extension of the roof and balconies acts as fixed horizontal screens that intercept the radiation during the summer, when the sun is at its maximum height. These screens are also crossed by radiation during the winter, when the height is minimal.

In particular, the shape should be a good compromise between collection of summer solar radiation and containment of winter dispersions. Containing north dispersions, volume has a northern lower height and a southern greater one where a large window encourages the sunshine. An improvement of energy efficiency is achieved also with a suitable interior arrangement. Indeed, spaces face toward south favoring direct solar radiation during the winter.

Natural ventilation is an important element for the government of summer environmental conditions. In effect, it expels thermal energy and promotes the body thermal transfer with convection and hygric-change.

The previous analysis shows few windy days. As a result, the space is designed with a double height and a large opening in the roof for encouraging natural ventilation. The cantilever is designed as an element structurally independent from the building volume avoiding thermal bridges.

The envelope characteristics are shown in the Table 1.

Through the analysis shown in Figure 8 (there is only August), it is possible to identify the critical hours because the operating temperature overflows from ASHRAE curves in buildings with natural ventilation.

Each point represents the operating temperature, which is determined by a specific hour in the building in relation to an external temperature.

There are different experimentation levels: practice, where the physical action is essential, the theoretical where the model is intangible and finally, numerical models that often offer the possibility of measuring building performance, in respect of Kelvin's logic, because if you cannot measure it you cannot improve it.

Numerical model experimentation have shown that in different climatic regions, by varying dispersal vertical surfaces, it is predictable hours number where internal temperature does not guarantee the adaptive physiological comfort. But above all, the hours number is so insignificant that it requires the use of air conditioning only in these limited discomfort conditions. This ensures energy efficiency during almost all year, based on a natural behavior of building envelope.

Table1: The envelope characteristics

OOF				
Material		Thickness [m]	Surface mass [kg/m²]	Thermal resistance [m²K/W]
	Outside surface			0,0400
1	Polyurethane slabs	0,120	6,00	3,7500
2	Weakly ventilated air chamber	0,040	0,04	0,0717
3	Polyurethane slabs	0,060	3,00	1,8750
4	Pine tree (flow perpendicular)	0,030	16,50	0,2000
5	Oak tree (flow perpendicular)	0,020	17,00	0,0909
	Inside surface			0,1000

General information		
Thickness	0,270	m
Surface mass:	42,54	kg/m²
Thermal resistance:	6,1276	m²K/W
Trasmittance:	0,1632	W/m²K

FLOOR ON THE GROUND				
Material		Thickness [m]	Surface mass [kg/m²]	Thermal resistance [m²K/W]
	Ground			0,0400
1	Concrete	0,100	40,00	0,5263
2	Concrete	0,400	680,00	0,4819
3	Weakly ventilated air chamber	0,200	0,20	0,1844
4	Concrete	0,050	30,00	0,2083
5	Polyurethane slabs	0,100	5,00	3,1250
6	Concrete	0,050	70,00	0,0862
7	Ceramics tiles	0,010	23,00	0,0100
	Inside surface			0,1700

General information		
Thickness	0,910	m
Surface mass:	848,20	kg/m²
Thermal resistance:	4,8322	m²K/W
Trasmittance:	0,2069	W/m²K

VERTICAL ENCLOSURE				
Material		Thickness [m]	Surface mass [kg/m²]	Thermal resistance [m²K/W]
	Outside surface			0,0400
1	Rivatone plus G15	0,002	3,60	0,0100
2	Leveling	0,008	9,60	0,0138
3	Polystyrene with graphite	0,080	1,56	2,6452
4	Leveling	0,005	6,00	0,0086
5	Hollow bricks cm.rif.1.1.17	0,300	206,00	0,8600
6	Internal lime-plastering	0,020	28,00	0,0286
	Inside surface			0,1300

General information		
Thickness	0,4150	m
Surface mass:	254,76	kg/m²
Thermal resistance:	3,7361	m²K/W
Trasmittance:	0,2677	W/m²K

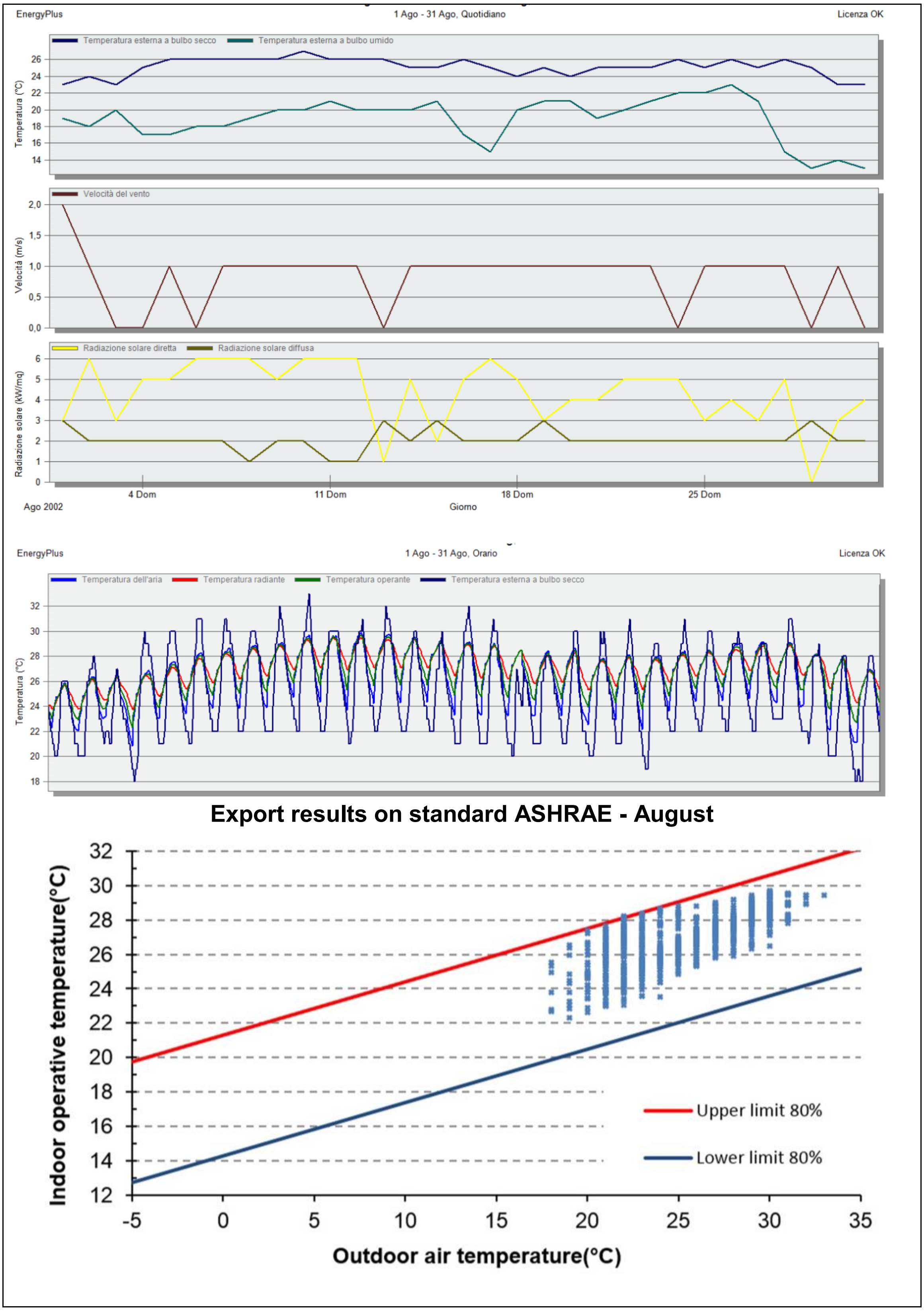

Figure 8: Graph of a project model with cooling spontaneous in a warm period - Dynamic analysis with EnergyPlus

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EVALUATING SUSTAINABLE PRACTICES AND COST ANALYSIS IN BRAZILIAN LOW INCOME HOUSING PROJECTS

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EVALUATING SUSTAINABLE PRACTICES AND COST ANALYSIS IN BRAZILIAN LOW INCOME HOUSING PROJECTS

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Abstract
The increasing social pressure towards sustainability demands improvements from the construction industry to reduce its environmental impacts. However, in Brazil the initiatives for sustainable construction are still limited, particularly those in low income housing projects. In this context, there are few studies which qualify and quantify the required costs in order to increase the level of the adoption of sustainable practices in low income housing projects. This paper aims to propose improvement on these projects aiming to fulfill sustainable requirements established by the environmental certification "Selo Casa Azul", developed for housing projects in the Brazilian context, analyzing the additional costs needed to include these requirements in the project. The main research strategy used in this study was case studies, carried out through a literature review and two empirical studies in low income housing projects in the Metropolitan area of Salvador-Bahia-Brazil, which are part of the Brazilian Government Project “Minha Casa Minha Vida”. In both studies, an evaluation based upon the requirements established by the "Selo Casa Azul" certification was developed. Based on these results, a set of improvement solutions was proposed, including an economic analysis for each one. The main sources for evidence were document analysis, interviews and cost survey. The findings point out that less than 50% of basic sustainable requirements from "Selo Casa Azul" were accomplished by both projects. It was estimated that in order to accomplish both Bronze and Silver categories, the studied buildings would have 1.5% of additional cost, while to accomplish the Gold category, a more significant increase was estimated, varying from 3.64% to 7.23% of the building's total budget. Finally, some strategies for low income housing projects were proposed for them to be considered sustainable practices, taking into consideration the different stakeholders, construction companies and Housing Finance Bank.

Keywords: *Sustainability, cost analysis, low income housing projects, environmental certification.*

Introduction
Sustainable development is based on the recognition that the environment plays an important role in supplying the material and environmental grounds, the ecosystem and the energy from which the economical processes rely on (United Nations 2010).

According to Silva (2003), sustainability is the search for the balance between what is socially desirable, economically viable and environmentally sustainable, usually described as the "triple bottom line", which composes the environmental, social and economical dimensions of sustainable development.

Over the last few years, the green building movement has gained tremendous momentum (Kats 2003). Real estate contributes to the environment through resource depletion, energy consumption, air pollution, and creation of wastes that are not easily assimilated by the environment (Addae-Dapaah, Hiang and Shi 2009). Real estate is among the many industries increasingly pursuing green technologies; since it affects both the environment (natural and built) and the occupants it houses (Dermisi 2009). In Brazil, such advances do not reach satisfactory levels because the production in the construction industry is still behind in many aspects, due to the fact that deadlines and cost are prioritized over other issues such as sustainability. Additionally, the lack of interest on the part of the supply chain in the Brazilian construction industry is a challenge.

The Brazilian housing deficit has always been a major obstacle to national development and a challenge to the governments that took interest in it. In a scenario in which the housing deficit is concentrated mainly in the low-income population and housing credit is easier to attain by the higher classes, in 2009 the *Minha Casa Minha Vida* Project was launched by the Federal Government and financed by the *Caixa Economica Federal* Bank.

However, the triple bottom line of the sustainability concept is often neglected when it comes to low-income houses. Not only because of its lower profit, especially when compared to the medium and high standard buildings, but also because sustainable projects have the reputation of being more expensive in a harmful way.

Therefore, there is a perception in the real-estate industry that building green is significantly more expensive than traditional methods of development, many sustainable building applications are prematurely labelled as "unproven" or "too costly", but a minimal upfront investment of about two percent of construction costs typically yields life cycle savings of over ten times the initial investment (Kats 2003).

Thus, the first question often asked about sustainable design is: does 'green' cost more? This raises the question: more than what? More than comparable buildings, more than available funds, or more than the building would have cost without the sustainable design features? The answers to these questions have been thus far elusive, because of the lack of hard data (Matthiessen and Morris 2004).

Based on the arguments mentioned above, it was noted that there are few studies that link the adoption of sustainable practices to low income houses, as well as the costs entailed. Furthermore there is a gap in the quantitative and qualitative analysis on the introduction of such changes into the low-income houses context.

The aim of this paper is to evaluate low-income housing projects in Brazil, based on the requirements of “Blue House Seal” (*Selo Casa Azul*), an environmental certification, identifying potentially sustainable solutions to meet those requirements at different levels of *Selo Casa Azul*, as well as to quantify the additional cost needed to achieve such levels. This certification was chosen because it has been developed for the Brazilian housing context, taking into account the economic viability of the solutions.

Environmental Rating Systems

The impacts caused by the construction industry and the increasing awareness about sustainability brought about the need to evaluate environmental performance in order to control and mitigate such impacts. The urgency emanating from this awareness has given rise to various schemes/programs to drive the green advocacy, such as worldwide rating systems (Addae-Dapaah and Chieh 2011).

These rating systems are meant to encourage environmentally and socially responsible building practices by awarding ‘‘badges’’ for buildings’ different degrees of ‘‘green’’ as well as differentiating green from non-green buildings, thus helping to promote a constructed environment that balances economic and social forces (Addae-Dapaah and Chieh 2011). Sustainability rating tools can potentially play a major role in distinguishing the level of sustainability in a building, which will facilitate a direct comparison between each building (Choi 2009).

An analysis made within a population of certified buildings confirmed that attributes associated with greater thermal efficiency and sustainability contributes to increases in rents and asset values in green buildings (Eichholtz, Kok and Quigley 2010). A recent analysis of the thermal properties of a small sample of LEED-certified buildings concluded that these buildings do consume less energy, on average, than their conventional counterparts (Eichholtz, Kok and Quigley 2010).

Among the different methodologies, it is worth noting the following ones: BREEAM (Building Research Establishment's Environmental Assessment Method), created in England in 1990 by researchers of the BRE (Building Research Establishment); LEED (Leadership in Energy and Environmental Design), created in the U.S.A. in 1996 by the USGBC (U.S. Green Building Council); AQUA (*Alta Qualidade Ambiental* - which means "High Environmental Quality" in English) created in Brazil by the Vanzolini foundation in 2007, inspired by the French method (HQE); and the *Selo Casa Azul* created in Brazil in 2009, was developed by Caixa Economica Federal Bank, since its main activity is associated with residential construction.

According to Agopyan and John (2011), even while adapted to the local reality, international certifications do not reflect a country's agenda sufficiently well and therefore their effectiveness is reduced. They may become arbitrary and meaningless in another environment. The certifications that are not part of a wider public police, such as BREEAM is in England, are doomed to act only on sophisticated commercial buildings. In Brazil, except for the *Selo Casa Azul* environmental certification, the practice has been restricted to high-level corporative buildings (Agopyan and John 2011).

Selo Casa Azul **Environmental Certification**

Selo Casa Azul CAIXA was developed through an extensive consultation procedure with experts, as well as researching national and international standards of sustainable construction. The *Selo Casa Azul* environmental system is suitable for low-income houses due to the fact that its criteria are practical to apply and there is a low cost to obtain the certification, both compared to other methodologies (John and Prado 2010).

With this certification, CAIXA intends to encourage the rational use of natural resources in housing construction, reducing the maintenance cost of buildings and the expenses of the tenants, as well as to promote the awareness of both entrepreneurs and tenants about the advantages of green building. In the context of low-income houses, in which the work is on a large scale, even simple changes generate considerable environmental benefits.

The evaluation process consists of a total of 53 criteria, among 6 categories, classifying the building in 3 levels according to the fulfillment of such criteria: Bronze label must meet 19 mandatory criteria; Silver label stands for 19 mandatory requirements plus 6 of free choice, and Gold for 19 mandatory plus 12 of free choice (31 requirements in total). This certification extends to six categories: urban quality, design and comfort, conservation of material resources, energy efficiency, water management and social practices, which are further detailed and presented on Table 1 (John and Prado 2010).

Table 1: Selo Casa Azul categories and criteria

Urban Quality	Quality of the Environment - Infrastructure (mandatory) Quality of the Environment - Impacts (mandatory) Improvements on the Environment Degraded Areas Recovery Real Estate Rehabilitation
Design and Comfort	Landscaping Project Flexibility Relation with the Neighborhood Alternative Transportation Solution Location for Selective Waste Collection Social, Sports and Leisure Equipment (mandatory) Thermal Performance - Sealing (mandatory) Thermal Performance - Sun and Wind Orientation (mandatory) Natural Lightning of Common Areas Natural Ventilation and Illumination of Bathrooms Adaptation to the Physical Conditions of the Land
Energy Efficiency	Low Consumption Lamps - Private Areas (mandatory) Saving Devices - Common Areas (mandatory) Solar Heating System Gas Heating System Individual Measurement - Gas (mandatory) Efficient Elevators Efficient Appliances Alternative Energy Sources
Conservation of Material Resources	Modular Co-ordination Quality of Materials and Components (mandatory) Industrialized or Pre-Fabricated Components Reusable Molds and Cement Waste (mandatory) Management of Construction and Demolition Waste (mandatory) Optimized Concrete Dosage Blast Furnace Cement (CPIII) and Pozzolan (CPIV) Pavement with Construction and Demolition Waste Easy Mobility and Maintenance of the Facade Planted or Certified Wood
Water Management	Individual Measurement - Water (mandatory) Saving Devices - Discharge System (mandatory) Saving Devices - Aerators Saving Devices - Flow Regulator Registry Rain Water Reuse Rain Water Retention Rain Water Infiltration Permeable Areas (mandatory)
Social Practices	Waste Management Education (mandatory) Environmental Education for the Employees (mandatory) Personal Development of the Employees Professional Development of the Employees Inclusion of Local Workers Inclusion of the Community in the Project Development Tenant Orientation (mandatory) Environmental Education for the Tenants Training for the Management of the Building Actions to Mitigate Social Risks Actions to Generate Jobs and Income

Urban Quality: evaluates if the project's location has an appropriate infrastructure that provides quality, well-being, safety and health to its inhabitants. Additionally, it is concerned about the relation between the building and its neighborhood, considering the impacts created by both.

Design and Comfort: deals with the aspects related to the planning and conception of the project, considering the design of the building in terms of the climate conditions, physical and geographic local features, as well as predicting the building spaces designated to specific purposes.

Energy Efficiency: aims to reduce the consumption and optimize the energy used by the inhabitants, by using more efficient equipment, alternative energy sources, saving devices and individualized measuring, which leads to a reduction in the tenant's monthly expenses.

Conservation of Material Resources: aims to reduce the material loss and waste generation, as well as avoiding the use of low quality materials, therefore improving their performance and reducing the waste of financial and natural resources.

Water Management: aims to improve the management and reduce the water use in each housing unit and in the whole building.

Social Practices: aims to promote social sustainability of the building by embracing the different stakeholders involved in the building's conception, construction and occupation, thus expanding environmental awareness as well as contributing to mitigate some social inequalities.

Research Method

The main research strategy used in this research was `case study` in order to evaluate low-income housing projects and their sustainable-concerned practices established by *Selo Casa Azul* environmental certification, aiming to propose sustainable improvements in these projects as well as to measure additional costs to adopt such improvements.

The first stage of this research was a literature review in order to gain a full understanding of the concept of sustainability, the link with the construction industry and the *Selo Casa Azul* environmental certification.

The cases studies were developed in two projects participating in the “Minha Casa Minha Vida” Project, located in the metropolitan area of Salvador- Bahia-Brazil, labeled in this paper as Project A and Project B. These projects were chosen since they are both part of the "Minha Casa Minha Vida" project, and also they use the two main constructive technologies (structural masonry and concrete walls) for this kind of project. Besides, the two companies studied have been developed most of the low income houses projects in Salvador.

Project A is in the 0 to 3 minimum wage tenants’ category of the **“**Minha Casa Minha Vida” Project. It contains 2,400 housing units distributed among 120 buildings, each one containing five floors. Each housing unit has 2 bedrooms, a living room, a kitchen, a bathroom, and an internal space of about 42m². The constructive technology adopted was one of concrete walls, which is the second most common one in this project.

Project B is in the 3 to 10 minimum wage tenants’ category of the project. It contains 440 housing units distributed among 9 buildings, each one containing five floors. It has two types of units, one containing 2 bedrooms, a living room, a kitchen and a bathroom and the other one containing 1 bedroom, a living room, a kitchen and a bathroom. The internal space varies from approximately 35 to 48m². The construction technology adopted was the most frequently adopted one in Brazilian Projects, which is structural masonry with concrete blocks.

Initially, Project A and B were evaluated based on *Selo Casa Azul* certification's criteria. Neither project was developed aiming to achieve any environmental certification, they were both evaluated for the criteria that were already considered on their initial planning regardless of certifications. The main sources of evidence were site visits followed by photos, along with document analysis such as budgets and architecture projects. Interviews with project managers were also conducted.

As mentioned above, *Selo Casa Azul* establishes 19 mandatory criteria and the other ones must be selected by the constructor, choosing those that best adapt to the building's reality, taking into consideration their environmental, social and economical relevance. In this paper the Bronze level contains all mandatory criteria, as earlier presented on Table 1. The Silver and Gold levels criteria taken into account in this work are described below:

a) Silver (Mandatory + 6 criteria): Efficient Appliances; Optimized Concrete Dosage; Personal Development of the Employees; Training for the Management of the Building; Inclusion of Local Workers; Environmental Education for the Tenants; and
b) Gold (Mandatory + 6 criteria): Alternative Transportation Solution; Natural Lightning of Common Areas; Natural Ventilation and Bathroom Illumination; Solar Heating System; Saving Devices - Aerators; Saving Devices - Flow Regulator Registry.

From the information collected, each criterion was classified as FULFILLED or NOT FULFILLED.

The second phase of the case study was the proposal of sustainable improvements in order to fulfill the remaining criteria so the buildings could attain the Bronze, Silver and Gold levels of *Selo Casa Azul*. Aiming to increase the knowledge to propose such solutions, two Minha Casa Minha Vida coordinators of the Project from *CAIXA Econômica Federal* Bank (2013) were interviewed, in addition to an architect specializing in environmental certification and a PhD. professor experienced in sustainable projects.

In this phase, improvement solutions were proposed which considered minimal changes on the project's reality, preserving its main features and with the lowest costs. Then, the economic analysis of each solution was analyzed. This analysis was based on each building's complete budget and the cost of each proposed solution. At the end, an additional cost in relation to the total project budget was calculated in order to achieve the levels Bronze, Silver and Gold of *Selo Casa Azul*.

In the last phase of the study, actions were proposed with regards to each stakeholder in the *Minha Casa Minha Vida* Project: constructors, *CAIXA Econômica* and the future tenants of the buildings.

Results

This section presents the evaluation of the Projects A and B in terms of the fulfillment of the *Selo Casa Azul*'s criteria by level of certification: Bronze, Silver and Gold, presenting the sustainable solutions to fulfill the criteria, and estimating the additional cost to adopt such solutions.

The total increase in each project's budget was calculated based on the price of each solution applied to as many apartments as the project had, divided by the whole cost of the buildings' condominium. Therefore, with the variation of the solution's cost in each city, the number of housing units, apartments and the initial cost of each building, the percentage may vary.

Bronze Level of Certification Analysis

Concerning the mandatory criteria of *Selo Casa Azul*, Project A fulfilled 9 of the 19 criteria (47%) and Project B fulfilled 10 of the 19 criteria (53%), according to the indicators established and detailed in Table 2. The criteria classified as not fulfilled in both studies was within the Design and Comfort category, especially in thermal performance. In Social Practices, simple criteria such as Waste Management Education and Environmental Education for the Employees unfortunately were not met.

Improvements solutions were proposed which aimed to fulfill unfulfilled criteria, followed by an analysis of each solution's cost to measure their implementation impact on the budget, as shown in Table 3. It is important to emphasize that through the analyses undertaken, an increase under 1.5% in the whole budget of each project to accomplish the Bronze level of the *Selo Casa Azul* certification is estimated. Below, comments regarding the solutions are presented.

<u>Landscaping:</u> according to John and Prado (2010), the use of solutions that focus on the cooling or heating of the buildings and are passive to the architecture may reduce the expenses in energy consumption and favor the economic sustainability of the building. In the case study, the costs referring to the implementation of landscaping were not considered, as such changes must be considered in the conception of the architectural project, period in which the changes can be made more easily with less expense.

<u>Thermal Performance - Sealing:</u> an estimated cost for the necessary increase of the window frames' areas to achieve the 15% of area related to the wall area was made, according to that established by *Selo Casa Azul*. The corresponding reduction in conventional masonry and the difference between both costs were also budgeted.

<u>Thermal Performance - Sun and Wind Orientation:</u> in an architectural project, wind direction, insulation, temperature, humidity and further natural features of the building's site must be considered as a way to provide better comfort to the inhabitants, lower energy consumption expenses in cooling and/or heating of the building (John and Prado 2010). In a similar vein to the Landscaping criterion, such changes must be elaborated at the conception of the architectural project so that the benefits can be taken advantage of without extra costs.

<u>Low Consumption Lamps - Private Areas:</u> the variation cost between fluorescent lamps and the incandescent lamps delivered in the buildings was estimated.

<u>Saving Devices - Common Areas:</u> the cost for the installation of presence sensors in the common areas was estimated.

<u>Individual Measurement - Gas:</u> the cost only for the installation of the measuring devices was estimated since both studies already had installed the mandatory pipeline for each housing unit.

Table 2: Fulfillment of the Bronze Level Criteria

CRITERIA	INDICATOR	FULFILLED?	
		A	B
Quality of the Environment - Infrastructure	To provide life quality to the tenants considering an infrastructure including: services, equipment for the community and commerce available in the building's environment.	YES	YES
Quality of the Environment - Impacts	Absence of factors in the building's surroundings that may be harmful for the tenant's health, well-being or security.	YES	YES
Landscaping	Existence of forest, vegetation and/or other landscaping elements that can provide an increase in the building's thermal performance.	NO	NO
Location for Selective Waste Collection	Existence of an appropriate place for the collection, sorting and storage of the recyclable waste	YES	YES
Social, Sportive and Leisure Equipment	Existence of equipment such as: sports court, game room, party room and children's play park, among others, according to the number of units.	YES	YES
Thermal Performance - Sealing	Fulfillment of general architectural conditions according to the bioclimatic zone where the project is located.	NO	NO
Thermal Performance - Sun and Wind Orientation	Fulfillment of general architectural conditions, according to the project's strategy, according to the bioclimatic zone where the project is located.	NO	NO
Low Consumption Lamps - Private Areas	Existence of energy-saving lamps with adequate power in every room of the Housing unit.	NO	YES
Saving Devices - Common Areas	Existence of presence sensors, timers or efficient lamps in the common areas of the condominiums.	NO	YES
Individual Measurement - Gas	Existence of individual measuring devices certified by INMETRO in all housing units	YES	NO
Quality of Materials and Components	Proof of the use of only products manufactured by companies classified as "qualified" by the Ministry of Cities - Brazilian Program of Quality and Productivity at Habitat (PBQP-H).	NO	YES
Reusable Molds and Cement Waste	Reduce the use of wood in low-durability applications, which constitutes waste, and encourage the use of reusable materials.	YES	YES
Management of Construction and Demolition Waste	Existence of a "Construction Waste Management Project - PGRCC" for the shell-work.	YES	YES
Individual Measurement - Water	Existence of an individual water measurement system.	YES	NO
Saving Devices - Discharge System	Existence of toilets provided with dual flux (3/6L) discharge system in every bathroom (3/6 L) system.	NO	NO
Permeable Areas	Existence of permeable areas at least 10% above that required by local legislation.	NO	NO
Waste Management Education	Existence of Educational Plan on Management of RCD.	NO	NO

Environmental Education for the Employees	Existence of an educational activities plan for the employees regarding the sustainability items present on the enterprise.	NO	NO
Tenant Orientation	Existence of at least one informative activity regarding the sustainability aspects foreseen in the project, including the distribution of the Owner's Manual (illustrated, didactic and with sustainability concepts).	YES	YES

Quality of Materials and Components: according to John and Prado (2010), low quality products are most likely to be repaired and replaced, which implies an increase in their environmental impact by the excessive production of replacement material and the premature generation of waste. In the planning phase of the project appropriate materials without a relevant increase on the cost estimation must be included.

Individual Measurement - Water: the cost for the installation of the water measuring device in all housing units of both case studies was estimated.

Table 3: Solutions and Estimated Cost Variation: Bronze Category

CRITERION	SOLUTION	ESTIMATED COST DEVIATION	
		A	B
Landscaping	*Qualitative Analysis*	-	-
Thermal Performance - Sealing	Replace miters to adapt to the minimum size	0.38%	0.09%
Thermal Performance - Sun and Wind Orientation	*Qualitative Analysis*	-	-
Low Consumption Lamps - Private Areas	Install low consumption lamps	0.14%	Fulfilled
Saving Devices - Common Areas	Install presence sensors	0.05%	Fulfilled
Individual Measurement - Gas	Install measuring device	Fulfilled	0.35%
Quality of Materials and Components	*Qualitative Analysis*	-	-
Individual Measurement - Water	Install measuring device	Fulfilled	0.64%
Saving Devices - Discharge System	Install dual flux discharge system	0.72%	0.27%
Permeable Areas	Replace asphalt paved parking lot areas with interlocked pavement	0.04%	0.06%
Waste Management Education	Material + Planning made by the company	-	-
Environmental Education for the Employees	Material + Lecture	-	-
Additional Cost to Achieve Bronze Level		**1.33%**	**1.41%**

Saving Devices - Discharge System: in order to calculate the whole cost estimation variation caused by the replacement of common toilets with dual flux 3/6L toilets, the variation cost between both was estimated, applied to all housing units.

Permeable Areas: in order to achieve the area predicted in the indicator, the parking lot paved areas of both studies were replaced by interlocked pavement and, later, the variation cost between both types of pavement's square meters was calculated.

Waste Management Education: the estimated cost for this type of solution was considered disposable compared to the total cost of the buildings since it takes only planning to include its content in the tenants counseling which the companies already provide, without including further costs.

Environmental Education for the Employees: the estimated cost referring to this solution is also disposable compared to the total estimated cost of the building since only lectures are needed for its implementation, which can be ministered by the company itself.

Silver Level of Certification Analysis

Silver level evaluation is shown in Table 4. Project A fulfilled 3 of 6 silver additional criteria which achieved 12 out of 25 criteria, attaining 48% of fulfillment. Project B fulfilled 2 of 6 silver additional criteria which achieved 12 out of 25 criteria, also attaining 48%.

The analysis showed once again that simple social practices criteria were not accomplished, as seen in the Environmental Education for the Tenants and Inclusion of Local Workers criteria, even though both companies have a Personal Development Program for Employees. The use of optimized dosed concrete, which is a great advantage for the construction companies, was accomplished by both studies; meanwhile neither accomplished the simple replacement of the appliances for more efficient ones with the PROCEL stamp.

Table 4: Fulfilment of the Silver Level Criteria

CRITERION	INDICATOR	FULFILLED?	
		A	B
Efficient Appliances	Existence of appliances with Procel or Ence Level A stamp, delivered in common use areas.	NO	NO
Optimized Concrete Dosage	Descriptive memorandum specifying the use of concrete produced with moisture control and mass dosage.	YES	YES
Personal Development of the Employees	Existence of a personal development plan for the employees covering initiatives related to: foreign language, literacy, etc.	YES	YES
Training for the Management of the Building	Existence of residents training to manage the buildings with minimum workload of 12 hours and target population coverage of 30%.	YES	NO
Inclusion of Local Workers	Existence of a document that explains the number of vacancies to hire local workers or future residents, considering a minimum of 20% of the employees.	NO	NO
Environmental Education for the Tenants	Existence of an environmental education plan for the residents which includes guidelines on rational use of natural and energy resources, selective waste collection, among others, with minimum duration of 4 hours and coverage of 80% of the residents.	NO	NO

There is no additional cost to adopt solutions to achieve Silver level, besides the additional cost of mandatory criteria, according to Table 5.

To replace the low efficiency appliances that are usually delivered in the enterprise for *Selo* A PROCEL appliances does not necessarily imply a significant estimated cost deviation, although it does increase their green performance and reduce energy consumption.

Similarly to other criteria in the social practices category, Training for the Management of the Building and Environmental Education for the Tenants are simple to accomplish, since it only takes lectures, something which does not imply significant extra costs.

The most important contribution of the Inclusion of Local Workers criterion is the involvement of the local community, which improves the relationship between it and the construction company and promotes local economic development.

Table 5: Solutions and estimated cost deviation: Silver Category

CRITERION	SOLUTIONS	ESTIMATED COST DEVIATION	
		A	B
Efficient Appliances	Replace regular appliances with *Procel A* stamped ones	0.00%	0.00%
Training for the Management of the Building	Material + lecture	Fulfilled	-
Inclusion of Local Workers	Include in the hiring	0.00%	0.00%
Environmental Education for the Tenants	Material + lecture	-	-
Additional Costs to Achieve Silver Level is the same as Bronze Level		**1.33%**	**1.41%**

Gold Level of Certification Analysis

The Gold Level evaluation is shown in Table 6. Both studies fulfilled 2 of the 6 gold additional criteria achieving 14 out of 31 criteria, which means 45%. The budget variation to accomplish the Gold Level is shown in Table 7. It demanded an increase of 7.23% in Project A and of 3.64% in Project B. The installation of bike racks, a Solar Heating System, Aerators and Flow Regulator Registries increases the building's cost and therefore these changes are not usually considered, especially in low-income houses, even though those solutions imply great green benefits.

Alternative Transportation Solution: bikes are healthier and cheaper than any other kind of transportation, and installing bike racks increases the use of bikes (John and Prado 2010). To accomplish this criterion, the installation of bike racks containing sufficient spaces for bicycles for 50% of the average population (4 people per HU) was estimated.

Solar Heating System: the cost for the installation of this system, according to the specifications of the criterion was estimated.

Table 6: Fulfilment of the Gold Category Criteria

CRITERIA	INDICATOR	FULFILL?	
		A	B
Alternative Transportation Solution	Existence of bike racks, bike lanes or an internal transportation system in the condominium	NO	NO
Natural Lightning of Common Areas	Existence of openings in the building facing the outside with an area of at least 12.5% of the floor area of the room.	YES	YES
Natural Ventilation and Illumination of Bathrooms	Existence of windows facing the outside of the building with an area of at least 12.5% of the area of room.	YES	YES
Solar Heating System	Existence of solar water heating system with collectors *ENCE/PROCEL* level A or B stamp, auxiliary heating tank equipped with electrical resistance, thermostat and timer.	NO	NO
Saving Devices - Aerators	Existence of taps with aerators in bathrooms and kitchens sinks.	NO	NO
Saving Devices - Flow Regulator Registry	Existence of flow regulatory registries in showers, lavatories, taps and sinks.	NO	NO

Table 7: Solutions and additional cost: Gold Level

CRITERIA	SOLUTIONS	ESTIMATED COST DEVIATION	
		A	B
Alternative Transportation Solution	Install bike racks	0.48%	0.18%
Solar Heating System	Install solar water heating system	5.31%	2.01%
Saving Devices – Aerators	Install aerators in all taps	0.02%	0.01%
Saving Devices – Flow Regulator Registry	Install flow regulatory registries	0.09%	0.03%
BUILDING'S BUDGET VARIATION		**7.23%**	**3.64%**

Saving Devices - Aerators: Aerators contribute to save 60% of the water consumed and reduce the water that needs to be treated (John and Prado 2010). The cost for installation of aerators in bathroom's and kitchen's taps to accomplish this criterion in Project B was estimated, and only in bathroom taps in Project A, since aerators were already in the kitchen taps.

Saving Devices - Flow Regulator Registry: Flow Regulator Registries contribute to save water in much the same way as aerators. For this criterion, the cost for installation of flow regulator registries was estimated only in the showers since they were the only water exit that did not have any measurement to reduce water consumption.

Discussion

The financing and purchase of the enterprises in the “Minha Casa Minha Vida” Project process involved many stakeholders. In the current reality, hardly any of them would be able to afford the increased cost of the proposed project. Thus, a set of actions that enables the incorporation of these costs in all parts is proposed.

For *CAIXA Econômica Federal*, while funding borrowers, there would be no loss of money. For the enterprises of 0-3 minimum wages, there is a maximum amount estimated that *CAIXA* provides to developers in which they must fit the enterprise. If the margin that builders use is not sufficient to encompass the 7.23%, necessary for the Gold certification, it is proposed that, as a form of encouragement, *CAIXA* should allow a higher amount for projects certified by *Selo Casa Azul CAIXA*, with the features of *Fundo Socioambiental CAIXA (FSA CAIXA).* The *FSA CAIXA* seeks financial support for projects and investments of a social and environmental character, consolidating and expanding the role of *CAIXA* in encouraging sustainable development, consisting of matching funds of up to 2% of the company's profit (*Caixa Econômica Federal* 2013). In enterprises of 3-10 minimum wages, the funding of *CAIXA* goes directly to the final borrower. To encourage the purchase of certified enterprises, *CAIXA* might increase subsidies provided to final users.
For the constructors, the inclusion of sustainable features in planning and architectural design would be required. Economically, an additional cost would not impact the projects of 0-3 minimum wages nor the minimum wages of 3-10. It is in the interest of builders to obtain an advantage such as an environmental certification, since the profit margins are not high and the market is competitive.

The additional cost to achieve the levels Bronze, Silver and Gold in the projects of 3-10 minimum wages, as was the case in Project B, would be fully transferred on to the final user. The benefits arising from the solutions presented for each criterion for the environment, and for the society are numerous; however, the main stakeholder that gains most is the final user. Higher quality of life and thermal and acoustic comfort are some of these benefits, but the starkest of them is reflected in the monthly savings generated.

The five main expenditures of the residents, in general, are: light, water, condo fee, payment of the acquired property and taxes**.** The final user would be able to afford this increase because, according to the analysis, the rise of 3.64% in the Gold category may have, in contrast, a 52% reduction of the electricity bill and 81% of the water bill. These initial estimates were based on the family consumption of 4 residents by habitation unit and in accordance with the energy consumption benchmark for household equipment by PROCEL and hydraulic equipment by a water supplier company. Furthermore, simulations were made based on data from the equipment manufacturers regarding the consumption reduction.

In addition to the analyzed reductions, in some cities in Brazil, such as São Carlos (SP) and Curitiba (PR), the "Green property tax" is already in place, which grants discounts proportional to the adopted measures in the residences with sustainable features, which may generate more savings for consumers who adhere to these solutions.

In order to a building to be certified, it must accomplish a number of criteria that ensures that its sustainable aspects and its performance are better than non-certified ones, and so this building stands out from others. To certify a building is to guaranty that this building is different and better in a specific number of ways, accomplishing sustainable features that others do not.

Conclusion

Integrating “sustainable” or “green” practices into building construction is a solid financial investment. In the most comprehensive analysis of the financial costs and benefits of green building conducted to date, this report finds that a minimal upfront investment of about 2% of construction costs typically yields life cycle savings of over ten times the initial investment (Kats 2003). In the present study, Project A’s findings show the following additional costs: 1.33% to accomplish the Bronze or the Silver Level and 7.23% for the Gold Level. Similarly, for Project B: 1.41% to accomplish the Bronze or the Silver Level and 3.64% for the Gold Level.

Thus, from the results presented, it can be observed that, despite the existing stereotype, it is indeed economically feasible to adhere to more sustainable solutions. Unfortunately, it is still more expensive to invest in sustainability, especially for low-income houses. However, with greater incentive for all the parties involved in the process (government, donor agency, builders and society), the generated savings will certainly pay off in all the three aspects of sustainability: social, environmental and economic.

The study presented had limitations, due to the fact that only two projects were evaluated, despite the similarities of these projects related to the majority of Minha Casa Minha Vida’s Projects in Brazil. In order to have better results, it would be appropriate to study a larger number of cases, as well as monitoring the property life cycle, and more accurately measuring the savings generated by the implemented solutions. Further research would be important to be applied to a larger number of case studies to measure effectively all the steps contained in this study, such as: the actual savings of all the sustainable solutions suggested and their cost reduction, the adhesion of all stakeholders involved, and an analysis of and solution to other problems that may arise and were not predicted in this study, in order that it can be as complete in practice as it is in theory.

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SUSTAINABLE REFURBISHMENT SOLUTIONS FOR HIGH-RISE RESIDENTIAL BUILDINGS IN SUBTROPICAL AREAS

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Abstract

Building maintenance and refurbishment has become a particular concern in developed economies, as there are many old buildings in urban areas. While various refurbishment methods have been developed for the purpose of sustainable development, these refurbishment approaches are designed for specific climatic condition and building characteristic. Until now, there is not much suggestion on which sustainable refurbishment methods are more suitable for subtropical areas like Hong Kong. This paper aims to bridge this gap by developing a set of sustainable refurbishment methods applicable to high-rise residential buildings in Hong Kong. The research begins by a comprehensive literature review of the existing sustainable refurbishment methods. The results of literature review form the basis of a preliminary screening according to the local climate and buildings feature. Interviews with experienced industry experts are conducted in order to confirm the applicability of the proposed methods. Through the above studies, a list of sustainable refurbishment methods for subtropical regions as well as a set of principles for selecting refurbishment methods are identified. The results of this study should help owners and design team members identify sustainable refurbishment to maximise the chance of success.

Keywords: *Sustainable refurbishment, residential buildings, subtropical areas.*

Introduction

The building sector in Hong Kong consumes a significant amount of electricity (Environmental Protection Department 2010) and is therefore one of the key contributors to greenhouse gas (GHG) emissions (Environmental Protection Department 2010). According to HKGBC (Hong Kong Green Building Council 2012a), the existence of a huge stock of inefficient existing buildings may compound the energy demand of a city, and any improvement to uplift the energy efficiency of existing buildings would be indispensable. However, it is never easy for owners and occupants to identify a set of suitable sustainable refurbishment solutions for their property as there are so many different options available and their effectiveness may vary substantially.

Until now, much research effort has been directed to improve the energy performance of offices and commercial buildings. Examples of these include the improvement in thermal insulation (Bojic, Yik and Leung 2002), introduction of switchable glazing (Yik and Bojic 2006) and other glazing systems (Bojic, Yik and Sat 2002), combination of space cooling and water heating system (Chen and Lee 2010), application of water cooled air-conditioner (Chen, Lee and Yik 2008), etc. Identifying suitable strategies to lower the energy consumption of residential buildings remains relatively sparse (e.g. Gao, Lee and Chen 2009) and this is especially the case in Hong Kong despite a large proportion of private and public apartments in the city.

Being a densely populated city, virtually all residential buildings in Hong Kong are of multi-storey multi-occupant form. With the diverse property rights, refurbishments are usually carried out in an *ad-hoc* manner unless a major overhaul is commissioned, for example, under the Mandatory Building Inspection Scheme as required by the local law. Therefore, relevant sustainable strategies shall be adopted to commensurate different scales of refurbishment.

Despite much experience has been accumulated in overseas countries, the distinctive climatic condition and building characteristics render them unsuitable for being applied in the Hong Kong scenario (Lam 2000). There is a need to identify a set of sustainable refurbishment strategies which can be applied to the multi-storey residential buildings in Hong Kong. The aim of this paper is to develop a list of feasible options to help owners and occupants of residential buildings in Hong Kong selecting the most appropriate sustainable refurbishment solutions.

The paper begins by outlining the methods used in this research. A list of sustainable refurbishment methods as identified from the literature is reported. The applicability of the identified sustainable refurbishment methods to the Hong Kong scenario is then examined. Finally, the suitable sustainable refurbishment solutions for multi-storey residential building in Hong Kong are highlighted.

Research Methods

With extensive existing body of knowledge in sustainable refurbishment around the world, a literature review should be carried out to identify all the possible sustainable refurbishment solutions. The literature review was not restricted to research papers and relevant reports, but it also covered information in the website. With a comprehensive list of sustainable refurbishment options, the authors can then narrow them down by eliminating those which are not corresponding to the climatic condition and building characteristics of Hong Kong.

As sustainable refurbishment is a rather new concept to the residential sector of Hong Kong, the opinions from construction professional would be extremely useful. Therefore, a series of semi-structured interviews was carried out with experienced industry experts to first confirm the applicability of the identified sustainable refurbishment options and then unveil the determining factor when selecting the sustainable refurbishment strategies.

Table 1 shows the profile of the participants. The samples were randomly chosen from the relevant telephone directories. Seven face to face interviews were conducted with a total of 13 experienced experts agreeing to take part in the interview. All of these 13 experts are holding senior positions in their organisations.

Table 1: Information of the participants

Interview No.	Organisation	Title	Number of participants
1	Government	Chief Manager	2
2	Consultant	Executive Director	1
3	Consultant	Development Director	2
4	Private developer	Project Manager	1
5	Academic	Associate Professor	2
6	Government	Senior Building Services Engineer	2
7	Government & Consultant	Chief Architect, Sustainable Engineer	3

With the consent from the interviewees, the interviews were recorded. The interview transcripts were analysed subsequently. The responses from the interviews concerning the following information were coded, categorized, and summarized: whether and why a method was applicable, and the principles of selecting sustainable refurbishment method.

Sustainable Refurbishment Methods

In the absence of a comprehensive study on sustainable refurbishment solutions for Hong Kong, a literature review was conducted to identify all potential sustainable refurbishment solutions. With increasing attention to the importance of the residential sector, some pilot studies have already been conducted researchers, e.g. EST (Energy Saving Trust 2007), CPA (Construction Product Association 2010), Thrope (2010), Burton (2012) and Hakkinen *et al*. (2012). Sustainable refurbishment measures for the non-residential, however, remain an area of interest to research scientists (e.g. Baker 2009; Gelfand and Duncan 2012). Others such as Clark (1997) and Xing, Hewitt and Griffiths (2011) examined the sustainable refurbishment methods for both the residential and non-residential sectors. This together with the useful findings *viz*. an introduction of sustainable refurbishment (Shah 2012), relevant guidelines (Hong Kong Green Building Council 2010, 2012b) and the tools/frameworks for sustainable decision making (Prupim Developments 2009, Konstantinou and Knaack 2013) provide a solid foundation for the authors to compile a list of sustainable refurbishment methods.

A total of 88 sustainable refurbishment methods were identified, and these methods can be classified into four broad categories namely:

a) building services;
b) building envelope and layout;
c) renewable energy; and
d) user-initiated approaches.

It is worth noting that the sustainable refurbishment methods identified have not been screened for the local relevancy at this stage to prevent some potential solutions being eliminated at this stage unnecessarily.

Preliminary Screening

A preliminary screening was conducted in order to better understand the suitability of the identified sustainable refurbishment methods. To minimize the risk of prejudice in the screening, the identification of criteria should be based on the possibility of applying those methods, instead of the cost, outcome, or any other external influence. At the end, three criteria were identified according to the context of high-rise residential buildings in Hong Kong, namely: pattern of energy consumption, suitability to domestic usage, and relevancy to high-rise building.

Pattern of energy consumption

Energy audits and field surveys conducted by researchers showed that air-conditioning dominate the electricity consumption in subtropical regions as summer season in these areas is hot and humid (Tso and Yau 2003 and Wan and Yik 2004). In contrast, the reliance on space heating is extremely sparse in Hong Kong, and not too many households in the city have installed with appliances for heating up the interior space. It is, therefore, reasonable to eliminate those sustainable refurbishment methods which are related to space heating, such as radiant heating, cogeneration, under floor heating, district or block heating system, mechanical ventilation with heat recovery, heat-recovery chiller system, thermostat for heating or cooling, solar heat intake air, ground source or air source heat pumps, etc. Moreover, as green energy procurement and biomass heating are not common in Hong Kong, these methods were not considered applicable at least in the near future.

Suitability to domestic usage
Compared with commercial buildings, multi-storey residential apartment have several distinctive characteristics. Except for very luxurious or service apartments, residential towers seldom have centralised heating, ventilation and air-conditioning systems making it impossible to introduce those concepts like the displacement systems, upgrade heat rejection of cooling towers, high efficiency air-cool oil-free magnetic chillers, thermal wheels to pre-cool fresh air, under floor air distribution, evaporative cooling, chilled beams or under floors supply, mixed mode ventilation, multiple-level switching, power-factor correction, etc. Other approaches being proposed by researchers including individual switches, operable windows, mechanical extract ventilation, internal roller blinds, desk fan or locally controlled fan, louvers, etc. should have already exist in most of the families. On the other hand, initiatives like appropriate zoning, shallow plans, and smaller sizes of framing elements are difficult to be implemented in an existing multi-storey building. In Hong Kong, most family members would have left home in the day time for work or school leaving those approaches such as light shelves, daylight and task lighting backup and automatic blinds impracticable.

Relevancy to high-rise building
In Hong Kong, over 90% of the population are living in high-rise residential buildings (Lam 2000). With different statutory, design and practical considerations, it is not easy to introduce any new components to the external envelopes of a building, such as green walls, canopy, dynamic insulation, and double skin façade external blinds, etc. Other initiatives such as roof pond, rafter insulation, loft insulation, integrated balconies in the thermal envelope, passive stack ventilation and basement insulation are not relevant to Hong Kong's multi-storey building perspective.

Applying these three criteria to the preliminary screening, a number of initiatives found in the literature are not applicable to the multi-storey residential buildings in Hong Kong. In the end, only 38 sustainable refurbishment methods are considered more relevant for further study.

Applicability
To better understand the suitability of the 38 identified sustainable refurbishment methods, semi-structured interviews were carried out with experienced industry experts. These experts were invited to express their views on the applicability of each proposed method based on the situation of Hong Kong.

Building services
The interviewees confirmed that low energy lamps such as T8 and T5 fluorescent tubes and electronic ballast are becoming increasingly popular in Hong Kong nowadays. Many refurbishment projects have applied these measures to increase the energy efficiency. While LED lighting is another possible solution, its cost is still rather high and it is doubted if the saving in energy bill can offset the initial cost. Besides, LED lighting works better in the indoor environment with a more stable temperature.

Daylight sensors and motion sensors can also be used to cut off the artificial lighting when the luminance is sufficient or when there is no human activity. In Hong Kong, the public buildings with open corridors would provide a greater opportunity for the installation of daylight sensors. Motion sensor is also restricted by the local fire safety codes, which stipulate that all the staircases must have the lights on throughout the night (Fire Service

Department 2012). Although the Hong Kong Housing Authority has developed and used a two-level lighting system with motion sensors in staircases for new buildings, applying this technology to existing buildings is yet to gain popularity. Time switches could enhance the energy efficiency by reducing the daily operational time of building services equipment. For example, some of the lifts for high-rise residential buildings could be switched off after midnight to reduce the energy consumption.

Power regeneration system and variable voltage variable frequency lift drive has almost become a standard design of new lifts. However, it is a major initiative for existing buildings and would only be justified when a major refurbishment scheme is carried out.

Building envelope and layout
Replacing clear windows with low-emissivity glass, tinted glazing, reflective glazing or multiple glazing can reduce the sunlight and heat from outside and thus cut down the thermal load of air-conditioners. However, the disruption caused by window replacement can be very high especially when the property is still occupied. Besides, some residents would prefer a better visual comfort by not having a heavily tinted glazing system. As for inter-pane glazing, the cost is too high to warrant a widespread usage in Hong Kong.

Although insulations play an important role in energy conservation, interviewees opined that it is almost impossible to upgrade the insulation property of the external envelop in residential buildings unless the external wall covering is completely replaced by one with better thermal insulation property. The chance for substantially improving the thermal insulation of the roof system is also quite low. Despite green roof can be installed to some buildings, the roof area is normally sold with the penthouse property. Furthermore, the effectiveness of the green roof depends on how well it is maintained and this can be rather expensive. As for the vertical fins and overhangs, they are effective means to shade off the sunlight provide they satisfy the statutory requirements and would not affect the structural stability.

All in all, refurbishing the building envelope is less effective than enhancing the building services system not only because of the difficulty and cost of installation but also due to the high maintenance cost. These measures are indeed more applicable to large scale of sustainable refurbishment schemes in order to achieve an ambitious goal of energy conservation.

Renewable energy
By installing phase change materials, the envelope could store heat during the daytime and warm the rooms at night. In subtropical regions like Hong Kong, however, residential buildings consume most of the energy at night as a result of space cooling. Using phase change materials would result in a higher thermal load, and thus adversely increase the energy consumption.

Solar water heating and photovoltaic panels should generate a certain proportion of energy provide there is sufficient sunlight in subtropical regions. However, the limited roof area in the high-rise buildings has restricted their capacity. When solar power is used for water heating, a lack of central hot water supply system for multi-storey residential buildings would restrict its application. Even of superfluous power can be generated by the photovoltaic panels, it cannot be fed back to the existing power grid under the existing regulation. As for wind turbine, none of the interviewees considered it feasible due to high investment cost, lack of space in the urban area and the noise generated. Therefore, renewable energy is not the most practical sustainable refurbishment option for Hong Kong.

User-initiated approaches
Apart from refurbishing the common areas, this study has identified six ways to conserve energy inside the units including reducing the storage temperature of electronic water heater, installing low-flow aerated showerheads, reconfiguring air conditioner's temperature, selecting energy efficiency appliances, stopping the draught, and using induction cooker. The interviewees have confirmed their applicability. However, the uptaking of these measures depends on the residents' awareness of sustainability rather than the technical concerns.

According to the above findings, a list of sustainable refurbishment methods applicable to the multi-storey residential buildings in Hong Kong is identified (Tab. 2).

Selection of Sustainable Refurbishment Methods
The interviewees suggested several principles for selecting sustainable refurbishment methods. Firstly, the condition of a building determines the opportunity of sustainable refurbishment as some measures like the installation of vertical fin, overhang, green roof, photovoltaic panel, and so on would depend on the structural soundness. It is absolutely indispensable to conduct a careful analysis of building condition before any drastic sustainable refurbishment initiative is introduced. On the other hand, policy makers should consider relaxing the regulations so that additional sustainable features can be added to the external envelop if the structure is sound enough.

Table 2: Sustainable refurbishment methods for high-rise residential buildings in Hong Kong

Category		Refurbishment methods
Building services	Lighting	Low energy lamps (T5 fluorescent)
		LED lighting
		Daylight sensors
		Motion sensors
		Electronic ballast
	Lifts	Lift with power regeneration system
		Lifts with advanced VVV-F control system
	Others	Time switches
		Replace water pumps with higher efficiency one
Envelopes and layouts	Windows	Simple coating
		Tinted glazing
		Reflective glazing
		Double / multiple glazing
	Roof and walls	Reflective surface (cool roofs or walls)
		Green roof
	Shadings	Vertical fins
		Overhangs
	Layouts	Rearrangement of lighting circuits to fully utilise daylight corridors
Renewable energy		Solar water heating
		Photovoltaic panels
		Wind turbine
User-initiated approaches		Reducing storage temperature of electronic water heater
		Installing low-flow aerated showerhead
		Reconfiguring air conditioner's temperature
		Selecting energy efficiency appliance
		Stopping the draught
		Using induction cooker

Of various considerations, cost-effectiveness is a key factor when selecting sustainable refurbishment methods. As a result, the life cycle cost as well as the payback period of various feasible sustainable refurbishment options should be thoroughly identified. Preference should be given to those methods with short payback period. In addition, the disruption during and after the sustainable refurbishment measures are introduced should not be underestimated. Any potential disturbance should be eliminated by careful planning and implementation.

While building environmental assessment schemes like the Leadership in Energy and Environmental Design (LEED) and the Hong Kong Building Environmental Assessment Method (BEAM-Plus) can stimulate owners and occupants' desire to adopt sustainable refurbishment measures, suitable policies should be introduced to reward those existing properties with outstanding energy performance. Subsidising owners and occupants to refurbish in a sustainable way can expedite the sustainable refurbishment programme in Hong Kong. A residential property with better energy performance may also result in a more attractive resale or rental value.

Conclusion

This research has identified a list of 88 sustainable refurbishment approaches. Of which, 50 have been considered irrelevant to the Hong Kong climatic condition and building characteristics. Another 10 sustainable refurbishment methods have been eliminated after interviewing the industry experts. Finally, 28 sustainable refurbishment methods are considered as appropriate for the high-rise residential buildings in Hong Kong, and these include measures pertinent to building services equipment, building envelop and layout, renewal energy and user-initiated approaches. The selection of suitable sustainable refurbishment solutions, however, depends on the cost. Government's subsidies would help realise some expensive sustainable refurbishment approaches which could lead to substantial reduction in energy consumption in existing buildings in Hong Kong.

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METHOD FOR IDENTIFYING CUSTOMIZATION DEMANDS IN SOCIAL HOUSE-BUILDING

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METHOD FOR IDENTIFYING CUSTOMIZATION DEMANDS IN SOCIAL HOUSE-BUILDING

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Abstract
In Brazil, there is much incentive and high availability of funding for social housing projects nowadays. This encourages product standardization and the application of mass production ideas, based on the assumption that this is the most effective strategy for reducing costs. However, the delivery of highly standardized housing units to customers with different needs, without considering their lifestyle and perception of value, results in inadequate products. Mass customization seems to be a much more effective strategy to improve value generation in social housing projects, and to avoid waste caused by renovations done in dwellings soon after occupancy. However, one of the main challenges to the implementation of mass customization is the definition of a set of relevant options based on users' perceived value. In fact, several companies design their customization units based solely on forecast demand and focusing only on product attributes. The aim of this paper is to define a method for identifying customization demands, based on perceived value, customers' profiles and changes made in housing units by their users. A case study was carried out in two housing projects delivered by a company that had introduced some mass customization ideas in the development of new projects. The method involved submitting questionnaires to final users, direct observation of dwellings after the project delivery, and analysis of some of the company's internal data and documents. In addition, the means-end chain theory was used as theoretical framework to connect means, or product attributes, and costumers' desired ends or values, through the application of a technique named soft laddering. The results were then compared with the alternatives that the house building company offered to potential buyers. The main contribution of this method is to indicate the customization units that are most important for users along with the explanation of why those units are the most relevant ones. In fact, some unexpected causes for the need to customize dwellings emerged in this study, such as the poor quality of some construction elements and the delivery of unfinished products.

Keywords: *Mass customization, social housing, laddering.*

Introduction
The Brazilian real estate market has grown at very high rates, partly due the large amount of investment by the Federal Government in social housing. This context encourages product standardization and large scale production (Castro and Shimbo 2011). Standardized product may lead to dissatisfaction among dwellers due to the diversity of family profiles (Brandão and Heineck 2003, Chaves, Leite and Formoso 2006 and Villa 2009) and variety of lifestyles in the population (Szücs 1998). As a result, many

changes are made in housing units by the dwellers themselves, can be costly and often lead to a reduction on product quality (Szücs 1998 and Chaves, Leite and Formoso 2006).

Mass customisation (MC) is an organizational strategy that seem to be adequate to this context. It aims to provide products that fulfil each customer's specific requirements through flexible process and organizational structures with delivery times and costs similar to those of mass production (Hart 1995, Pine II, 1994; Silveira, Borenstein and Fogliatto 2001 and Jiao and Tseng 2003). One of the key decisions in MC is the level of customization of the product, which is determined by the range of choices relevant to customers and also how and when they will make the selection from those (Silveira, Borenstein and Fogliatto 2001). However, not much has been published on how to determine this level of customization based on customers' requirements and organizational capabilities (Silveira, Borenstein and Fogliatto 2001).

Rocha (2011) defined as customization units the attributes that can be customized in the product and the range of options offered for the final client to choose from. The definition of this set of options involves a series of decisions (Fogliatto and Silveira 2008), and, organisations must identify customization units that can effectively generate value for clients, as well as be able to balance creativity in the offer and efficiency to minimise operational costs (Silveira, Borenstein and Fogliatto 2001 and Schoenwitz, Naim and Potter 2012). That is important in order not to overwhelm customers with too many alternatives, and to enable them to make choices that meet their needs (Hart 1995). However, only a few studies have explored the decisions taken prior to the offer of customization options, or on the choice of which options should be considered in MC (Fogliatto and da Silveira 2008). Those studies are mostly focused on demand forecast and suggestions based on prior preferences of customers, instead of market segmentation (Fogliatto and Silveira 2008) and on understanding customers' perceived value. Moreover, none of those studies deals with housing production. In fact, many house-building companies define the range of customization units without a systematic analysis of customer profile and requirements, making decisions simply on product attributes (Rocha 2011).

Woodruff (1997) suggested that for understanding customers' preferences beyond product attributes Gutmans' (1982) conceptual model should be used, its named means-end chain (MEC) which associates the means, the physical aspects of the products, with the achievement of the desired ends. The application of the MEC results in a tree diagram, called hierarchical value map (HVM), through which decision makers can understand the aims, perceptions and decisions of their customers (Gengler et al. 1995). There are several techniques that can be used for mapping the relationships between the product's attributes, its consequences in use, and desired values, such as association pattern technique (APT), hard laddering (Leppard, Russell and Cox 2004), soft laddering (Reynolds and Gutman 1988, Russell *et al.* 2004 and Leppard, Russell and Cox 2004). In this study, the soft laddering technique was chosen, due to its ability to cope with complex products, providing an overview of customers' perceived value which can be used for generating new ideas.

The aim of this paper is to propose a method for identifying customization demands, based on perceived value, customers' profiles and changes made in housing units by their users. The soft laddering technique has been used to explain why those demands are relevant for final customers and hence support decision making about the customization units to be offered by house-building companies.

Mass customization

A successful implementation of MC in organisations depends on a stronger relation between the organisational capacities and the value for final customers, as well as on a balanced consideration of these factors in decision making (Pine II 1994, Hart 1995, Duray *et al*. 2000 and Jiao and Tseng 2003). Such a balance should also be present when defining the product customization level and, consequently, when limiting the options (Silveira, Borenstein and Fogliatto 2001 and Frutos and Borenstein 2004). The offer of customization units focused on perceived value should enable customers to make their choices among the desired options, instead of among the available options, since overburdening customers with information gives a negative connotation to the decision process (Schoenwitz, Naim and Potter 2012).

Means-End Chain Theory

As mentioned above, the MEC conceptual model focuses on the relationship between where the user would like to be and the means chosen to get there, i.e. a product is a set of attributes that are consumed in order to obtain the desired consequences, in a trade-off with the undesired consequences in order to arrive at a value (Gutman 1982). The soft laddering technique make those relationships explicit by undertaking in-depth interviews, consisting mainly of questions like “why is this important to you?” (Reynolds and Gutman 1988). The application of this technique involves the following stages:

a) interviews;
b) analysis of the content of the ladders, which is a sequence of answers by an interviewee to questions ranging from the attribute to the highest level of abstraction, and the codification of those answers in means-end chains;
c) elaboration of the implication matrix, where the relations between the elements in the means-end chains are analysed;
d) construction of the hierarchical value map (HVM); and
e) interpretation (Reynolds and Gutman 1988).

The results of the MEC applications can be used for market analysis and segmentation, product planning and evaluation, and promotional strategy (Gutman 1982). There are only a few applications of MEC for housing, but there are promising results, and the challenge lies in the complexity of the product, due to the large number of attributes (Zinas and Jusan 2012).

Research method

Design science research was the methodological approach adopted in this study. It is a form of scientific knowledge production that involves the development of innovative constructions, intended to solve problems faced in the real world, and simultaneously makes a kind of prescriptive scientific contribution (Lukka 2003). An important outcome of this type of research is an artefact that solves a domain problem, also known as solution concept, which must be assessed against criteria of value or utility (March and Smith 1995). In this research study the proposed artefact is a method for identifying customization demands in social housing. Moreover, this investigation aims to make a theoretical contribution by adapting constructs of the MEC theory into the context of house-building.

This research project started by understanding the practical problem, the product development process of social housing in Brazil, followed by a literature review on mass customization and MEC theory.

After devising the first version of the method, it was applied in a house-building company, based in the Metropolitan Region of Porto Alegre, South of Brazil. The company suggested two projects for testing the method. For each project, a number of housing units were selected for the interviews, using the simple random sampling technique with finite population correction. A sampling error of 10% and a significance of 90% were considered. Table 2 presents an overview of the sample. The interviews were conducted presentially with 42 families.

Table 1: summary of the sampling process, company L projects

Proj.	Type of housing unit	Gross floor area	Number of housing units	Designed sample	Actual sample	Price	Delivery
DL	1 and 2 bedroom apartments	55.32 to 63.62m²	64	32	32	R$ 96,000	March 2008
DE	2 and 3 bedroom apartments	63.62 to 110.12m²	20	15	10	R$ 130,000 to 230,000	May 2009

Proposition of the method of characterisation the housing units' customization demand

The proposed method for identifying customization demands is divided into three phases. Figure 1 schematically represents the activities carried out in each phase, and the main outcomes.

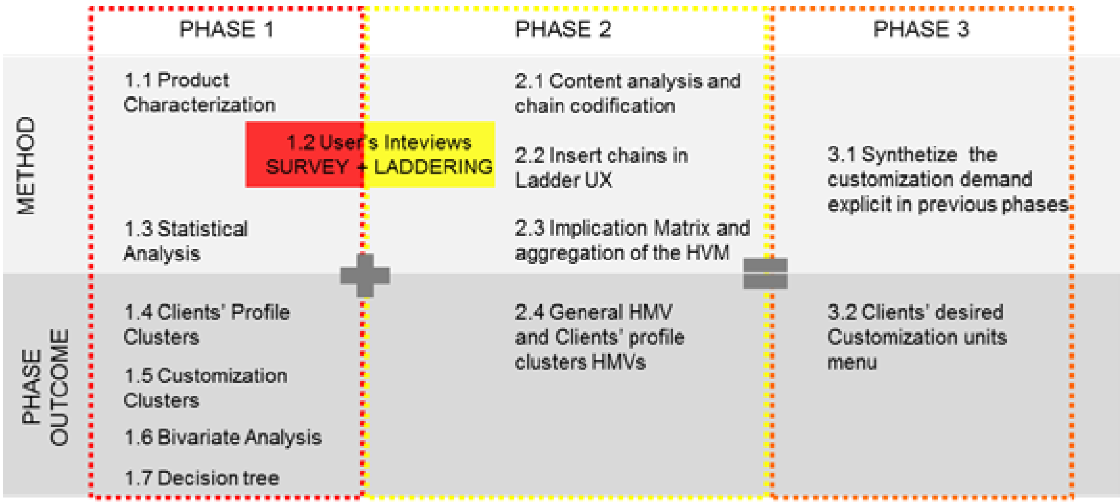


Figure 1: Activities involved in the proposed method and outcomes

Phase 1 corresponds to the identification of the customization demand of each group of customers, with the primary aim of understanding the product and which attributes could be customized (1.1). A semi-structured questionnaire is applied to final users, mostly concerned with the customer profile, the customizations (changes in house units) that have been made or are still desired, their relevance, the degree of satisfaction with product attributes (1.2). In data analysis, some descriptive statistical techniques are initially used, followed by hierarchical cluster techniques, bivariate analysis, and decision trees for associating the groups of customers with customizations (1.3). The hierarchical clusters should be applied according to the nature of the variables: for the profile clusters, the two-step method is applied (1.4), and for the customization clusters, the phi+between method is more adequate (1.5). The main outcome of this phase is a set of customizations that is consistent with each customer profile.

In Phase 2, the reason why each customization unit is important is explained by the relationship between the customizable attributes, their consequences in use and the values and objectives desired by customers. The soft laddering technique is used, which starting with the question: what are the three customizations – carried out or desired – that you and your family consider the most important and why? (1.2). The analysis of the answers to this question should be carried out as prescribed by Reynolds and Gutman (1988). Firstly, an analysis of the content of the answers is made, in order to identify a set of recurring constructs or summary codes that summarise the ladders in attributes, consequences and values, resulting in a list. From that list, the ladders are decomposed and reordered to form the means-end chains, such as in the example presented in Table 2 (2.1).

Table 2: example of ladder and codification in means-end chain

LADDERS	MEANS-END CHAINS
The wall painting didn't give it much life; the white. More about the aesthetics. Much lower quality paint. Feeling good. A place to rest. Like a clean and well looked after room. Well-being	ALL ROOMS | WALL FINISHING | QUALITY OF MATERIALS | HYGIENE | AESTHETICS | RESTING AND ENJOYING ONE'S FREE TIME | WELL-BEING

A software package, such as the ladderUX software, can be used to generate the implication matrix and HVMs (2.2). The HMVs must take into consideration the cut-off point that represents 66% of the relationships, according to Reynolds and Gutman (1988), or when a balance between reduction and retention of information is achieved (Gengler, Klenosky and Mulvey 1995) (2.3). In addition, in order to associate the customer profiles with the relevant customizations, it is necessary to make specific HVMs for each demographic cluster (2.4).

The third phase of the method consists of providing information to decision makers about the most important customization units from the point of view of the customers. In this phase results must be summarised and displayed in a simple way, so that the results can be understood by decision-makers. That will support house-building companies to define a choice menu and hence be able to offer their clients customization units that will increase their satisfaction and generate more value.

Application of the method

The implementation of the method was divided in 4 stages:

a) secondary data collection at the building company;
b) data collection from a sample of housing units;
c) systematisation and analysis of the data; and
d) characterisation of the customization demand based on the customers' perceived value and profile.

Secondary data collection included design drawing, database of customizations made in housing units due to customer requests, and material used to advertise the project.

Each housing estate were visited for applying questionnaires and also for direct observations when researchers were allowed to enter the housing units (1.2).

Two databases were built, one for quantitative data (1.3) and the other for qualitative data (2.3).

In order to assess the relevance of customization units, the laddering interviews (1.2) were analysed. That resulted in a HVM, which was generated with the cut-off point of 4 relationships or 59% of the relationships (Fig. 6). Through an analysis of the HVM it was possible to point out the attributes that were most relevant for users, their consequences in use and the values pursued through customization. In addition, specific HVMs for each cluster of customers were made, to choose customizations according to the target groups of each project.

Finally, the results of the previous phases were summarised in a summary menu (3.2), (Fig. 8), and the customization units were compared with the alternatives offered by the building company at the time of purchase.

Product 1.4: Demographic Clusters
With regards to the socioeconomic profile of the families interviewed, the majority are small families, 90% of them consisting of up to 3 members, and 36% consisting of couples with children (Fig. 2a). There is, however, an evident diversity of configurations, as shown in Figure 2a, confirming the results of the study carried out by Chaves, Leite and Formoso (2006) and Villa (2009) In terms of family income, the large majority of interviewees' income is above 3 minimum wages (m.w.), most of them earning between six and nine minimum wages (Fig. 2b).

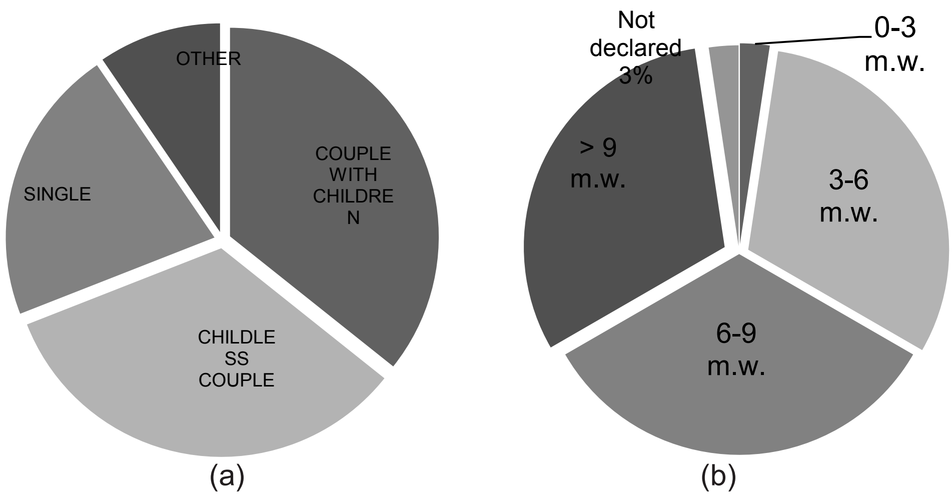


Figure 2: Frequency charts (%) of (a) family configuration and (b) family income

The groups of customers resulting from the hierarchical cluster analysis are illustrated in Figure 3, in a comparison diagram where you can see the mode values for each cluster, and a circle representing how many respondents had this characteristic. They were named according to their main characteristics: cluster 1 consists of couples with children, being a female the head of household; cluster 2 corresponds to being a male the head of household; and cluster 3 consists of childless couples, being a female the head of household. The clusters that have women as heads of household predominantly have university degrees. In terms of income, the three clusters have different characteristics, with the households headed by men having the lowest income and the households without children, the highest.

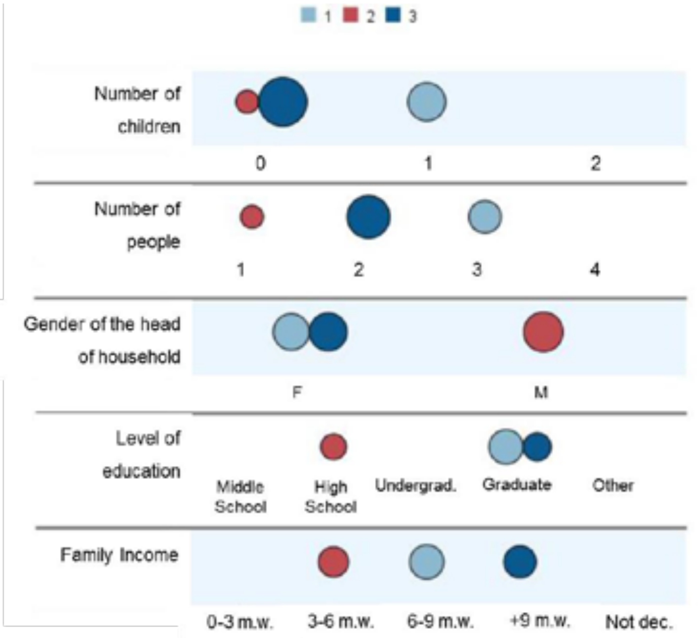


Figure 3: Profile cluster comparison

Product 1.5: Customization Clusters

The customizations were analysed based on three perspectives, the ones made at the design stage, as product specifications, those made by users after delivery, and those that the users still desire to make. The customizations most frequently made and desired by customers are in the finishings of the housing units. In the living room and dining room, as well as bedrooms, even though 40% of the housing units had customized floors at the design stage, changes were made after delivery and others are still desired, including floor lining or painting the walls (Fig. 4). The recurrence of these customizations may be related to the lifestyle of users, who privilege social interaction and entertainment in those areas. Besides, some interviewees were dissatisfied with the fact that the property was delivered without flooring in the living/dining room or in the bedrooms. However, in the case of the laundry and kitchen finishings, the unit was delivered with ceramic tiles on the floor and walls up to half-height, which had specifications changed by customer demand in 25% of units. Therefore, 40% of customizations made after delivery of the unit consisted mostly of painting the walls or completing the tiles up to the ceiling. According to the respondents, their dissatisfaction with the finishing was due to the difficulty to clean and the low quality of the paint.

After the purchase of the unit, many users changed the sanitary ware (30%), which caused dissatisfaction for aesthetics reasons. There were some desired customizations that were very difficult to implement: air conditioning installation (20%) and change in the layout of the kitchen and living/dining room (20%). The air conditioning had the lowest median among all attributes evaluated due to the difficulty of adding of new points, both because it would imply façade changes and lacking capacity of the electricity network. Kitchen and living/dining room layout was desired because dwellers prioritise social interaction, and the current arrangement does not allow it because the kitchen area is too small.

Some of the customizations were the result of the necessary repairs due to building pathologies, such as cracks, window sealing, low-quality of painting, and poor performance, such as lack of acoustic insulation.

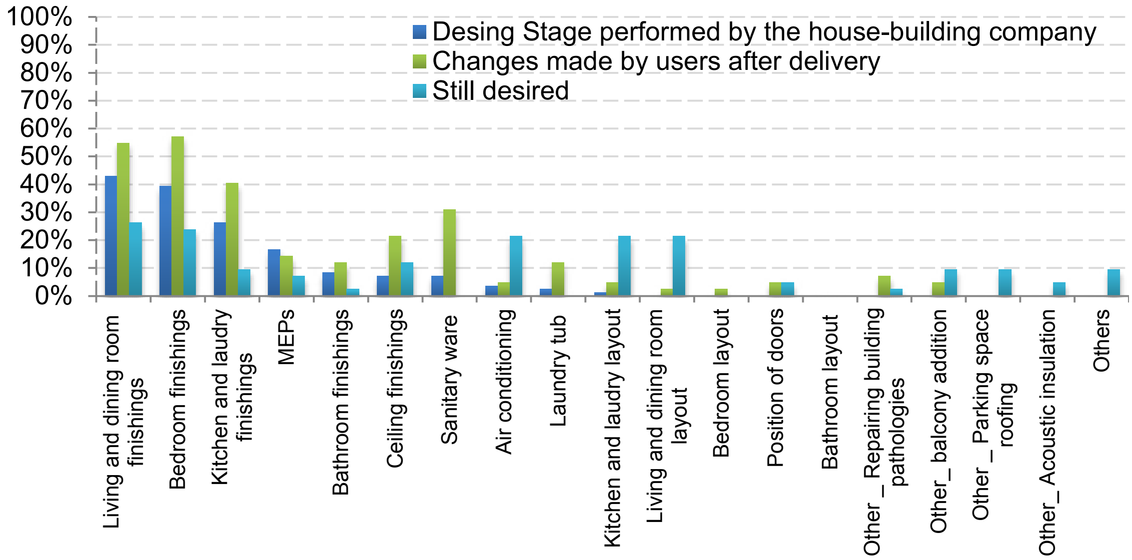


Figure 4: Relative frequency of customizations

Customizations undertaken together were grouped, by using hierarchical cluster analyses, in the same perspectives used before as shown in Table 3.

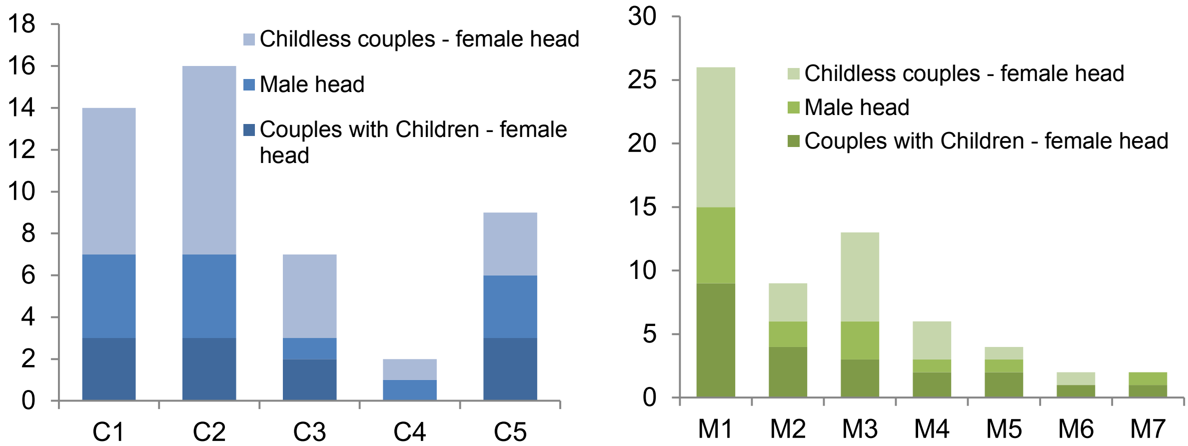
Product 1.6: Bivariate Analyses

By combining the demographic customer profile clusters with the customization clusters (Figures 5 and 6), some trends became evident:

a) households headed by women customize more than those headed by men, and couples without children customize even more, which may also be related with a higher family income;
b) the clusters that mentioned the need for air conditioning points, which stands out as a source of dissatisfaction, are not related to a specific profile;
c) the childless couple cluster, as they have higher income, tend to choose costly customizations, such as floor lining and ceiling and change of sanitary ware; and
d) families with children apparently invest less in improving the housing unit, probably because they privilege other types of expenditure.

Table 3: Clusters of customizations performed by the company, changes made by users, and still desired customizations

Design stage customization performed by the house-building company as product specification		Changes made by users		Still desired customizations	
Kitchen and laundry finishings	1	Kitchen and laundry finishings	1	Kitchen and laundry finishings	1
Bathroom finishings	1	Living and dining room finishings	1	Ceiling	1
Sanitary ware	1	Bedroom finishings	1	Bathroom finishings	1
Living and dining room finishings	2	Bathroom finishings	1	Living and dining room finishings	2
Bedroom finishings	2	Lining	2	Bedroom finishings	2
Laundry tub	3	Sanitary ware	3	Others	2
Ceiling	4	Laundry tub	3	MEPs	3
MEPs	4	MEPs	4	Addition of a balcony	3
Air conditioning	5	Position of doors	4	Air conditioning	4
		Air conditioning	5	Position of doors	4
		Fixing construction problems	5	Kitchen Layout	5
		Kitchen Layout	6	Living and dining room Layout	5
		Living and dining room Layout	6	Repairing building pathologies	5
		Bedroom Layout	6	Parking space roofing	6
		Others	7	Acoustic insulation	6



(a) made by the building company (b) changes made by users

Figure 5: Bivariate analysis of the frequency of demographic profile clusters in relation to customization clusters

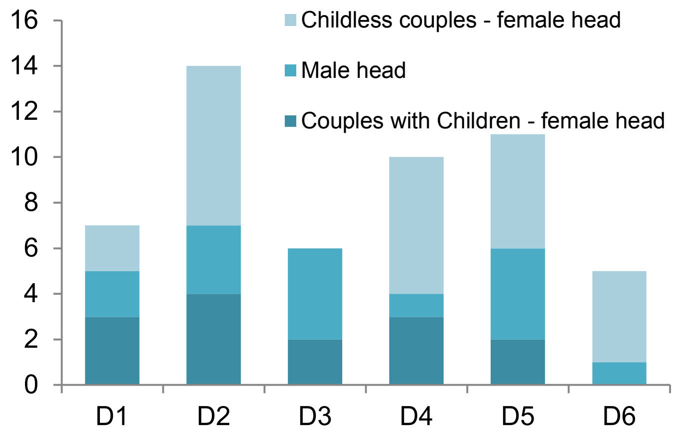


Figure 6: Bivariate analysis of the frequency of demographic profile clusters in relation to the desired customization clusters

Product 1.7: decision trees

In order to associate the customers profile data with the customizations that they have undertaken or still desire, this study used decision trees (1.7), which are diagrams that can be easily interpreted, resulting from consecutive statistical tests at different levels, creating paths between the profiles. They were made for all clusters, and results with a frequency lower than 5% were discarded. Figure 3 presents the decision tree for the cluster of changing finishings in the whole apartment (cluster 1 in Table 3). This change was made by 26 respondents (Fig. 7). All the heads of households that made this customization are 50 years old or younger, the majority of them have university degrees (14 respondents), and 10 respondents are female heads of household. Moreover, this cluster could be offered to household heads with high-school education or above, as it is indicated in the third line of differentiation.

Product 2.4: Hierarchical Value Maps

The general HVM (Fig. 8) represents the main relationships that between the product attributes, the consequences obtained in use, and the expected values, based on the perception of users, expressing the importance of different customization units. For instance, it is possible to visualize the relationship between floor and wall finishings in different rooms, in terms of the quality of materials and how easy these are to clean, which implies hygiene and reflects on users' health, and hence quality of living, a strong motivation for the changes. That explains also users' complaints about the quality of the paint used by the building company, making it difficultly to clean the walls. The floor finishings were chosen based on how it feels, i.e. tiled floors are connected with spacious sensation while wooden floors are connected with warmth. They influence the configuration of a pleasant environment, aesthetics, customization, tranquillity, identity and finally, quality of life.

The items that generated dissatisfaction due to the lack of design flexibility also appear on the map. One of those is the desire to integrate the living- and dining room area with the kitchen, shown in the map by the strong relationship between these two environments, and by the abstract attribute of dimension and the layout of the rooms, followed by integration. This customization is concerned with social interaction, aiming at family's well-being and integrity. The need for air conditioning systems is related to both thermal comfort and quality of living. Moreover, quality of execution and materials is related to the family's safety and physical integrity.

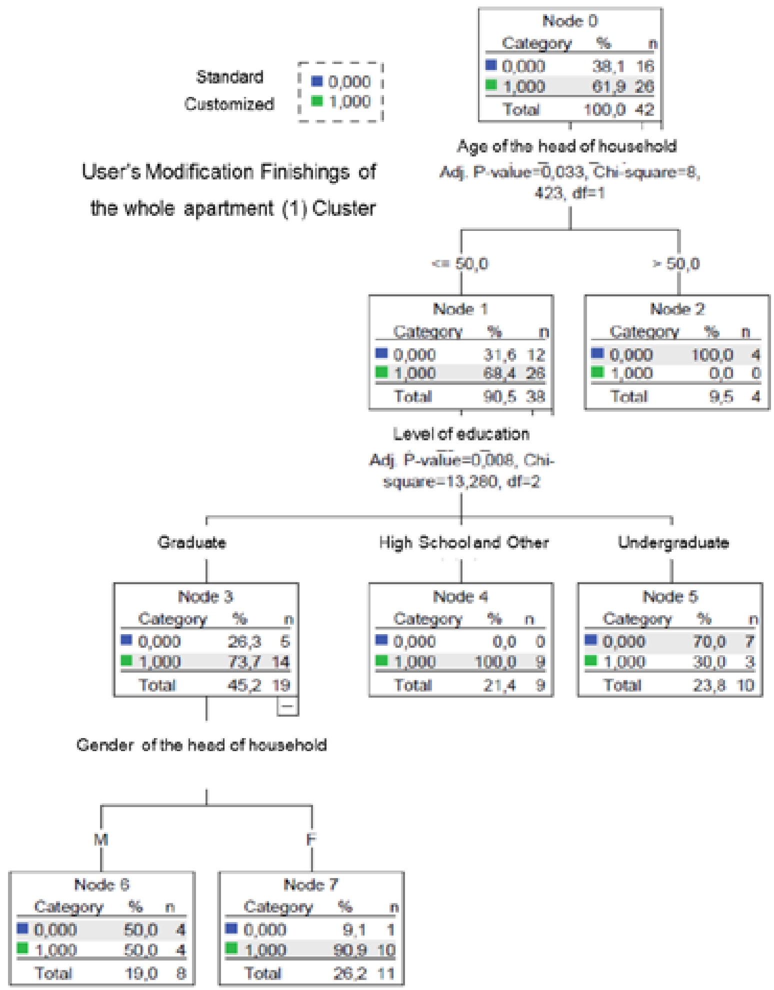


Figure 7: Decision tree of customizations carried out after product delivery (cluster 1)

One of the central elements of the map is aesthetics, since it is related to different attributes, including finishings, sanitary ware and ceiling, and to consequences that lead to terminal values, such as customization and care for the acquired property, personal and family fulfilment and social interaction. The construct "being able to rest and enjoy one's free time" was repeatedly cited in connection to comments about a hectic daily life and working hard to be able to buy the apartment. Therefore, it is closely related to personal and family fulfilment as well as with quality of living. The terminal values mentioned by those interviewees were well-being and quality of living, which seem to have similar meanings. However, in this context, a distinction was made by the respondents: quality of living was referred as an improved and lasting future condition, while well-being was related to feeling good momentary.

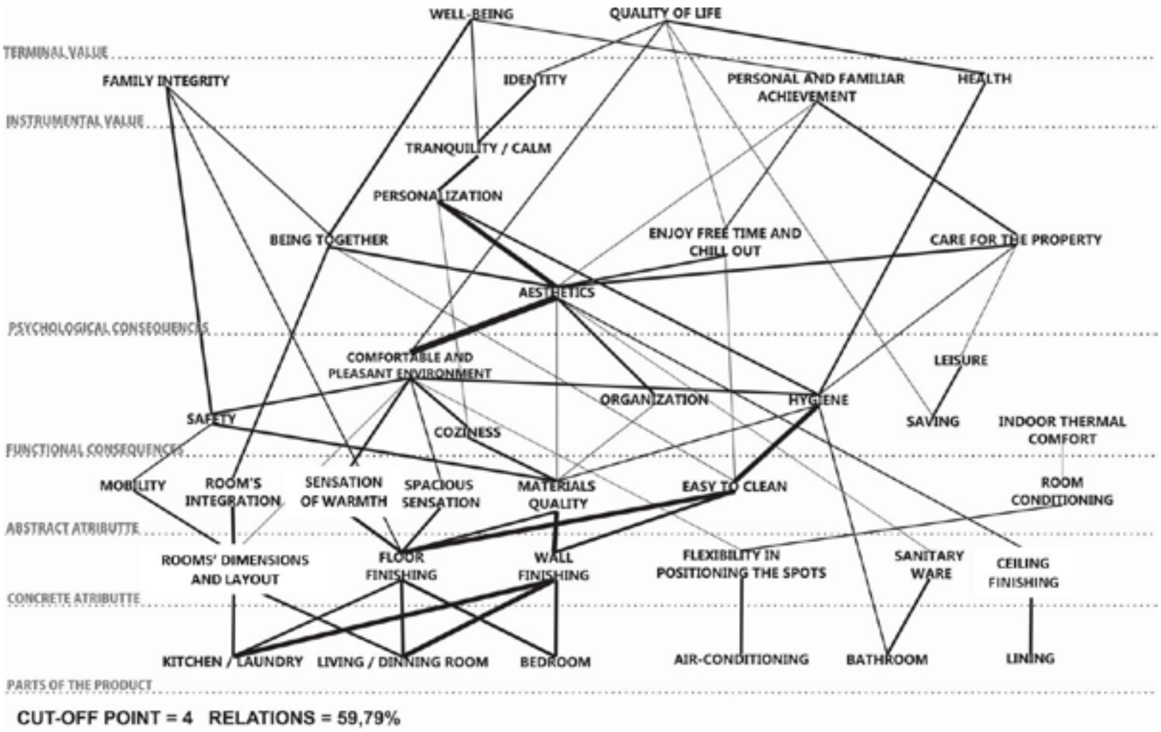


Figure 8: general HVM

Some more specific HMVs were also produced for different customer profiles. For instance, Figure 9 displays the map for the profile *couples with children with female head of household*.

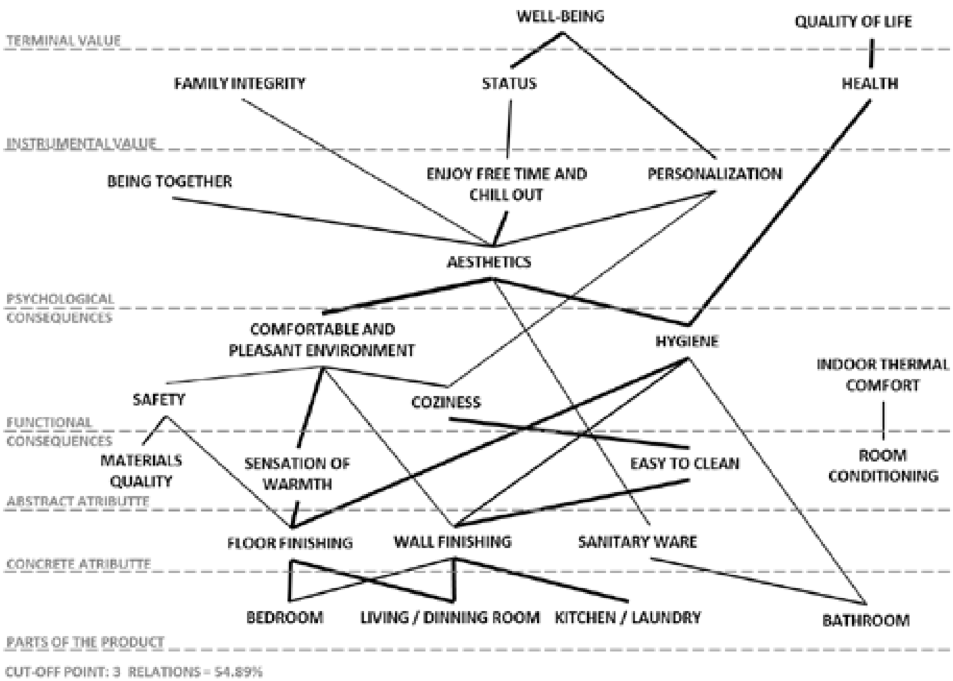


Figure 9: HVM of the cluster *couples with children with female head of household*

Product 3.2 Summary Menu

In order to summarise the previous phases, and help decision makers on the definition of customization units for each group of customers, a summary menu was prepared (Fig. 10). This figure shows a list of customization units, and the available options, in relation to the demographic profiles. In this set of customization units only those with a frequency above 10% are included, as suggested by Schoenwitz, Naim and Potter (2012). It also includes the customizations desired by over 20% of respondents.

The two first customization units shown in Figure 10, related to changes in finishings, were those most frequently carried out in all rooms of the housing units, despite the fact that painting customization was not offered by the building company. It is important to highlight that the areas of social interaction where most daily activities take place were the ones with the highest number of customizations. Moreover, these elements significantly contribute to the overall satisfaction with the property. Hence, building companies should focus on the quality of those elements and on offering choices aimed at potentializing the possibility of achieving a pleasant and hygienic environment, with the appearance desired by the customers, in order to achieve the goals of health, well-being and quality of life.

The customization units related to the ceiling and the sanitary ware have a target public that is basically female, and their frequency increases according to family income. As previously mentioned, female heads of household are more concerned with the appearance of the home, indicating their care for the home and well-being. With regards to sanitary ware, the company should consider suppressing this equipment.

The customization units concerned with electricity services and air conditioning are primarily carried out by female heads of household .These customizations are aimed at offering comfort to the family, where air conditioning means thermal comfort and feeling well in their living environment, while savings and convenience in the electricity services is related to quality of living. The building company offered the option of changing the voltage, because many buyers come from towns with a different voltage, so that they do not need to spend money on replacing domestic appliances.

The only customization that is dependent on the layout of the housing unit is the layout of the kitchen with dining/living room. Although the building company offered that option at the design stage, many users reported that they did not know about it, and once the unit was delivered it was no longer possible to do it. No changes in that requirement have been made after delivery due to the need of changing structural elements of the building. In fact, Schoenwitz, Naim and Potter (2012) state that customers tend not to change structural elements of their homes due to lack of confidence, but they prefer to alter those elements in which they can imprint their lifestyle and personal values, such as finishings. Hence, when the building company offers that customization, there will be more confidence that it will be done without damaging the building’s structure and it will generate more value for clients.

Customization units	Options	Socio demographic profile	Importance	Related problems
Floor finishings	Ceramic floors	Couple with children woman as the head of the household	Hygiene → Health → Quality of life	Living and dining room and bedrooms are delivered without floor finishings, to execute it by the house-building company was to expensive.
		Men as the head of the household	Spacious sensation→ Comfortable and pleasant environment → Aesthetics → Tranquility	
	Wood veneer floor	Couple with children and childless couple woman as the head of the household	Sensation of warmth → Comfortable and pleasant environment → Aesthetics → Being together → Well-being	
Wall finishings	Painting	Couple with children woman as the head of the household	Hygiene → Health → Quality of life	Poor quality of the painting, comes of when you clean.
	Ceramic (kitchen, laundry and bathroom)	Men as the head of the household	Easy to clean → Comfortable and pleasant environment → Enjoy free time and chill out → Being together	
		Childless couple woman as the head of the household	Quality of the materials → Hygiene → Comfortable and pleasant environment → Aesthetics → Well-being	
Lining	Standard	woman as the head of the household, higher the income higher the frequency	Aesthetics → care for the property → Well-being	
	Gypsum liner			
Sanitary and laundry ware	Sink (removal)	Couple with children and childless couple woman as the head of the household	Aesthetics → Well-being	Too small causing difficulties to place the furniture.
	Toilet			
	Laundry Tub	Childless couple , income higher than 9 minimum wages		Fixation problems and broke easily
Electrical installation	Voltage exchange	Couple with children woman as the head of the household and singles, higher the income higher the frequency	Saving → Comfortable and pleasant environment → Quality of life	Poor quality of the wiring and plugs, risk of electrocution and fire.
	Flexibility of the spots		Comfortable and pleasant environment	
Air conditioning	Number of spots	Couple with children and childless couple woman as the head of the household	Room conditioning→ Comfortable and pleasant environment → Well-being	Impossibility to add new ones caused dissatisfaction
Kitchen, living and dining room layout	Segregated			Kitchen is to small
	Kitchen/dining room	Men as the head of the family and Couple with children woman as the head of the household	Rooms integration → Being together →Family integrity → Well-being	

Figure 10: Summary menu of the customization demands

In addition, the summary menu highlights unexpected elements that emerged during the process, such as customers' complaints, which should be considered so as to ensure minimum level of quality of the product before offering further choices, as indicated by authors like Pine II (1994), Barlow (1998) and Svensson and Barfod (2002). The most frequent complaints about product quality referred to low-quality and unwashable paint, electricity services and building pathologies.

Conclusions

This paper has proposed a method of identification of the customization demands in social housing. Its main practical contribution is to provide a step-by-step process to connect customizable attributes with the benefits pursued by a group of customers. By segmenting its market in customer profiles, a housing-building company should be able to offer the most relevant product features to specific customers as a way to achieve their goals such as quality of living, and use that information as an input to analyse the feasibility customization units, considering organizational capabilities. The outcomes of the method can also be used to target the marketing strategy of the projects by communicating the image of a product related to customer desired values. Furthermore, the information produced by the method can be used to offer the set of customization units that are usually undertaken by customers that have the same profile, through the interpretation of hierarchical clusters and decision trees.

In relation to the existing literature, this investigation has made a contribution in terms of using MEC for a complex product such as social housing. Such complexity demands an additional effort for clarifying the relationship between the parts of the product and the customizable attributes, consequences experienced in use and the values desired. In fact, it was necessary to adapt elements of the MEC conceptual model, by inserting a new category at the bottom of the hierarchy, concerned with product attributes. In order to the complexity of considering too many attributes in the hierarchical value map, only the most relevant customizable attributes were addressed in this application.

The method was applied in two similar projects with the aim of doing a preliminary assessment. In future studies, the authors intend to apply the method in a larger sample of projects, with different target audience established by Brazilian housing policy, with the aim of generating representative data of final customers. Another possibility for future studies is to implement the method in the context of an organisation in order to further evaluate its utility and applicability.

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THE RELATIONSHIP BETWEEN MASS CUSTOMISATION AND DIMENSIONS OF VALUE IN THE CONSTRUCTION INDUSTRY

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THE RELATIONSHIP BETWEEN MASS CUSTOMISATION AND DIMENSIONS OF VALUE IN THE CONSTRUCTION INDUSTRY

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Abstract

End-users' needs have required building design to consider a variety of components that can be customized. This fact highlights the concept of Mass Customisation (MC), emerged in the manufacturing industry, as an important element to achieve companies' value proposition for their clients. The aim of this study was to conduct a Systematic Mapping Study (SMS) to identify research studies that have focused on MC in connection with quality dimensions and value from the end-users' perspective. We first established a general framework for dimensions of values by combining MC, value and quality concepts for construction. Then, we have conducted a SMS (scoping review), seeking to find these value dimensions in the articles selected by using this method. SMS is a technique rooted on the evidence-based paradigm and precedes Systematic Literature Reviews. SMS was carried out mainly to identify the amount and coverage of a particular topic in the literature and to identify evidence of scarcity. Ten different value dimensions were established in order to propose a taxonomy for the 14 articles that were selected after conducting the SMS. Furthermore, research gaps were identified to suggest future research.

Keywords: *Mass customisation, value, construction.*

Introduction

Mass Customisation (MC) has its roots in 1980s, emerged from mass production. It consists in the ability to seek and promote more customised products and services, through flexibility in large scale, reducing costs substantially. Several authors have defined MC as the organizational structure system, information technology, and process capable of delivering a specific product and service through the individual customer needs. Silveira, Borenstein and Figliatto. (2001) classified MC concept in three fields. The first one introduces new types of flexibility in manufacturing and information technology, aiming to produce high levels of variety with relatively low cost. The second field deals with faster increases in variety and customisation to fulfill competitive and market requests. The last one deals with upgrades in production strategies, focused on individual end-user, as a consequence of industrial competitiveness.

The relationship between MC and product quality is important to increase the product market position as an additional improvement for satisfaction, considering needs, desires, and satisfaction for a relatively reduced price. However, in order to do that, it is necessary to adapt the MC concept to to the context of value in construction. A building has a high level of complexity and must respect client needs, combining the benefits that a customized product can offer to a house.

According to Monroe (1990), satisfaction is associated to the value and the end-users reaction, regarding the use of a specific product. It would be compared in level of product standardization, although some way this level would change depending to the end-users' value perception, as consequence of perceived value. Marketing has much emphassis on measuring important constructs related to the value generation, such as satisfaction, perceived value, benefits, and retaining (Miron 2008). Kowaltowski and Granja (2011) emphasize that user satisfaction should prevent new design and retrofit endeavours avoiding error repetition and stimulating the use of incremental improvements. Moreover, an attempt should be made to Identify opportunities to improve housing quality, since construction industry shows important difference between stakeholders, when desired values are discussed (Kowastowski and Granja 2011).

In the construction industry, a customised product can better fulfil product's user requirements. MC increases the level of finishing and seeks to meet the individual needs of end-user as a competitive advantage. It is considered as a new way to understand competitive market in the construction industry, identifying needs and desires with no sacrifices. Also, MC has a huge potential towards reducing product costs, increasing efficiency and quality as an important and essential factor, considering MC as a response to end-users' needs (Noguchi and Hernàndez Velasco 2005). Noguchi (2003) has described a customised home in Japan relating to cost-performance and market strategy. In a Brazilian research study, Formoso, Leite and Miron (2011) emphasize that professionals responsible for developing products must have more information about the end-users to deliver a customised product.

This article aims to identify how MC and value dimensions for end-users are related, by applying a Systematic Mapping Study (SMS), based on published research studies on value, requirements and quality in construction. SMS precedes Systematic Literature Reviews in an Evidence-based Paradigm approach and aims to identify some suitable areas for conducting a SLR. The data analysis was divided into two phases. The first stage was conducted by a broad understanding of the value concept and previous background information. Some theoretical definitions on value dimensions were obtained in the literature from the architectural, manufacturing and MC perspectives. Furthermore, a SMS was performed to identify MC studies focused on value in the construction context within known databases. We merged the dimensions of value from theory and adopted 10 new dimensions to promote a taxonomy for the final SMS results within value dimensions proposed by the authors. Conclusions are presented to provide a combined analysis to show the relationship amongst dimensions of value approach in each selected publication. The taxonomy analysis supports the identification of possible research gaps and proposes new ways to observe and introduce value perceptions in research studies about MC.

Preparing –Dimensios of value arrangement

Three different concepts about value were selected from the theory:

a) the first one from Architecture (Hershberg 1999);
b) the second one from construction management (Picchi 1993); and
c) the third one from the MC literature (Bock and Linner 2010).

In Table 1, the value definitions were based on concepts arising from values in architectural design (Hershberg 1999) in the first column, followed by quality dimensions from manufacturing in the construction industry (Picchi 1993) and suggestion to adopt for value system in industrialized customisation for construction (Bock and Linner 2010), as defined by the respective authors.

Hershberg (1999) has classified contemporary values in 8 items, as a basis for the architectural design process: human values, environmental, cultural, technological, temporal, economic, aesthetic, and safety values at the first column (Tab. 1). Those elements would be considered as recommendation for contemporary values, in order to be used in a design development process as a briefing phase. It aims improvements for the whole project in essential design concepts and end user desires, especially for the architectural requirement planning (Kowastowski and Granja 2011).

In the second value dimension perspective, Picchi (1993) proposes an approach about quality dimensions for construction sector, based in manufacturing industry theories (Juran and Gryna 1988, Garvin 1987 and Teboul 1990). The values dimensions in construction were rated by 4 fields of knowledge in value dimensions: psychosocial, performance, legal (contractual) and ethics, and services associated to the product.

The third value dimension comes from MC point of view, by Bock and Linner (2010), whose publication contained an important analysis from Sekisui and Toyota Home, which promote a construction for customised houses in Japan. In that research, the value system could be applied through a variety of co-adaptations in terms of value system for industrialized customisation in construction. It aims to promote high flexibility and a responsive organisational entity, classified in this study.

Table 1: Value dimensions combining MC, value and quality concepts

Contemporary values (Hershberg 1999)	*Values from quality dimension (Picchi 1993)*	*Value system suggestion for industrialized customization in construction (Bock and Linner 2010)*	*Dimensions of Value (proposed by the authors)*
Humans	Psychosocial	Product Framework	Value added in design phase- (design improvements and product structuring operations)
Environmental	Non-Cited	Non-cited (Presented in Product Framework and Configuration Process)	Environmental Values - Urban and sustainability
Cultural	Psychosocial	Market Strategy and Business Strategy/ Flexibility	Cultural and Regional values
Technological	Performance	Configuration and Assembly Process	Technology and Innovation
Timing Value	Performance	Flexibility/Customised Production/ Configuration and Assembly Process	Flexibility towards new customised options and level of choice
Economics	Legal (law) and ethics	Supply chain management/ Organizational efficiency/ Market Strategy and Business Strategy	Economic values – price and cost to Operation and Maintenance
Aesthetic	Psychosocial	Non-Cited (Presented in Product Framework and Configuration Process)	Visual and Aesthetical product's values
Safety	Performance	Non-Cited (Presented in Product Framework and Configuration Process)	Safety requirements - Warranty and Customer Care
Non-Cited (Presented in Cultural value)	Legal (law) and ethics	Non-cited	Legal and contractual values
Non-Cited	Services associated with product	End-users’ relationship	End-users' support and technical assistance

A classification system was proposed concerning 10 dimensions of value (presented in the last column of Table 1) reporting to the three different areas as well values from architecture, manufacturing, and mass customisation.

Subsequently, the ten dimensions of value proposed by the authors were defined and described as a synthesis of the presented values from literature. **Value added in design phase** is viewed as end-users' needs and functional requirements, which consist of social relationship and customer needs. It also goes through with physical, physiological and psychological features demanded by users. This dimension of value is frequently applied in Product Development Process. **Environmental values** are related to urban planning and sustainability questions such as location, ground, view, urban environment, and natural resources. **Cultural values** are related to historical, institutional, political, and legal aspects. The cultural value has being extended to development in terms of design, concept, and innovation. **Technological values** include material resources, structural systems, construction processes, and conceptions of different shapes and technologically developed, focused in technological innovations. **Flexibility** is related to the idea of evolution over the time as well growth, changing, and permanence. **Economic Values** involves in financial aspects, cost and price, connecting all construction steps, operations and maintenance. **Visual and aesthetical values** go directly to the question of the concept, form, space, and product meaning. **Safety** features calls for all questions which are involved with security for the building and final users such as structure fire, chemical issues, personal protection; crime as vandalism are included as an important dimension of value focused on security. **Legal and ethical values** deals with contractual terms, resulting as guarantees according to the promises made to the end-user for a specific product. **End-users' support values** are associated with all services offered to the end-users, such as customer relations, technical assistance, and maintenance during the product lifecycle.

Research Method: Systematic Review

The present study has been emerged from a Evidence-Based Paradigm, which seeks to collect primary empirical studies in an object to find evidences and support a particular research hypothesis through an unbiased manner (Bailey *et al.* 2007). The principal tool of the Evidence-Based Paradigm is the Systematic Literature Review (SLR) or its short form: Systematic Review. The SLR had been described by Petticrew (2001) as a method of finding, evaluating, and synthesising evidence. It has been applied in researches with a large content of publications related to the main topic.

SMS aims to identify some suitable areas for conducting a SLR and also in areas where primary studies are more appropriate (Kitchenham and Charters 2007). In this research, the SMS method aims to identify studies which correlate MC with dimensions of value in the construction industry. SMS can also be used to provide a categorization or a taxonomy of phenomena, as applied in this research, and can be functional to summarize the data to answer the research question preceding SLR.

Data Analysis – SMS Application

Three international databases were used for the sake of carrying out the SMS: SCOPUS, Web of Knowledge and Science Direct. Two search text strings were defined for the very first literature mining: "Mass Customisation and Construction" and "Mass Customisation and Value". Those strings delivered a general and broad outcome not covering the research goal precisely. Search results have shown publications in MC in general environments, but construction (Silveira, Borenstein and Fogliatto 2001, Fogliatto, Silveira and Borenstein 2012 and Jarrat *et al.* 2011). No publications focused on construction were found on those initial search strings. For this reason, two other strings have been selected to address this issue:

a) “Mass Customisation ‘and’ Value ‘and’ Construction”;
b) “Mass Customisation ‘and’ Construction ‘and’ Case Study”.

The main results for “Mass Customisation ‘and’ Value ‘and’ Construction” showed occurrences related to the creative, design and production processes. They have shown 208 articles from the 3 databases accessed. The new combination of text strings “Mass Customisation ‘and’ Construction ‘and’ Case Study” resulted in 112 articles. Moreover, 61 published articles at 1st ZEMCH[1] conference were added to the results. The SMS culminated in 381 select papers.

After the first literature mining stage, a second extensive filtering based on closer examination of the 381 articles was carried out in accordance with the research aim. Articles that directed their focus outside of the construction industry were not considered.

It is important to note that the term "value chain" refers to a process and performance activities in industry and within the company seeking competitive advantage in a management level (Porter 1985). Therefore, “value chain” is not related to the aim of our research. For this reason, articles that used this term as primary focus were also excluded.

The SMS exercise ended up with 14 articles.

Results

Table 2 shows the bibliometric analysis of the 14 articles relating MC which value and quality concepts. It became clear that this discussion have been more pronounced in the last ten years, once MC is a novel concept in the construction industry.

We have identified a range of approaches regarding the use of MC in construction. Three of the 14 articles addressed development of information technology. They described software development in the design process as a tool to promote MC, (Schramm *et al*. 2008, Benros and Duarte 2009 and Shin *et al.* 2008). Other articles were related with MC strategy and process beeing case studies developed in Brazil, UK, and Mexico (Barlow *et al*. 2003, Noguchi and Hernàndez-Velasco 2005, Carvalho 2004, Rocha, Formoso and Santos 2012 and Rocha and Formoso 2012).

The issue of MC delivery process have brought two specific publications focused specifically in Mexican social housing by Noguchi and Hernàndez–Velasco (2005) also by Tillmann and Formoso (2008) applied in a Brazilian situation.

Case studies which have discussed MC for performance as prefabricated houses for habitation modules factories were done in Japan and Germany. These studies have evidenced constructive processes and deliveries for custom homes. Furthermore, research focused on implementation of MC in connection with sustainability have also been found (Bock and Linner 2010, Thuesen and Hvam 2011, Schoenwitz, Naim and Potter 2012 and Nijs 2011).

In Table 3, from the 14 final articles a new taxonomy had been proposed with dimensions of value due to a definition proposed by the author (presented in Table 1).

[1] 1stZEMCH - Zero Energy Mass Custom Home International Conference. Glasgow, UK. 2012.

This relation showed that some dimensions had been considered in most of the articles and cited more than others. However, some values criteria have been paid little attention, as well aesthetical values and safety requirements when observed in a whole view.

Table 2: Bibliometric analysis of the 14 articles which related MC to value and quality concepts

N.	*Country*	*Research type*	*Research approach*	Reference
1	Japan/UK	Case Study	Customisation approach and supply chain	Barlow *et al.* 2003
2	Brazil	Case Study	Customisation Strategy	Carvalho 2004
3	Mexico	Theory	Customisation approach and Delivery Process	Noguchi and Hernàndez-Velasco 2005
4	Brazil	Case Study	Customisation – Delivery process for low incoming house in Brazil (Product development)	Tillmann and Formoso 2008
5	Colombia/ Brazil	Case Study	Information Technology	Schramm *et al.* 2008
6	Korea	Case Study	Customisation - Delivery process toward Information Technology	Shin *et al.* 2008
7	Portugal	Theory	Mass Customisation approach based in Information Technology	Benros and Duarte 2009
8	Japan	Case Study	Customisation – Delivery process	Bock and Linner 2010
9	Japan	Theory	Customisation and Technology	Bock and Linner 2010
10	Germany	Case Study	Customisation – Delivery process- construction site	Thuesen and Hvam 2011
11	Netherland s	Case Study	Customisation strategy and sustainability	Nijs 2011
12	Brazil/UK	Case Study	Conceptual framework for customisation strategy	Rocha, Formoso and Santos 2012
13	Brazil/UK	Case Study	Customisation Strategy	Rocha and Formoso 2012
14	Germany	Case Study	Customisation Strategy	Schoenwitz, Naim and Portter 2012

Discussion

This combination of results shows that values related with design, technological, and flexibility issues were more frequently found in the 14 articles. Opportunities for adding optional components for a product are also the biggest advantage to promote MC. Another benefit of MC turns around product and price throughout its fabrication, due the possibility to faster reduce costs. The following discuss each dimension of value (Tab. 1 and 3) according the SMS exercise.

Value added in design phase- (design improvements and product structuring operations), Technology and Innovation and **Flexibility toward new customised options and level of choice** have been assessed mostly. In some articles, the concept of value was presented as a secondary approach, considering the relevance of the design development and delivery for MC settings. Flexibility is an important dimension of value related to MC. Under a construction perspective, it is important to link the issue with all remaining dimensions of value. Production lead times of MC artefacts can also be seen as an intensive research topic in the last five years. Furthermore, new strategies and fabrication process analyses were adopted to improve MC housing as shown in Barlow *et al.* (2003) Bock and Linner (2010), Schoenwitz, Naim and Potter (2012).

Table 3: Analysis of the 14 papers acording to dimensions of value and number of articles

Articles (Table 2) / Dimensions of Value (10) (Tab. 1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Nº. of Articles per value dimension
Value added in design phase- (design improvements and product structuring operations)	X	X		X	X		X	X	X	X	X	X	X	X	12
Environmental Values - Urban and sustainability		X						X	X		X			X	05
Cultural and Regional Values	X	X								X					03
Technology and Innovation		X	X	X	X	X	X	X	X	X	X	X	X	X	13
Flexibility towards new customised options and level of choice	X	X	x	X		X	X	X	X	X	X	X	X	X	13
Economic values – price and cost to Operation and Maintenance	X			X		X	X	X		X	X			X	08
Visual and Aesthetical product's values		X				X									02
Safety requirements - Warranty and Customer Care									X						01
Legal and contractual values				X				X				X	X		04
End-users' support and technical assistance					X	X		X	X			X	X		06
Value dimensions and articles	4	6	2	5	3	5	4	7	6	5	5	5	5	5	

Some articles related to **Economic values – price and cost to Operation and Maintenance** have superficially commented the importance of cost as a main factor for MC, but have not deeply explored the topic. For instance, Thuesen and Hvam (2011) have shown figures comparing benefits between cost and value. Therefore, the linkage between costs constraints and value perception by end-users is a topic that deserves further research efforts.

The domain of **End-users' support and technical assistance** lack investigations in relation to marketing strategies and technical assistance as well. More pronounced scarcity of evidences were detected in some value dimensions. Contrary to expectations, the SMS exercise found just five articles related to **Environmental Values - Urban and sustainability**. Local, surroundings and urban spaces did not receive much attention. **Cultural and Regional Values, Visual and Aesthetical product's values, Safety requirements - Warranty and Customer Care** and **Legal and contractual values** deserved little attention in the 14 articles, representing interesting gaps of knowledge to be further explored.

Conclusions

The problem of identifying the existence of research related to MC in connection with quality dimensions and value from the end-users perspective was studied. First, we have developed a general framework consisting of 10 dimensions of value by combining MC, value and quality concepts for construction. Then we have conducted a SMS in order to perform a bibliometric analysis of the 14 articles which related MC to value and quality concepts. The proposed taxonomy of articles in relation to the value dimensions allowed us to find new research opportunities.

The most pronounced scarcity of evidences were found in the dimensions of value for Cultural and Regional Values; Visual and Aesthetical product's values; Safety requirements - Warranty and Customer Care and Legal and contractual values. Broadly speaking, these results evidence the need of better assessing the MC concept for construction adding the dimensions of value and quality.

Future research could extend the presented research in order to improve the proposed taxonomy about value through the SLR technique.

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IDENTIFICATION AND CHARACTERIZATION OF PARTICULATE MATTER CONCENTRATIONS ON CONSTRUCTION SITES

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IDENTIFICATION AND CHARACTERIZATION OF PARTICULATE MATTER CONCENTRATIONS ON CONSTRUCTION SITES

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Abstract

The identification and characterization of particulate matter (PM) concentrations from construction site activities pose major challenges, due to the diverse characteristics related to different aspects, such as concentration, particle size, particle and composition. Moreover, the characterization of the particulate matter is influenced by meteorological conditions including temperature, humidity, rainfall and wind velocity. This paper is part of a broader investigation that aims to develop a methodology for the assessment and reduction of environmental impacts caused by the PM emissions arising from construction work, and aims to determine the concentration of air pollution caused by particle emissions during different construction phases. This assessment seeks to contribute to the identification of appropriate measures of mitigating impacts caused by particulate matter, also reducing this impact on the health and well-being of the population, especially construction workers and neighbouring areas. The aim of this paper is to identify and characterize the MP on a construction site with different aerodynamic diameters (PM 2.5, PM 10, Total Suspended Particulates - TSP), based on an exploratory study. Initially, a protocol was developed to standardize criteria for the selection of the construction site, laboratory procedures, sample collection in flowerbeds and laboratory analysis. This protocol was applied on a residential building site in three different phases (earthworks, superstructure and finishing) and aimed to measure and monitor PM concentrations onsite construction. As a result, the exploratory study validated the previously developed research protocol. Also, the findings showed the characterization of different PM aerodynamic diameters during the different phases measured. The concentration values obtained in this study did not exceed the limits set by CONAMA 03/90 national standards. However, some of the levels of concentration measured exceeded the parameters set by World Health Organization, and represents an increase in short-term mortality.

Keywords: *Air pollution, Particulate matter, Environmental impacts, Construction sites.*

Introduction

Environmental protection is an important issue throughout the world. Compared with other industries, the construction industry is a main source of environmental pollution (Ofori, Gang and Briffett 2002). Building construction and operations have a massive direct and indirect effect on the environment (Cho, Alaskar and Bode 2010 and Levin 1997). Pollution sources resulting from construction processes include harmful gases, noise, dust, solid and liquid wastes (Tah and Abanda 2011).

Despite the development, the construction industry is considered an important source of particulate matter, which is the atmospheric pollution associate with a negative impact on human health and the environment. Worldwide, it is estimated that PM2.5 (particulate matter less than 2.5μm diameter) ambient air pollution is responsible for approximately

0.8 million premature deaths and 6.4 million years of life lost annually (Cohen *et al.* 2005).

Dust and PM10 emissions can arise from a number of sources. Not only do construction activities need to be considered, as do emissions from on road vehicles associated with the construction site and on-site machinery (off-road emissions) - including both static and non-road mobile machinery (Guidance Note Construction Sites 2010 and Resende 2007). The detrimental health impacts of PM10 are not confined to the construction site. These particles can travel further than coarser dust and so can affect the health of people living and working in the surrounding area of the site (Councils London 2006 and Resende 2007).

Emissions of particles and dust from construction can also have an impact on indoor air quality in the neighbouring area. Dust and other air pollution from demolition and construction can impact greatly on the health and quality of life of people working on and living close to these sites if they are badly managed (Guidance Note Construction Sites 2010).

Fine particles can be transported thousands of kilometers and remain in the atmosphere for a number of days. Coarse particles can settle rapidly from the atmosphere (within hours) and normally travel only short distances. However, when thrust high into the atmosphere, as in dust storms, the smaller-sized, coarse-mode particles may have longer lives and travel greater distances. The coarse PM constituents have shorter lifetimes in the atmosphere; so their effects tend to be more localized (Environment Agency 2004 2004).

PM10 is of more concern to human health as the particles can enter the lungs, causing breathing and respiratory problems, with long-term health effects dominated by cardiovascular rather than respiratory problems (Councils London 2006). PM10 size fraction is associated with a range of effects on health, including respiratory and cardiovascular systems (i.e. asthma) and mortality (premature deaths). Particles can also carry adhered carcinogenic compounds into the lungs. The most vulnerable people are the elderly, the very young and those with existing heart and lung conditions. (Councils London 2006).

A crude distinction is that particles of less than about 2.5 mm penetrate the alveoli and terminal bronchioles, while larger particles of up to 10 mm will deposit primarily in the primary bronchi and much larger particles (up to 100 mm), will deposit in the nasopharynx (Kelly and Fussell 2012).

The growth of construction and its environmental impacts emphasize the importance of the need for sustainable construction processes and actual ways to manage sustainability measures for sustainable construction. It is very important to predict what the environmental impact of construction is and how it can be prevented before starting an activity (Amor 2012).

Despite the fact that the issue of environmental pollution has been well studied in the academic area, as well as the existence of general pollution standards and methodologies, there is a lack of specific methodology to measure and evaluate particulate matters in onsite construction. Therefore, there is a need to measure the relevance of emission sources of particulate matters in different construction phases, as well as to identify mitigating measures to reduce its impact, generating better air quality in the workplace.

Additionally, the Brazilian code for air pollution does not establish quality standards levels, or consider the generating source and the chemical composition of the material, only taking into account the mass concentration, highlighting potential toxic risk. Thus, there is need for the establishment of emission levels standards of particulate matter in construction sites (Resende 2007 and Maioli 2011).

This paper is part of a broader investigation that aims to develop a methodology for the assessment and reduction of environmental impacts caused by the PM emissions arising from construction projects, and aims to determine the concentration of air pollution caused by particle emissions during the different construction phases. This assessment seeks to contribute to the identification of appropriate measures to mitigate impacts caused by particulate matter. The objective of this paper is to identify and characterize the MP onsite construction with different aerodynamic diameters (PM 2.5, PM 10, Total Suspended Particulates - TSP), based on an exploratory study.

Atmospheric Pollution and Particulate Matter

According to Daly and Zannetti (2007), air pollution is defined as anthropogenic emissions of harmful chemicals that alter the chemical composition of the natural atmosphere and have an adverse effect on the health of living things, an adverse effect on anthropogenic or natural non-living structures, or a reduction in the air's visibility.

Air pollutants are any substances emitted into the air from an anthropogenic, biogenic, or geogenic source, that is either not part of the natural atmosphere or is present in a higher concentrations than the natural atmosphere, and may cause a short-term or long-term adverse effects (Daly and Zannetti 2007).

Most dust particles are too big to be inhaled but can cause eye, nose and throat irritation and lead to deposition on cars, windows and property (Councils London 2006).They include evidence of cardiovascular disease exacerbation as noted by multi-center studies assessing the association between ambient air pollution and cardiovascular disease mortality (Schwartz, Zanobetti and Bateson 2003) Other recent studies are providing incomplete but intriguing results suggesting that particle induced pulmonary and systemic inflammation, accelerated atherosclerosis, and altered cardiac autonomic function may be part of the patho-physiological pathways linking particulate air pollution with cardiovascular mortality (Peters and Pope 2002).

Particulate matter (PM) is composed of inert carbonaceous cores with multiple layers of various adsorbed molecules including metals, organic pollutants, acid salts, and biological elements such as endotoxins, allergens, and pollen fragments (Gualtieri *et al.* 2009). PM is classified in the following types:

a) **Total Suspended Particulates** (TSP) is a name given to particles of sizes up to about 50µm. The larger particles in this class are too big to get past our noses or throats, so they cannot enter our lungs. They are often from wind blown dust and may cause soiling of buildings and clothes. However, TSP samples may also contain the small PM10 and PM2.5 particles that may enter our lungs (Environment Agency 2004);
b) Total suspended particulate matter (TSP) with additional subcategories of **particles smaller then 10µm in diameter** (PM10), and **particles smaller than 2.5** µm in diameter (PM2.5). PM can exist in solid or liquid form, and includes smoke, dust, aerosols, metallic oxides, and pollen. Sources of PM include combustion, factories, construction, demolition, agricultural activities, motor

vehicles, and wood burning. Inhalation of enough PM over time increases the risk of chronic respiratory disease (Daly and Zannetti 2007);

c) **Inhalable coarse particles**, such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter (Environment Agency 2004);
d) **Fine particles**, such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air (Environment Agency 2004); and
e) "**Smoke**" is the visible suspension of particles in air (mostly un-burnt carbon) arising from the combustion or part combustion of any material. It comprises a wide range of particle sizes including the fine particles (PM10 and smaller) that have the most effect on health (Milford and Davidson 1985).

Size and chemical composition are among the most important parameters influencing the way in which airborne particles interact with the environment. Deposition from the atmosphere onto soil, vegetation, and other surfaces is a function of particle size (Milford and Davidson 1985).

The extent to which airborne particles penetrate the human respiratory system is determined mainly by size, with possible health effects resulting from the presence of toxic substances. Visibility degradation is known to be a function of both size and composition of airborne particles.

A crude distinction is that particles of less than about 2.5 mm penetrate the alveoli and terminal bronchioles, while larger particles of up to 10 mm will deposit primarily in the primary bronchi and much larger particles (up to 100 mm), will deposit in the nasopharynx.

By far the greatest number of particle fall into the ultrafine size range, consisting of PM with a diameter of 0.1 mm or less (PM 0.1). These ultrafine particles (UFPs) dominate the surface area of particulate pollution but do not contribute large quantities to PM mass.

This size fraction arises largely from primary combustion emissions and secondary particles produced by gas-to-particle conversion processes. They are inherently unstable and grow into larger particles through coagulation and condensation. These particles are dominated by sulphates, nitrates, OC and EC. UFPs pose a particular health threat in that their small size allows greatest lung penetration and onward passage across the airblood barrier (Kelly and Fussell 2012).

The lifetime of PM2.5 in the atmosphere is typically in the order of several days in the absence of precipitation because fine particles have a negligible sedimentation rate and are not removed rapidly by dry deposition processes (Seigneur 2001). They can be transported thousands of kilometers and remain in the atmosphere for a number of days. Coarse particles can settle rapidly from the atmosphere (within hours) and normally travel only short distances (United State Environmental Protection Agency 2004).

Therefore, the significant novice effects in constructions site are limited to the construction site itself, such as damages in machines and equipment, workers health and safety, neighborhood, contrary to the fine particulates that can be transported for thousands of kilometers (Fernandes 2005).

The chemical composition of particulate matter is an essential piece of information for assessment of its sources and health effects. Thanks to knowledge about its composition, one gets a wider look at the potential harmful effect of PM (Sielicki *et al*. 2011).

Standards references are established in order to differentiate between polluted and non-polluted atmosphere. The distinction is carried out through Air Quality Standards, which are concentrations of atmospheric pollutants that, if bordered, will affect the health and safety of the population (Primary Standard), as well as damages to the flora, fauna, material and environment as a whole (Second Standard). These standards were established based on scientific studies concerning the effects produced by specific pollutants.

The National Council on the Environment Regulation number 3 (Conselho Nacional do Meio Ambiente 1990) states that when areas' classes are not established, primary standards should be adopted. In Brazil, the standardized pollutants are: TSP, Smoke, Sulfur Dioxide (SO_2), inhalable particles, Carbon Monoxide (CO), Ozone (O_3), Nitrogen Dioxide, according to Table 1. Conama Regulation 03/1990 also outlines critical scenarios of air pollution, which are: attention, alert and urgency (see Tab. 2).

The World Health Organization (World Health Organization 2006) recommends the standards for PM2.5 air quality based on well-known health effects, including short and long term (see Tab. 3). According Table 3, the Brazilian Regulations do not have standards for PM2.5, while the American Regulations do not have standards for suspended particulate. Both regulations do not establish air quality taking into account the generation source and the chemical composition of the material, but rather establish only the weight and the potential toxic risk.

Table1: Brazilian National Air Quality Standards (Companhia de Tecnologia de Saneamento Ambiental 2004)

Pollutant	Averaging Time	Primary Standards	Secondary Standards
Total Suspended Particulate – TSP	24 Horas¹ Geometric Annual Avarage	240 µg/m³ 80 µg/m³	150 µg/m³ 60 µg/m³
Inhalable Particles (PM10)	24 Horas¹ Aritimetic Annual Avarage	150 µg/m³ 50 µg/m³	150 µg/m³ 50 µg/m³

Note: [1]Does not exceed once a year.

Table 2: Critical scenarios of air pollution (Companhia de Tecnologia de Saneamento Ambiental 2004)

Pollutant	Attention	Alert	Urgency
STP (µg/m³) – 24 h	≥ 375	≥ 625	≥ 875
PM10 (µg/m³) – 24 h	≥ 250	≥ 420	≥ 500

Table 3: Air quality Standards for PM2.5 in μg/m³ (Companhia de Tecnologia de Saneamento Ambiental 2013)

Countries	Average	Standard (μg/m³)	References
Canada	24h	30	Lee (2010)
European Union	Annual Annual	25 (in 2010) 20 (in 2015)	Directive 2008/50/CE (2008)
USA	24h Annual	35 15	USEPA (2006)
Mexico	24h Annual	65 15	Lee (2010)
WHO	24h Annual	25 10	World Health Organization (2006)

Research Methods

The research strategy adopted in the current work is an experiment consisting of a planned procedure, starting from a problem and hypothesis, which aims to provoke phenomena under controlled conditions, and to observe and also analyze its results (Souza *et al.* 2002 and Neto, Scarminio and Bruns 2002).

Thus, the data collecting was obtained by PM2.5, PM10 and TSP collection through MiniVols equipment (manufactured by Airmetrics) that was installed in three different construction phases (earthworks, superstructures and finishing) over a 10-day period for each phase, in a residential building construction site in Salvador, Bahia, Brazil. Furthermore, the sedimentation rate was collected by sticky pads set up in the neighborhood in order to identify the emission impact of the activities that emit particles in the neighborhood.

In order to monitor the environmental conditions to which this PM was issued, the Davis Vantage Vue weather station was used. The weather station was installed 5 days before the MiniVols installation and was located at the exit of the construction site, taking into consideration the prevailing wind of the region, and, from the data analysis, the correct sampling position was set in order to attain a accurate data for each measurement.

The directional criterion was used to monitor the particulate material, being useful for review of the critical emissions in neighboring buildings after the implementation of a construction site. This technique involves the use of samplers pairs located in opposite positions in the predominant wind line, one being located at the construction site entrance (measuring the contribution of PM emissions entering in the construction site) and the other situated in the same line, at the other end of the construction site (measuring the emission contribution from the construction site) (Fig. 1). The measurements were taken at the same time in two points, following two schedules: During the operation of the construction site (7:00 am – 3:00 pm) – measurements at about 8 hours and adding the night shift (5:00 pm – 3:00 a.m.) – measurements in 22 hours.

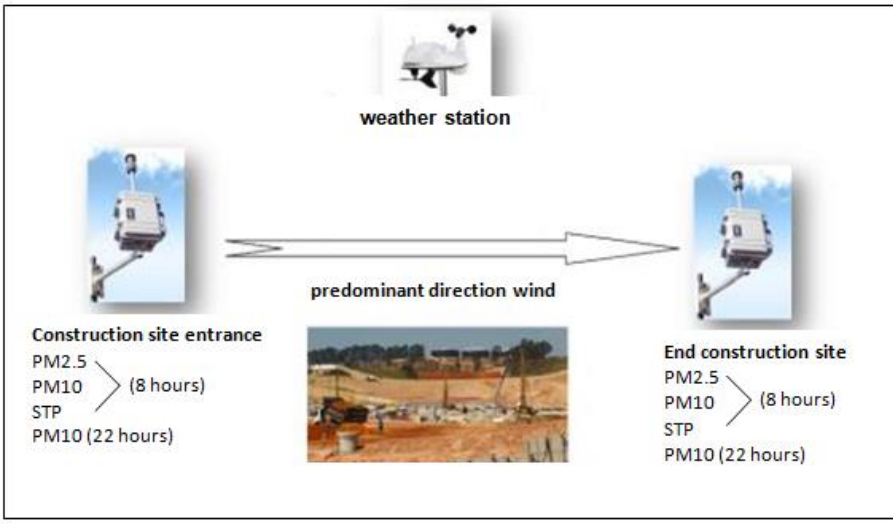

Figure 1: Schematic positioning of equipment at a construction site

In the first stage, a diagnosis through the on-site observation was carried out seeking to identify emissions risks, as well as dust generating activities for the construction phase, including the observation of materials that were used in the production process and also the technologies used to execute construction process.

Moreover, the measurement process followed a protocol of data collecting developed in order to standardize the procedures and occasional variability, as well as to measure the pollution concentrations of particulate matter and evaluate the effects caused by the emission of these particles in the neighborhood. It also checked whether these emissions were within the standards established by national and international regulation.

The chemical and physical analyses of those particles were carried out in a specialized laboratory in the city of São Paulo at São Paulo University. The reading of stick pads was also performed in situ since it does not require laboratory analysis. Table 4 presents the summary of data analysis.

The physical analysis were undertaken through the Mettler Toledo analytical balance from LAPAT/IAG/USP, used in order to obtain the sampled filter mass, and also for gravimetry and concentration calculations. The chemical analysis were performed with the X-ray florescence equipment EDX 700 HS “Energy Dispersive X-Ray Sppectrometer” model, from LAPAT/IAG/USP Shimadzu, utilized to quantify the periodic table elements with an atomic number from 11 to 82 (Na to Pb). Thereafter, the results derived from this analysis were converted to concentrations of each identified element by the WinQXAS (Windows Quantitative X-ray Analysis System) program, through spectral line adjustments. The chemical analysis was not finalized by the deadline for this paper, so this paper will present only the physical analysis.

Table 4: Summary of samples for data analysis

Analysis		Phase 1 - Earthworks	Phase 2 - Superstructures	Phase 3 - Finishing
Physical Analysis	Concentration calculations	PM 2.5 8h entrace PM10 8h exit TPS 8h entrance PM 2.5 8h exit PM10 8h exit TPS 8h exit PM10 22h entrance PM10 22h exit	PM 2.5 8h entrance PM10 8h entrance TPS 8h entrance PM 2.5 8h exit PM10 8h exit TPS 8h exit PM10 22h entrance PM10 22h exit	PM 2.5 8h entrance PM10 8h entrance TPS 8h entrance PM 2.5 8h exit PM10 8h exit TPS 8h exit PM10 22h entrance PM10 22h exit
	Gravimetry	PM 2.5 8h entrance PM10 8h entrance TPS 8h entrance PM 2.5 8h exit PM10 8h exit TPS 8h exit PM10 22h entrance PM10 22h exit	PM 2.5 8h entrance PM10 8h entrance TPS 8h entrance PM 2.5 8h exit PM10 8h exit TPS 8h exit PM10 22h entrance PM10 22h exit	PM 2.5 8h entrance PM10 8h entrance TPS 8h entrance PM 2.5 8h exit PM10 8h exit TPS 8h exit PM10 22h entrance PM10 22h exit
Chemical Analysis	X Ray (Primary analysis)	Not finished yet	Not finished yet	Not finished yet
	X Ray (Secondary analysis	Not finished yet	Not finished yet	Not finished yet
	Chromatography	Not finished yet	Not finished yet	Not finished yet
Sedimentation Rate	Sedimentation Rate	Reading of stick pads	Reading of stick pads	Reading of stick pads

Characterization of the Construction Site

The construction site studied is located in Salvador, Bahia, Brazil, along Latitude 12 ° 57'46" South, Longitude 38 ° 24'32" west and at 34m above sea level. It has an area of 32.780m ², and entails the construction of 6 residential towers with 16 floors each, totaling 464 housing units.

The construction site is located in a residential urban area (up to 02 floors) where there is a presence of flora and fauna, including a lake. Within an area of 100m, primary pollution sources, such as the presence of other construction, industries, traffic routes and airports, are absent.

Despite the fact that the methodology proposed involved the measurement of PM in different phases, due to the fact that the selected construction site was undergoing all the phases of execution simultaneously, it was observed that, instead of regarding the measurement in phases, it was necessary to consider it in steps, so that, from the chemical composition of the MP, it could be possible to report the construction activities and, thus, the construction phases.

Therefore, it was required to consider the entry point as a fixed point, since it was not shifted along the three different steps, and the exit points as Points 01, 02 and 03. The equipment was installed in 01 fix point at the main entrance of the construction site and in three distinct points (Point 01, Point 02 and Point 03), located at the construction site exit in different phases, using as a base the prevailing wind direction (southeast). Moreover, the Mini Vols was located next to the activities that exhibited a predominance of the main stages of the construction site: Point 01 – earthworks, Point 02 – superstructure and Point 03 – finishing (Fig. 2).

Figure 2: Position of points 1, 2 e 3

Due to the vast types of construction processes along the construction development and the variation in weather conditions, the control and prevention of particulate matter during the construction may be different and specific for each project. Therefore, the emission planning and control before the beginning of the construction is essential.

The construction site studied has taken into consideration measures to control the particulate matter from the beginning of the Project, mitigating the dispersion of this pollution. Some examples of mitigating measures used are: (1) use water as dust suppressant in pathways and directly to the soil (earthworks), (2) loads entering and leaving site are covered, (3) use water as dust suppressant in pathways during superstructure and finishing stages; (4) use of physical barriers such as nets to minimize dust generating activities during superstructure and finishing stages.

Results of the data collection

The samplings performed during the construction site activities accumulated an extensive database, compiled by the MiniVols equipment (240 samplers). However, the 22 hours period of measurement in the Points 01, 02, 03 and 04 are not presented in this work due to the fact of sampling errors, since the gravimetry found in its filters provided very small values. Thereafter it was assumed that the filters saturated. In order to analyze the 22-hour period, only the fix point data at different stages of the measurement was used.

The Figures 3, 4 and 5, and Table 5, it is possible to notice that the TSP showed the highest concentrations, followed by PM10 and after PM2.5. Through box plot graphs of the concentration from TSP, PM10 and PM2.5 outliers concentrations were identified and they were plotted in Figures 2, 3 and 4.

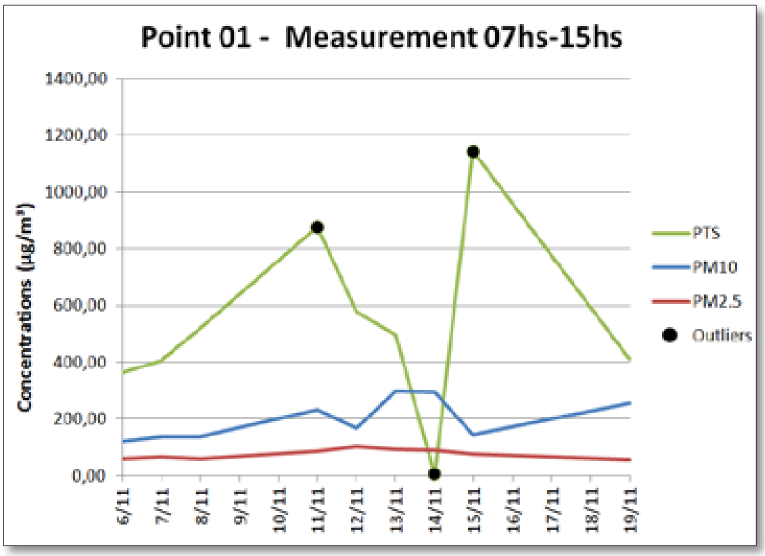

Figure 3: Evolution graph comparing the concentrations of STP, PM10 and PM2.5 in µg/m³ at different measurement days of Point 01

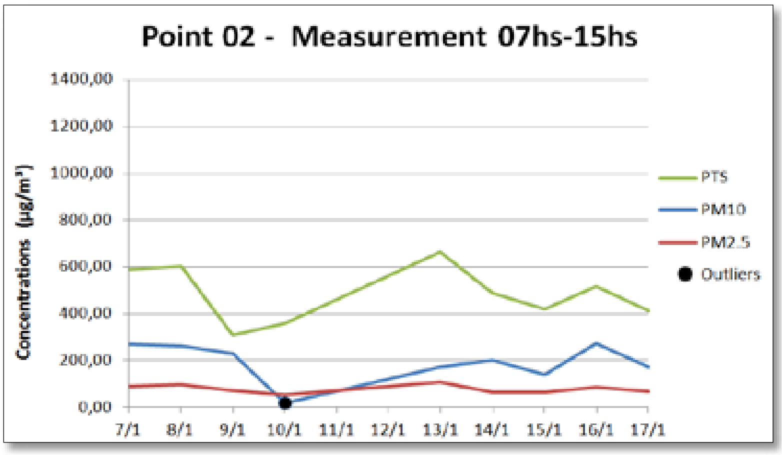

Figure 4: Evolution graph comparing the concentrations of STP, PM10 and PM2.5 in µg/m³ at different measurement days of Point 02

The concentrations of the Point 02 in the fractions presented higher values comparing with Point 01 and Point 03. In terms of concentration of PM, the point 02 emits more TSP, PM10 and PM2.5 with average concentrations of 483.12 µg/m³, 213.94 µg/m³ and 77/85 µg/m³, respectively, in relation to Point 01 and 03. In Point 01 the average concentrations are 462.25 µg/m³, 198.09 µg/m³ e 75.89 µg/m³ and in the Point 03 the average concentrations are 212.31 µg/m³, 90.00 µg/m³ and 46.84 µg/m³. Regarding the medians, except for the PM2.5 emissions with a higher median in Point 01, the other fractions had higher medians in Point 02, followed by Point 01 and finally Point 03.

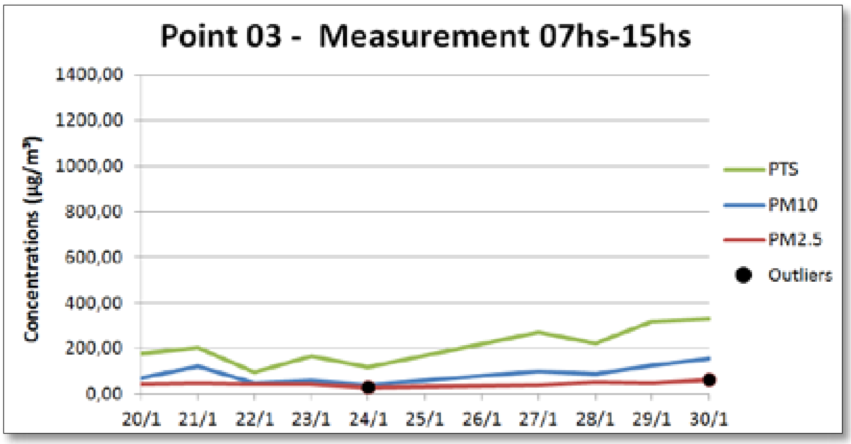

Figure 5: Evolution graph comparing the concentrations of STP, PM10 and PM2.5 in µg/m³ at different measurement days of Point 03

The data showed that Point 2 was the most environmentally impacted by concentrations of particulate matter during the studied period due to the fact of this point was located in the middle of the construction site, where several activities were carried out simultaneously along the six towers, such as masonry, concrete and cement projection, structure execution, vehicular traffic on soil, storage material at workplace, transportation and excavation and other were in development. The closest activities developed to point 1 were related to excavation activities, moving and transporting soil. This justifies the high level of PM concentration, causing major impact on the workers, the neighboring area and the environment. The influence that the construction activities represented in the PM emission will be proven by the subsequent chemical analysis of the material collected, as yet not available for this article.

In relation to the gravimetric samplers, it was observed that the founded values for TSP were 462.25 µg in Point 01, 1083.71 µg in Point 02 and 473.89 µg in Point 03. For the PM10, the values were 421.08 µg in Point 01, 452.88 µg in Point 02 and 197.11 µg in Point 03. And finally for the PM2.5 were 165.52 µg in Point 01, 168.26 µg in Point 02 and 100.14µg in Point 03.

Table 5: Descriptive statistics of concentrations in µg/m³ of Point 01, 02 and 03

Concentrations in µg/m³ of Points 01. 02 and 03									
Descriptive statistics	Point 01			Point 02			Point 03		
	TSP	PM10	PM2.5	TSP	PM10	PM2.5	TSP	PM10	PM2.5
Maximum	578.86	298.84	101.91	664.19	270.70	105.84	331.13	156.91	50.96
Average	462.25	198.09	75.89	483.12	213.94	77.85	212.31	90.00	46.84
Median	454.32	165.48	75.15	485.60	215.37	71.69	206.35	88.50	46.24
Minimum	361.34	121.52	55.77	307.65	138.28	53.24	95.63	39.73	42.89
Standard deviation	82.81	71.69	16.74	119.17	50.88	17.19	82.48	39.43	3.21
CV	18%	36%	22%	25%	24%	22%	39%	44%	68%

According to the data collected, it is possible to affirm that the field activities impacted environmentally through a higher emission of TSP during the studied period, which has an aerodynamic characteristic that favors its deposition on the immediate vicinity of the field. TSP are particles that have lower remaining time in the atmosphere, and therefore have deposition near the emission sources.

For data analysis, the calculation of the concentration of PM atmospheric was carried out through the mass obtained measuring the particles (Gravimetry) divided by the volume of air in each unit obtained on each sampling day.

The analysis of Fix Point of PM10 indicates PM10 concentrations (8:00 a.m.) and PM10 (10:00 p.m.). The average gravimetries obtained to PM10 (8 hours) for steps 01, 02 and 03 were: 208.75μg, 194.63μg and 200.63μg, respectively. Thus the average gravimetries found to PM10 (10:0 p.m.) were 325.36μg, 316.38μg e 283.29μg, for steps 01, 02 and 03, respectively.

The analysis of the concentrations of PM10 (10:00p.m.) indicates that the values obtained were always below the concentrations of primary and secondary standards of the Brazilian Conama Regulation 03/1990 (150 μg/m³ - 24 hours). The highest value was 78.32μg/m³ which was measured in the following days: 18 and 11/19/2013 of the first point. However, it is noteworthy that the data from this research sometimes exceeded the strict data from WHO (World Health Organization 2006) related to the Interina Goal (IT-3) (concentration limit of 75μg/m³), increasing the rise in short-term mortality over AQG value – air quality guideline. On the other hand, it is necessary to pay attention to the fact that these values represent the study period, and that the concentrations of particulate tend to vary significantly throughout the year (see Tab. 6).

Another analysis of the study was the rate of sedimentation of particles in the neighborhood, through the use of adhesive "stick pad" which consists of the provision of these adhesives within a range of 5, 10, 20, 50 and 100 meters. As to the to the stick pads results, it was noticed that the neighborhood is susceptible to emissions of the construction activities in its own neighborhood at its worst level, as the results presented “serious nuisance” in all collections, except the step 03 measurements of 50 metros from the stick pad, which presented a likely claim.

Table 6: Descriptive statistics of PM10 concentrations in mg / m³ in the Fixed Point

Concentrations (μg/m³) in Fixed Point						
Descriptive statistics	Concentrations (μg/m³) PM10 (8:00 a.m.)			Concentrations (μg/m³) PM10 (10:00p.m.)		
	Step 01	Step 02	Step 03	Step 01	Step 02	Step 03
Maximum	131.11	108.01	117.46	78.32	63.22	56.86
Average	90.71	89.31	78.30	53.26	51.77	46.96
Median	87.82	88.97	74.12	41.16	43.26	33.22
Minimum	64.18	60.74	45.43	48.52	53.24	48.33
Standard deviation	23.96	16.00	23.12	13.38	7.08	8.88
Coefficient of variation	26%	18%	29%	25%	13%	19%

Final Comments

Based on the results obtained in the three phases of the study and also based on specialists’ opinion, the need for adjustments in the methodological procedures adopted in order to obtain appropriate data to the reality of the study was observed.

It is necessary to adjust the criteria for directional measurement in order to measure the impact of the particulate matter to the neighborhood. Firstly, instead of installing the first group of equipment at the entrance of the construction site, which had collected contributions of the construction activities from the interior of construction site, the new proposal is to install the group in the neighborhood, so that they can get data dissociated from the emission of particulate matter from the construction site.

The measurement of the sedimentation rate performed using the sticky pads in the end provided insufficient data for the purpose of this study, because the PM that stuck to the stickers came from the construction and the neighborhood, instead of only the construction. Therefore, the suggestion is that the measurement of PM should be one using only MiniVols located in the neighborhood, and in this way, it will be possible to identify the discomfort in the neighborhood as a result of the MP and also to determine its origin.

Finally, this article presented the validation of the research protocol application, in order to determine the air pollution contribution by PM, so that it can be monitored on construction sites. However, further research is necessary in order to measure the MP on construction sites by adopting the adjustment in the proposed methodology presented in this paper and also to identify appropriate mitigating measures for different construction phase and use of constructive methods.

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BUILDING MAINTENANCE IN THE MINHA CASA MINHA VIDA PROGRAM: A CASE STUDY

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Abstract

The Minha Casa Minha Vida Program (MCMVP) was launched by the Federal Government in 2009, and it has funded more than two million Brazilian homes for low-income families, leveraging not only the segment of affordable housing in the country as well as the construction industry as a whole. For any housing project, it is important to provide information about building maintenance for final users. Therefore, an important role for the companies involved in the development and construction of housebuilding projects is to pass information at an adequate level of detailing for final users to perform maintenance activities, so that those properties have a long life according to the level of performance initially established. The objective of this research work is to understand how the developers of MCMVP identify difficulties and problems related to maintenance and how those companies have prepared themselves to meet the demands of the new Brazilian building performance standard, NBR 15.575. This is an exploratory qualitative research study based on case studies carried out in companies involved with MCMVP. Four semi-structured interviews with company directors from Juiz de Fora were held. This study aims to show the reality of maintenance services of the MCMVP projects according to the builders' perspective. The main contribution of this research work is concerned with the notions and impressions of entrepreneurs regarding maintenance of MCMVP buildings, and also regarding their understanding and knowledge about the building performance standard.

Keywords: *Maintenance, management, housing, Minha Casa Minha Vida Program.*

Introduction

The Minha Casa Minha Vida Program (MCMVP) was created by the Brazilian Federal Government in 2009, in order to finance, at low cost with funding lines of up to thirty years, housing for low-income families (Caixa 2012).

Since it was launched, the program has contributed to substantially reduce the housing shortage for low-income families in Brazil. These are the main figures of this Program for July 2013 (Caixa 2013):

a) 3.012.848 Contracted Units;
b) 497.703 Units being prepared for construction;
c) 808.867 Units in construction;
d) 1.706.278 Completed units; and
e) 1.405.710 Units delivered to the user.

Juiz de Fora is a town in the state of Minas Gerais. The city has a population of 516 247 inhabitants, its land area is 1,435.664 km2, and it has a population density of 359.59 inhabitants/Km^2 (Instituto Brasileiro de Geografia e Estatística 2010). In Juiz de Fora, MCMVP has delivered 21 projects, 5,078 dwellings, involving 250 million reais of funding (Duarte 2014).

The objective of this research work is to understand how the developers of MCMVP identify difficulties and problems related to maintenance and how those companies have prepared themselves to meet the demands of the new Brazilian building performance standard, NBR 15.575 (Associação Brasileira de Normas Técnicas 2013). As this is a new housing program, no research work has been developed so far about building maintenance in this context, from the point of view of housebuilding companies involved in those projects. This investigation explores the difficulties faced by those companies regarding the maintenance of these projects and how they are getting prepared to meet the new building performance demands.

Maintenance in Residential Buildings

Building performance is concerned with how buildings behave in use, according to certain conditions. However, it is a shared ambition of every society that buildings meet the users' expectations during a certain useful life and that they fulfill their technical and socio-economic function for each development in the country (Borges 2008).

It is also important to emphasize the need for maintenance to buildings, regarding technical and administrative actions. Technical actions are those taken by a qualified professional aiming to remedy maintenance problems. Administrative actions are those documenting the performed maintenance or the one to be perfomed, in order to replace or even restore parts of the building, making it thus able to maintain its original function with a satisfactory performance (Othman 2008).

Unfortunately, no plans are usually produced to perform the building maintenance that should occur as scheduled, so only corrective maintenance is carried out to correct defects and problems found after the delivery of buildings (Ricobom and Silva 2010).

According to the law of evolution of costs, the impact of an error during the project, in terms of costs, may result in building maintenance costs five times higher. Thus, if maintenance activities are properly performed, these will result in lower life-cycle cost and higher durability of buildings (Helene 1992).

All building components and their respective elements require regular inspections. Cleaning and maintenance work are essential to keep the building in perfect conditions. It is necessary to have good access to information in order to perform maintenance activities and designers are also expected to be coherent and to have knowledge of relevant technical standards and of all legal requirements so that an adequate access to maintenance can be provided (WU *et al.* 2007).

However, building maintenance should acquire a strategic character for the benefit of the users, so that they might enjoy their property permanently. This determines that the maintenance of the building should be effective and that this service must be available, reliable, of low cost and high quality (Pinto and Nascif 2012).

The environmental conditions where the building is located are also very important for maintenance, especially in tropical regions, which are characterized by environmental conditions based on major climate variations and variations in atmospheric pressure and humidity due to the presence of rainy periods. The location of the buildings, either in urban, rural, industrial, or near the coast areas should also be evaluated according to the macro-environment in which the building is located. Regarding microenvironment conditions, the following aspects must be taken into account: height, size, the solar orientation of the building and its use. All macro and micro conditions of the project environment should be taken into consideration so that a suitable process of building maintenance could be developed (Chew and Tan 2003).

According to Gomide (2011), regarding the dangers and lack of maintenance on buildings:

> The building accidents caused by failures in the construction or building maintenance have caused deaths and unjustifiable damages, especially with the aging and devaluation of our buildings. Landslides, fires, fall of marquees and façades, leaks and infiltrations can be avoided with preventive measures […].

Brazilian Standards for Residential Buildings Maintenance

By upgrading the standard for maintenance, the NBR 5.674 – Building Maintenance (Associação Brasileira de Normas Técnicas 2012), came to refer to building maintenance directed to management, which did not exist in the previous versions. This standard proposes a flow of documentation for the building maintenance process, as shown in Figure 1.

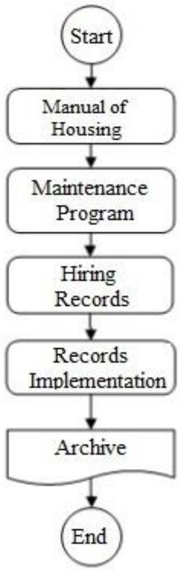

Figure 1: Flow of maintenance documentation
Source: NBR 5674 (Associação Brasileira de Normas Técnicas 2012).

Early in the building maintenance process, it is possible to observe the need for the evaluation of the user's manual for operation and maintenance, as described by NBR 14.037 - Guidelines for preparation of user's manuals for operation and maintenance of buildings (Associação Brasileira de Normas Técnicas 2011). This standard provides guidelines for the preparation and delivery of the manual by the developer or builder of the property to its owner. In turn, it is necessary that the owner performs the maintenance, in order to achieve a desirable useful life, with safety, solidity and reliability in this housing.

In order to perform a good maintenance, it is necessary to know the performance of the building, with the inclusion of the need for maintainability, which is nothing more than keeping the ability of the building and its systems to favor or allow inspections as established in its operating manual. The intention is that, with this maintenance, the building can achieve the project life cycle (LCP), as proposed by the NBR 15.575 – Performance for Residential Buildings (Associação Brasileira de Normas Técnicas 2013). This LCP is a theoretical estimate of the useful life of a building and it will only be met if the owner of the residence in question follows all maintenance assumptions of the owner's manual. Without the knowledge of these guidelines it is likely that the building does not achieve its LCP, bringing with it some frustration on the part of the owner. Figure 2 shows the LCP curve and the need for periodic maintenance in buildings.

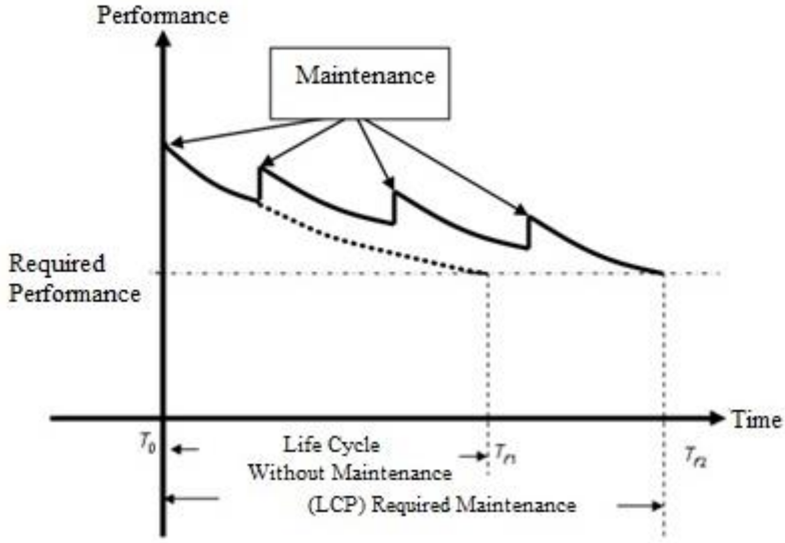

Figure 2: Performance over time
Source: NBR 15575 (Associação Brasileira de Normas Técnicas 2013).

Based on this information, it can be said that there is a strong link between the three standards: NBR 15.575 (Associação Brasileira de Normas Técnicas 2013); NBR 5.674 (Associação Brasileira de Normas Técnicas 2012) and NBR 14.037 (Associação Brasileira de Normas Técnicas 2011); since they deal with maintenance in buildings and they are of great importance within the analytical context of this research work.

Methodology

The research methodology used for this study is based on the implementation of semi-structured interviews with MCMVP entrepreneurs of the city of Juiz de Fora. Thus, we interviewed four entrepreneurs that, at some point, had been involved with the program and have delivered buildings to MCMVP, at least one year earlier (i.e. buildings delivered by the end of 2012), so that a post occupancy evaluation of these dwellings can be made from the perspective of construction companies and developers.

The companies were chosen according to the data provided by the Department of Urban Development of Caixa Econômica Federal (CEF) of Juiz de Fora (GIDUR/JF): the four local companies that have projects delivered to MCMVP with at least one year of use. There are other construction companies involved in the MCMVP in the city of Juiz de Fora. However, they were not listed since the scope of this study comprises only companies from this city.

The interviews were conducted directly with the directors of the companies participating in the MCMVP. Each participant answered 11 questions:

1. How long has the company been involved with the Minha Casa Minha Vida Program?
2. How many projects have been delivered to MCMVP?
3. Does the company intend to continue working with these developments?
4. Is the main focus of the company building for the MCMVP?

5. Is there a demand for maintenance by the users?
6. Is some measure taken in planning the future maintenance of this building during the process of designing these projects?
7. Is some stage of construction or construction method developed focusing on the future maintenance of this building during the execution of the work?
8. Does the company produce the user's manual? Does it deliver the manual to the owners and to the building manager separately?
9. Which are the most recurrent maintenance-related complaints by the users?
10. Is the company aware of the performance standard?
11. Which preparation is being made for future projects to be launched with respect to its performance?

In order to maintain the confidentiality of the respondents and their respective companies, the names of the companies participating in the research, as well as the names of their managing partners were not disclosed, as agreed with them. During data analysis, these companies were called: Company 01, Company 02, Company 03 and Company 04. Based on the answers to these questions, we analyze the data for each question, i.e., an individual analysis will be performed.

Data Analysis
The first question asked to the respondents referred to the time that the company is dedicated to MCMVP. All companies have participated of the MCMVP for at least 3 years. Three of the companies started the activities along with the program, in 2009. Only Company 04 began in 2010. Company 01 has not operated in the MCMVP since 2012. Companies 02 and 03 have been involved in this program from its beginning.

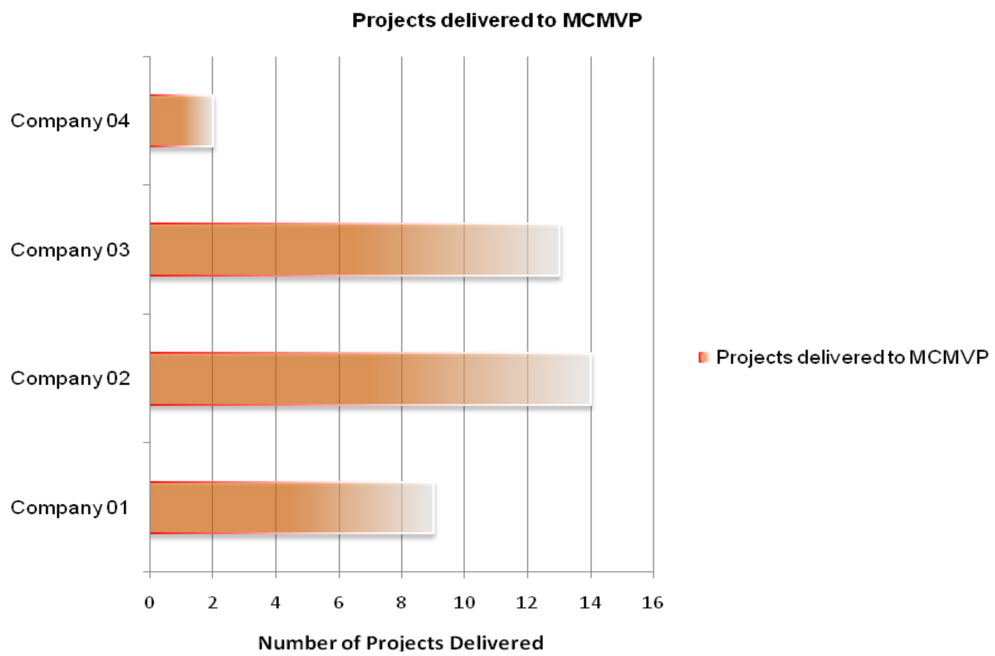

Figure 3: Projects delivered to MCMVP per company

Altogether, the four companies participating in this study have had 38 projects delivered to the program. Different types of housing projects were produced, such as apartment buildings, single houses and semi-detached houses. Not all projects were built in Juiz de Fora. Some of the developments were made in Volta Redonda (RJ), Niterói (RJ), Uba (MG) and Barbacena (MG). This variety of projects in different cities meets the reality of the deployment location of the projects. Another striking factor for companies to move from its headquarters in Juiz de Fora is the value enclosed in each housing unit, which may be more attractive for certain municipalities and regions. This value varies with the size of the city where the project will be implemented, and it is tabulated by CEF.

When respondents were asked if they wished to continue working with the developments of MCMVP, there were different opinions. Two of the companies said that they intend to continue working with the program and the other two have no interest in continuing building.

The companies that have an interest to stay in the program (Company 01 and Company 04) highlight the ease of working with MCMVP, with simple designs that fit the dynamics of the company, for having skilled labor accustomed to work with the construction methods used in the program. Another feature is the use of the same design to suit different regions. According to the interviewees, there is an increased production of labor for working in a systematic and sequential manner. It is possible to work with small teams of high productivity. Another factor indicated by the entrepreneurs concerns the turnover of labor. Since there are trained and prepared staffs to work in this type of venture, it is necessary to be always building something so that they do not miss these teams of workers already formed and trained with high productivity.

On the other hand, Companies 02 and 03 have no interest in continuing working with MCMVP, at least for now. Among the issues raised, the following ones were pointed out: low profitability in building for the program, high level of maintenance, lack of conditions granted by the municipality, and even difficulty in delivering the project.

Of the four companies participating in this study, only Company 04 is focused on the MCMVP. However, it is worth noting that it is a temporary situation, since the parameter considered in this comparison is the percentage of gross revenues accumulated in the last year, which surpasses the other ongoing developments. For Companies 02 and 03, the program represents about 30% of their current income. Company 01 has no MCMVP venture currently running.

The existence of building maintenance for the post-construction period is a consensus among the listed companies. All companies stated that there is a good demand for maintenance from the delivery of the property, and that these requests decrease with time. Company 03 respondent emphasized that the rate of requests for maintenance decrease gradually up to two years after the delivery of the property Still, according to the directors of Companies 02 and 03, often, the request for maintenance by the user is not consistent with the demand, and it is done incorrectly, whether due to the lack of maintenance and cleanliness by the user or even the to the misuse of facilities or building systems or to the lack of prior reading the user’s manual. The maintenance made by the company in these buildings is of corrective nature, since some defects related to the construction process itself or even artisanal ones might occur. For most users, it is common sense among respondents that there is no preventive maintenance. According to the interviewees, even if the owner's manual mention how to proceed with such maintenance, users do not have the habit to do preventive maintenance, which results in some visits by the companies due to defects caused by the absence of this type of maintenance, for which, in turn, the company has no responsibility.

Regarding the user’s manual, all companies deliver their manuals to the property’s final user. An edition of the owner's manual is also delivered separately to the building manager in case of multifamily developments. Manuals are delivered along with the delivery of the property. According to the entrepreneurs, there are no difficulties in making such manuals, because many of them already delivered manuals when the NBR 14.037 (Associação Brasileira de Normas Técnicas 2011) came into force in 1996. The owner of Company 04 also mentioned that the manual is prepared according to material provided by the SINDUSCON/MG, which has a booklet with guidelines for its preparation.

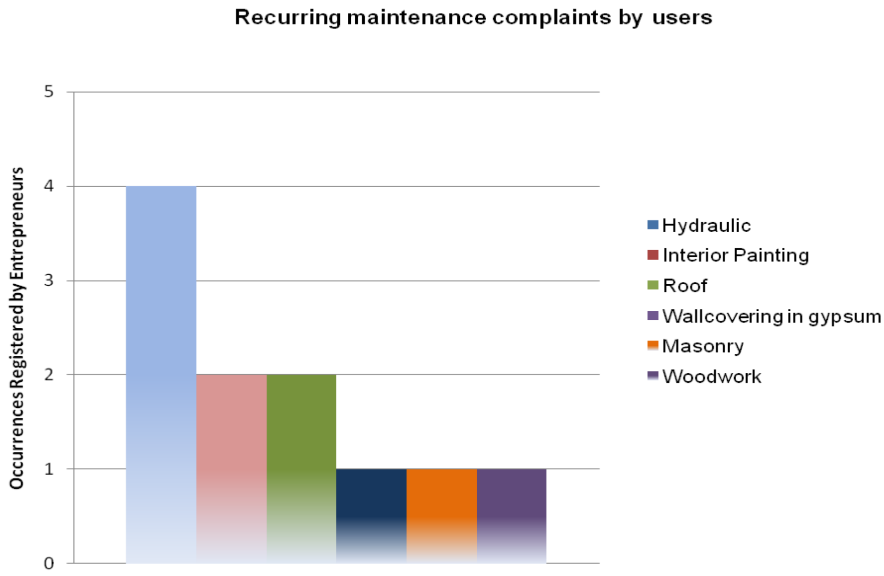

Figure 4: Maintenance request by users

As explained in Figure 4, respondents were asked about the higher maintenance rates in dwellings delivered to MCMVP. Each of the four respondents had the opportunity to list the major events in their respective companies. Therefore, we quantified all occurrences listed by the respondents. The number of occurrences reflects the sum found for the four interviews.

When asked about the demand for maintenance by the users, all respondents were unanimous in saying that the biggest problem with the maintenance of these projects goes through the plumbing. Most of these problems are related to leakage caused by the drain of bathrooms and by the connection of toilets with the sewage system.

Internal painting and roof maintenance are also recurring maintenance requests. According to Company 02, internal painting draws attention because it is often misused by the users who let the inner walls get wet with water. Maintenance requests for roofs normally occur due to the incorrect installation of satellite antennas and related devices on these structures and also due to the inappropriate traffic of residents on the toppings.

Other events: plaster coating, carpentry and exterior painting were randomly raised during the interviews because these are occasional problems, found only in a particular venture or housing.

In relation to the local needs for maintenance, entrepreneurs were asked about the existence of concerns related to the maintenance for the stage of project design. All entrepreneurs were quite adamant in saying that during the design phase there are many concerns with maintenance. Among these, they cited:

a) specification of materials aimed to ease the maintenance by the user. For example: traditional materials in the construction industry or materials easily found in local shops;
b) development of design, as much as possible, with a single “damp wall” (wall in which water pipes and sewage tubes are installed) joining the points of probable maintenance of kitchen, laundry and bathroom pipes, thus making it easier to find probable water infiltrations and leaky pipes;
c) roof design with detailed wood or metal crating and tiles covering;
d) definition of expansion joints at the design stage, especially for buildings in structural masonry. These should be established along with the structural design;
e) concern with the design for wastewater and rainwater systems, so that they are not in places of difficult access and maintenance. They must be designed so that grease traps and pass boxes remain in areas of common use, in order to give access to all residents; and
f) definitions regarding restricted areas, sealing materials and construction methods used. Three companies interviewed reported a special concern about sealing the wet areas, at the design stage of the project, due to maintenance history.

In relation to the existence of precautions in executing building works aiming at their maintenance, again, all agreed that there are several precautions:

a) the laying of floors for wet area, the way in which mortar is spread on ceramics and floor, with uniform joints which must be well cleaned before the application of grout, because, according to one of the interviewees, poorly settled floors generate high maintenance due to the early detachment of ceramic pieces;
b) another important point, which is also a consensus among respondents, is the installation of plumbing. This procedure is closely monitored due to the high degree of maintainability. The whole procedure of gluing and clamping pipes, hydraulic connections and parts must be observed. As important as connecting pipelines, they also highlighted the installation of toilets and laundry tubs that complement the hydraulic assembly services and are also performed by plumbers;
c) the paving of common areas is also considered of paramount importance, since Company 02 has had problems with paved parking lots without the appropriate load support for trucks; and
d) external cladding was also cited by Company 03 as a service that should receive extra attention so that there is no maintenance, since, for most residential buildings of MCMVP the external cladding is made by using large panels, through scaffolding assembled for the execution of this type of service. Therefore, according to the entrepreneur, it is very important to carefully monitor this service because the façade maintenance is very expensive for the company.

When questioned about the NBR 15.575 (Associação Brasileira de Normas Técnicas 2013), all companies reported to know the standard and that its adoption has been enforced by law. However, the projects executed by all these companies were approved before the law entered into force, so there was still no projects being executed according to the requirements of that standard. The director of Company 04 said that the standards are difficult to apply to low cost housing projects, due to the large number of requirements and intervenients mentioned in those standards. This view contradicts the expected development for the sector, since the entry into force of those standards is a fact and the market must adapt to it. Company 01 says that it is seeking solutions together with its technical and legal department about the new demands to be adopted. Companies 02 and 03 say they are looking for solutions together with the external designers and with the company's technical analysts. However, nothing conclusive was presented by the respondents in order to implement the performance standard in their projects.

Conclusion

During the study, some concerns on the part of entrepreneurs were identified, both in the design process and in the implementation of projects for the Minha Casa Minha Vida Program. This concern can be explained by the duties of the entrepreneur in relation to the user, which are set by the Consumer Protection Code, since within the warranty period, the company needs to meet the demand for corrective maintenance requested by the user.

We have also concluded that from respondents' perspective, preventive maintenance is virtually non-existent, and that users do not follow the maintenance guidelines mentioned in the users' manuals, so they improperly require companies to perform any kind of maintenance that occurs on their property.

The study has some limitations since it uses the data from only four companies, and the results are based on the perceptions of respondents. However, it is believed that some measures can be taken in order to improve this situation through a better dissemination:

a) of the good maintenance practices in the companies, in order to enable them to develop more suitable users' manuals for the type of work in question; and
b) of the need for residents to conduct the preventive maintenance proposed by the user's manual.

Regarding the NBR 15.575 (Associação Brasileira de Normas Técnicas 2013) - Performance for Residential Buildings, effective measures for the deployment of standard assumptions were not yet taken by the companies. Information on this issue provided by the companies is still very reticent, and there is nothing conclusive to be done regarding the new MCMVP buildings. This demonstrates the need to disclosure the performance standard by employers, either by symposia, meetings or seminars, aiming to resolve all doubts inherent to the process of implementing the standard.

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