The Visibility of Zero-Energy Housing

PROCEEDINGS
30th October-1st November 2013, Coral Gables, FL, USA

ZEMCH 2013
INTERNATIONAL CONFERENCE

MIA MI
PREFACE

The ZEMCH2013 International Conference is a follow-up to the 2012 conference that was held in Glasgow UK. It brought together academic and industry experts from Australia, Canada, China, Italy, Japan, United Kingdom, United States, United Arab Emirates, Spain, Philippines, Iran, Saudi Arabia, Qatar among others in interactive sessions that discussed the issues surrounding the analysis, design, production and marketing of low- to zero-energy mass customizable homes and communities from around the world. The conference was open to any stakeholders who are involved in housing research, business, teaching, and policy.

The effect of climate change is widely experienced around the world to include rising sea water levels, ambient temperatures that would impact on the indoor comfort of those in buildings. Yet housing is a complex system of energy and environment that demands a delicate balance between the needs and wants of the society. Housing is a major building block of the urban core of cities and a major contributor of carbon emissions and changes are needed in their design to ensure the emissions are lowered. The changes include the reliance on renewable energy, recycling of resources and use of appropriate technology that are customized to the end-user.

Housing is a system of energy and environment and required to accommodate wants and needs of individuals and society, which are usually considered to be diverse and dynamic. The 'needs' factor often reflects minimum quality of end-user products (i.e. housing) and may embrace 'adequacy' being prescribed in conventional codes, while the 'wants' may be satisfied only if they are defined clearly by stakeholders (e.g. house-users and builder/developers) at the design decision making stage. 'Mass customisation' is an oxymoron or, perhaps, a paradigm case of a systems approach to identifying the aforementioned wants and needs that should be incorporated into the design of end-user products (or homes). Albeit increasing market demands for achievement of social, economic and environmental sustainability in housing today, conventional homebuilders (and housing manufacturers alike) who are often reluctant to spending extra time, money and effort for information gathering of new products and services are still barely able to adopt recently emerging innovations including mass custom design approaches to the delivery of sustainable affordable homes.

Over the years, interest in Zero-energy homes/buildings is beginning to bear fruit not only worldwide but also in the United States. Not only is the ZEMCH Network working hard in promoting the academic-industry collaborations. The papers presented at the conference explored themes such as sustainability from the social, and economic, design and Construction Management; and environmental perspectives. In addition, it examined how sustainable mass-customization and personalization; value analysis and visualization contributed to reduction in carbon emission. It also took into perspective the effect of user behavior and choice on energy consumption, renewable energy and technology among others.

The works presented here in the proceedings are examples from different countries around the globe representing different climates that highlight the hope in a sustainable future.

Dr. John Onyango, ZEMCH Network Miami regional director, School of Architecture, University of Miami, Coral Gable, FL USA
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Chapter 1: Social and Economic Sustainability

THE EMPIRICS OF EMOTION - WHAT ADVERTISEMENT REVEALS ABOUT THE HOUSING STAKEHOLDERS’ GENUINE MOTIVATIONS

Eric Firley

Abstract

With special emphasis on sustainability issues, the paper investigates marketing strategies in housing, adding to a more orthodox and conventional body of knowledge regarding the “needs and wants” not only of the alleged end-user, but also of other entities participating in the process of housing production.

There is little doubt among professionals that sustainability is together with affordability the main challenge for new housing construction and the renovation of the existing housing stock. Due to the complexity of the development process, its relative inertia, the multitude of protagonists, as much as financial and regulative pressures, it is however difficult to evaluate, let alone measure the consumer’s real attitude towards sustainability and his willingness to - directly or indirectly - pay for its improvement. This is also the case for the here-discussed restricted definition of sustainability that focuses on ecological performance through energy-savings and the reduction of carbon emissions.

In a similar way as for other products, the analysis of advertisement techniques and content in the residential sector does not only reveal information about the product itself, but also about the (alleged) desires of the consumer group that it targets. New trends are either created or identified at a very early stage. As one of the main theses of the paper, it is hence argued that a comparative analysis of housing advertisement will help unveil information that neither sales figures nor direct surveys can provide. Another outcome of this exercise is a better understanding of what aspects of sustainability are considered to be the most attractive: depending on the market, are the recipients mainly interested in the health aspects, in potential savings, or in civic responsibility?

Introduction:

The author based his research on a sample of 60 privately developed condominium projects in four American and European cities. Of these 15 multi-family developments in each of the four cities, the vast majority is still in planning or construction. The chosen markets are Munich and Berlin in Germany, Paris in France and Miami in the US. All projects are situated within the political boundary of the city itself, excluding the metropolitan region. This is specifically relevant in the case of Paris
and Miami where the metropolitan regions in terms of surface and population are several times larger than the cities themselves. The choice of projects has been made through national- or city-specific internet portals that advertise condominiums to the wider public. Even though the author cannot claim that the selection has been made according to a scientifically random procedure, it should have representative character, as the only criteria of exclusion and pre-analysis have been size and authorship. The aim was hence to select developments of a certain minimum size, only one (in Paris) counting less than 20 units, and to restrict repetition to a maximum of two projects by the same developer in each city. According to these simple rules, the search of 15 projects in the two German cities was - as a result of a larger offer - easier than in Paris or Miami. In the latter case, the difficulty to gather 15 new projects was not only due to the city’s limited surface and recent real-estate crisis, but also to the prevalence of the tower typology. Each of the developments counts in average almost the double amount of units compared to the samples of the three other cities.

The decision to choose two of the four cities from the same nation, Germany, has been triggered by the motivation to investigate potential regional differences in terms of market approach. The results will indeed confirm that a differentiation by nation is neither sufficient nor accurate. The following table highlights some of the four cities’ fundamental features: size, population, density per square mile and average condominium price per square foot (as of the end of 2012).

<table>
<thead>
<tr>
<th></th>
<th>Munich</th>
<th>Berlin</th>
<th>Paris</th>
<th>Miami</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>1,448,000</td>
<td>3,479,500</td>
<td>2,234,000</td>
<td>400,500</td>
</tr>
<tr>
<td>Surface (sq. miles)</td>
<td>119.97</td>
<td>344.35</td>
<td>40.7</td>
<td>35.87</td>
</tr>
<tr>
<td>Density</td>
<td>12,070</td>
<td>10,105</td>
<td>54,889</td>
<td>11,165</td>
</tr>
<tr>
<td>Price per sq. ft in $</td>
<td>460</td>
<td>270</td>
<td>1,012</td>
<td>366</td>
</tr>
</tbody>
</table>

Table 1: Key data for the four chosen markets (2012)

Interestingly, and maybe deceptively, the price order in these four places goes in line with the order of densities. Regarding the latter parameter, the French capital, as the western world’s densest large city, is clearly leading and over four times denser than the second ranked Bavarian capital. The figures’ close ranges for Munich, Berlin and Miami veil a different type of spatial and morphological organization, specifically for the Floridian city. With just 400,000 inhabitants of a metropolitan region of over 2.3 million, an analysis within the city boundaries does not reflect the poly-nodal urban reality that spreads extensively along the coast between the sea to the east and the Everglades to the west. In addition, higher overall densities can be found outside the city itself, for example in Miami Beach or Hialeah. The three European places follow comparably simpler population logic, featuring the highest densities in the center and concentrically dropping ones towards the boundaries.

In terms of market cycles it might be useful to mention the specificity of the American case, recovering strongly from a severe real estate crisis that had abruptly halted a spectacular wave of residential development in inner-city areas between 2000 and 2008. The major particularities on the European markets are the difference in reaction to the European Debt Crisis, in which the German market seems to take profit of its neighbors’ weaknesses. For the first time since the mid 1990s, Paris has in the last two years experienced mildly decreasing apartment prices. The relatively
gloomy outlook of the French economy might also explain why it is the only one of the four tested markets in which the average price of the 15 new projects is roughly in line with the average apartment prices of the city as a whole. In the three other places, the new-built developments are offered at a considerably higher price than the current average. Berlin, due to its still relatively new status as the German capital, is an extreme case of this phenomenon, and has over the last five years - despite major budget issues and stagnating population growth - registered average price increases of over 10%, starting though from a low level. Unlike Paris and Munich, over decades infamous for prohibitively high prices and a chronic scarcity of offer, Berlin has historically not been a developers’, but a renters’ market. This is also literally the case, over 80% of the population living in apartments that they do not own.

<table>
<thead>
<tr>
<th></th>
<th>Average price (per sq. ft in $)</th>
<th>High (per sq. ft in $)</th>
<th>Low (per sq. ft in $)</th>
<th>Ratio (high/low)</th>
<th>Average size (in sq. ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munich</td>
<td>776</td>
<td>1,304</td>
<td>494</td>
<td>2.64</td>
<td>1,050</td>
</tr>
<tr>
<td>Berlin</td>
<td>474</td>
<td>845</td>
<td>345</td>
<td>2.45</td>
<td>1,036</td>
</tr>
<tr>
<td>Paris</td>
<td>1,159</td>
<td>1,645</td>
<td>858</td>
<td>1.92</td>
<td>755</td>
</tr>
<tr>
<td>Miami</td>
<td>457</td>
<td>1,036</td>
<td>347</td>
<td>2.99</td>
<td>1,300</td>
</tr>
</tbody>
</table>

Table 2: Price and size comparison for 2-bedroom condominiums (based on a sample of 15 recent projects on each market)

Key to the accurate understanding of this paper is the fact that the presented research only relates to the comparison of marketing material in the form of internet-websites and brochures. The research idea is hence not the analysis of effective building performance, but the analysis of what building features are given priority in terms of communication between the developer and the prospective buyer. The author was for example interested to know, if a developer considered it relevant or helpful to advertise his building with the mention of a sustainability label. He was not interested to know, if it actually received a label, or if this label entailed stricter requirements in one market than a different label in another. Theoretically it is possible that this study counts the most energy-efficient project as one that defines itself only through design, lifestyle or safety features. It is assumed that the marketing strategies of these multi-million dollar investments are highly professionalized, and that each word, image or video as been chosen with great care in order to trigger a positive reaction. If an important feature is explicitly not mentioned, the omission as such is arguably conclusive.

Main part:
The Miami samples do not only offer the largest amount of units per development (211, compared to 120 in Munich, 86 in Berlin and 70 in Paris), but they are also consistently high-rise, 14 out of 15 examples counting more than 10 floors. All three European cities together offer only 3 towers as a living option, the Parisian case being the renovation of an existing structure. Except of Paris, where the construction of tall buildings is (still) prohibited within the city-boundaries, this is not only a question of zoning laws and building codes, but also of preference and real estate logic. The plus-value provided by unobstructed sea-views in Miami seems to easily pay for the additional construction cost of high-rise. In terms of average size of a 2-bedroom apartment the two German markets represent with around 1040 sq. ft the middle ground, the same Parisian offer being
approximately 25% smaller, and the Floridian one over 25% larger. These disparities become more pronounced, if the size comparison is extended to the total offer, including condominiums with more than two bedrooms. Targeting in majority the top market, the largest units in Miami can reach over 8,000 sq. ft. Two brochures even mention the availability of domestic quarters in the penthouses.

A similar multi-millionaires’ market exists in Paris, and to a smaller extend in Munich and Berlin, but is usually not to be found in the new-built sector. Miami’s excessive reputation seems to fit the fact that it holds the highest price variations per sq. ft, the top products asking for almost three times more than the most affordable. In the French capital, by far the most expensive market per sq. ft, this ratio remains under two. Even though Berlin appears with 9 multi-lingual websites out of 15 as the most international market, this impression might be deceptive, as German is also the least widespread language of the three. Therefore, the regional comparison between Berlin and Munich is more meaningful, as none of the Bavarian samples tries to reach non German-speaking clients through the internet.

For the chosen projects, Munich appears in general as the most local, homey and sober market. Lacking most of the lifestyle-oriented marketing of the other three cities, the documentation usually focuses on the praise of the locational advantages of the districts in which they are situated. Highlighting different spatial development logic than the other markets, these districts are in 13 out of 15 cases not in city-center locations. A stark difference can be noted in the type of internet use in each market: in Berlin and Miami, almost all projects have their own website, in Paris only six, and in Munich all content with the developer’s main site or advertisement through specialized sales portals. All markets are transparent, even on the internet, and only the most exclusive developments in Paris and Miami, one example in each city, remain confidential and do not publish any prices on the web. In Paris, several companies, for five projects out of 15, collect client information in making brochures accessible only after the provision of name and e-mail address. It can be assumed that the actual sales and marketing procedure differs considerably in each of the four markets, but the Floridian case stands out through the apparently stronger position of the realtor. For several towers, the websites seem to be conceived by them and not the developer. Sometimes both co-exist in parallel. Security-issues count much more as a sales argument in Paris or Miami than on the two German markets, which seem to limit their efforts and needs to the video-intercom (1/3 in Munich, 2/3 in Berlin). In Paris, additional protection is usually provided through secured gates and reinforced apartment doors. Concierge services and video-surveillance, almost a standard in Miami, also due to the size and spatial organization of the developments, remain however an upscale offer in Paris for only four of the tested case studies.

As a result of a comparably fact-based communication style, four out of 15 products in each of the two German cities do raise the topic of investment-opportunity and attractiveness as a rental unit. Though arguably not less important in Paris or Miami, these financial issues are completely banned from the first layer of communication that the author scrutinized. Even more surprising is the quasi omission of affordability or value-for-money. Only 4 of the 30 German projects explicitly raise this point as a sales argument. Miami appears again as the extreme case, not a single brochure even mentioning the topic. On the contrary, nine of the 15 projects are marketed as decidedly luxurious, explicitly targeting the very top market. In terms of investment-calculation, it might be worthwhile
mentioning that the comparably low Floridian prices per sq. ft can be misleading. The abundant offer of communal services including pools, spas, club rooms and fitness centers as a standard for almost all new projects, entail monthly maintenance fees of approximately 1$ per sq. ft, far more than in the smaller European units in which communal amenities, valet and concierge services are very rare.

Regarding the fittings of the private units, certain standardization can be perceived especially in the two German cities, all projects featuring hardwood floors, floor heating and electric shutters. The Parisian market is similar, though floor heating seems to be an upscale option. In Miami the offer is more diverse in terms of materials, also due to the different climate. Custom interior design and furniture services included or at an additional expense, have become an increasingly popular offer, in line with home automation (Paris and Miami). Bright light conditions through high ceilings and floor-to-ceiling windows are a standard for all markets, as much as privatized exterior balconies, terraces or loggias. The position of architectural qualities as a sales argument, measured for our purposes indirectly through the mention of the architect’s name, differs considerably according to the markets: in Miami and Paris, with respectively 11 and 8 out of 15 cases, the description of the architect and his building concept is an important component of the presentation material. Berlin follows with 6 occurrences, and Munich with only one. In addition, the strong correlation of high prices per sq. ft and the architect’s explicit mention suggests that the top market consistently believes in the marketing attraction of the architect. The extreme case is again given by Miami, in which the two most expensive projects have been designed by two world-renowned London and Copenhagen-based starchitects. In stressing the expression 'museum-quality' several times, one of these projects makes very clear what type of additional value the developer expects through his investment in world stars. A similar logic can be perceived for other projects through the hiring of famous (product) designers, presented despite their much more limited implication usually not along, but in front of the architects. On this peculiar Floridian market, architecture, art and hip design merge together into an extreme example of image-oriented marketing for which it is difficult to judge, if it exemplifies a new international trend or just the excess of an old way of doing. In a city that - due to its young age - still cannot compete with the cultural treasures of the three European counterparts, it seems compelling to sell sophistication as an internalized feature, through the use of acclaimed designers, but in some cases also through the showcase of art collections in the buildings’ communal spaces.

<table>
<thead>
<tr>
<th></th>
<th>Dedicated Website</th>
<th>Multiple languages</th>
<th>Mention of architect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munich</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Berlin</td>
<td>14</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Paris</td>
<td>6</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Miami</td>
<td>14</td>
<td>3</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 3: Differences in communication on the four markets (based on 15 developments in each city)
Regarding questions of architectural style, it is remarkable to realize that all 60 projects consistently follow a modern or contemporary tenor. It can only be assumed that this is not only a style-question, but indirectly linked to the above-mentioned consumer demand for partly or fully glazed facades.

The position of “green issues” in the condominiums’ sales strategy - this paper’s main focus - can be interpreted in different ways and according to numerous criteria. In terms of scale, the author distinguishes between urban components - mainly public transport and pedestrian connectivity -, architectural features and interior qualities. Regarding the content of what is meant to be considered “green”, energy-efficiency is investigated next to well-being and ecological responsibility. Of special importance is the mention, or not, of dedicated sustainability labels.

In a stronger way than expected, the four markets differ considerably in the appreciation of these components. In regard to “family living in the green”, Munich appears as the most uniform one, probably also due to the less central situation of the projects. Most developers praise the environmental, pedestrian and infrastructural qualities of the respective sub-centers, stressing the healthy lifestyle that their family-oriented clients will be able to enjoy. It is difficult to evaluate, if this sub-urbanism preference is the random result of the small sample, if it responds to the actual demands of the clientele, or if it is the consequence of the non-availability of city-center plots. The Berlin and Paris case-studies do almost in their entirety equally mention green elements in the form of neighboring parks, planted courtyards or terraces as a major sales argument, but the spotlight clearly is on the excitement of urban life, including the ubiquity of public transport. In the case of Paris this commercial strategy can easily be explained through the fact that the less dense areas are situated outside the administrative city-limits, and are hence not part of the selected sample. On the current Berlin market the situation is slightly more complex, and the elevated price-level as much as central situation of the majority of projects suggests that the vibrant and hip metropolitan qualities of the new German capital are meant to be sold at a premium to new arrivals and German or foreign investors. Slightly less dense than Munich, Berlin has from a spatial perspective very much the opportunity to address green family needs, but currently this seems not to be the market demand, at least not the one of the upscale market that most developers target. It is revealing that the average per sq. ft price for a 2-bedroom apartment of our sample is sold at over 75% above Berlin’s average sq. ft price - old and new - in the last quarter of 2012. In Munich this figure stands at a still impressive 69%, in Miami at 25%, and in Paris at 15%.

In Miami the relation to the sea is unsurprisingly a key marketing component, but sophisticated city-life and pedestrian qualities are highlighted in almost all brochures. However, the connection to public transport is mentioned in only four of the 15 examples. This might be linked to the usually abundant availability of parking spaces, car-oriented lifestyle in general, or the limited reach of the existing transit network. Private parking spaces are publicized in 12 to 13 cases out of 15 of the German and Miami markets. In Paris, only 8 out of 15 brochures do mention such amenities. Even though a detailed analysis is not part of this study, there seems nonetheless to be a difference in parking ratios, as several of the parking’s of the European examples contain fewer spaces than apartment units.
Regarding the building itself, as a lifestyle product and not part of an urban agglomeration, less than a third of the two German markets insist on ecology as a genuine focus, even though the double amount of projects do mention some energy-saving building technologies, usually in the form of triple-layered windows. In Miami, real-estate marketing appears to avoid the topic of sustainability, only one development mentioning energy-savings and ecological performance. In comparison to the German examples, which in 8 and 10 out of 15 cases refer to specific labels of ecological building performance, only one of the Floridian projects mentions a certification (LEED Gold). In view of these flagrant differences in terms of communication strategy, it would be interesting to know, if Miami is representative for the US market, or an exception.

Within our selection, the Parisian market takes a special position. This fact relates to the conclusiveness of the figures as much as to the political background of how these figures have emerged. Dwelling much more intensely on the issue of sustainability than even the German examples, the French developers’ communication strategy leaves the impression that green issues have become a key sales argument. 14 out of 15 projects refer to at least one sustainable construction label, 11 further insist - directly or indirectly - on green living as a lifestyle choice, and 9 go into technical details regarding the implementation of energy-savings.

<table>
<thead>
<tr>
<th></th>
<th>Affordability</th>
<th>Targeting luxury market</th>
<th>Video Intercom</th>
<th>Other security features</th>
<th>Energy-saving features</th>
<th>Presented as sustainable</th>
<th>Mention of specific labels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munich</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Berlin</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Paris</td>
<td>1</td>
<td>2</td>
<td>8</td>
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<td>9</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Miami</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: Affordability, security and sustainability features, as mentioned in the marketing brochures for the four markets (based on 15 developments in each city)

Conclusion:
However, what crystallizes as one of this paper’s major surprises - arguably putting at-absurdum some of its fundamental precepts - is the fact that this insistence on green issues has been in many cases master planned by the collaboration of the private and public sector. The majority of the large developers, as part of a federation, have signed the "Plan Climat", an initiative of the Mayor of Paris that aims to surpass federal regulations in terms of ecological performance. The first stipulation of this charter mentions the agreement to communicate about sustainability issues to the wider public.

The average condominium builder hence assumes an educational role, even in its sales campaigns, and does not only cater to the « (alleged) desires of the consumer group that it targets », as stated in this paper’s abstract. These complex workings, emblematic for a country, which is notorious for the power of its public sector, have considerable political and economic implications. Of value as
potential recommendations for other markets, they can however not always be literally translated. Taming down the singularity of the educational argument, it can be assumed that the developers would not engage in a communication strategy, if they feared a negative economic response. It is thus not proven that the green bias of the Parisian samples does not go in line with a more pronounced interest of the public in these issues.

As a technical observation regarding the different sustainability labels and certification systems, the semantic analysis of the four markets’ 60 case-studies and brochures raises some questions regarding the verification of the constructions’ actual performance. Conspicuously often, the documentation mentions « efforts » or « determination » to fulfill specific ecological benchmarks, rather than a certainty to do so. Within the frame of this paper it is not possible to determine, if this is just due to legal caution, or to more fundamental issues of technical evidence.

In summary, this study suggests that sustainability issues have, with the exception of Miami, started to penetrate the marketing discourse on the condominium market. However, in view of the urgency of contemporary environmental problems, and their ubiquity in the professional and public media, the space dedicated to this topic remains relatively modest, even in the case of Paris. The impression prevails that there still exists a pronounced incoherence between the perception of the issue and its conceptual understanding and communication as a successful sales argument. This is also the case of many projects that do attend to fairly high ecological building standards. Very rare are the examples that manage to present ecological issues with a certain amount of glamour, a quality that seems to be of key importance for the attraction of buyers. From this point of view, the condominium market shares some similarities with the car market, and might be able to learn similar lessons. Fuel-efficiency, the use of recycled materials or the preference for smaller sizes are still not at the center of marketing campaigns, but brands like Tesla, Smart and Daimler’s Bluetec models have been able to attract attention with a new understanding of « green chic ». The above-mentioned condominium buyers’ apparent insistence on oversized glass elements bears by the way some similarities with the appearance of « fuel-efficient » SUVs or sports cars, symbolizing a certain paradox between the consumer’s desires and his ecological conscience.

Notions that cannot that easily be translated from the automobile to the real-estate market are the ones of scale, process and community. Our deliberate focus on the mass market might explain why the here presented random selection does not comprise projects that explore a more sophisticated approach to ecological living, including health aspects and alternative architectural compositions. One reason might indeed be the rarity of such projects, but another one is the fact that some groups of builders have lost confidence in the professional offer and decided to implement their own concepts. Conceived by owner-occupiers, the often exciting results of these initiatives will by definition not appear on the new-built market that we decided to examine. A good example for this tendency is the “building group” trend in Germany, where individuals team up in order to develop multi-family housing according to often specific ecological and social demands. This extreme case of small-scale and bottom-up development does not need advertisement, but political support in order to have access to land. The vision of a condominium as a simple consumer product is hence questioned. Equally questioned through these small-scale examples, though not necessarily refuted,
is the simplistic vision of ecological progress through the use of economies of scale by large development companies. Who is really driving progress, how and why?

As a final comment, the author would like to stress the importance of the link between sustainability and affordability. As a preoccupying result of this study, it has become obvious that even on markets with limited pressure, cost-efficiency is not a quality that developers are focusing on. As long as there is a suspected demand from the upper market - may it be local or global - housing providers will try to address it. This raises not only social questions of inclusion, mixture and access to employment, but it also has considerable impact on city-life itself, through the use of public space and the long-term growth perspective of economic capital. Are completely gentrified cities really the innovation centers of the future, and if they are not, shall it be left to state intervention alone to cater to the demands of the population’s vast majority?

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URBAN ACCESSIBILITY AND SOCIAL SUSTAINABILITY

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Abstract
The research “Design without barriers” (coordinated by prof. Alessandro Greco) belongs to the applied studies developed by the STEP Laboratory (Laboratory of Science and Technology for Building and Design) of the Department of Civil Engineering and Architecture (DICAr) of the University of Pavia, focusing on the accessibility of historical buildings and urban pedestrian mobility. It deals with the assessment of the accessibility level of the urban centres of Pavia, Vigevano and Voghera, the three major urban centers of the Province. In particular, this contribution presents the specific study case of Voghera. The accessibility assessment tool, consisting of parameters that can be objectively detected and surveyed, lets to define the accessibility level (high, medium, low) of streets and squares, divided into path sections and pedestrian crossings. The analysis is applied to paths related to the main elements of the town, with particular social values, also considering tourism (the Cathedral, the Town Hall, the Railway Station, the Post Office, the main Hospital, the main Schools, the Cinema, the Museum and the Castle). This project is developed in collaboration with UICI - Unione Italiana dei Ciechi e degli Ipovedenti ONLUS (Italian association for blind and visually impaired people) with the aim to involve people who directly experience the difficulties caused by the architectural and sensorial barriers, in order to get important considerations from their particular perspective. In addition, the specific survey method involves students from institutes for surveyors also because they will be the next designers in the near future. This methodological approach has the main purpose to create a strong relationship between designers, researches, students, associations and people with disabilities in order to increase the participation and the inclusion of all, improving the knowledge of accessibility as one of the main aspects of the so called Social Sustainability.

Keywords: Social Sustainability, Accessibility, Participation, Inclusion.

Introduction
The STEP Laboratory (Laboratory of Science and Technology for Building and Design) of the Department of Civil Engineering and Architecture (DICAr) of the University of Pavia investigates the issue of accessibility and usability of urban spaces and buildings with studies and researches started since the year 2006, with the project “Pavia città per tutti” (Pavia town for all). Within these experiences (projects, researches and teachings) the theme of accessibility is addressed with the aim to assess its specific level and find the best solutions to improve the accessibility of built environments both at the urban scale and at the scale of building.

Regarding the Italian normative framework, the “accessibility” is defined as the “possibility for people with reduced or impaired motor or sensorial capabilities to reach, to enter and to enjoy buildings and environments in conditions of safety and autonomy” (DM 236/89, art. 2). This concept, together with the themes of Equity, Empowerment, Participation, Cultural Identity and Institutional Stability, represents one of the main aspects of Social Sustainability (KHAN 1995). For these reasons everyone should share the purpose to create physical and cultural conditions to let people with disabilities obtain their full participation into society, education and workplace, with independent and safe ways.

According to the European Concept of Accessibility Network (EuCAN) built environments, including elements and components, should be designed in order to enable everybody to access the different opportunities: culture, space, buildings, communications, services, economy, participation, etc. For these reasons an “accessible environment” should be:
• respectful - it should respect the diversity of users. Nobody should feel marginalized and everybody should be able to get to it;

• safe - it should be free of risks to all users. Therefore, all those elements which form part of an environment have to be designed with safety in mind (slippery floors, parts jutting out, dimensions, etc.) in order to have safe spaces where all users can move and carry out the activities for which the space is designed, without taking risks for themselves and for others. This environment is “sustainable” because it ensures the safety of all users regardless of their capabilities or age;

• healthy - it should not constitute a health risk or cause problems to those who suffer from illnesses or allergies. Even more, it should promote the healthy use of spaces and products;

• functional - it should be designed in such a way that it can carry out the function for which it is intended without any problems or difficulties, inspired by the principles of Universal Design and overcoming some standardized solutions that could create problems for wide users;

• comprehensible - all users should be able to orient themselves without difficulties within the space. The environment needs clear information (using icons that are common to different countries, avoiding the use of words or abbreviations from the local language which may lead to confusion) and clear spatial distributions, coherent and functional, avoiding disorientation and confusion;

• aesthetically pleasant - the result should be aesthetically pleasant, as this will make it more likely to be accepted by everybody. The design solutions should be consistent with the socio-cultural context in which they fit.

According to these principles, the architectural and sensorial barriers overcoming means to adapt the environment to the widest number of users. Designers, architects and engineers, who have the possibility to change and adapt the environment, have to keep into consideration the “Universal Design”, the new design approach summarized into seven main points: equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, size and space for approach and use. This approach is able to form objects, buildings and public spaces accessible and usable by the largest number of people, without the need for adaptations, modifications or subsequent special pieces (MACE R. L. 1998).

It must be considered that disability is not an individual characteristic but it deals with a complexity of conditions, also created by social environments and temporary aspects. People with disabilities means not only people on wheelchairs but also sensory impaired people, families with strollers, elderly people, people with a broken limb, and so on. In particular, according to the bio-psycho-social approach introduced by the ICF model (International Classification of Functioning, Disability and Health, WHO 2001), the condition of “disability” is created by the relationship between personal factors and environmental factors. This new approach emphasizes no longer disabilities as results of a linear evolution of diseases, but the concept of “activity” (that means what the person can do), highlighting the cyclical dependency with contextual environmental factors. For these reasons any person, at any time of his life, may be in health conditions that, in a negative environment, become disabilities.

Within the specific case of the historical heritage (buildings and urban spaces), the accessibility can be considered as one of the necessary conditions for its use and conservation. Regarding historical cities and towns the accessibility means also to enhance services and facilities that meet the needs of all tourists. The instances of historical and cultural heritage conservation are closely connected to the building re-use with public services, and putting the monument in a circuit of tourist usability goes hand in hand with its conservation and preservation: “the potential artistic culture resources can create, through tourism, an economical spin-off that can become a strong incentive for preservation and protection of the city” (ARENIGHI 2000).

In this way the accessibility of urban spaces and public buildings becomes an important quality to guarantee the improvement of the so called Tourism of All. Therefore, in order to pursue the goal of
an "accessible city" we have to guarantee not only the overcoming of architectural and sensorial barriers, but also the sources of danger and the causes of discomfort or fatigue.

Among the aims of “urban accessibility”, these useful guidelines can be identified (VESCOVO F. 1997):

- To improve the comfort of urban space for all citizens by overcoming or reducing the obstacles, architectural barriers, sources of danger and situations of fatigue or discomfort; these are, for example, to walk excessive distances, or standing up at bus stops for a long time;
- To increase the quality of life of urban spaces, understood as the relationship between the goals and quantity of the psycho-physical energies;
- To make more tangible the concept of equality, understood as the achievement of equal opportunities choices, regardless of the specific conditions of disadvantage of individuals;
- To increase the possibility of individual options by enhancing personal autonomy;
- To strive for a more accurate and intelligent use of psycho-physical energies of men and women, understood also as a resource.

**Methodology: accessibility assessment tools for urban spaces**

The methodological approach can be summarized in three different phases:

- Development of the research method and setting of the assessment tools;
- Surveys (geometric, photographic and material surveys, supported by the assessment tool);
- Synthesis of the collected results (done at the laboratory of the University of Pavia).

The accessibility assessment tool used for the project “Design without barriers” consists of parameters that can be objectively detected and surveyed and it lets to define the accessibility level (high, medium, low) of streets and squares, divided into path sections and pedestrian crossings.

For its development the reference is the accessibility assessment tool defined by the project “Pavia città per tutti” (“Pavia town for all”). During the period between 2006 and 2008, the University of Pavia collaborated with the Department of Social Services of the Municipality of Pavia to develop studies and researches aimed at the overcoming of architectural and sensorial barriers of urban spaces, in order to facilitate the accessibility and the enjoyment of the historical centre and the most significant areas and touristic elements by all users, regardless of their capabilities.

the project “Pavia town for all”, ten buildings were defined as “tourist attractors” for the significance of their history and as reference of civil, religious and cultural activities. The main aim was to assess the accessibility of selected paths connecting these ten tourist attractors in order to identify the more accessible path that could enhance the tourism for all. The approach was studied to overcome the difference between “normal users” and “people with “motor disabilities” or “sensorial disabilities”, finding solutions to improve the accessibility and usability of urban environments for all people, regardless of their abilities. In particular this accessibility assessment tool was composed of 6 synthetic indicators, and several parameters:

- General characteristics (length, type, sidewalk, protection from atmospheric agents, lighting, profile);
- Paving (type, characteristics);
- Pedestrian crossings (longitudinal, type and position, transverse, type and position);
- Parking and transportation (presence of parking reserved for disabled users, other public transport, public transport stops);
- Urban furniture (rest areas and their furnishings, location of furniture, any items that could be dangerous);
- Urban signs (general orientation signs, specific orientation signs related to "tourist attractors", type of signs, presence of other tourist attractors).
For each parameter the assessment tool gave automatically a score (from a minimum of -2 points to a maximum +2 points). The sum of the different scores defined the accessibility level of the whole street.

After the surveys, the research developed a map with the synthesis of the accessibility levels for each street investigated, identified with 3 different colors:

- Red - for low accessibility;
- Yellow - for accessibility with assistance;
- Green - for high accessibility.

In addition, the project developed a specific map with a path characterized by a level of a medium-high accessibility, that from the north to the south of Pavia, connects all the ten “tourist attractors” considered in the research. This result became the map “Pavia per tutti” (“Pavia for all”), widespread at the Tourist Promotion Agency of Pavia.

This methodological approach, structured on objective indicators and parameters, can be applied to different study cases. The exportability and the flexibility of this assessment tool to different contests are the fundamental features that let the development of future studies and researches, like the project “Design without barriers” presented in this contribution.

The project “Design without barriers”

The research here presented belongs to the project “Progettare senza barriere. Percorsi di sensibilizzazione sulla progettazione senza barriere rivolti agli Istituti Secondari Superiori per Geometri della provincia di Pavia” (Design without barriers. Paths to raise awareness about barrier-free design targeted to Institutes for Surveyors of the province of Pavia), started in 2011 and ended in 2012.

This project, born thanks to the collaboration of the University of Pavia with the association UICI - Unione Italiana dei Ciechi e degli Ipvovedenti ONLUS (Italian association for blind and visually impaired people), focuses on the accessibility assessment of the historical centre of Pavia, Vigevano and Voghera in Italy.

It provides the involvement of students from the institutions for surveyors and a research group of the University of Pavia, coordinated by prof. Alessandro Greco.

The research is divided into these steps:

- Laboratory development of the assessment tool by the research group, from the methodological approach developed with the project “Pavia town for all”;
- Frontal lessons to the students of the institutes for surveyors involved, in order to introduce the concept of accessibility of urban spaces, the specific normative framework and the methodological approach of investigation, with the explanation in detail of the accessibility assessment tool;
- Surveys with students and the research group of the University along the urban paths under investigation;
- Elaboration of the data (assessment charts and photographs) collected during the surveys;
- Processing of the synthesis of the collected results and elaboration of the accessibility assessment maps.

This accessibility assessment method is applied to Pavia (on different paths in respect to the project “Pavia town for all”), Vigevano and Voghera. The research is carried out with the involvement of students from the institutes for surveyors “Volta” (Pavia), “Casale” (Vigevano) and “Baratta” (Voghera).

The methodology used for this project directly derives from the one developed within the research “Pavia town for all” described above: it concerns the identification of macro-indicators structured on objective parameters in order to identify the accessibility level of street and urban areas. Each area of investigation includes several elements to be carefully considered and the tool is structured to give automatically a value in relation to a “tick” or “not tick” of these elements. The sum of each
value gives a number (positive or negative), which is the reference to assess the accessibility level of the path detached.

Unlike the research “Pavia town for all”, the assessment tool developed for the project “Design without barriers” defines the accessibility level of urban spaces divided into path sections and pedestrian crossings. Breaking up pedestrian crossings and dividing the streets into path sections lets to obtain more detailed and precise results. Furthermore the identification of the specific architectural or sensorial barrier is clearer and easier.

The analysis of the path sections is divided into 4 macro-indicators, and each macro-indicator is articulated with several parameters:

- General characteristics (type of path, sidewalk, covered path, path profile);
- Paths paving (type, characteristics)
- Car parking and public transports (parking for disable people, other means of transport, bus stops)
- Urban furniture (rest areas, urban furniture properly or non-properly placed, elements located at a height less than 210 cm from the ground).

The analysis of pedestrian crossings is structured with the same methodology, but with only two parameters: type and position.

The research also contains a specific chart for the urban sign system. This analysis is not included in the accessibility assessment of path sections and pedestrian crossings because of the breakdown of the streets into short parts. However, it is useful to create a punctual survey of the sign system in view of possible future interventions with inclusive architectural solutions: the analysis of the urban sign system includes both signposts and information signage, with particular attention to people with visual disabilities.

**The study case of Voghera (2011)**

The results here presented, concern the accessibility assessment of the centre of Voghera, an Italian town 70 km south from Milan and 30 km south from Pavia.

The analysis is applied to paths (streets and squares) related to the main elements of the town with particular social values, also considering tourism. In particular, it concerns street and urban spaces between the Cathedral, the Town Hall, the Railway Station, the Post Office, the main Hospital, the main Schools, the Cinema, the Museum and the Castle.

During two different surveys (November 2011), 28 streets were investigated, with a total of 170 charts for path sections (Fig.1) and 190 charts for pedestrian crossings (Fig.2). The surveys, with students from the Institute “Baratta” and the research group of the University of Pavia (composed of the engineers Valentina Cinieri, Riccardo Gandolfi, Valentina Giacometti and coordinated by prof. Alessandro Greco) let to make a detailed database with charts and photographs that can be an important objective starting point for the accessibility assessment of the urban space.

Finally, the collected results let to make a map of the accessibility level of the historical centre of Voghera (Fig.3). All the path sections and the pedestrian crossings detected, using the assessment charts, are represented in the map with:

- Red - low accessibility (for values equal or less than 0);
- Yellow - accessibility with assistance (for values between 1 and 4);
- Green - high accessibility (for values equal or more than 5).

The accessibility assessment map highlighted critical points in the public area of the Railway Station, in the area of piazza Duomo (Cathedral square) and along via Emilia nearby the Hospital. Other parts of the historical centre are not accessible in autonomy by people with disabilities, but they can be accessible with assistance.
According to the research, the major problems that affect the accessibility of the town centre of Voghera are:

- Difference in height not connected with ramps, along path sections and between the path section and pedestrian crossings;
- Absence of adequate maintenance which involves a state of advanced deterioration of paving, materials and urban furniture;
- Non-homogeneous paths paving;
- Urban furniture incorrectly placed that creates narrowing along pedestrian paths;
- Urban furniture incorrectly designed that prevents its use for people with mobility or sensorial impairments.

It is necessary to underline that a low accessibility level can be caused by several problems, resulting not only by urban elements, but also by the wrong behaviour of citizens; this concept is clear for example thinking about the parking without rules of cars, motorbikes or bicycles which could form a physical barrier to the free and safe use of public spaces. This problem is created both by the lack of specific parking places (architectural problem) but also by the lack of attention and sensitivity by the citizens (cultural problem): the urban space have to respect people, including people with disabilities, elderly people and children, but at the same time people have to respect the urban space with a civil and responsible approach.

**Conclusion and Perspectives**

At the end of this research that led to the definition of the accessibility assessment map of the historical centre of Voghera through the filling of assessment charts, the achieved objectives are:

- sensitizing the engineers and designers of the future about the importance of design and technical solutions to improve the accessibility for all users;
- Identifying accessible paths within the town of Voghera throughout a system of objective assessment, based on parameters appropriately selected;
- Recognizing the critical points within the historical centre of the town, offering the possibility to the Municipality of Voghera to define intervention strategies to improve the accessibility and the usability of the urban space.

As in any research, in parallel to the obtained results, it is equally important to list the future scenarios opened by the studies. They can be summarized in:

- improving the accessibility of the areas with the most important problems stressed from the survey, focusing on the touristic attractors;
- completing the mapping of the historical centre of Voghera in order to create accessible paths for all users;
- enhancing the attractiveness and the town tourism offer through the reporting and recognition of accessible paths linking the historical and cultural centers with the main means of transport (trains and buses), offering people with disabilities and fragile users the opportunity to visit the town with accessible paths, equipped for their needs;
- identifying the points of major interest in which to intervene with architectural solutions or in which to locate multisensorial maps (three-dimensional tables in Braille language and high contrast colors) to support reading even for visually impaired users;
- sensitizing the students and citizens in general to avoid all the barriers created by distraction and selfishness of the users.

In addition, the research, with the collaboration of UICI - *Unione Italiana dei Ciechi e degli Ipovedenti ONLUS* (Italian association for blind and visually impaired people), has the aim to involve also people who directly experience the difficulties caused by the architectural and sensorial barriers, in order to get important considerations from their particular perspective. Furthermore, the specific survey method involves students from secondary schools (in particular the institutions for surveyors) also because these people will be the next designers in the near future. This methodological approach has the main purpose to create a strong relationship between designers, researches,
students, associations and people with disabilities in order to increase the participation and the inclusion of all, improving the knowledge of accessibility from a social point of view.

As the European Concept for Accessibility Network (EuCAN) highlights, creating accessible and inclusive environments facilitates interaction among people. It is a definitive step towards equal opportunities, offering everybody “the possibility of exercising the right to the life they want, to be independent, autonomous: to be a person”.

In light of these considerations, the systematic application of the assessment method described in the specific case of the town of Voghera, can represent an important starting point to create accessible and safe urban environments, keeping in mind that accessible heritage (historical buildings or urban areas) should be considered a growth from several aspects (GRECO A. 2013):

- Cultural - by increasing the degree of development and education;
- Social - because the respect and the involvement of all categories allows the recognition of their specificity and their belonging to a larger group;
- Economic - because larger integration also means lower costs;
- Civil - as an expression of solidarity between citizens.

All these general aspects, which can be guaranteed respecting the requests of accessibility both of urban spaces and of buildings, become part of the concept of the Social Sustainability.
**Figure 1: Assessment tool for path sections.**
**Example of Via Cavour in Voghera.**
Figure 2: Assessment tool for pedestrian crossings.
Example of a pedestrian crossing along Via Cavour in Voghera.

Figure 3: Results map of the accessibility assessment of Voghera.
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The First Contemporary Urban Plaza in Tehran, a Pace towards Creating a Sustainable Urban Space

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Abstract

This article is compiled according to the experience of the author throughout the designing of the first urban plaza in Tehran city named Emam-Hossein Square. In fact, the process of transitioning a chaos open space with lots of cars to a public urban space with pedestrian priority and without any cars is introduced. The principles of plan, theory framework of urban plaza idea, design and also participation in an action plan at Emam-Hossein Square, which was referred to KHOD-AVAND Consulting Engineers by the municipality of Tehran as an urban design project, are explained. The opportunities of creating innovative spaces are provided with the advent of visual arts and examples including fresco and traditional celebrations or modern customs, art and cultural exhibitions are considered in this article. Additionally the most important aspects of sustainable urban spaces are researched analysed. These include the sense of place, identity and people behaviours as evidenced by the advent of their memories and values and beliefs and specifically demonstrated at Emam-Hossein square. The author of this article explains the role of all the technical features and manageable aspects of the process of creating sustainable urban spaces in cities and specifically undeveloped ones through both professional experience and academic knowledge.

Keywords: Plaza, Sense of Place, Identity, Sustainable Urban Space

Introduction

Following the Industrial Revolution the issues of cities’ public spaces have become one of the main and critical issues in all countries and specifically in developing countries. The unplanned and hasty development in the fringe areas of the cities of these countries, which has occurred as a result of various political, economic, social and managerial factors, has made all planning and design efforts fruitless. This paper explores a trend of creating public spaces in the city of Tehran in chronological order. It explains and highlights the project of designing Emam-Hossein Square, which has been a sign of the revitalization of the previous public urban space, and the principles that guided this process.

The paper is divided into five parts. Following this introduction the second part will be a review of the literature of public spaces and concepts of sustainability. In the third part, a number of historical public open spaces are introduced as examples of how space and sustainability are used in Iran and will be introduced in a chronological order. The examples have been selected from three periods of time namely Ghajar period (before Pahlavi), during Pahlavi monarchy and after The Islamic revolution of Iran, which involves three recent decades. The fourth part introduces the design concept of Emam-Hossein Square as an urban plaza according to KHOD-AVAND Consulting Engineers on behalf of the municipality of Tehran. In this part, the process of transitioning from a chaotic open space with lots of cars to a public urban space with pedestrian priority is discussed. At the end the fifth part presents some concluding remarks.

Urban public spaces, Squares, and plazas
What is the exact meaning of an urban space? Can every space, shaped in the cities, been called urban space? What are the characteristics of an urban space? How can the sense of place be created in urban residents? How many of existing public spaces are dedicated to the pedestrian priority scheme? To answer these challenging questions one needs to present a clear definition of a proper urban space and its qualities.

When being seen as a panorama, the quality of city’s open spaces or in other words, the public realm, can be affected by impressive individual buildings and the city’s skyline.

Squares and plazas as city nodes may enhance the understanding of urban structure. Lynch found the node to be one of the elements by which a city is recognized and understood. In short, the node is an important element, which improves the imageability of cities. According to Lynch: ‘Nodes are points, the strategic spots in a city into which an observer can enter, and which are the intensive foci to and from which he is travelling’ (Lynch, 1960; 47). Or the nodes are: ‘…the conceptual anchor points in our cities’ (Lynch, 1960; 102).

Squares, or plazas, take on an extraordinary range of configurations with a variety of enclosing elements (Krier, 1990; Cerver, 1997). The character of a square depends on the enclosing buildings, their heights and what happens on their ground floors as much as the design of the square itself. There are two main methods of categorizing squares – by function and by form. There are numerous examples of recent plaza design where one or other of these two equally important criteria of excellence has been neglected (Moughtin, 2003).

Creating open spaces in cities are always a good idea, anywhere and everywhere. One of the lessons of the twentieth century is that in terms of urban life this belief needs to be tempered (Jacobs, 1961). Through careful research we have learnt much about what makes lively, well-loved urban spaces (Whyte, 1980; Cooper Marcus and Francis, 1990; Madanipour, 1996, 2003; Carmona et al., 2006).

Generally, open spaces, parks and other landscaped areas need to be well located and well designed for specific functions in terms of how people use them and how the natural world works. These functions need to be understood. In the Anglo-American world there is also the belief that trees and plants are automatically desirable elements of the cityscape. Often they are, but the world is replete with examples of much-loved treeless squares, such as the Piazza San Marco, and similar streets. Cities are replete with forlorn, tired, unloved parks that do not even serve as ‘lungs’ for the city. Handling cars in cities remains a problem. Many great squares of Italy and other European countries serve as parking lots today, at least during the daytime. The original functions have been lost. In arid climes they can be detrimental (Lang, 2005).

Human organizations consist of public and private components. The distinction is not always clear because there are also semi-public and semi-private behaviours and places. In addition, what is considered to be private and what is considered to be public varies from culture to culture and within cultures over time (Madanipour, 2003). A fruitful way of looking at the public realm is to consider it as a set of behaviour settings – a term coined by ecological psychologists in the 1960s. A behaviour setting consists of a standing (or recurring) behaviour pattern, a milieu (pattern of built form) and a time period (Lang, 2005).

Therefore, public urban spaces are one of the most important elements of the structure of each city within which pedestrians have an opportunity to be free and participate in many optional activities. More and more city administrations recognize the importance of open-space design in creating positive images of their cities. These days’ similar trends are gradually getting shaped in different cities of Iran specifically the capital city of Tehran.

Sense of place and identity
Meanings such as identity and sense of place are also important concepts, which seek special notice. How these concepts relate and their role as the qualities of space needs to be defined:

The term ‘sense of place’ deals with two concerns; one is sociological and the other psychological. The first has to do with the sense of one’s location, or one’s society’s location, within a larger social unit, and the second with a sense of belonging to a reign and a regional culture (Lang, 2005). In urban designing, the first has to do with the imagery of built forms and the meanings they communicate – their associational value, and the second with the ecological and cultural soundness of built forms with reference to local terrestrial and cultural conditions (Norberg Schulz, 1980).

Sense of place is always socially constructed, and a fundamental element in the social construction of place is the existential imperative for people to define themselves in relation to the material world. The roots of this idea are to be found in the philosophy of Martin Heidegger, who contended that men and women originate in an alienated condition and define themselves, among other ways, through their socio-spatial environment (Knox, 2011).

Paths, nodes, landmarks, districts and edges all have a significant role in determining the legibility of the city (Lynch, 1960), but even at the smaller scale of the district or city quarter they have similar functions of giving identity to place. There is now a clear consensus amongst urban designers that development should aim to create a sense of place and community. A legible development can also be created by the emphasis given to paths, landmarks, nodes, edges and districts (Moughtin, 1995).

Designing for a healthy biogenic, sustainable environment peculiar to specific climatic niches will steer architects and urban designers in the direction that they will have to go in defining a sense of place. Such a goal has both social and physical design dimensions and both urban spatial and building design implications (Lang, 2005). The street and the square are both important elements of the public realm: each street and each square has its own individual identity and design requirements. Nevertheless, as features of a linked public realm they take on added significance, as indeed Camillo Sitte noted in his studies of medieval towns in Europe (Moughtin, 2003).

These studies cast doubts on the link between place and space, which is making a framework of social interactions. The very context prepared the sense of place and being memories. Thus, the public squares and plazas would be a place for determining the social identity of each community.

**Sustainability of urban public spaces**

Being a complex issue sustainability depends on many factors such as environmental (including transport), social and economic (Bahrainy and Hajibandeh, 2011).

Although there are some differences considering the interpretation of the characteristics of sustainable urban space in different parts of the world, there are many common underlying and enduring themes that appear to be essential in promoting sustainable urban space.

The most commonly cited definition of sustainable development has been drawn from the Brundtland report of well over a decade ago (WCED, 1987). Its broad concern that actions taken today should not compromise meeting future generations’ needs still remains a valid starting point. However, it is such a broad definition that the term sustainable development has often been seen to mean different things to the different interest groups that use it (Jenks and Burgess, 2004).

Everyday management of urban space, rather than its spatial pattern and scale, is a crucial contributor to social sustainability. Overall social sustainability is not just dependent on neighbourhood physical characteristics and urban form but also a function of urban management and limited in particular by the extent and concentration of poverty within a city (Jenks & Jones, 2010).
In consideration of environmental sustainability, while there is an extensive literature focusing on the social benefits, and usage, of managed urban green spaces (e.g. Faber et al., 1998; Payne et al., 2002; Burgess et al., 1988), there has been relatively little empirical investigation of the social benefits of non-managed public spaces and private gardens. Furthermore, very little is known about whether or how the perceived social benefits and usage of urban green spaces varies with the density of the built environment (investigated by only one empirical study by Syme et al., 2001), nor how frequently local green spaces are used and what benefits are perceived to be associated with them.

In the case of social sustainability, although the sustainability of certain physical aspects of the built environment such as density, compactness and design have been the subject of much research (van Diepen, 2000; Williams et al., 2000; Carmona et al., 2001), in certain places these studies cast doubts on the link between built form and end user behaviour. However, so far no comprehensive studies have concentrated on behaviour or lifestyles associated with sustainable urban spaces. The social dimension of sustainability has become increasingly prominent but there is still a lack of coherence and shared understanding of the concept. According to Jenks & Jones, (2010) the main social dimensions of sustainability are equity and community, and it embraces issues of social inclusion, social capital and social cohesion.

A holistic understanding of sustainable urban development can best be achieved by basing research on the urban spaces within which human activities take place, across an urban area as a whole. Spaces between buildings are as important as the building form to ensure appropriate levels of air movement, daylight and solar access in urban spaces, and the availability of natural energy resources on building facades. The design of urban space also helps to control pollution, favour ventilation of the urban fabric and moderate thermal conditions (Jenks and Burgess, 2004).

It is apparent that few of the claimed benefits and features of ‘sustainable’ urban public spaces have been tested systematically, and the evidence to date is inconclusive. While it is possible to identify particular gaps in knowledge, there exists a deeper issue that needs to be addressed. Even where successes have been identified and positive claims made, there is a considerable lack of evidence-based explanation, prediction and theory about the extent to which form and features of urban spaces as a whole contributes to sustainability. Many of the issues in this complex field interact and conflict. There may be many trade-offs and compromises to achieve advances in sustainability and to satisfy users of the public places.

**The components of sense of place**

The 'idea of place' is Canter's starting point. There can be no doubt that this area is important to those who work with design on the physical environment: to architects, planners, urban designers. They need a clear understanding of the images that they use themselves and also an insight into the values, assumptions and behaviour patterns of others (Canter, 1977).

Canter, an environmental psychologist, called the place an experiential unity, which refers to a specific physical setting and has three main components: activities, conceptual evaluations, and physical properties (Canter, 1986, 9). Based on Relph’s and Canter’s ideas, Punter (1991) and Montgomery (1998) located the components of sense of place within urban design thought (Carmona, 2006, 98) (Fig.1).
Relph argues that, in our modern era, an authentic sense of place is being gradually overshadowed by a less authentic attitude that he called placelessness: “the casual eradication of distinctive places and the making of standardized landscapes that results from insensitivity to the significance of place” (Relph 1976, Preface).

By the identity of a place, he refers to its “persistent sameness and unity, which allows that [place] to be differentiated from others”. Relph describes this persistent identity in terms of three components: (1) the place’s physical setting; (2) its activities, situations, and events; and (3) the individual and group meanings created through people’s experiences and intentions in regard to that place (Relph 1976, p. 45).

According to the theoretical framework of this article based on sustainable urban form and the elements of sustainable place and also based on explanations of sustainability in scale of urban space, casting about for factors of sustainable urban spaces would be 1-function of place, 2-physical features of place, and 3- identity and meaning of that place.

The city of Tehran has been mainly developed during three recent centuries. In the historical fabric of the city the importance of public open spaces is apparent because of the existence of several squares around the city. To investigate the characteristics of these spaces the mentioned factors of place making will be assessed in the squares of Tehran in three periods of time namely Ghajar period (before Pahlavi), during Pahlavi monarchy and after The Islamic revolution of Iran, which involves three recent decades.

**Consideration of precedence of pedestrian spaces In Iran/Tehran Ghajar period (before Pahlavi)**

Some samples of public urban spaces and plazas in various cities of Iran during the time exactly before the first Pahlavi period are exemplified in this article. These places give us more data about our previous sustainable spaces and have helped us make improvements in the quality of recent urban space projects. In fact, they allow us to be more familiar with various dimensions and features of such spaces that were designed with the peoples’ participation and priority of pedestrian throughout the space. They also give priority to user’s operation of the space wherein it is possible to give everyone use of the equipment of place. The most public urban spaces of that era were the centre of neighbourhoods in the traditional cities like Gorgan, Yazdr, etc figures number 2 and 3. Here we focus on the historical public urban spaces of Tehran in a chronological order and the factors of place in that city.
Therefore the time is divided into three categories based on the advent of cars in public spaces in Tehran according to the modernization at the start of Pahlavi era. The public urban spaces such as Arg Square, Sabzeh Meydan Square, Toop-khaneh Square are grouped under the title of “Before the first Pahlavi period” during the reign of Ghajar. Then during the reign of Pahlavi, simultaneous modernization, cars are seen in the public urban spaces and we see a general slump in the shaping of public spaces and their qualities. Finally, the trend of shaping public urban spaces in three recent decades will be assessed with the Emam-Hossein square project. First of all the components of sense of place will be assessed on urban squares of Tehran before the first Pahlavi period.

Arg Square in Tehran
The square, which was first called Monarchial Arg, was the sign of governmental majesty with a lot of regal and royal buildings. Gradually the function of the square had been changed from governmental to public urban space. Although people were allowed to be present at this space, the priority was for governmental function.

This square was placed in down town and most of important institutional buildings were around it. The physical and formal features of square have complete solidarity. The design and shape of this place has an integral pattern with the symmetric components. Therefore, sense of place has a strong identity for its users (Fig.4).
Figure 4: Arg Square during the reign of Ghajar at left hand compared with the same space during the reign of Republic of Islamic of Iran at right hand shows sustainable public space after revitalizing.

Sabzeh-Meydan Square in Tehran
This place as a public space is placed besides the main Bazar of Tehran. One of the main entrances of Bazar is inside the square, which embraces a richness of the place. All dimensions and scale of buildings components are in human scale and well proportioned. They are related to the natural elements like green trees, spaces and water, which are, repeated orderly around the place (Fig.5). Sabzeh-Meydan Square is the centre of peoples’ connections and the place of various traditional and ceremonial events showing the cultural of how people live. It invites people to be present for their grouped customs and ceremonies (Fig.6). This memorial place is so semiotic giving people a deep meaning of being as they gather in groups. It gathers them together for different activities such as shopping and talking together etc.

Figure 5: Sabzeh-Meydan square during the reign of Ghajar shows sustainable public space.

Figure 6: Sabzeh-Meydan square where a lot of people gather together for participating in ceremonial Ashoura
Toop-Khaneh Square in Tehran
This important square is placed also near down town and it is a noticeably popular urban public space with many activities for people. In fact, this square was shaped after the transition of city centre from Sabzeh-Meydan Square to this new place during the reign of Naseredin Shah earned a richness public space (Fig.7). The functionality of this governmental place transitioned from military to a more social function until the reign of Pahlavi. The most important factor of this place had been the priority given to pedestrians. There were main institutional buildings around this square like “Nazmiyeh”, “Telegraf-Khaneh”, Shaahi Bank”, and “Ghour-Khaneh” which were pivotal monuments but some of them have not remained (Fig.7).

The square is a rectangle placed in an East-West orientation with the length and width ratio of 2 to 1. The length of the square would be 220m and the width would be 110m. Six streets were joined to the square with facades given an orderly placement around it with a specific modulation.

Figure 7: Toop-khaneh square during the reign of Ghajar with governmental function at firs.

To sum it up, the relationship between urban squares and the components of place is shown by the table (Fig.8).
Consideration of precedence of pedestrian spaces In Iran/Tehran During Pahlavi Monarchy:
In this period the transition from Ghajar to the reign of Pahlavi is analysed. It led to extended changes to provide new shape to the city. Physical development coupled with population growth brought a new modernization and encouraged the advent of new connections with an International style. Then the modernization of the city motor vehicles entered the previous public pedestrian spaces and degraded their qualities (Fig.9).

It appears that during this modernization the components of sense of place were lost and the integrity to the ideals to the importance of the elements of public spaces disappeared. This downward trend has continued to worsen through the years even to our present time. The historical squares that gave high quality and meaning to physical settings and activities designed for the presence of people were replaced with disorderly places giving priority to vehicles and cars.

Figure 8: the components of place investigated in the main urban squares of Tehran.

<table>
<thead>
<tr>
<th>Meaning/Identity</th>
<th>Physical features</th>
<th>Function</th>
<th>Components of Place Urban Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional architectural technics with strong sense of place</td>
<td>Facades symmetry and applying integral components</td>
<td>Governmental</td>
<td>Arg Square</td>
</tr>
<tr>
<td>Traditional architectural technics with strong sense of place</td>
<td>Human scale and details on facades</td>
<td>Social</td>
<td>Sabzeh Meydan Square</td>
</tr>
<tr>
<td>Applying simple architectural components; towards mixed architecture</td>
<td>Applying integral components &amp; details on facades</td>
<td>Governmental, Military and social</td>
<td>Toop-Khaneh Square</td>
</tr>
</tbody>
</table>

Figure 9: Toop-Khaneh Square is shown during the reign of Pahlavi. With modernization of the city motor vehicles enter the previous public pedestrian spaces and degrade their qualities.
Consideration of precedence of pedestrian spaces in Iran/Tehran

After the Islamic Revolution of Iran which involves three recent decades:

After decades with vehicles been given priority in Iran's urban spaces and the degradation of human public spaces without any notices to suitable places with human scales, there is now evidence of a movement to revitalize some previously valuable public spaces in various cities. Environmental pollution caused in part by motorcycles and cars has helped further the goal of improvement of pedestrians' role in urban public spaces. Some of the main corridors in cities like Tabriz, Mashad, Shiraz, and Tehran have now been designed to become pedestrian-friendly. These trends have been led to re-shaping urban plazas in recent years, figures number 10 and 11.

Figure 10: Tarbiyat corridor only for pedestrian uses in Tabriz in left-hand and two pictures of Janat corridor only for pedestrian uses in Mashad in right-hand.

Figure 11: Marvy corridor in left-hand and 15 Khordad corridor besides the main Bazar in right-hand only allow for pedestrian uses in Tehran.

Emam-Hossein Square; the First Contemporary Urban Plaza in Tehran

One of the goals of community design has been for designers to consider that all places are a composition of social, biological, and physical aspects. In addition, any design decision should be made to fulfill the future needs. Some questions that should be addressed include “What will happen? What is better? Better for whom? And how can better design be achieved and improved?” (Rapoport, 1990: 81). In order to answer these questions, design must be based on knowledge and that knowledge should be concerned with environment-behaviour interaction. Design means to “visualize the genius loci and the task of the designer is to create meaningful places, whereby he helps man to dwell” (Norberg-Shulz, 1980). The design should then make human needs and expectations and environmental features congruent with one another.
The role of design is to bring some sort of order out of chaos. However, the results of the activities performed by architects or those involved in urban design are widely different (Moughtin, 2003).

The design of this plaza followed an approach called ‘critical reconstruction’ in which the stand taken is that the identity of the very precinct is established by its history and does not need to be reinvented simply because that identity is something from the past. The most important element of this case was the mosque of Emam-Hossein where was placed at the back of the common building at the front side of the square.

According to the peoples’ requirement to have urban public space for gathering together, holding customs and religious ceremonies, designing the plaza in one of the most important parts of the city became an important consideration in the planning process. Additionally, addressing the environmental problems and sustainability issues had been a challenge during the re-shaping of this plaza. In this part, the process of design from decision making to concept and proposed 3D sketches are explained.

From Idea to Feasibility
Emam-Hossein Square with its strong identity and a long historical background was confronted with a lot of social and physical problems. Therefore, in order to achieve the necessary environmental and sustainability goals, the concept of designing a plaza was shaped. The strategic plan is shown which explains analysis of potentials of the site in the left hand. The site is surrounded by the municipal regions of 7, 12, and 13 in Tehran, the picture in the right hand (Fig.12)
Because of the public transportation terminal, there was much air, noise, and visual pollution in the square. In addition to all this pollution, there was disorder in various land uses, which led to disturbance in public activities in space. In fact, the process of transitioning a chaotic open space with lots of cars to a public urban space with pedestrian priority without any cars was started. Therefore, the opportunities of creating innovative spaces were provided with the advent of visual arts. Examples include fresco, the celebration of traditional or modern customs, art and cultural exhibitions. Besides that, the most important aspects of sustainable urban spaces include a sense of place, identity and peoples’ behaviours which were shaped by their memories, values and beliefs which specifically helped shape this square. The proposed plan of this square as a plaza without any cars as the first contemporary urban plaza in Tehran, led to a pace towards creating a sustainable urban place, where people can freely do various activities with their participation and own responsibilities in respect to maintaining the place (KHOD-AVAND, 2011).

The process of providing the project plan was held at consulting meetings over about twenty sessions. Guidance was given by the Deputy of Urban and Architecture, the municipality department of Urban Design and with the aid of professional expertise given by related organizations such as Organization of Tehran Beautification, Organization of municipality Traffic and Transportation, etc. Then the final documents were prepared to include last confirmations as 1: 2000 scaled maps. After that, detailed plans and comprehensive 3D sketches and designs were completed giving the feasibility of performance in respect to the research completed considering the economic and environmental factors (KHOD-AVAND, 2011).

The design process was as follows: First of all a Goals and Vision plan were determined considering both planners’ expertise and peoples’ perspectives. The vision plan had been: Emam-Hossein square would be the best place for people and would be shown to enhance the collective life of people with many sociable contractions. It would be suitable for holding collective costumes and religious ceremonies. It would be shown providing sustainable urban public space with the components of place such as activity, meaning, and physical setting.

After that, design of the ground and facades were finished. In this case, the method was to use the pattern of historical buildings with valuable architecture according to vertical and horizontal rhythm of facade elements. One should also notice that the skyline was a coordinating factor through the whole facade of buildings (Fig.13).

According to the identity and traditional background of the square, it would become a strategic place for the region. After studying the site plan (goals oriented) and analysis of weak points and problems, an action plan had been prepared. The process of design is shown in figure number 14. Proposing an action plan was allocated to three groups such as short term, medium term, and long term actions (KHOD-AVAND, 2011), which would be explained in the next part.
Figure 13: The process of Proposed Facade of Emam-Hossein Plaza Designing Project is presented.
Figure 14: The Process of Emam-Hossein Plaza Designing Project is presented.
Short Term Actions
These kinds of actions were involved in projects that need to be accomplished in a very short time. They included the proposed design of ground for pedestrians around the square with an increase in its width from 3.5 meter to 8.5, furnishing pedestrian bridges with escalators, and fixing the facade of Tehran cinema and Emam-Hossein a mosque placed in the square (KHOD-AVAND, 2011). Another short-term action included a cost analysis to determine cost.

Medium Term Actions
These kinds of actions were involved in projects needed to be done during the period of six months up to one year such as landscaping of the mosque surroundings or the designing of Shahrestany-Bazar (KHOD-AVAND, 2011). A cost analysis was also necessary.

Long Term Actions
These kinds of actions were involved in the maximum number of extensive and expensive projects involving an extended period of time from one to five years such as the transition of the square into a dynamic and vital plaza without any weak points of status quo (KHOD-AVAND, 2011).

One of the proposed plans was the necessary framework of design. The policies were derived from the analysis SWOT table. The most important point, which should be considered here, is to notice the components of sense of place and the suitability of these components as they are applied in defining the space of the plaza (Fig.15). According to that, it seems that this plaza can continue the trend toward shaping such sustainable historical spaces from their role in the past.

Figure 15: The view of proposed space of Emam-Hossein Plaza is presented. The components of place such as activity, meaning, and physical setting are suitably used in that.

Originally, the experts were challenged with these concepts, which appeared to them too idealistic, and lacked feasibility and they did not agree with the proposal. They only proposed very simple actions like changing the urban furniture, ground design or fixing some small green spaces and ornamental gardens. However after a lot of meetings with related organizations, the Khod-Avand consultant engineering Co. was successful in presenting the plan to the municipality of Tehran city. With the decisive action of the city management, this plan finally acquired the necessary confirmations for the performance phase to begin due to peoples’ satisfactions of the plan (KHOD-AVAND, 2011). In fact, the success of this plan truly demonstrates the existence of integral
management coupled with peoples’ participation both in decision-making and decision taking on the process of the project.

Some of the noticeable and beneficial factors in this case, would be the degree of peoples’ satisfaction, agreeability, and acceptability with the goals of the plan. The greater the participation of the people, the more the feasibility the plan will increase. Therefore, with transparent data and goals of the plan, it could be more understandable for residences and a dialectical context between people and experts could be agreed upon.

If the public spaces are to be accepted and enjoyed by the end user or residents, the place needs to become vital and guarantee social sustainability. Giving value to cultural programs and ceremonial functions at the plaza can be the most important factor of motivations for civil life. Additionally, ensuring the components of a sense of place improves the social function of the plaza as a place for gathering together and holding religion ceremonies and costumes. The physical setting of the plaza according to traditional architectural style leads to integrated form, which is a symbol of the plaza identity. Use of memorial land marks and identity symbols in plaza design can make this place understandable for all people and can be a pace toward sustainable public place with pedestrian’s priority and lot of urban activity opportunities.

Conclusion

This article has focused on the public urban spaces of Tehran and has analysed the various factors that contributed to sense of place and the historical transition that progressed in Tehran in chronological order. Therefore the time-tine was divided into three categories based in large part on the advent and effects of cars in public spaces in Tehran according to modernization at the start of Pahlavi era. The first category called “Before the first Pahlavi period” during the reign of Ghajar involving explanation of the public urban spaces such as Arg square, Sabzeh Meydan square, Toop-khaneh square. Then during the reign of Pahlavi simultaneous modernization of public urban spaces were greatly influenced by automobiles and a general deterioration of sense of place occurred due to a slump in the dedication to shaping public spaces in a quality manner. Finally, the trend of re-shaping public urban spaces in a recent three-decade span was assessed analysing the Emam-Hossein square project. This project high-lighted the movement toward a much needed revitalization of urban spaces that at one time has utilized sustainable urban space but over time had deteriorated.

The results show that traditional urban spaces in historical Iran were associated with lower levels of car availability, which in turn were associated with lower trip, noise and pollution. The historical perspective suggests that a return back to those public spaces void of automobiles and a regeneration to making pedestrians a priority with a healthy and safety place to walk and provide suitable social interactions is a necessity. The data suggests a real movement towards sustainable public urban spaces is taking place. The facts indicate there were sustainable public spaces in a previous time in Iran but that over a transition period of three recent decades an era was changed to unsustainable ones. The fact remains we have seen some detrimental and chaotic spaces that gave little priority to pedestrian. Today we see a movement to revitalize such previous underutilized spaces to become sustainable public spaces in which everyone is provided access to a more suitable urban experience. It seems that revitalization of previous public spaces would be the appropriate strategy to deal with the current problems of public spaces that fail to provide a sense of place for its people. To bring these places into the contemporary era and move these areas toward sustainable urban spaces should be worthy goal. This revitalization movement we see in developing countries will be the best hope toward a better future for people and society in general.
References


Chapter 2: Environmental Sustainability

Development of a Whole-Building Performance Research Laboratory for Energy, Indoor Environment and Building Envelope Durability Study

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Abstract
While buildings are designed to create a comfortable indoor environment, they are also expected to be durable and energy efficient. These three design goals are interrelated. Thus, the hygrothermal performance of alternative building designs should be evaluated through simultaneous analysis of these three functional requirements rather than separately. Ignoring the interrelated and coupled effects of the three design aspects and dealing exclusively with only one aspect of the building design may result in poor overall building performance.

The Building Science Centre of Excellence (BSCE) at British Columbia Institute of Technology (BCIT) is currently developing a Whole Building Performance Research Laboratory (WBPRL), a field-experimental facility that enables to undertake research and development of various building design options with the objective of choosing design parameters that can lead to not only energy efficient but also durable building while at the same time maintaining a good indoor air quality and comfortable environment for occupants.

WBPRL consists of two identical side-by-side buildings with a floor area of 17.84 m² (192 square feet (sq.ft)) each. The buildings are oriented in the same direction and exposed to similar climatic conditions. One of the buildings is used as a reference and the other one as a test building during evaluation of alternative design options. The exterior walls of the buildings are exposed to the natural environment including solar radiation, rain and wind pressure. The building envelope components, including all the walls and the roof, are removable and fully configurable to allow testing various building envelope systems. Each building is equipped with separate mechanical systems for heating, cooling, ventilation, humidification and de-humidification. In the paper, the concept, design, construction, instrumentation and commissioning of the research infrastructure are discussed and presented in detail.

Keywords: whole-building performance, integrated analysis, energy, indoor environmental quality, building envelope durability, field measurement, experimental design

Introduction
Considerable amounts of natural resources, materials and energy, are utilized during building construction. The building consumes additional energy during its operational phase. According to Natural Resources Canada (NRCan 2013), in 2010 the residential, commercial and institutional building sector consumed almost one-third of the nation’s total energy (28%) and released about 26% of its total greenhouse gas (GHG) emissions. When building fails, there is also a high economic loss. The massive building envelope disaster in British Columbia in the 1990s, the ‘leaky-condo crisis’, was estimated to have cost homeowners and governments $1 billion (Barrett 1998). Traditionally, building researchers investigate the performance of building envelope systems, energy, and indoor environmental quality in isolation (Tariku and Simpson, 2013, Al-Homoud, 2005,
Collinge et al., 2013). Ignoring the interrelated and coupled effects of these design aspects may result in poor overall building performance. For example, many buildings in Europe and North America were built or retrofitted in the early 1970s to be more airtight and more highly insulated, as a means of reducing energy consumption. Although the energy efficiency of the buildings improved, building envelope problems were created by the high moisture accumulation resulted by due to low air exchange. Indoor humidity levels were also elevated because of the reduced air exchange, which resulted in low occupant comfort and health problems. To overcome such undesired outcomes, buildings need to be designed in a holistic manner with the objective of balancing their energy efficiency, durability and indoor environmental qualities.

In whole-building performance analysis, the building is considered an integrated system with dynamic interactions between the building envelope, mechanical systems and indoor environments. Within the IEA’s Annex 41 project (Hens, 2008), the interactions between the indoor environment, mainly temperature and humidity, and building envelope components are studied both through experimental (Holm and Kunzel, 2006) and numerical (Rode and Woloszyn, 2008) analysis. In this project, the moisture buffering potential of interior finishing and its effect on indoor humidity levels are studied using mock-up rooms built in conditioned space with relatively stable temperature and relative humidity conditions (Yang et al., 2011 and Yoshino et al. 2005). LEINSFELD et al. (2007) conducted a similar experiment in rooms, which all except one wall is an exterior wall, which is subjected to outdoor climatic conditions including solar radiation and wind-driven rain in real time. In a whole-building performance optimization study, though, it is important to consider a building with all its surfaces exposed to outdoor climatic conditions since some of the important thermal and moisture loads (wind, solar radiation and wind-driven rain) are directional and vary with time. In such kind of facility, it is possible to simultaneously assess the hygrothermal performance of individual building envelope components, occupants’ comfort in relation to different building envelope interior surfaces temperatures, interior surface condensation and mold-growth potential, perceived indoor-air quality, building energy consumption and mechanical system performance. In this paper, the development and commissioning of a new research facility called “Whole-Building Performance Research Laboratory” (WBPRl), which helps to study the above-mentioned issues simultaneously, is presented. The facility is designed to be flexible and capable of simulating different building operations. The buildings’ response to outdoor climate and occupants’ activities are captured with sensors in the various layers of building envelope components, mechanical systems and indoor space.

General descriptions of WBPRl
WBPRl comprises two experimental buildings built side by side, and their performance in regard to durability, energy efficiency and indoor air conditions measured in real operating conditions and analysed in an integrated manner. Each building is 3.05 m (10’) high, and has a floor dimension of 3.66 m (12’) and 4.88 m (16’). One of the buildings is designated as a test building and the other one as a reference building. In a typical experimental study, the effects that a test parameter has on the test building performance will be compared with that of a standard or convensional configuration in the reference building.

The building envelope components, including all the walls and roof, are removable and fully configurable to allow testing of various building envelope systems. All the building envelope components can be instrumented with thermocouples, heat flux transducers, moisture pins (for wood products) and relative humidity sensors to measure the thermal and moisture responses of the building envelope components. Each building is equipped with a mechanical system for heating, cooling, ventilation, humidification and de-humidification, and indoor heat and moisture generators that simulate occupants’ heat and moisture generation in accordance with their number and activities. Appropriate sensors are installed to measure the indoor temperature, relative humidity, and pressure as well as air velocity at different heights and locations in the buildings. The outdoor climatic conditions to which the buildings are exposed to, including temperature, relative humidity,
wind speed and directions, solar radiation and rain loads, are measured in one minute interval using an on-site weather station. The weather station is installed on the rooftop of a nearby two-storey high building, which is referred as Building Envelope Test Facility (BETF).

For a test case under consideration, the mechanical systems operations are regulated with an in-house developed control system and their energy consumptions are measured using power meters. The building envelope responses, the temperature and humidity of the supply/return air conditions as it passes through the various stages of the mechanical systems, and the indoor environmental conditions are continuously recorded for further data analysis. In addition to analysis and optimization of building performance, the WBPRL helps to increase the fundamental understandings of different building element interactions, and generate the highly sought experimental data for validation of whole-building hygrothermal models such as HAMFitPlus (Tariku et al., 2010).

**WBPRL Design**

1. **Buildings Positioning**

WBPRL is located in a relatively open area at the southeast corner of BCIT’s Burnaby campus where all building surfaces exposed to the local climatic conditions, including solar radiation and wind-driven rain. The site has an elevation of 5 m, and located at 123° Longitude and 45° Latitude (Figure 1). The nearest building, BETF, is 31.50 m (103 ft.) away from the South building in the southeast orientation. Hereafter, the two WBPRL buildings are referred as ‘South’ building and ‘North’ building—the designations are consistent with their relative position on the site. Two deciduous trees of 3.0 m (10 ft.) high are about 17.37 m (57 ft.) away from the South building. Trees with about 7.62 m (25ft) high exist in the northeast, west and south orientations of the buildings at an approximate distance of 16.38 m (54 ft.), 43 m (141 ft.) and 48 m (157 ft.), respectively.

![Figure 1: The Whole-Building Performance Research laboratory (WBPRL) site](image-url)
As WBPRPL is designed for comparative study of different buildings designs and operations using one of the buildings as a test and the other one a reference building, the boundary conditions including solar radiation on the two buildings need to be approximately the same to make a correct comparison of the buildings’ performances. To ensure this design constraint, a solar shading analysis is performed to identify locations, where the buildings will be exposed to similar solar gain and minimum solar shading from the nearby structures. The shading created by the existing structures (BETF and trees) and the two buildings to each other at every hour is calculated using Equation (1), which is derived from the trigonometric relationship created by the solar ray, structure height and shade length (Figure 2).

![Figure 2: Schematic representation of shading (Si) created by a structure (h)](image)

\[ S_l = \frac{h}{\tan \beta} \]  

(1)

Where, 
- \( h \): is the height of the nearby structure
- \( S_l \): the length of the shadow forecasted by the structure
- \( \beta \): is the solar altitude angle

and the direction of the shadow for each hour is determined from the hourly solar azimuth angle (\( \phi \)). The solar altitude and azimuth angles can be calculated using Equation (2) and Equation (3) (ASHRAE 2013).

\[ \sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta \]  

(2)

\[ \sin \phi = \cos \delta \sin H / \cos \beta \]  

(3)

Where, 
- \( L \): is the latitude of the location
- \( \delta \): is the solar declination
- \( H \): is the solar hour

In the analysis, nearby existing structures including a 6ft tall tree is the east, 25 ft. tall trees in the south, west and northeast orientations, a 20 ft. high building in the southeast and the shading created by the WBPRPL buildings to each other at every hour of a typical day of a year are considered. Figure 3 shows the solar shadings that are created by the nearby structures during the 21st of each month calculated from sunrise to sunset. The objective of this analysis is to locate a position on the site for the two buildings where minimal shading occurs. Based on the result of the analysis (Figure 3), the buildings are positioned in the north-south line 12.19 m (40 ft.) apart. The few hours of shading that the buildings experience during the summer period (shown on the third quadrant of Figure 3) occur in early morning or late evening when the solar radiation intensity is low. The thermal gains on the buildings at those times are considered to be negligible when compared to the rest of the hours in the day. In the absence of locations on the site with no solar shading at all time, the areas identified in Figure 3 for the WBPRPL are found to be appropriate.
2. Building Permanent Structure

Figure 4 shows the three-dimensional view of one of the WBPRl buildings. The buildings are designed with permanent structures and removable building envelope components. The removable components allow reconfiguration and installation of different wall systems and roof structures as needed. The permanent structures of the buildings include: concrete foundation, HSS beams and columns, and columns enclosure. Each building has a footprint of 5.66 m (18'-7") by 4.45 m (14'-7"), and an interior space height (from the top of the concrete slab to the roof sheathing) of 3.05 m (10'-0"). The buildings are equipped with a set of mechanical systems, which are placed in an HVAC room at the northwest corner of the respective buildings.
Figure 4: 3D views of one of the WBPRL buildings

Figure 5 shows the sectional view of the concrete foundation structure. The slab is 102 mm (4”) below the finish grade and has a thickness of 305 mm (12”) thick. For thermal and moisture control, 76 mm (3”) EPS rigid insulation and 6 mil polyethylene sheet are placed between the slab and the soil. The foundation wall extends 203 mm (8”) above finish grade. The width of the foundation wall is set to 305 mm (12”) to allow installation and testing of thick wall systems. Damp proofing is applied to the exterior surface of the foundation wall (only below grade section) for moisture control, and 76 mm (3”) EPS rigid insulation is installed between the foundation wall and the soil (Figure 5) for thermal control. At the four corners of the building, 102mm x 102 mm (4” x 4”) HSS load bearing columns with steel plate and anchor at the bottom are embedded 305 mm (12”) deep in the concrete foundation wall. The HSS columns and horizontal HSS beam welded at the top to form the load carrying structure of the buildings. HSS beams of two sizes: 76 mm x 76 mm (3” x 3”) and 127 x 76 mm (5” x 3”) are used for the short sides (west and east) and the long sides (north and south) of the buildings, respectively. To reduce the heat transmission through the conductive column and beam steel structure, the void in the HSS is filled with spray foam insulation and insulated on the exterior as shown in Figure 6.
3. Building Envelope

As part of the WBPRL commissioning exercise, five 2.44 m (8') by 2.44 m (8') and one 1.22 m (4') by 2.44 m (8') wall panels are fabricated in the shop and installed between the HSS columns and a
The removable roof assembly is anchored on the HSS beams completing the building envelope. Figure 7 shows the typical cross-section of the wall panels. The panels are designed as rain-screen wall system with a 2 x 6 wood-frame and comprises the following layers of materials: a fiber cement board as a cladding, airspace as a capillary break, a spun bonded polyolefin sheet as sheathing membrane, plywood as sheathing board, fiberglass insulation filled in the stud cavity, a polyethylene sheet as both vapour and air barriers, and drywall as a finishing layer.

![Figure 7: Vertical section view of test wall assembly](image)

The roof assembly is made of 2 x 12 (38 mm x 286 mm (1 1/2” x 11 1/4”)) wood joists and rafters and the following layers of materials: two layers of SBS modified bitumen roofing as water tight membrane, plywood sheathing, an air gap for ventilation, R-40 glass fiber insulation filled in between joists, a polyethylene sheet as both vapour and air barriers and drywall as a finishing layer. The roof assembly weight is transferred to the HSS beams through 2 – 2 x 12 wood frame. The frame is connected to the HSS beams with bolt and nuts and metal plates on both sides. This design allows for the roof assembly to be changed according to the experimental study requirement. The detail of the roof and wall connection is shown in Figure 8. The wall panels are held in position with removable angle bars and plates, which are anchored on the HSS beam and foundation wall, respectively. This attachment enables easy reconfiguration of wall panels. To reduce thermal bridge at the roof-wall connection regions, 76mm (3”) and 12.5 mm (1/2”) rigid insulation boards are installed on the exterior surface of the wood frame and HSS beams, and between the HSS beams and the removable metal angle bars, respectively.
4. Air tightness

To increase the airtightness of the buildings, gaps between the wall panels and structure joints are filled with XPS insulation and sealed from the interior using polyurethane spray foam, Figure 9. In addition, the pinholes created on the vapour/air barrier, polyethylene sheet, the stapler seals wires with tack tape. After such effort, the blower-door test results of the two buildings revealed that at 4 Pa reference pressure, the North and South buildings have an effective leakage area of 25 cm$^2$ and 29 cm$^2$, which can be translated to 29 and 31 mm diameter openings, respectively. In relation to the buildings’ exterior surface area, the North and South buildings have 0.43 cm$^2$/m$^2$ and 0.49 cm$^2$/m$^2$ air leakage area. According to ASHRAE’s (2013) buildings’ airtightness classification, buildings with over 5.4 cm$^2$/m$^2$ air leakage area are classified as leaky buildings, 2.8 cm$^2$/m$^2$ as normal, 1.4 cm$^2$/m$^2$ as good and below 0.7 cm$^2$/m$^2$ as tight buildings. Since the airtightness of the two buildings’ are much lower than the upper limit of the ASHRAE airtight buildings, the buildings can be classified as tight buildings with a relatively small leakage area.
5. Door and windows

Each building has one exterior metal door and two vinyl frame windows. The exterior doors are 1.22 m (4’) wide and 2.44 (8’) high, and they are installed in the north orientation of the respective buildings. In each building, two windows, one on the north wall and the other one on the south wall are installed. The windows are air filled double glazed windows with dimensions of 0.914 m (3’) width and 1.22 m (4’) height. The window to floor area ratio is 0.125.

6. Mechanical system

One of the main requirements of the WBPRL design is the ability to control, measure, monitor and deliver desired supply air temperature, humidity and ventilation rates to the buildings. Unfortunately, acquisition and adaptation of commercial HVAC (heating, ventilation and air-conditioning) and humidification and dehumidification components weren’t an option due to the size of the buildings (relatively small) and the high flexibility in control and operation requirements set in the WBPRL design. Thus, a mechanical system for heating, cooling, ventilation, humidification and dehumidification is designed in-house and installed by the research group. Sensors are installed at the critical locations of the mechanical system to measure local temperature, relative humidity and air flow rate.

The mechanical system has two major components: forced air flow (Figure 10) and air-conditioning (Figure 11) systems. The forced air flow system controls and delivers desired ventilation rates and is flexible enough to implement continuous or demand controlled ventilation strategies, such as time controlled, relative humidity controlled or CO₂ controlled. The main components of the forced air flow system and their role are as follows: 1) Air Handling Unit (AHU) — houses mechanical components that condition the incoming air to meet the indoor air temperature and humidity set-points; 2) Variable Speed Blower and Controller—supplies desired volume of air to the test room as defined by the experiment; 3) Laminar Flow Element (LFE) — device to measure the actual air supply (ventilation rate) into the test room; 4) Motorized Dampers—computer controlled dampers to establish different proportions of return air and fresh air into the supply air stream. The dampers can be regulated from fully closed (100% air recirculation) to fully open (100% fresh air system), and can be adjusted to give different proportions of return and fresh air mixture; 5) Reverse flow blocker, shown in the forced airflow system schematic diagram below, is intended to prevent suction of outside air through the exhaust opening while the system operates in recirculation or mixed air.
supply mode; 6) 76 mm (3") diameter ABS and sheet metal ducts are used for the transport of air to and from the conditioned room; 7) Air Filter—removable filter to provide clean air to the test room; and 8) Diffuser and Return vent—create an inlet and outlet points for the air exchange in the conditioned space. They are positioned at the ceiling level and at the partition wall near the floor level, respectively.

![Diagram of the forced air system in the WBPRL mechanical system design](image)

**Figure 10: A schematic diagram of the forced air system in the WBPRL mechanical system design**

During the buildings’ operation, the temperature and humidity of the supply air should be adjusted to the appropriate states to maintain the test rooms conditions. These conditions are met by the components in the AHU, Figure 11. Thus, in the WBPRL mechanical system design, appropriately sizing and easy integration of the components in the AHU were critical design requirements. The main components of the air-conditioning system include the components in the AHU, which are involved in the treatment of the incoming air from the entry to the exit of AHU (Figure 11 (a)), and the cooling and the heating sources (Figure 11 (b)). The AHU is manufactured from sheet metal and houses a condensing coil, a pair of heat exchangers, an in-house developed humidification system and a trim heater to fine tune the supply air temperature. The main cooling and heating sources for the buildings are from the chiller baths and the heating and cooling baths, Figure 11 (b). The chillers are connected to the condensing coils and tasked to dehumidify the incoming air to a desired humidity level by setting appropriate set points. The heating and cooling baths are connected to the heating and cooling heat exchangers to provide desired supply air temperature. Through in-house developed software, the operation of the various mechanical system components are controlled, and their performance are recorded for further analysis.
In addition to the outdoor climatic conditions, the indoor heat and moisture sources also contribute on the heating/cooling and humidification/dehumidification loads, and subsequently influence the indoor air temperature and humidity and energy consumptions of the mechanical system. Occupants and utilities they use in the indoor space generate heat, moisture and CO$_2$. The magnitude and frequency of these gains depend on the type and level of activities they are engaged in. To capture these gains and implement in the whole-building performance experiments, a computer controlled heat, moisture and CO$_2$ generators as shown in Figure 12 are developed and placed in the test environment.
room. The generators have wide range of operation and can simulate various routines/schedule representing different occupant densities and level of activities in time. The moisture simulator is made of two mist producing nebulizers, a fan and a water supply system (pump and reservoir). Based on the moisture production profile needed (programmed), the system releases a mist of water vapour into the test room. Similarly, occupants’ CO\textsubscript{2} production and release to the test room is simulated by releasing metered CO\textsubscript{2} that reflects occupant's density and activity in the test room. The system comprises a small CO\textsubscript{2} tank, a laminar flow element (flow meter) and solenoid valve. The heat generation by occupants’ and their activities, such as cooking, is simulated using a radiant heat source. These three indoor sources will help to study the effects of occupants’ activities on the indoor air quality, thermal comfort, building envelope durability and energy usage.

![Figure 12: Indoor moisture and heat production system](image)

**Sensors layout**

To monitor the thermal and moisture performances of the buildings, temperature, moisture content and relative humidity sensors are installed on the various layers of the walls and roof assemblies. Figure 13 shows the sensors locations on the wall assemblies in plan view. One wall panel in each orientation, and wall sections under the windows (north and south orientation) are fully instrumented. Such sensor layout helps to capture the relative performance of wall systems in response to the directional thermal and moisture loads (wind-driven rain, solar and wind). Figure 14 shows the vertical view of a typical wall frame and sheathing board assembly instrumentation. Thermocouples and moisture pins are installed on the upper, middle and lowers sections of the sheathing board and the studs. The interior and exterior sections of the top and bottom plates are also instrumented with the same kinds of sensors. In the stud cavity (insulation layer) and the air cavity (between cladding and sheathing membrane), combined relative humidity and temperature (RHT) sensors are installed to measure the moisture contents and temperatures in the respective layers. To establish the temperature gradients at the mid heights of the respective wall cross-sections, thermocouple wires are installed at the interfaces of each layer of material and on the exterior and interior surfaces of the wall assemblies (Figure 13).

The thermal and moisture responses of the roof assemblies are captured with measurements made at the four corners and central regions of the roof. At each location, moisture pin and thermocouple on the sheathing board, RHT sensor in the insulation cavity and thermocouple wire on the ceiling are installed.
The temperature profiles across the floor assembly are measured at the center and 6’ away in the east and west of the center point. At these three locations, thermocouples are placed at the interfaces of the slab, the rigid insulation and the polyethylene sheet, and also 9” below ground,
Figure 15. These thermocouples are laid out prior to casting the concrete slab. To establish the temperature field outward of the foundation wall, additional thermocouples are installed along the height of the foundation wall and at different depths in the surrounding soil.

![Thermocouple layout around the foundation structure](image)

**Figure 15: Thermocouple layout around the foundation structure**

**On-site Weather Station**
A rooftop weather station provides the outdoor climatic condition measurements for the WBPRL’s experiments. The weather station is on BETF’s roof, which is located 31.50 m (103 ft.) away from the WBPRL South building in the southeast direction. The on-site weather measurements include temperature, relative humidity, wind speed and direction, global horizontal solar radiation, and horizontal rain. Wind-driven rain gauges and Pyranometers are mounted on the WBPRL buildings’ facades to measure the actual wind-driven rain and vertical solar radiation loads on the walls. The weather data are recorded in one-minute interval.

**Preliminary Results**
As part of the buildings commissioning and sensors verification exercise, the hygrothermal responses of the building envelope components (wall, floor and roof) and mechanical system operation are monitored. In this section, a sample of data that is collected from the South building from June 6 to June 14, 2013 are presented for demonstration purpose. Figure 16 shows the moisture content measurements on the upper, middle and lower sections of the plywood sheathing board in the north wall. During this monitoring period, the average moisture content (MC) on the plywood varies along the height, that is, from 9.5% at the lower section to 11.5% MC at the upper section, while the middle section maintains an average of 10.5% MC.
Figure 16: Moisture content measurement on the north wall of the South building

Figure 17 shows the temperature measurement across the cross-section of the south wall along with the outdoor air temperature. The daily temperature variations in the gypsum board and the interior surface of the stud are relatively low. As the solar gain increases, the temperature reading on the cladding, plywood and outer section of the stud increases significantly. During nighttime, the temperature readings on these outer sections are lower than the outdoor air temperature, which must be associated with the night time cooling that has resulted from the long-wave radiation heat exchange between the cladding and the sky.
In Figure 18, the temperature measurements at the interfaces between the slab, rigid insulation and polyethylene sheet along with the soil at 9" depth are presented. In the figure, the roof sheathing board temperature is also shown. As the figure shows, the temperature readings under the slab are relatively stable. They are not significantly affected by the outdoor air temperature fluctuations and solar radiation gains. The average temperature of the soil during the monitoring period is 7.5°C, which is about half of the slab bottom temperature, 14°C. The rigid insulation under the slab contributed to the high temperature difference between the two points and limit heat flow to the ground. As can be seen in the figure, the temperature of the roof sheathing fluctuates significantly, and can be as high as 43°C and low as 2°C.
In this paper, the data collected from one of the mechanical system commissioning and verification test cases is presented. In this test case, the chiller temperature set point is set at 5°C, and the ventilation system is configured to deliver 100% fresh air at a rate of 14.16 l/s (30 CFM). As shown in Figure 19, the outdoor air that is drawn into the mechanical system has a temperature of 18°C to 19°C. At the AHU inlet, the temperature of the drawn air reaches to 20°C. The slight temperature increase observed in the drawn air is associated with the convective and radiative heat gains the air duct received in the mechanical room. As the air passes the first mechanical system component, the condenser, its temperature drops from 20°C to 6°C and get dehumidified. Figure 20 shows the absolute humidity of the air just before the condenser coil and at the outlet of the AHU. The amount of moisture removed by the condenser coil is determined by the incoming air conditions, chiller set point and air flow rate. The incoming air has an average temperature and relative humidity of 20°C and 69%, and dew-point temperature of about 15°C. Since the condenser coil temperature is much lower than that of the incoming air dew point temperature, removal of excess moisture from the incoming air is possible. In the test case presented here, the condenser (dehumidifier) reduces the moisture content of the incoming air from 12 g/m³ to 8.8 g/m³. After the condenser, the air passes through a heat exchanger, humidification unit and trim heater, and finally delivered to the test room at 12°C. Since this particular experiment focuses on testing of the mechanical system's operation under cooling and dehumidification modes, the humidifier and the trim-heater are turned off.
Conclusion
New technologies and design approaches must be evaluated simultaneously for their implication not only to energy conservation but also to indoor air quality (IAQ) and building durability. Currently these elements are assessed in isolation. However, because buildings are in essence systems with dynamic interactions of all construction and operational elements, this is a limitation at best. The twin Whole-Building Research Laboratory (WBPRIL) buildings are capable of evaluating all components
concurrently. The facility helps to advance green materials and sustainable building design through analysis of their effect on the whole building performance including energy consumption, indoor environmental conditions (related to occupant comfort and mold growth potential), and building envelope durability. The full reconfiguration capabilities of the buildings enable researchers to evaluate the relative performance of various innovative building technologies (envelope and mechanical systems) in comparison to that of a corresponding conventional system, using one of the buildings as a reference and the other one as a test building.

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Reference


ENVIRONMENTAL PERFORMANCE, DESIGN AND COST ON HOUSE RENEWAL

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Abstract
All buildings in Japan, including existing detached houses, are required to be Carbon Neutral by 2050. In order to improve existing buildings to Zero Energy, the development and accumulation of various, innovative renewal techniques is indispensable, and integration of the requirements for environmental performance, architectural design and cost is also required. This paper introduces a renewal example of an ordinary wooden house in Tokyo and discusses the integration process of the requirements and its thermal and energy performance.

The two stories house was built in a traditional way in 1983 and had single glazed windows and thermal insulation of 50-mm-thick glass wool. After refinement, this house achieved the energy self-sufficiency rate of 64-74%, resulting from a PV system of 3.2 kW, a heat pump hot-water supply system and many low energy appliances such as LED lighting. But the noteworthy points are the thermal insulation techniques applied to existing walls and windows.

Regarding the walls, for example, the sand-finish walls in Japanese style rooms are covered from the inside by high-performance thermal insulation board (made of 12-mm-thick phenol foam and 1-mm-thick paperboard with fireproof paint) without removing the inside finish of the walls, in order to meet the thermal insulation standards of Japan. These walls are not finished with wallpaper in the usual way because the surface of the paperboard already has a good texture and looks like a sand wall. This renewal method provides fine Japanese-style wall, good performance and low cost.

Inner window was added to the living room’s biggest window and the bathroom window. But all other windows were installed with Window-Inside Doors (WID). WID is made of super insulation board, therefore the insulation effect is high and the cost is much lower than that of adding inner window. Furthermore some WID have small holes for lighting and they provide a light, pleasing impression.

Keywords: building refinement, thermal insulation method, window insulation, ZEH

Introduction
Japan’s seventeen building-related associations proposed mid- and long-term goals towards the year 2050 for buildings, cities, and regions in the “Vision 2050: Building-related Measures to Counteract Global Warming ~ Towards Carbon-Neutralization” (AIJ, 2009). In this vision all buildings, including existing buildings, are required to be Carbon Neutral by 2050. It is difficult to improve existing buildings to Carbon Neutral, furthermore to Zero Energy Building (ZEB) and Zero Energy House (ZEH) and therefore innovative renewal techniques for building stocks that meet the requirements of environmental performance, architectural design and cost should be carefully considered.

The integration of these requirements will differ according to the conditions of the buildings and the desires of the owners. Therefore it is important to accumulate various, innovative renewal
techniques for building stocks and to find common, universal methods. We have been studying this theme from the Tokyo Metropolitan University 21st Century COE Programme (FUKAO, S, etc., 2007)

On the other hand, most architects still consider that architectural design is more important than cost and environmental performance (Table 1). Housing companies, builders and owners may consider cost to be the most important, and researchers studying environmental issues may consider environmental performance to be the most important.

<table>
<thead>
<tr>
<th>Table 1: Importance Degree between Environmental Performance, Design and Cost</th>
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<tr>
<td><strong>Today</strong></td>
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<td><strong>ZEH age</strong></td>
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From this perspective, the integration of the requirements for environmental performance, architectural design and cost is difficult, too. To solve this problem, the education, especially to architects, is important. For example, ‘Architects who have insufficient knowledge of passive design will be able to master actual passive design methods if allowed to practice a few projects in collaboration with architectural environment specialists, like our COE programme’ (SUNAGA, N, etc., 2007).

This paper introduces a renewal example of an ordinary wooden house in Tokyo and discusses the above-mentioned points.

**Renewal of Ordinary Wooden House**
The house has a wooden structure and two stories. It was built in a traditional way of this area in 1983 and had single glazed windows and thermal insulation of 50-mm-thick glass wool before renewal. Figure 1 illustrates the exterior view and the plan of the house. The measurement points of temperature and humidity are also shown by red numbers (No.1-6). Table 2 shows the outline of the house after renewal. The house has a PV system of 3.2 kW, a heat pump hot-water supply system and many low energy appliances such as LED lighting. But the noteworthy points are the techniques of thermally insulating the existing walls and windows.

![Figure 1 Exterior, plan and measurement points of the renewal house](image)

<table>
<thead>
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<th>Table 2: Outline of the renewal house</th>
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<tr>
<td><strong>Floor area</strong></td>
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<td><strong>Thermal insulation</strong></td>
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**Outer Wall Insulation**

The sand-finish walls in Japanese style rooms are covered from inside by high-performance thermal insulation board (made of 12-mm-thick phenol foam and 1-mm-thick paper board with fireproof paint) without removal of the inside finish of the walls, as illustrated in 'Plan 2' of Fig. 2. It fulfills the thermal insulation standards (U-value 0.53 W/m2K) of Japan. These walls are not finished with wallpaper in the usual way because the surface of the paperboard has a good texture that looks like a sand wall (Fig. 3).

The first plan for wall renewal, as illustrated in ‘Plan 1’ of Fig. 2, was to cover the old sand-finish wall with plywood and finish with wallpaper printed with a sand-pattern. The owner wanted to refine it as shown in ‘Plan 3,’ because he liked the appearance of the sand-finish of the old house and wanted to improve the thermal resistance of the wall. But a new sand-finish is very expensive, and the paperboard of the insulation has a good texture. As a result, ‘Plan 2’ was selected. This renewal method provides good impression of Japanese-style, good performance and low cost.

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<table>
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<th><strong>Outer Wall Insulation</strong></th>
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<td>Additional insulation</td>
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<td>for windows</td>
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<tr>
<td>Heat loss coefficient</td>
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<td>PV power generation</td>
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<td>Hot water supply</td>
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<td>Air conditioning</td>
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<td>Floor heating</td>
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<td>Lighting</td>
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The western style walls in the living room and bedroom are finished as shown in ‘Plan 11’ in Fig. 4. ‘Plan 14’ is ideal, but very expensive. Next, ‘Plan 12’ was examined. It meets the thermal insulation standards, but it needs an extra frame to cover the edge of the insulation board. It will make a line at the surface of the frame of the window and might not be strong because of the small wood member.
‘Plan 11’ has a flat finish between the wallpaper and the original window frame, utilizing the original difference in level. But the thickness of the phenol foam is 9 mm and the U-value of the wall does not meet the thermal insulation standards that require 12-mm-thick. The outside of the wall covered by a galvanized-iron board, has glass wool of 18 mm built-in, to protect the mortar, but its thermal resistance is not considered to calculate U-value in Japanese standard because there is an air layer opened to the outside air. Considering the effect of this outside finish, the architectural design is given priority in this case.

Figure 6 shows the surface temperature in the Japanese style room. The wall temperature is higher than that of wood column. That demonstrates the good thermal insulation performance of the wall.

**Figure 4: Renewal ideas on living and bedroom wall (horizontal cross section)**

**Figure 5: The level between the wall surface and the window frame. (Left; before, Right; after renewal)**

**Figure 6: Thermo-graphs of Japanese style room**

**Window Insulation**

In houses, most heat loss occurs through the windows. Nowadays, low heat loss windows such as low-e-coating double-glazing and evacuated-glazing can be used, but they are expensive. In this house, inner window (plastic sash and secondary glazing) was added to the biggest window in the living room and the bathroom window for daylight and to avoid moisture problems, but all other windows were installed with
Window-Inside Doors (WID), as illustrated in Fig. 7.

WID is made of super insulation board (12-mm-thick phenol foam sandwiched by 1-mm-thick paperboard), which provides high thermal insulation and much lower cost than inner window. Some WID have small holes for lighting. They provide light and give a pleasant impression because small holes appear when the outside is lighter than the inside and fade out by overlapping two WID doors (Fig. 8).

![Figure 7: The kind of renewal windows (vertical cross section)](image)

The glazing of inner window was supposed to be pair glazing, but it was single glazing due to a mistake in the order. The south window of the living room created cold drafts; therefore the single glazing was replaced with evaporated low-e-coating glazing in the second winter. Figure 9 shows the results of measuring by thermo camera. The left picture shows the temperature drop by the
small holes in the WID is about 1 degree. Also the right pictures clarify the effect of WID and the evacuated low-e-coated glazing; their surface temperatures are almost the same as that of the wall.

**Thermal Insulation of Shoji**

Shoji, traditional Japanese sliding doors, are not good thermal insulators, because they are made of wooden frames and shoji-paper. Figure 10 shows the section of window with shoji. There are shoji with double shoji-paper from several tens of years ago, but the performance is not clear. Using WID instead of shoji provides high thermal performance, but the amount of light is not sufficient. Therefore the penetrant insulation material (polyethylene foam of 10 mm) is sandwiched between double shoji-paper in his house. Shoji-paper made of plastic is used on the inside to prevent moisture transmission.

![Figure 10: Section of windows with shoji and WID](image)

The shoji of the house are combined of the only double shoji-paper and the double shoji-paper filled with the penetrant insulation. The parts that have only double shoji-paper are brighter than the parts filled with the penetrant insulation in daytime, but at nighttime the parts filled with the penetrant insulation are brighter, as shown in Fig. 11. It is considered that there is some possibility of new design by utilizing this phenomenon.

The insulation effect of shoji of the house is shown clearly in Fig. 12. The surface temperature of double shoji-paper with insulation is about 10 degrees higher than that of glazing and 2 degrees higher than that of only double shoji-paper.

![Figure 11: Inside view of shoji of the house](image)

![Figure 12: Thermographs of](image)
Room Thermal Environment and Energy Balance

After refinement, we measured the PV power generation, the electricity consumption, the temperature and the relative humidity of the house. The electricity is measured by the PV power system and also by the Home Energy Management System (from June, 2012). To monitor the temperature and humidity, small thermometers with memory were used. Figure 13 shows the monthly average temperature and relative humidity of the house. The average room temperatures of the living room, bedroom and Japanese-style room in summer are about 26 degrees C. The living room temperature in winter is about 20 degrees C, and is higher than that of the other rooms. The reason for this is that the bedroom and Japanese-style room are on the upper floor and the cooling in summer is for a long time and the heating in winter is for a short time.

Figure 13: Monthly average temperature and relative humidity

![Figure 13: Monthly average temperature and relative humidity](image)

Figure 14: Monthly PV power generation, electric consumption and their charges

![Figure 14: Monthly PV power generation, electric consumption and their charges](image)

Table 3: PV power generation and the balance of charges

<table>
<thead>
<tr>
<th>Year</th>
<th>PV power generation (Charge of sell power*)</th>
<th>Total energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st year (2011.6 – 2012.5)</td>
<td>4,060 kWh (143,872 Yen)</td>
<td>6,328 kWh (101,469 Yen)</td>
</tr>
<tr>
<td>2nd year (2012.6 – 2013.5)</td>
<td>4,454 kWh (158,110 Yen)</td>
<td>6,043 kWh (92,939 Yen)</td>
</tr>
</tbody>
</table>

*The buying rate of sell power (2009) is 48 Yen/kWh.

The monthly PV power generation, total electric consumption and their charges are shown in Fig. 14 and table 3. PV power generation from May to October is greater than the total consumption, but in winter the consumption is much greater than the generation. In total the amount of PV generation is about 4.0 MW (1st year) – 4.4 MW (2nd year) and the total consumption is 6.4 MW (1st year) – 6.0 MW (2nd year). Therefore the energy self-sufficiency rate of this house is 64 - 74%.
Considering the PV system’s power is only 3.2 kW, this result is mainly due to the good thermal insulation and the low energy consumption by the heat pump hot-water supply system and many other low energy appliances such as LED lighting.

In the 3 months from December to February the charge of purchase power is greater than that of sell power, but the simple balance of the charge is “plus” 42,000 Yen (1st year) and “plus” 64,000 Yen (2nd year). The owner paid over 120,000 Yen/year for heating and lighting expenses before they moved to this house. Therefore the gain including heating and lighting expenses are over 170,000 Yen, which means the repayment term of the PV system cost (about 1,700,000 Yen) is about 10 years.

Conclusion
It is difficult to improve existing buildings to Zero Energy. Therefore the development of innovative renewal techniques is indispensable, and integration of the requirements for environmental performance, architectural design and cost is also required. The integration of these requirements will differ according to the conditions of the buildings and the desires of the owners. Therefore it is important and required to accumulate various, innovative renewal techniques for building stocks and to find common, universal methods.

Although the example described in this paper is for a Japanese wooden house, some new methods for improving the wall and window performance considering the architectural design and cost are illustrated. The ideas may provide useful information for other renewal cases and also new buildings.

Acknowledgment
I would like to thank LIXIL JS Foundation for a grant for the development of WID in 2010.

References


VERNACULAR VERSUS SOCIAL HOUSING IN THE ALGERIAN SAHARA; 
WOMEN’S QUEST FOR COMFORT

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Abstract
This study originates from the social, spatial and environmental failure of the social housing erected in Algeria over the last four decades. The contextual background of the urban evolution in Algeria is briefly covered in the context of this study i.e. the Algerian desert called Sahara. Vernacular habitats are eloquent examples of man’s symbiosis with his natural environment, where social, cultural and spatial practices were synchronized with the geo-climatic dimension of the local environment. Sudden and radically different housing models emerged in the last four decades, as a response to a tremendous demand. The consequences of this rupture in the housing sector are multiple and of different nature.

This paper examines the effect of this brutal change on the women’s daily home activities in the social housing of the city of Biskra, a major oasis in the Sahara desert. First, the daily women’s activities and their spatial manifestations are identified in the traditional desert dwellings. Second, the inhabitants’ adaptation dilemma in the public housing is then investigated through a field study carried through observations and interviews. The results of this preliminary study attempt to appraise the occupants’ efforts in general and the women in particular, to adopt and adapt this new type of housing while underlining the new forms of socio-spatial practices.

Keywords: Social Housing, Women Socio-Spatial practices, Vernacular Architecture Comfort, Algeria

Introduction
As a context, Algeria is a land of contrast. A vast country, in fact it holds the title of the largest country in Africa since the split of Sudan in 2011. It spreads from latitude 36° to 19° and covers an area of over 2 million square km, (915,000 square miles), with a population over 37 million, of which 1/3 is under the age of 15 (ONS, 2013). Around 52% of the population lives in major cities. The major urban and rural settlements lie within the narrow costal band (with densities of 200 to 2000 person/km), whilst 4/5 of the country is occupied by the Sahara desert and is comparatively less populated. The economy depends mainly on oil and gas exports. Historically, Algeria has been successively colonised by the Romans, the Phoenicians, the Spanish, the Arabs, to the Ottomans and then the French before becoming an independent state in 1962. Each of these eras in urban and architectural grounds has left its testimony. Roman ruins, old medinas, a colonial French heritage and contemporary urban realizations might be found close by.

Vernacular housing has traditionally been an expression of the environmental, social and cultural symbiosis, often drawing its references from women’s daily activities and socio- spatial practices (Paravicini, 1990). A reference heightened by the Arab-Muslim background, strongly impacting the spatial organization of the house, dictating spatial hierarchy, centrality, introversion while delimiting gender space access and usage.

However, since the late 70s, Algeria, an oil-producing country with a long period of a high uncontrolled birth rate and expectations of modernity turned to mass-produced industrialized
housing to overcome tremendous housing demands. Housing has been in a perpetual crisis and constitutes one of the biggest national political and social issue that each successive government has failed to resolve. It remains a critical subject carrying social tension and political pressure (African Research Bulletin, 2013). Therefore, the main concern has been the quantitative aspect of housing production with hardly any consideration of the repercussion on traditional construction methods, way of life, cultural context, environmental comfort or energy usage. The result has been a rapid growth of internationally-styled buildings and infrastructure, forced upon an essentially traditional environment.

The consequences of this rupture in the housing sector are multiple and of different nature. This paper examines the effect of this brutal change on the women’s daily home activities in the social housing sections of the city of Biskra, a major oasis in the Algerian southeast desert. First, a brief overview of the vernacular desert housing is presented where the daily women’s activities and their spatial manifestations are identified. The inhabitants’ adaptation dilemma in the public housing is then investigated through a field study carried through observations and interviews. The results of the preliminary study presented in this paper attempt to appraise the occupants’ efforts in general and the women’s in particular, to adopt and adapt this new type of housing while underlining the new forms of socio-spatial practices.

Vernacular Architecture in the Desert

The vernacular architecture in desert regions characterised by extreme heat has been extensively studied, highlighting its adaptation to the context and its heat mitigation using passive strategies. Actually, the basics of dealing with the extremes of summer conditions are similar from Morocco to India, where most of the hot climate zones prevail. Houses have developed simple but very efficient strategies to cope with the climate. However, some architectural variations exist within this vast area and are often the reflection of religious, social and cultural interactions.

Under the extreme heat of the Algerian Sahara, well-illustrated by the towns in the M’zab Valley and the “ksours” (fortified desert villages), the site was the first climatic response to the harshness of the climate and the sparse arable land. Most of the human settlements are set on the rocky part of the hills, saving the fertile land for agriculture. In the M’zab Valley, social and architectural differences are unique, due in part to the puritan conduct of the local Islamic indigenous population, the Ibadite, who erected five new towns one thousand years ago. Ghardada, the largest, located at 32° North latitude is in one of the harshest desert climate, with extremely hot summers.

The clear planning of these towns with fortified outer walls, the dominant central mosque and the carefully designed courtyard house make these communities one of the most fascinating in Algeria. Each town has a permanent winter town and a summer town located in the nearby oasis. The winter town is the main residence for most of the year. The summer town is used during the hottest period of the year when the population migrates to an environment that is cooler and shaded by date palms, a pattern that is still followed today. The overall structure of the main town is compressed and condensed (Figure 1). Houses are often part of one another where walls are shared and boundaries are not easily recognizable. The resulting network of streets is narrow, enclosed and sometimes entirely covered, easing movements between neighbourhoods. The towns are all terraced; streets descend in circles from the high point following the contours of the land. On all but the south facing slopes, houses are open at the top.
The organisation of the house follows the same pattern found in the Medinas of the north with few necessary adaptations to the harsh climate. For instance, in the M'zab Valley, a central courtyard diminishes in area through two or three stories to a small skylight. On the southern side, the rooms, which usually surround the terrace on all four sides, are left open to the south. The courtyard house in the M'zab is an overlaying of two courtyards, as the typical house is three-stories high. The ground floor is organized around the central physical element of the house and receives light and air from a small opening in the roof called the Chebeq (net) (Figure 2). The 'Chebeq' is a typical feature in a Mozabite dwelling a roughly squared opening in the ceiling which makes up for almost the total absence of windows. An iron grille covers protects it, and depending on the season and the time of day, may be partially or totally be obstructed. The first floor is more open and used mostly in winter times.

The terrace in the second floor is well protected by a high parapet and serves as a sleeping area during the hot summer months. What should be stressed here is the multi-functionality and polyvalence of these spaces. There is seasonal nomadism between the two floors as well as a daily one. The inhabitants move around the house to take full advantage of the optimum living conditions as well as to accommodate the daily women’s activities within the house.

The Courtyard and the Terrace: the Woman’s Domain

Within the traditional houses, domestic activities took place inside the house when space permitted it and if not it expanded horizontally to the courtyard, and vertically to the terrace. The most important space within the house is 'Wast edar' meaning the core of the house (courtyard), with the rooms organized around it. It housed or accommodated most of the daily women’s home activities (Figure 3). It offered the spatial qualities needed to fit certain activities like carpet weaving, or preparing the couscous (main staple food for the region) for the winter season as
well as washing clothes and doing the dishes. It is also the space were women gather for chatting or for group activities (Figure 4).

![Diagram of traditional house](image)

**Figure 3:**

Organisation of the traditional house around the courtyard *(Wast edar)* with the opening to the sky
(Source: Architectural survey in the city of Biskra (author*), photo, Ravereaux, 1981)

*Wast edar* is characterized by its comparatively large dimension and its more regular square shape featuring a small opening to the sky to admit ventilation and natural light. In winter, the sun patch 'synchronized' the daily activities. In summer, the net is obstructed with palm leaves, *which* soften and diffuse the light rendering the indoor spaces more comfortable. This feature heightens its polyvalent function in summer and winter times. In the past, except for the reception room and the room dedicated to the men of the house, all of the remaining spaces were exclusively the women's domain and territory.

![Images of women around the courtyard](image)

**Figure 4:** The courtyard; women's domain and recipient of various activities
(Source: ; Ravereaux, 1989)

Another space as determining as the courtyard for the daily women's activities is the terrace called *'Stah'. Beside its function as a sleeping area during the summer to escape the heat trapped within the enclosed internal spaces, this space offers multiple usage opportunities. In fact, some women activities are transposed to the terrace in winter while looking for some winter sun. In the *Stah* was done the weaving, the sorting of dates, sewing and above all, a social gathering of
female family members and neighbors. Similarly, to the male’s meeting spaces such as the streets, squares and cafes, the terrace represents a vertical extension for the women’ meeting spaces. The separation between the houses always presented a place with a lower height that allowed communication and sometimes even crossing from one terrace to another; mobility at a higher level that did not require going out of the house (Figure 5).

Figure 5: The terrace: a women dedicated space used also for gathering and socializing (Source: Ravereaux, 1989)

Because spaces are not rigidly set in one structure, we need to look at the traditional spaces today. In general, this traditional housing has symbolically and physically degenerated or atrophied. It atrophied physically by the disappearance of the external spaces (gardens, courtyards). Land speculation has encouraged owners to sell any empty space reducing the house to the bare minimum: the built up part. Symbolically it atrophied from being called "the big house" (Dar el kbira) where everything can be done to "the old house" (Dar legdima), that does not or cannot anymore accommodate the present needs of its inhabitants, with all the negative connotations it can carry. Within this context some of the traditional domestic women’s activities are disappearing or at best carried in total discomfort. Of more relevance to the objective of this research, has been the accommodation of the women’s daily activities in the contemporary housing.

State of Contemporary Housing

In all its variety, the current dominant type of housing is in the form of social housing, the state response to an ever increasing shortage and high demand. From 1999 to 2009, 1.5 million units were delivered with a budget totaling $17.5 billion dollars (Habitat et Urbanisme en Algérie, 2013). The 2010-2014 Strategic plan targets a higher production, 1 million units in 5 years. If it is widely recognised that the country has distinct climatic zones and a regionally specific heritage, quality housing production is a newly expressed target, but remains vaguely defined (Habitat et Urbanisme en Algérie, 2013). Housing production has yet to demonstrate adaptation to these specificities.

Social housing has summarized in an abstract form, the habitat to a number of standardized functions, independently from the specificities of the socio-cultural and geo-climatic context. Identical prototypes have been erected throughout the country in the form of dense standardized units (Figure 6). Social housing seems to yield discrepancies with the cultural model of its occupants, where they have been submitted to the architecture and functionalist urban planning imposed by bureaucrats (Tebib, 2010). The main concern has been the quantitave aspect of housing production with hardly any consideration of the repercussion on traditional way of life,
climatic, cultural context or environmental comfort, where occupants needs and comfort have not been addressed (Bouchair, 1984; Gasmi, 1987; Benrachi & Lezzar, 2013).

![Image of social housing](image)

**Figure 6: Social housing, prevalent standardized typology found throughout Algeria (Source: author1)**

The generalization of the industrialized housing production has disoriented the design of housing spaces from a response to comfort to mere economic considerations. Hence, spaces became smaller, less private and have lost their polyvalent functions, which used to be the solution for most daily women’s activities in the traditional habitat setting. The inadequate size of social housing, for reasons of profitability or cost control, results on overcrowding, and could only lead to a unceasingly studied and well-documented discomfort, transformations and rapid deterioration (Bouchair, 1984; Gasmi, 1987; Lalonde, 2010; Tebib, 2010; Benrachi & Lezzar, 2013).

![Image of social housing](image)

**Figure 7: Social Housing; occupants” adaptation dilemma (Source: Author1)**

One of the natural consequences of this rupture is the rapid vanishing reference to the feminine dimension in the house, carrying discomfort of different types; physical, psychological and social. This is probably a more critical issue in the conservative human settlements in the Sahara. On the other hand, it is widely accepted that most women’s daily activities have now evolved, many have transformed, and some have even disappeared while others have been maintained
with great authenticity. Hence, the next step of this research aimed to investigate women’s daily activities level of comfort in the new form of habitat: the social housing in the city of Biskra.

**Field Study; Women Daily Activities in Social Housing and the Quest for Comfort**

The next step of this research aimed to investigate the level of comfort of the women’s daily activities in the new current prevalent type of housing; social housing in the city of Biskra. A major settlement oasis, Biskra lies in the northeastern Sahara border and is characterized by hot desert climate with very hot summers and mild winters. The typical dominant housing unit (referred to as F3) has an area of 67m² and includes the following main spaces: 1 living room (20m²), 2 bedrooms (12m²), Kitchen (10m²), hall (7m²) and a bathroom, all units would have at least one loggia (Ministère de l'Habitat et de l'Urbanisme, 2007). Larger units will have additional bedrooms of similar size (around 12m²).

![Figure 8: Typical social housing prototype (Source: Author²)](image)

The qualitative pre-investigation in the form of observations, semi-structured interviews and architectural surveys was carried out, evolving around the main theme namely; "The physical comfort of women daily activities in the home", of which the preliminary outcome is presented in this paper. The interviews were developed around the following sub-themes:

- Identification of women's daily activities in the house.
- Physical comfort of these activities.
- Lifestyle adaptation and the quest for comfort.

Five primary questions were used to identify the topics in relation to comfort and spatial interactions. Each of the 50 women interviewed responded to the following:

- Chronological detailed description of the daily activities, with specifically where each activity took place.
- Identification of non-daily / occasional activities.
- Identification of any difficulties encountered to carry these activities.
- Identification of any problems encountered during the hot and cold season.
- Solutions adopted to deal with heat and cold weathers.
- Description of the ideal home.
To increase interviewees’ representativeness, the investigation was carried out in one of the largest social housing development (Al Amal or the 1000 units) in the city of Biskra.

**Women’s Adaptation Dilemma: Preliminary Results**

The first observation is that women activities in the house fall into two categories each containing two contrasting components, based mainly on occurrence frequency:

- Household cleaning and maintenance activities / recreational activities.
- Daily or regular activities / occasional activities.

The interview responses revealed that the conception of comfort within the home encompasses visual, acoustic, psychological and physical dimensions that interfere at various levels with the daily activities. The evaluation of the preliminary results indicates three main activities that are conducted in great discomfort: preparation of meals, sleeping and socializing.

The traditional spaces housing culinary work shrank in the current housing models and are reduced to a single space “the kitchen”. Whereas the traditional art of cooking requiring large spaces are maintained with great authenticity (preparing bread, couscous). They are now constrained to a very cramped, exiguous space of less than 6m² (around 65 square feet). Hence, often now, these activities extend beyond the kitchen space to invade the loggia, the hallway as well as the reception room, living room (for example to roll the wheat for couscous).

In fact, the living room with its more advantageous size, lighting and ventilation characteristics tends to be the substitute space for the courtyard in the traditional house for many women’s activities. However, turning the reception room into a polyvalent space for daily activities is considered very disruptive. Traditionally and in wealthier homes, the reception room is the showcase of the wealth, organization and the women taste and an indicator of her status and ability to run the house. It is usually well maintained and hardly used on a daily basis. It has to be redone to receive guest whenever these may turn up unexpectedly. In the absence of a dedicated reception room, these unintended activities disrupt the traditional setting, requiring extra effort from the woman to keep it in order or to rearrange it several times a day.

As for the meeting or get together spaces women used to have in the terrace of the traditional houses, they are now happening in the stair landings with all what it implies in terms of time restriction, opportunities to meet and socialize, and sometimes even in terms of clothing restriction.

Another outcome of an extra constraint to the women’s daily activities is to be found in the use of air conditioning. Because of the very uncomfortable thermal condition in the present housing and the high cost of the equipment, air conditioning is mostly limited to the reception room. In the summer time and in the absence of a terrace as a substitute sleeping area as in the traditional home, the entire members of the family would use this space for sleeping. This often means reorganizing the furniture to accommodate sleeping arrangement for the whole family. Everything has to be put in order the following morning as the room has to act as a reception room, translating into a great deal of daily extra work for the women.

Based on this qualitative pre-study, a more detailed research through a directly administered questionnaire with over 300 women living in the same social housing community is under way, investigating further the issue of the home discomfort and difficulties for the women to conduct their daily activities in the house, potentially presenting a clear sign of the loss of the feminine dimension in the conceptualization of the house with all the discomfort it carries.
Conclusion

The type of social housing proposed as the solution to the housing crisis, has been a total negation of all inherited conceptual women dimension references. The results from the qualitative study indicate a distorted spatial practice, a rupture in the normal evolution of the way of life and an atrophied habitat. As explored in this study, some of the identified women’s daily activities are carried in great visual, physical and psychological discomfort, often carrying additional physical work.

Besides the on-going detailed research, it might be relevant to envisage extending the study to other forms of housing which offer an alternative approach to this issue. The self-built houses present a typology that has evolved from the traditional housing and represent a real projection made by the occupants in their dwelling. The result obeys to the rule of all the authentic forms that have been produced through error and trial and will probably better reveal the development or evolution of the way of life as well as the women’s daily activities in relation to the development of the women’s condition itself.

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Building Energy Modeling for Zero Energy Homes in Saudi Arabia

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Abstract

The world faces a string of serious energy and environmental challenges. The global energy and environmental scenarios are closely interlinked – the problems with the supply and use of energy are related to wider environmental issues including global warming, air pollution, deforestation, ozone depletion and radioactive waste. The building sector has a major role to play in tackling these issues as it is responsible for over 40% of the world’s total primary energy consumption and up to 30% of the total Carbon Dioxide (CO₂) emissions. Development of low and zero energy homes could be a possible solution to reduce the energy and environmental burdens associated with this sector. The article presents the findings of an ongoing research project on the development of zero energy homes in the Middle East.

Introduction

The building sector is a major source of energy consumption. Typically, buildings are responsible for 40% of the total primary energy consumption in most countries. The energy used by the building sector continues to increase; primarily because new buildings are constructed faster than old ones are retired. Commercial and residential buildings account for 15.3% of global GHG emissions, including 9.9% for commercial buildings and 5.4% for residential [1]. These GHG emissions are either direct such as emissions from fuels combustion, or indirect such as emissions associated with the consumed electricity.

The role of buildings in the Kingdom of Saudi Arabia is even more critical as the building sector accounts for almost 80% of the total electricity consumption and the residential buildings alone use 52% of the total electricity produced in the country. Estimates also suggest that in order to meet the needs of the growing population, 2.32 million new homes are needed by 2020 [2]. As an important stakeholder in the national energy and environmental scenario, it is therefore imperative for the building sector in Saudi Arabia to switch to energy efficient and renewable integrated buildings. Compared to other sectors i.e. transportation, and industry, buildings have the greatest potential to reduce energy consumption and environmental emissions. According to the United Nations, energy consumption in buildings can be reduced by 30 to 80% using proven and commercially available technologies [1].

The article presents the findings of an on-going research project that aims to determine the technical and economic viability of zero energy homes in the Middle East with particular reference to the Kingdom of Saudi Arabia. It describes the fundamental concept of zero energy homes. Based upon a questionnaire survey a typical residential home has been designed. Energy modelling has been carried out for the designed home in five different cities each representing a climatic zone in the country. Integrated Environment Solutions (IES) has been used for this purpose. The article also provides the results of the energy modelling of the designed home.

Zero Energy Homes

There is growing realizing in the world that the energy consumption in buildings and the consequent GHG emissions are required to be curtailed in order to promote sustainable development. A great
emphasis is being placed on the development of energy efficient and low energy/carbon buildings. The concept of Zero-Energy Homes (ZEB) is also finding increased acceptance especially in the developed countries.

Zero energy homes essentially incorporate advanced energy saving features and renewable energy technologies respectively to reduce the consumption of energy and to generate energy without releasing GHG emissions. A precise definition of ZEH is provided by Trocellini et al (2006:1) as: “a residential building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies” [3]. In ZEH, off-sit renewable energy generation can also be employed in case the on-site renewable systems are not practical or are not sufficient to support the energy requirements of the building.

Studies on zero energy homes date back to as early as 1977 when Esbensen and Korsgaard conducted a study in 1977 on an experimental ZEH in Denmark [4]. Over the years, the framework for ZEH has been further developed by researchers. Many countries around the world are now pursuing the idea of ZEH. Some of them have already developed ZEHs mainly for the demonstration/experimental purposes while others are working on the feasibility of these buildings. The US Department of Energy has set up a strategic goal to achieve ‘marketable Zero-Energy Homes in 2020’ [5]. The UK has also developed four ZEH projects. One of these is the Beddington Zero-Energy Development (BedZED). Besides incorporating excellent insulation features, this development employs solar photovoltaic and biomass resources to generate energy [6].

Global Trends

The concept of zero energy homes is being incorporated in policies across the world. A number of countries have taken initiatives and have set targets to reduce their energy demand by promoting low and zero energy homes and buildings. Figure 1 shows the zero energy homes already developed in various countries.

Figure 1: Zero energy homes built across the world

The European Union has a set a target of reducing energy consumption by 20% by 2020 compared to business as usual scenario. It also has a target of slashing greenhouse emissions by 20% and
drawing 20% of energy from renewable resources [7]. Some of the key features of this policy are as under.

- **Governments** to reduce energy consumption by renovating at least 3% of public buildings every year, and making energy efficiency a condition of all goods and services they buy
- **Consumers** to be provided with free and better access to information on their energy use, allowing them to better manage their consumption
- **Large companies** to undergo audits identifying ways to reduce consumption - smaller ones would be given incentives to do the same
- **National energy regulators** to take energy efficiency into account, in particular when approving network charges

**Design of Typical Saudi Home**

To design a zero energy home, it is first important to establish the typical housing demands. In this respect, a typical Saudi home has been designed on the basis of a detailed questionnaire survey that was carried out to determine the type of dwelling Saudis target for. The participants were selected randomly from different regions covering all climatic zones in Saudi Arabia. A total of 453 responses were received from residential building users through online survey. The majority of the questionnaire survey participants were chosen their targeted future home to be two-floor detached house (villa) with a total site area between 400 m² and 600 m².

Results suggest that in terms of heating, ventilation, and air conditioning (HVAC) system, about 56% of the participants have chosen mini-split system. In terms of lighting, Compact Fluorescent Lamp (CFL) is the preferred choice. Figure 2 describes the home designed on the basis of survey results.

**Building Energy Modeling**

Building Energy Performance Simulation (BEPS) tools are used to simulate the building systems and to predict the building performance under specified conditions. The BEPS allows the designer at early
stages to accurately evaluate and contrast different “what-if” scenarios, and then optimize the overall building performance. The use of simulation tools at an early design stage helps determine the optimum combination of zone layout and constructional scheme that will provide a climate responsive solution and then reduce the need for mechanical plant [8]. Furthermore, careful long-term decisions in the design and operation of buildings can significantly improve their thermal performance and then reduce their energy consumption [9]. Design decisions made during earlier phases of the design process cost less and have more significant impact on the performance of the building. Early design decisions are the most effective and the cost of making changes to improve the thermal performance of buildings at later stages in their life is high and sometimes not effective. Typically, the results obtained from any BEPS tool are as accurate as the inputs to the tool as highlighted by Maile et al [10] in Figure 3.

Integrate Environmental Solutions <Virtual Environment> (IES <VE>) is an example of an advanced BEPS tool. IES <VE> provide detailed evaluation for building systems, allowing them for optimization with regard to comfort criteria and energy use. It consists of a suite of integrated analysis tools to evaluate construct a virtual environment and evaluate the building performance during the design stage.

**Modeling Analysis**

The results of the simulation significantly depend upon the orientation of the designed home especially in terms of its energy performance. In this study, the virtual house has been simulated in each location to eight different orientations covering the 360° compass range in steps of 45°. The orientation was optimized on the basis of the minimum total household energy requirement. The difference between the optimum and the worst orientation vary from location to location. Results suggest that though air conditioning load varies from region to region, it still accounts for most of the energy use in residential buildings. In the Jeddah region, for example, heating, ventilation and air conditioning system accounts for as much as 73% of the total domestic energy needs as shown in Table 1.
Table 1: Breakdown of Energy Consumption of all models

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>Dhahran</th>
<th>Guriat</th>
<th>Riyadh</th>
<th>Jeddah</th>
<th>Khamis Mushait</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>64.8%</td>
<td>35.7%</td>
<td>57.3%</td>
<td>73.0%</td>
<td>16.8%</td>
</tr>
<tr>
<td>Appliances</td>
<td>23.5%</td>
<td>32.6%</td>
<td>26.8%</td>
<td>18.7%</td>
<td>53.2%</td>
</tr>
<tr>
<td>Lights</td>
<td>9.7%</td>
<td>13.5%</td>
<td>11.1%</td>
<td>7.8%</td>
<td>22.1%</td>
</tr>
<tr>
<td>DHW</td>
<td>2%</td>
<td>18.2%</td>
<td>4.8%</td>
<td>0.5%</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

Results of the analysis indicate that internal gain accounts for the largest load on the air conditioning system accounting for nearly 42% of the total heat gains as shown in Figure 4. A breakdown of internal gain suggests that human occupancy and appliances have a respective share of 51% and 35% as shown in Figure 5.

Conclusions
Zero energy homes can help achieve sustainability in the energy sector. Building Energy Performance Simulation (BEPS) tools are important to simulate the building systems and to predict the building performance under specified conditions. The findings of the work suggest that air conditioning is the biggest contributor to domestic energy consumption in hot climates like Middle East. Results of the energy modeling of typical domestic homes in Saudi Arabia, for example, indicate that the heating, ventilation, and air conditioning system (HVAC) may account for as much
as 73% of the total domestic energy needs. To reduce the energy needs of a home, HVAC system and building envelope need the greatest attention.

References

UNEP, [http://www.unep.org/sbci/AboutSBCI/Background.asp](http://www.unep.org/sbci/AboutSBCI/Background.asp) (accessed on 10 July 2013)


Chapter 3: Sustainable Design and Construction Management

A COMPARATIVE PERFORMANCE STUDY OF DOMESTIC ENERGY SIMULATION TOOLS APPLICABLE TO THE HOUSING DESIGN DECISION-MAKING PROCESS

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Abstract

Today, energy simulation tools (ESTs) are readily available being utilised to assist designers (and builders) in achieving energy efficiency targets and fulfilling code regulations. Likewise, the United Kingdom (UK) government recommends the use of the Standard Assessment Procedure (SAP) for energy rating of dwellings. In order to facilitate the assessment procedure, the National Energy Services developed a SAP-based simulation software tool called ‘NHER Plan Assessor’. Despite the usability, or ease of application, its accuracy tends to be questioned in view of the limited sources of energy use and climatic condition applied to SAP simulation. Today, a number of similar tools are applied around the globe—e.g. Passive House Planning Package (PHPP) and HOT2000. Unlike the UK’s SAP simulation tool, PHPP and HOT2000 have widely been applied to domestic energy simulation beyond their countries of origin—i.e. Germany and Canada, respectively. This study was aimed mainly at demonstrating a way to compare the usability of these ESTs in the design decision-making process. The comparative performance study was carried out using an existing housing prototype called ‘ZEMCH 109’ in Prestwick, Scotland. This paper identifies the significance of ESTs’ information management, agility and adaptability and the correlation to the design decision-making stages, which affect the energy performance of housing. Further investigation on the application of weight evaluation approaches to criteria identified was recommended in this study.

Keywords: Housing energy simulation tools, NHER Plan Assessor, PHPP, HOT2000, design decision-making process.

Introduction

The drastic acceleration in the population growth and the life expectancy along with the highly increased energy consumption per person has generated the continuous rise of energy demands (Edwards and Hayett 2001). Consequently, the world has been suffering from fuel poverty (Boardman 1991). This is to some extent reflected by the constant increase of energy costs. Clegg (2007) articulates that the necessity for reduction of not only energy consumption, but also greenhouse gas emissions including carbon dioxide (CO\(_2\)), which contributes to raising environmental issues, such as global warming. Thus, the link between energy use, CO\(_2\) emissions and global warming is inextricable. In order to mitigate global warming, the ‘Kyoto Protocol’ was introduced in Kyoto, Japan, on 11th December 1997, linked to the United Nations Framework Convention on Climate Change (Breidenich, Magraw and Rowley 2013). This protocol set targets for reduction of CO\(_2\) emissions and agreed sanctions for those who fail to meet the targets. Consequently, Scotland is planning to reduce its CO\(_2\) emissions by 80% by 2050 in reference to the 1990 levels, having an interim target to reduce the emissions by at least 42% by 2020 (The
Scottish Government 2012). The residential sector was responsible for around 24% of UK greenhouse gas emissions in 2011, with 15% (74 million tonnes) of all CO\textsubscript{2} emissions (Department of Energy & Climate Change 2013). Therefore, the UK government (excluding Scotland today) has implemented the ‘Code for Sustainable Homes’, which is an environmental assessment method for rating and certifying the performance of new homes (Communities and Local Government 2010). The ‘European Union energy label’ is another environmental performance standard implemented in European Nations including the UK (Department for Environment, food and Rural Affairs 2013). It is a legible colour scheme that ranks products’ energy saving levels with the aim to encourage consumers towards the energy efficient choice.

‘The Government’s Standard Assessment Procedure for Energy Rating of Dwellings’ (SAP) is a system adopted by the UK Government as the method of calculating the energy performance and CO\textsubscript{2} emissions of self-contained dwellings (of any size and any age) and it is based on the energy costs associated with: space and water heating, ventilation and lighting (BRE 2011). SAP can be utilised at both initial and final stages of design decision-making. The following section revisits general meanings of the housing design decision-making process.

Housing Design Decision-making Process

The housing design is based on a methodology, which helps the designer to understand how to proceed from the past and present to a forecast of the future (Brawne 2003). This process involves ideas and information, which require successive looping steps or stages and each aims to achieve more resolution than the previous one (Pressman, 2012). Pressman (2012) states that the cognitive elements of design process may be viewed as follows:

- Problem definition: it includes functional requirements and relationships in qualitative and quantitative terms. Project budget, time schedule and objectives are those that can be considered to be part of the concerns.
- Information gathering: it aims to examine project precedents, construction techniques and identifies applicable codes and regulations as well as the site conditions.
- Analysis: it is a process to evaluate the problem identified and aims to trigger design ideas translating the project data into graphic representation.
- Systematic to diagrammatic schemes: this is the step to establish design concepts and strategies aiming to develop the project programme related to the Site conditions, circulation patterns, environmental impacts and design aesthetics.
- Schematic design development: this process intends to convert design concept strategies into the experience of the building in question. It includes the selection of building materials and systems as well as construction technologies and performance.
- Soliciting and responding to critical feedback: it is a step of continuous improvement for the design solutions towards the project resolution.

These cognitive elements of design process can simply fall into the following stages:

Early conceptual design stage: this is an explorative phase (Cu, Hendrickson and Hitter 2006). It encompasses design organisation techniques such as brainstorming, flow charts, modeling and sketching to help visualize the conceptual design (Brawne, 2003). The aforementioned problem definition, information gathering, analysis and systematic to diagrammatic schemes elements may be included in this stage.

Final design detailing stage: it is characterised by verifying design solutions through a feedback loop that aims to fulfill the project’s demands and requirements (Angelil and Hebel, 2008). This
stage may include the aforementioned schematic design development and soliciting and responding to critical feedback elements.

To examine the building energy performance, ESTs tend to be applied at the final design stage alone today. However, in order to make proper design decisions towards energy efficiency in building, ESTs should be utilised at the early conceptual design stage as well (Hayter, Torcellini and Hayter, 2001). Moreover, ESTs can also contribute to securing thermal comfort at optimal operating energy costs.

Housing designers (and homebuilders) are relatively familiar with environmental issues arising today and they have begun to approach the building simulation field (Attia, Beltran and De Herde 2009). However, seemingly, they tend not to comprehend how to incorporate the simulation results into a proper design decision-making process, although ESTs are adequate to support early stage design decision-making (Bambardkar and Poerschke 2009). With the intention of facilitating the SAP assessment procedure, the National Energy Services developed an EST called ‘NER Plan Assessor’. The software is recognised by the UK government for assessing the energy efficiency of new-build homes and it is approved for issuing Energy Performance Certificates (National Energy Services 2013). The aim of this study is to investigate strengths and weaknesses of this SAP based software and its usability in the housing design decision-making process. In order to identify the aforementioned strengths and weaknesses, this study compares NHER Plan Assessor with two different ESTs selected – i.e. Passive House Planning Package (PHPP) and HOT2000. These tools were selected because of their similarities with NHER Plan Assessor. These two tools are widely recognised worldwide being utilised to verify the delivery of energy efficient homes called ‘Super-E’ and ‘Passive house’.

Energy Simulation Tools Selected
NER Plan Assessor: it is the EST developed by the National Energy Services to facilitate the SAP (National Energy Services 2013). It is specifically designed to cover the energy rating of dwellings in the UK. The EST is inapplicable to the energy rating of dwellings outside the UK. The version used for this study is the NHER Plan Assessor version 5.4.2.

The NHER Plan Assessor data can be exported into Excel or XML format (National Energy Services 2013). The simulation result scan instantly be showed on the computer screen and the data can be processed into SAP sheets that are used for verification by building authorities (Fig.1).
This EST is characterised by user-friendly interface and the use of a traffic light colour system, errors and missing data facilitate the operation (Fig. 2).

The key strengths of NHER Plan Assessor were identified as follow:

- A regularly updateable product library for heating and ventilation systems.
- User-friendly interface.
• Established default component options.
• Instantly signaled error notification. The weaknesses were:

• Limited energy sources applied to the calculations.
• Inapplicability to housing outside the UK.
• No interactive graphic images that instantly visualise the energy use profile.
• No heating and cooling load estimates in addition to the energy demands.

Passive House Planning Package (PHPP): It is the EST created and operated by the Passive House Institute, applied mainly for verifying domestic and non-domestic buildings in European countries today as ‘Passive houses’ (Passive House Institute 2012). This certificate refers to the voluntary energy efficient buildings that reduce its ecological print. This study utilised the PHPP version 7. PHPP requires Microsoft Office software to be able to run, because it is based on an Excel worksheet (Fig. 3).

![Figure 3: PHPP interface based on an Excel worksheet](image)

The PHPP interface combines input and output in the same worksheets, which facilitate interaction between the data input and the graphical representations (Fig.4).
The key strengths of PHPP were identified as follow:

- Use of widely applied MS Excel worksheets.
- Interactive graphic images that instantly visualise the energy use profile.
- High level of customisability.
- Global scale applicability.
- Heating and cooling load estimates in addition to the energy demands. The weaknesses were:

- No error signal representations.
- Lack of menus with default component options.

HOT2000: It is the EST that was developed by the Canadian government with the aim to measure the housing energy efficiency (Canada 2013). R-2000 and Super-E homes are verified using this tool nationally and internationally. This study utilised HOT2000 v10.51, which is downloadable for free of charge unlike PHPP and NHER Plan Assessor.

The interface includes multiple choices of default component options and/or user direct input and this helps increase the level of accuracy (Fig.5). Furthermore, HOT2000 interface contains a large number of simple illustrations that also allow the users to choose the default options so as to mass-customise the configurations and simulate the energy consumption (Fig.6).
Figure 5: HOT2000 input interface

Figure 6: HOT2000 mass-customisable default illustrations
The key strengths of HOT2000 were identified as follow:

- A large number of default options accompanied by illustrations.
- Error reports.
- Global scale applicability.
- Heating and cooling load estimates in addition to the energy demands. The weaknesses were:

- No interactive graphic images that instantly visualise the energy use profile.
- Complexity in bespoke user input.

This study consists of testing the usability of selected ESTs by making use of a housing prototype proposed in Prestwick, Scotland. Afterwards, in consideration of literature reviews, evaluation criteria were proposed with the aim to compare the ESTs and identify the levels of usability. The following section describes the housing prototype in question.

ZEMCH 109
This study selected a housing prototype proposed NRGStyle in partnership with the Mackintosh School of Architecture and it was intended to be built in Prestwick, Scotland, which falls into a cool climate region (Figs.7&8). It was planned to be a “Zero Energy Mass Custom Home” (NRGstyle, 2013). The prototype encompasses a number of passive design techniques as well as advance renewable energy technologies. The application of a passive design approach to housing contributes to operating energy savings, which in turn affect the costs (Williams 2012).

Figure 7: South west facade image of ZEMCH109

Figure 8: ZEMCH109 site
The design parameters taken to test the selected ESTs are as follows:

- End terrace house.
- 3 storeys.
- Rectangular plan.
- South-east and north-west elongated facades.
- Family structure: 3 adults and 2 children.
- 1 extract fan in the kitchen and 2 fans in restrooms.
- Ventilation air change rate of 0.60 h⁻¹.
- No mechanical ventilation heat recovery system.
- Econoflame main gas boiler with 88.9% efficiency.
- 113 litter hot water tank.
- 25 mm foam insulation material over pipes.
- No cooling mechanical system.
- Gas cooker.
- 1 dishwasher
- 1 washing machine.
- 1 tumble dryer.
- 1 refrigerator.
- 100% CFLs with an average power of 11W per bulb.

Furthermore, as-designed U-values of building components applied to the house are described below (Table 1).

<table>
<thead>
<tr>
<th>Building Components</th>
<th>U-values (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External wall</td>
<td>0.14</td>
</tr>
<tr>
<td>Sealed solid party wall</td>
<td>0.00</td>
</tr>
<tr>
<td>Warm roof</td>
<td>0.13</td>
</tr>
<tr>
<td>Slab on grade floor</td>
<td>0.15</td>
</tr>
<tr>
<td>Windows</td>
<td>0.80</td>
</tr>
<tr>
<td>Entrance door</td>
<td>1.20</td>
</tr>
</tbody>
</table>

The EST assessment result of delivered energy consumption is tabulated below (Table 2).

<table>
<thead>
<tr>
<th>NHER Plan Assessor</th>
<th>Delivered Energy Consumption (kWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Comparative analysis of ESTs selected**

Contemplating the aforementioned ZEMCH 109 design parameters, the selected ESTs were compared using the following criteria proposed in view of the literature reviews:
• Information management: it is an evaluation category that aims to rate the level of management for entering, processing and presenting data (Attiaa, Hensen and Beltrán 2012).

• Agility: it is an evaluation category that aims to rate the tools’ capability for the prompt response to the parametric changes required for interactive design decision-making.

• Adaptability: it is an evaluation category that aims to rate the level of allowance to flexibly adapt the design parameters that help assess energy and environmental performance.

Based on the evaluation criteria proposed, as described above, the usability of each EST selected was analysed in a comparative manner. The assessment extended subcategories in view of the data input method—i.e. defaults and user input. The denotation of each is described below:

D: Default input. U: User input.

Moreover, to evaluate each category, the following scale was used:

0: Not applicable.  
1: Minimum level of inclusion.  
2: Medium level of inclusion.  
3: High level of inclusion.

The assessment results of the ‘Information Management’ category can be found below (Fig.9 and Tables 3 & 4).

![Figure 9: Information management comparison chart](image-url)
The assessment results of the ‘Agility’ category can be found below (Fi. 10 and Tables 5 & 6).

<table>
<thead>
<tr>
<th>Information management</th>
<th>Summary</th>
<th>NHER</th>
<th>PHPP</th>
<th>HOT2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friendliness</td>
<td>12</td>
<td>11</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Interface</td>
<td>17</td>
<td>7</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>35</strong></td>
<td><strong>24</strong></td>
<td><strong>29</strong></td>
<td></td>
</tr>
<tr>
<td>Level of default input</td>
<td>30</td>
<td>20</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Level of customisability in operation</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Energy Simulation Tool</th>
<th>NHER</th>
<th>PHPP</th>
<th>HOT2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria</td>
<td>D</td>
<td>U</td>
<td>D</td>
</tr>
<tr>
<td>Use of different types of metrics</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>User need of environmental background knowledge</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>User guide and/or tutorial</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Provision of calculation flow diagram</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Software include a sample file</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Facility to change entries</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Undo/redo tool</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Default options accompanied by illustrations</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Friendly help menu</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Error Diagnostic</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Input presentation</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Control and navigation</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mapping internal data</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Inclusion of energy cost estimates</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flexible selection of output data</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Quality and quantity of instant result graphics</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Mapping results</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Legible format</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 10: Agility comparison chart

Table 5: Agility comparison table summary

<table>
<thead>
<tr>
<th>Agility</th>
<th>Summary</th>
<th>NHER</th>
<th>PHPP</th>
<th>HOT2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design options</td>
<td>16</td>
<td>12</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Libraries</td>
<td>20</td>
<td>6</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td><strong>40</strong></td>
<td><strong>26</strong></td>
<td><strong>35</strong></td>
<td></td>
</tr>
<tr>
<td>Level of default input</td>
<td>31</td>
<td>3</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Level of customisability in operation</td>
<td>9</td>
<td>23</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Table 6: Agility comparison table summary

<table>
<thead>
<tr>
<th>Criteria</th>
<th>NHER</th>
<th>PHPP</th>
<th>HOT2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Energy Simulation Tool</td>
<td>D U</td>
<td>D U</td>
<td>D U</td>
</tr>
<tr>
<td>Weather data input</td>
<td>3 1</td>
<td>1 1</td>
<td>2 1</td>
</tr>
<tr>
<td>Building plan and type</td>
<td>2 0</td>
<td>0 1</td>
<td>2 0</td>
</tr>
<tr>
<td>Number and characteristics of occupants</td>
<td>0 0</td>
<td>1 1</td>
<td>3 0</td>
</tr>
<tr>
<td>Thermal mass input</td>
<td>2 2</td>
<td>0 2</td>
<td>2 1</td>
</tr>
<tr>
<td>Building service input</td>
<td>2 0</td>
<td>1 2</td>
<td>2 1</td>
</tr>
<tr>
<td>Thermal bridge input</td>
<td>3 1</td>
<td>0 2</td>
<td>3 0</td>
</tr>
<tr>
<td>Materials for building envelope</td>
<td>3 1</td>
<td>0 1</td>
<td>2 1</td>
</tr>
<tr>
<td>Ventilation products</td>
<td>3 1</td>
<td>0 1</td>
<td>2 1</td>
</tr>
<tr>
<td>Heating systems</td>
<td>3 1</td>
<td>0 1</td>
<td>2 1</td>
</tr>
<tr>
<td>Cooling systems</td>
<td>0 0</td>
<td>0 1</td>
<td>2 1</td>
</tr>
<tr>
<td>Domestic hot water systems</td>
<td>3 1</td>
<td>0 1</td>
<td>1 1</td>
</tr>
<tr>
<td>Renewable energy technologies</td>
<td>3 1</td>
<td>0 1</td>
<td>1 1</td>
</tr>
<tr>
<td>Energy consumption and CO2 emissions</td>
<td>2 0</td>
<td>0 3</td>
<td>1 0</td>
</tr>
<tr>
<td>Instant results</td>
<td>0 0</td>
<td>0 2</td>
<td>0 0</td>
</tr>
<tr>
<td>Notice for regulation compliance</td>
<td>2 0</td>
<td>0 3</td>
<td>0 1</td>
</tr>
</tbody>
</table>

The assessment results of the ‘Adaptability’ category can be found in below (fig. 11 and Tables 7 & 8).

Figure 11: Adaptability comparison chart

In view of the aforementioned evaluation criteria, the assessment results of the ESTs selected were compared. In order to help grasp the outcomes at a glance, a comparative diagram was developed as follows (Fig. 12). In the light of the information management criterion, NHER Plan Assessor reached the highest level among the selected ESTs, while PHPP was considered to be the lowest. Regarding the agility criterion, the same tendency was observed. However, PHPP
achieved the highest level in terms of the adaptability criterion, while NHER Plan Assessor was estimated at the lowest.

![Information management chart](figure12.png)

**Figure 12: Selected ESTs summary comparison chart**

**Conclusions**

The high level of the information management criterion studied may facilitate housing designers with or without environmental design experience to use energy simulation tools (ESTs) for the assessment of energy efficiency performance during the design decision-making process. The agility to use ESTs permits the completion of the assessment in a short period of time and this allows the users to examine different design alternatives. The choice of design alternatives affects housing energy efficiency performance; therefore, it is preferred to be carried out at the early design decision-making stage. The applicability of the tools to worldwide contexts may be desirable to accommodate a wide range of projects around the globe. Moreover, the high level of the adaptability (and customisability) somewhat links to the accuracy of energy simulation. In fact, the energy simulation of the ZEMCH 109 housing prototype demonstrated indicates that the estimate using PHPP, which was rated at the highest level of adaptability, resulted in the largest delivered energy consumption (12,166.77 kWh/year). On the other hand, HOT2000 with the second highest level of adaptability followed the PHPP (11,473.20 kWh/year), while NHER Plan Assessor with the lowest adaptability level came into the third place (10,371.77 kWh/year). Nonetheless, the accurate simulation may be relevant to the definitive selection of housing components that needs to be made at the final design and purchase decision-making stage.

This study was aimed mainly at demonstrating a way to compare the usability of ESTs in the design decision-making process. However, each project and stakeholder may have different viewpoints, needs and desires. Accordingly, some weight evaluation approach to criteria identified in this study should be incorporated in order to accommodate the diversity of housing projects. Therefore, the EST assessment model demonstrated in this paper may need to be studied further.
Acknowledgments
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Introduction

Global climate change results in more dramatic temperatures and humidity levels, which leads to uncomfortable living environments. To combat these conditions, energy consumption is increasing and must be addressed using more efficient ventilation techniques.

History

Ralph Middleton Munroe built The Barnacle in 1891 on Biscayne Bay in Miami’s village of Coconut Grove. Munroe drew from boat design and Caribbean architecture when building his home and it served as a social gathering space for local settlers who taught each other how to adapt to the tropical landscape. [1] This included becoming acquainted with the landscape, methods for keeping cool in the tropical heat, and how to deal with humidity. The Barnacle was surrounded by natural, tropical landscape and was Munroe’s personal and family home until his descendants donated it to the Florida Park Service in 1973. [1]

House Context and Heat Gain

“Division and separation of housing space in two internal habitable zones: a heat generating zone (Zone “A”, comprising the kitchen, laundry, dining room, living room, commercial local or office, bathroom) that should be shaded and with maximum air flow permeability, and a no-heat generating zone (Zone “B,” the bedrooms) with walls and windows overheating avoiding measures.” [8] In the Barnacle, Zone A is in the naturally shaded area of the house in the back. This helps to keep the hotter rooms of the home as cool as possible using the natural landscape that surrounds the home. Zone B is in the front of the home with many windows and more natural light to give the living areas and bedrooms natural light and views of the bay. The heat gain in these two room zones is different due to the functions of the rooms. In general, sources of heat gain come from internal and external sources and include internal heat gain from lights, appliances, and people using double-pane glass on windows. This can be reduced by the use of removable canvas on roofs, insulation in walls and roofs, and proper orientation of buildings. [9] The Barnacle has a Zone B front façade to receive winds and natural light from the bay that cross ventilates throughout the house. Below are the main sources of heat gain from internal and external loads and they can be decreased using certain techniques discussed later in the research.
Climate

To understand how to combat heat gain, there must be a basic understanding of the climate on the site. South Florida’s climate includes temperatures that can reach 95 degrees Fahrenheit and humidity levels up to 90%. [2] The Barnacle’s South East façade is dominant because it faces the bay and is shaded with porches on each level and many openings to catch breezes from the bay. This side has the bedrooms on the top floor and the living areas on the ground floor. The North West and South West sides are shaded with natural landscape and this is where the Zone A rooms are located. The North East side receives the most sun and requires the most cross ventilation.
Building Materials

The building materials of this home include Dade County Pine, salvaged lumber from ships, wood-paneled rooms with slanted ceilings, [1] and a red tile roof. Originally, the structure was one story raised off the ground on wood pilings so that it wouldn’t rot [1] and the porch was made with wood planks to support it until a second floor was added below the original floor. [3]

Sustainability

Munroe incorporated sustainable concepts into his design as seen in the hipped roof that was built because it was less susceptible to hurricane damage. Also, he added porches on the South West side to protect the walls from the direct sunlight and keep the home cool. [1] The interior concept is where the name “The Barnacle” originated because it has a central octagonal shaped room. The house remained a one-story bungalow until more space was needed, at which point he raised the house up and placed another level underneath to make a full two story home. He also built a cupola with a ventilation system similar to a chimney and drew the warm air up and out. [1]
Natural Landscape

Natural landscape takes up most of this four acre site and includes many native species. In general, the landscape is considered a tropical hardwood hammock, meaning it is a small shaded forest. Specifically, this site contains palm fronds, Dade County pine that are a good building material because they are strong and termite proof, poisonwood trees, live oak with Spanish moss, fig trees, fig trees, pigeon plum fruit trees, white stopper trees with leaves used to make tea, and gumbo limbo trees. [1] It took the new inhabitants years to determine the natural remedies and purposes of these plants and the local settlers adapted over time together as they figured out the new landscape in the tropics. Many of these species are also used as natural shading devices for the home.
Methodology

Quantifying the Problem

Based on a survey done in the U.S. in 2005 [4], the energy consumption per household for a single family detached house with 5 or more bedrooms, is 160 MBtu per year (46,950 kWh/year). This is equivalent to 33.22 metric tons of CO2 emissions per household per year. To decrease this number, steps can be taken including ventilation cooling, heat transfer, passive cooling, and shading. “Ventilation improves thermal comfort by replacing hot humid air near the occupants with fresh air and improves the air quality by diluting the contaminant.” [5] Ventilation cooling can result in more neutral temperatures and a more comfortable overall environment. Another technique is passive cooling, which can reduce heat transfer to the building. This can be accomplished by using thermal insulation or shading, which are both effective measures in tropical regions. Shading can be broken down into landscaping, roof overhangs, shade screens, photovoltaic cladding, and nearby buildings. [6]

Building Form

Careful study is required to arrive at a footprint and orientation that are most energy efficient. The best option would cater to the sun, wind, and function of the building. To achieve this, the building succeeds in shading the South East façade with porches and overhangs. Most of the building is already in the shade due to the dense hammock landscape so that is naturally taken care of. “Shading trees have a potential cooling effect on the surrounding air up to 1.5 degrees C during hottest hours of the day for Mediterranean sub-tropical climate of the Los Angeles bay.” [11] In terms of ventilation, the building has the most windows on the South East to capture the breezes from the bay and the rest of the facades have windows on both stories to provide cross ventilation throughout the house.

Results

Stage 1

Stage 1 examined the relative humidity, temperature, and CO2 levels in the Barnacle over a twelve-hour period from 2pm to 3am on July 27 and 28, 2013. This time frame was chosen because it is the hottest and most humid time of year, with the hottest time of day being around 4-5pm due to heat accumulation throughout the day. This particular part of the study was done in the kitchen, which is in Zone A and is in the back of the house in a shaded, but poorly ventilated part of the house. Upon entering the house, the feeling of heavy heat was overwhelming, but in reality the interior of the house was in the mid 70’s Fahrenheit and the feeling of heat came from the humidity and lack of cross ventilation. During most of the day, the home is cross-ventilated with many windows and it is kept in the shade by the natural canopy of trees that surrounds the structure on three sides. Due to this, the temperature stays pretty consistent throughout the day despite the outdoor temperature fluctuating about fifteen degrees Fahrenheit during this time of year.

The second study was done a few days later in the front of the house in the living room facing the bay. This particular room is exposed to the winds of the bay and has many windows that provide cross ventilation to the rest of the home. With this in mind, the results are logical. For example, the humidity in the front of the house was much less, as was the temperature and CO2 levels. The CO2 levels fluctuated more in the front of the house, perhaps due to the irregularity of the wind patterns coming in and out and also due to people opening and closing the windows throughout the day. Overall, the CO2 levels were highest around 5pm when the temperature also hits its maximum for the day.
Stage 2

Both the CO2 levels and relative humidity were recorded at very high levels upon installation and as the device was being removed from the house. These numbers are considered natural error and once the device was stable, the numbers remained consistent and in accordance with each other. The comfortable indoor temperature range is approximately from 67 degrees Fahrenheit to 75 and average temperature of the Barnacle during the study period was at the top of this range. The average relative humidity was 60% and the average CO2 was 37 ppm. The CO2 levels were similar to those found outside which shows that the building is relatively sustainable and efficient in this aspect because there was minimal affect from the building to the CO2 levels that are found in nature.

“Relative humidity generally decreases when air temperature increases. This means when air temperature is high, relative humidity is low but occupants’ thermal sensation increases because air temperature has more effect on occupant thermal sensation than the effect of relative humidity.” [10] Therefore, the sensation of feeling hot or cold can be determined not only by temperature, but by the humidity as well and can make the temperature seem more dramatic than it really is.

Stage 3

With this data, steps can be taken to further increase the energy efficiency of the Barnacle. These steps include a green roof, cross ventilation, improved levels of the envelope, and shade. Two sides of the home are already shaded and the other sides receive winds that cross-ventilation so the home is adequately efficient in this aspect. A courtyard could be added to provide better cross-ventilation, but the central octagonal chimney type ventilation system yields similar results.

Another step that could be taken is the addition of a green façade or living wall. “Living walls were found to have healthy effects on the human environment as well as environmental, economic, and
social benefits such as, for example, reduction of air temperature, improvement of the air quality by filtering airborne particles, water runoff reduction and consequent decrease of drainage infrastructure costs, decreasing of the climatic stress on the envelope with the reduction of maintenance costs, increase of plant and green areas leading to an increase of livable spaces to play, relax, and improve social relationships.” [11] Therefore, not only would a living wall provide a cooler interior, it would also have the potential of improving the quality of life of the people who experience the home.

Conclusion
The best alternative to mechanical cooling systems is passive cooling because it is eco-friendly and provides a comfortable environment, but it can’t reduce humidity and its performance fluctuates with the weather. [6] Other than a cooling system that depends completely on passive cooling, there are simple air handlers that use the outside air to ventilate the indoor environment. The most effective of these devices for controlling temperature is an air handler air controller that provides scheduled ventilation. In terms of humidity, a spot fan that is activated 30 minutes after a moist event inside is more effective. [7]

References
Chapter 4: Sustainable Mass Customization and Personalization

CODE FOR SUSTAINABLE HOMES: OPPORTUNITIES OR THREATS FOR OFFSITE MANUFACTURING AND MASS-CUSTOMIZATION?

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Abstract:
This study intends to, firstly, discuss current status of zero carbon homes in the UK, and secondly, to investigate the feasibility of using offsite construction methods to deliver mass customised zero carbon homes. The study concludes that mass customised offsite housing could be an answer to overcome the current barriers to achieve zero carbon homes in the UK; however, more work is required to increase the confidence of stakeholders including clients, designers, and housebuilders in offsite manufacturing in order to increase the share of such methods in the construction industry.

1 Introduction
The UK needs around 233,000 housing units per annum during the next two decades [1]. This is while the current economic conditions have considerably affected the housing outputs during the recent years. Housing supply in 2010 sunk to 102,730 units, its lowest rate since 1924 [2], and only 146,000 units were added to housing stock in 2011 which is 43% less than 2008 [3]. Housing industry is one of the major sectors, which should contribute [4] towards the UK Government’s long-term objectives to reduce carbon emissions by 80% by 2050 [5,6]. Domestic sector stands for around 29% of all the CO₂ emissions of the UK 66% of which is related to space heating, 17% to hot water, 15% to lighting and appliances, and 3% to cooking [7]. The UK government has announced its ambition to make new homes carbon neutral by 2016 [8,9,10]. This should be achieved through gradual amendments in building regulations based on the Code for Sustainable Homes (CSH) standards [11,12]. Energy efficiency standards have been included in the UK’s Building Regulations since 1965 [11]; however, it was not until 2007 when CSH was introduced for achieving zero carbon homes [13]. According to CSH, houses are classified under six levels where Code Level 6 is the most sustainable level and achieves zero carbon emission [14]. The energy saving/improvement figures over the Building Regulations, Approved Document L (2006) for Code Level 1 to Code Level 6 have been estimated as 10%, 18%, 25%, 44%, 100%, and finally, zero carbon for Code Level 6 [15,16,17]. Code Level 3 is currently implemented through the building regulations and Code Level 4 will come in force through the building regulation amendments in 2013, before the 2016’s regulations when zero carbon homes become mandatory (Table 1) [10,12,18].

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2013</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy/Carbon improvements over Building Regulations Part L (2006)</td>
<td>25%</td>
<td>44%</td>
<td>Zero Carbon</td>
</tr>
<tr>
<td>Code For Sustainable Homes Level</td>
<td>Code Level 3</td>
<td>Code Level 4</td>
<td>Code Level 6</td>
</tr>
</tbody>
</table>

Table 1: Gradual improvements to building regulations based on CSH standards.
Source of Table: [18]
The key drivers for the delivery of zero carbon homes are the legislations and regulations [19]. Limited knowledge and skills [19], and considerable extra over costs [16,18,20] are also the major barriers towards achieving zero carbon homes in the UK. It has been suggested that offsite methods of construction can help to achieve zero carbon homes [18] thanks to their higher quality [21] and fixed costs [18] compared to traditional methods of construction. Yet, mistakes made in the 20th century, which led to low quality dull offsite/prefabricated houses, and, consequently, bad public attitudes towards such methods are major barrios towards broader application of offsite methods of construction in the UK [22]. Mass-customisation seems to be a decent strategy to increase the share of offsite construction in the UK housing industry while avoiding the mistakes of previous decades.

This study intends to, firstly, discuss current status of zero carbon homes in the UK, and secondly, to investigate the feasibility of using offsite construction methods to deliver mass-customised zero carbon homes.

2 Zero carbon home

According to the Department for Communities and Local Government (DCLG) [18] a house could be considered as zero carbon if it genuinely produce a net annual zero carbon for the consumed energy for heating, cooling, washing, cooking, lighting, ventilation, hot water and electric equipment. This house could be described as Code Level 6 in the Code for Sustainable Homes [9]. Three requirements must be met for a home to be considered as a zero carbon home: [19,20,23]

1- Complying with the Fabric Energy Efficiency Standard (FEES) in terms of U-values, airtightness, etc.

2- Complying with the established Carbon Compliance limits (Table 2), established for zero carbon homes (after considering heating, cooling lighting and ventilation requirements); and

3- Reducing the remaining carbon emissions to zero

The third requirement can be met by intentional over-performance of the first and second requirements (by using, for example, photovoltaic panels, solar hot water, etc.) or can be achieved by investing in Allowable Solutions [20,23].

CSH was originally very ambitious requiring all regulated (heating, cooling, hot water, ventilation, auxiliary services and lighting) and unregulated energies (home appliances) to be zero carbon [10]. The “Allowable Solutions” was proposed in 2008 to provide some flexibility due to the difficulties (e.g. high costs, and feasibility issues on many sites) of delivering zero carbon homes on the basis of entirely “on-site” strategies [20]. The idea is that developers could pay to an Allowable Solution, which could be a small, medium or large offsite carbon saving project, to offset the remaining on-site carbon [20].

<table>
<thead>
<tr>
<th>Building type</th>
<th>Fabric Energy Efficiency Standard (FEES)*</th>
<th>Carbon Compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached house</td>
<td>46 KWh/m2/year</td>
<td>10 KgCO2/m2/year</td>
</tr>
<tr>
<td>Semi-detached house</td>
<td>46 KWh/m2/year</td>
<td>11 KgCO2/m2/year</td>
</tr>
<tr>
<td>End of terrace house</td>
<td>46 KWh/m2/year</td>
<td>11 KgCO2/m2/year</td>
</tr>
<tr>
<td>Mid terrace house</td>
<td>39 KWh/m2/year</td>
<td>11 KgCO2/m2/year</td>
</tr>
<tr>
<td>Apartment house</td>
<td>39 KWh/m2/year</td>
<td>14 KgCO2/m2/year</td>
</tr>
</tbody>
</table>

Table 2: Fabric Energy Efficiency and Carbon Compliance requirements set by CSH standards

Source of table: [20]

* FEES are the proposed maximum space heating and cooling energy demand for Code Level 6: Zero Carbon Homes.

** Carbon Compliance is the maximum permitted CO2 emissions from heating, cooling, hot water, lighting and ventilation.
2.1 Costs of delivering zero carbon homes

Achieving such high standards is not only difficult but is also expensive [16, 18, 20]. Dwellings built based on Code Level 6 in 2016 could be up to 50% more expensive compared to the 2010 regulations. According to the Department for Communities and Local Government the total costs for achieving zero carbon homes is around £34 billion with an economic return of around up to £22 billion [17]. It has been estimated that Code Level 3 and Level 4 households can, respectively, save around £25-105 and £25-146 per annum. Code level 6 households may save up to £359 per annum based on the entirely onsite solutions [18]. This is while another study by DCLG in 2011 indicates that the extra cost ranges for three-bed semi-detached house at Code Level 3 were between £907–£1,588, £4,295–£5,361 for Code Level 4, £16,407–£29,326 for Code Level 5, and £31,127–£36,191 for Code Level 6 [16].

As shown in Figure 1, a major portion of costs for achieving zero carbon homes is related to energy efficiency, which is achieved through fabric improvements (insulation, airtightness). For example up to 79% of the “extra over costs” for a semi-detached three bed house is related to improvements on the energy efficiency while it accounts only for around 36% of the weight for the allocated points towards zero carbon homes [16].

![Figure 1: Extra over costs of 3-bed semidetached houses for different CSH levels from baseline Part L 2010](source: [16])

2.2 Examples

Building Research Establishment (BRE) has established a permanent exhibition since 2005 in Watford, near London, known as BRE Innovation Park with the purpose of introducing Modern Methods of Construction, zero carbon homes and other innovative technologies [24]. The following are some examples of houses built in the BRE Innovation Park. Kingspan Lighthouse is the first home certified to Code Level 6 in the UK and Barratt Green House is the first zero carbon home built by a major UK housebuilder. The BRE Innovation Park not only provide builders with an opportunity to test and showcase their construction technologies and capabilities, but also is a great opportunity for designers, experts, and the public to see the innovations and emerging technologies and approached towards achieving a sustainable construction industry [24].

2.2.1 Kingspan Lighthouse

Kingspan Lighthouse was constructed in 2007 in the BRE innovation Park [24]. Kingspan Offsite has constructed its innovative 93 m², two and a half storey, two-bedroom Lighthouse (Figure 2) that is environmentally friendly and is designed according to the Government’s CSH Level 6 to which all new UK houses should be designed and built by year 2016. The annual heating cost for the house (including water and space) is about £30, which means around 94% saving on fuel costs. The energy bills of a similar house with the same size and shape built based on the 2006 Building Regulations would cost around £500 [25].
Kingspan’s TEK Building System, which is an offsite SIP (Structural Insulated Panel) system, has been used in the Lighthouse. Heat-losses through the building envelop, compared to a standard house, have decreased to around one third thanks to the very low U-value of the walls, roof and floor (0.11 W/m²K) along with the airtightness of less than 1m³/hr./m²@50pa. Triple glazed windows (0.7 W/m²K), low energy lighting, photovoltaic (4.7KW, 46m²), wood pellet boiler (10 KW), rainwater harvesting, and the 88% heat recovery mechanical ventilation, in addition to A++ rated white goods [25] make the Kingspan’s Lighthouse considerably energy efficient.

Moreover, proper use of thermal mass, passive ventilation, and solar shading helps to reduce energy consumption as well as maintain the indoor air quality. The rather low average daylight factor of 1.5 to 2% is however an area where improvements could have been made to make the Lighthouse even more environmentally friendly. Having been the first house certified to Code Level 6 standards, Kingspan’s Lighthouse was a proper example for the UK’s housebuilders and manufacturers during its rather short life from 2007 to 2012. It was demolished adopting a sustainable “zero-waste-to-landfill” approach last year [24].

2.2.2 Barratt Green House

The Barratt Green House (Figure 3) is a three-storey, three-bedroom family home built to Code Level 6 Standards. Barratt Green House was constructed in 2008 in the BRE innovation Park [24]. It is the first home built by a major UK housebuilder, which meets the requirements to achieve zero carbon emission [24,26]. The Barratt house is constructed from wall with aircrete masonry blocks with thin-joint mortar, concrete floor slabs, Structurally Insulated Panels (SIP) roof and low U-value triple glazing [26].

Similar to the Kingspan’s Lighthouse, Barratt Green House can achieve very low energy bills thanks to its high levels of insulations (180mm= 0.11W/m²K), airtightness (1m³/hr/m²@50pa) [27], use of PV panels, rainwater harvesting, solar shades, heat recover mechanical ventilation, and highly efficient appliances [26]. Application of triple glazed windows with a low U-value of 0.68W/m²K [27]
has also helped to achieve a good glazing to floor area ratio of 25% [26] providing sufficient natural lighting while maintaining low heat-losses through the window.

![Figure 3: Barratt Green House Source: Authors](image)

3 UK Housing and Offsite construction methods

Offsite construction is also known as prefabrication, system building, modular construction, system building, off-site manufacturing/assembly/production/fabrication, and industrialised construction [28,29,30]. Offsite construction in 2009, as a whole, accounted for £2-3 Billion or around 2% of the UK construction industry [31].

Due to many reasons offsite construction has not been very successful in the UK construction industry [22]. UK saw an extensive use of prefabricated methods during the 20th century to answer the massive housing demands caused by the World Wars. During the 20th century about one million prefabricated homes were built [32] which led to negative public attitude toward prefabrication due to the low quality of design [33], poor materials and building skills [34]. The 1960s was the era of high-rise flats applying prefabricated building methods. At the same time, arguments against such types of buildings and methods of construction were becoming more evident [32,33,35,36,37]. Extreme use of prefabricated methods along with the uniformity and dullness of prefabricated houses gave rise to the arguments to replace these methods with alternatives to allow for more diversity, British identity, and personalisation [38,39]. Industrialisation of the construction industry was criticised by the society because quantity was valued much more than quality. In many cases designers failed to consider technical matters in conjunction with aesthetics while local authorities were criticised for losing their tenants’ identity which caused several social problems such as depression, vandalism and other crimes [40].

The arguments on the necessity to increase offsite methods of construction has risen again during the recent years due to the needs for improved quality and providing affordable and sustainable houses in the UK. Supporters of offsite methods claim several advantages for these methods such as: improved speed; improved quality; improved health and safety; improved control conditions;
addressing skilled labour shortage; not weather dependent; minimized waste & energy consumption; enhanced value for money; cost predictability [34,41,42,43,44,45,46,47].

One of the major barriers towards broader application of these methods in the UK is their extra immediate costs [47,48,49] compared to traditional methods of construction. This is while traditional methods and practices have increasingly become less productive while their costs have increased significantly [28]. Moreover, successful examples, such as DFM 60K house competition in 2005, prove that offsite methods can be used to build affordable, high quality, sustainable houses [50,51]. Offsite methods have some other financial benefits, such as earlier rent and shorter borrowing periods, thanks to their less onsite construction periods compared to traditional methods [52]. However, given the current economic conditions and housing demand, housebuilders have no interest in faster construction period or in the improved quality offered by these methods. Buyers also seem to be more interested in the price and location of the properties than in the quality of houses. Therefore, developers are more likely to stick with the minimum requirements set by the building regulations than building high quality houses with less profit [47]. The main driver for using offsite methods of construction, therefore, seems to be the mandatory thermal and quality requirements set by the Building Regulation Part L [47].

4 Discussion
Although zero carbon homes can be achieved by traditional methods of construction [23], considering uncertainties in the quality and construction period of traditional methods [53,54], it is becoming more and more difficult and expensive to meet the requirements using traditional methods of construction [47]. Therefore, sooner or later, there will be a greater demand for the offsite products bringing the output/supply capacity under more pressure. According to Housing Forum, offsite-manufacturing (OSM) output in 2004 has been around 70% with expected increase to 80% in 2006 [55]. However, like many other industries, OSM is obviously suffering from considerable reductions in the UK housing output meaning that the production capacity is unlikely to be an issue in the short and mid-term. Given the current economic and housing conditions of the UK, it seems very unlikely that there would be a significant increase in demand for offsite products before 2016 when Code Level 6 becomes mandatory.

There are other issues, which should be addressed for successful delivery of zero carbon homes in the UK. Lack of enough knowledge and skills in the construction industry is considered as one of the major barriers towards delivering zero carbon homes [19]. Meanwhile, UK builders seem to have no objections against the increased use of offsite methods; however, they are concerned about whether offsite manufacturers can deliver products that match their specific needs and requirements [47]. Thus, offsite manufacturers should demonstrate as to how their products can address the current concerns on the knowhow, design, and delivery of zero carbon homes to increase the confidence of the industry in offsite methods.

Despite supports for offsite methods on delivering zero carbon homes, the general belief is that prefabricated methods may limit design flexibility and customisation [54]. This issue should be addressed by providing buyers, builders, and designers with more design flexibility without imposing extra costs. In fact, cost is the key factor for increasing the share of offsite methods and achieving mass-customisation (MC) [56]. Yet maximum standardisation is critical in achieving economies of scale. This should be achieved by generalising the design features, such as structural elements and dimensions, to be able to reuse the knowledge, processes and equipment throughout the production process. This has, to some extent, been applied by some builders who offer customisation on houses at late stages of construction through different elements and accessories such as external claddings and interior designs and fittings [31,57]. However, the ideal situation for designers and buyers would be to integrate customisation early in the design stages to provide buyers/designers with more flexibility.
Once, reducing costs of construction by removing costly and highly labour intensive tasks, such as bricklaying, was the objective of offsite methods of construction [36]; whereas MC is today one of the key concepts. When considering MC, suppliers should adapt quickly to the clients’ specific requirements without scarifying the efficiency of mass production [58]. Applying computer-aided design and manufacturing (CAD/CAM) systems have created an opportunity to have significant variety in the products without affecting the construction feasibility [56,59].

However, there are always some limits to the extents to which customisation can be achieved [60]. The fundamental question, therefore, remains the same that as to what degree standardisation should be considered to avoid monotony and to make the products aesthetically acceptable even with the price of rather less efficiency in terms of costs and economies of scale. Unlike the UK medium and large housebuilders, which may provide up to 30 plan options [57] with minimum or no options for customisation [61,62], Japanese MC housing providers, for example, may provide up to 300 standard plan and elevation designs [57], combined with internal specifications, finishes, and fit outs giving a countless customised options to the customers to choose from. The choices are however regulated by the economies of scale for the external claddings, planning regulations, size and orientation of the plot, predefined approved set of fittings and fixtures, and last but not least the income of the clients [57]. Similar approaches may be adapted by the UK housebuilders to maximise benefiting from offsite construction without increasing the costs and decreasing the aesthetic values of design.

5 Conclusion

Despite several efforts, offsite methods have never been able to take the place of traditional construction methods in the UK [22]. The history of the UK housing has shown that traditional systems are here to stay regardless of regulations and standards. Traditional methods have always improved themselves by becoming more efficient and cost effective competing with offsite methods of construction. Therefore, although CSH standards and building regulations will probably make the offsite methods more desirable, it would be unrealistic to assume that CSH would significantly decrease the share of traditional methods replacing them with offsite methods of construction.

Moreover, considering the current higher prices of offsite construction methods, there should be doubts about the arguments, which suggest that building to zero carbon standards would be cheaper if offsite methods are used. In fact studies on similar claims about the prefabricated methods during the past century suggest that claimed reduced costs of prefabricated methods at the time had more to do with the efficient construction processes by well organised developers than being purely related to the methods of construction [36]. The majority of the available costing figures are based on the assumptions and comparison of rather different housing developments. Costs are greatly affected the volume, size and form, energy efficiency figures, construction methods and technologies, finishing standards, provided services, and infrastructure [63]; hence more research is required to compare the costs of traditional methods with the offsite methods of construction when building to zero carbon standards.

Considering the very high standards of zero carbon homes, higher quality and fewer defects of the offsite methods (thanks to the factory quality controls) are probably stronger and more realistic arguments, which may encourage housebuilders to consider such methods. Offsite suppliers therefore should not only rely on the regulations drivers but also should seek for other incentives, such as reducing the overall costs and associated risks, to make offsite methods more attractive to the stakeholders including the clients, builders, and designers.

One of the major barriers towards broader application of offsite methods of construction is the negative public attitude towards such methods [59]. UK construction industry is still suffering from
the bad memories of the 20th century when dull and boring prefabricated houses caused several social and economic problems [22]. Providing variety and personalisation through MC is a way out of this dilemma to rebuild the public confidence in these methods.

The UK offsite manufacturing is immature particularly in the mass customisation housing. Much work is required to understand the requirements of the UK housing market based on which offsite manufacturers and developers can adapt their products and services to match those requirements. Yet there are great opportunities for offsite methods to gradually increase their share in the UK construction industry. Mass customisation would be a crucial issue in the future; however, given the current situations, cost is the key factor in the success or failure of offsite methods of construction and mass customisation in the UK.

6 References
1 CIH (2012). The housing report (ed. 3), Coventry: The Chartered Institute of Housing.


Abstract
The overview of the concept of living has been characterized for decades by a contrast between the ideas of globalization and between local cultural realities, which often differ from the actual needs and performance requirements of this historical period.
In Europe, through the introduction of new regulations and protocols sophisticated, trying to change the system of the new buildings, in order to promote the growth of the concept of environmental sustainability, among all concerned.
In Italy, ITACA and CASACLIMA protocols provide environmental certifications starting from the same input data but proceeding with different methodologies in particular the assessment of the characteristics of the building envelope.
Assuming that a new eco-friendly construction achieves its goal through a right mix of building envelope and contribution of technological systems, this study aims to weigh the contribution that the building envelope, alone can give.
You will be shown how the building systems based on the use of natural materials and from renewable sources themselves can contribute to the construction of environmentally sustainable buildings and how it is possible to do this without the use of sophisticated calculation method.

Keywords: Sustainability, ITACA protocol, CASACLIMA, building envelope, energy requirement

"Now everything has been invented." Thus ended the inauguration of the first steam locomotive during the Industrial Revolution of the nineteenth century. Period of ideas, a time when flashes of madness materialized in front of horrified spectators instilling a sense of fear and at the same time pride of being part of the race who had been able to accomplish what they were witnessing.

From that moment, every step forward has had only an enthusiastic reaction from those who took advantage of the progress made by the human race, regardless of the indelible marks left behind.
Even today, as then, the ideas represent the engine of progress in every field with the only difference of having to face a very different historical context and having need of deep reflection before being approached in all its aspects. It is changed the way we think, relate and live and also the environment in which it is done. We can no longer ignore the concept of "impact", from the effects of our actions on our surroundings and the sense of responsibility that should infuse all this. Responsibility is the key word of the approach to the desirable environment, which is now materialized at the international level.

The proof is the Kyoto Protocol of 97 `, signed by over 180 countries in the world which is now recognized as a reference point of the need for change in the relationship between man and environment. It may be, therefore, this document considered as a spark to trigger a common consciousness?

Starting with the certainty that we live in a world numerically and geometrically finite, consuming resources to do so, we are forced, more than ever, to establish a balance between the need and availability, respectively interpreted by man and land ecosystem. It seems consequential, therefore, to notice the need to estimate the parameters and the precise coordinates of that relationship respecting balances and right correlations.
Thus it was born, powerfully than ever, the concept of eco-sustainable and with it the "green building" meant to revolutionize and cushion the impact of human "living". For decades the green-building “must” resound and now we feel the necessity to clarify and to estimate parameters for assessing the objectivity of what we claim, giving due importance to the various factors.

This trend has developed in a global context numerous protocols for the assessment and environmental certification (LEED USA, BREEAM UK, HQE France) in a kaleidoscope of different parameters and approaches. Source of discussions in this area can only be the case of Italy where the presence of multiple certification protocols generates a sense of loss and lack of persuasion in the new user. ITACA Protocol and CASACLIMA represent the stakeholders of the matter.

The philosophy of ITACA (Institute for Innovation and transparency in government procurement and environmental compatibility) provides for
- the promotion of sustainable buildings,
- activities promoting the recognition of buildings with high environmental performance,
- the diffusion of the principles and practice of sustainable construction industry incentivizing programs and initiatives through training and professional development.

The evaluation process allows you to demonstrate the performance of the building giving a common reference for stakeholders, realizing all in a score having as macro input parameters leasing and construction qualities. The contributions of the different evaluated parameters are distributed through the coefficients called "weights" placed at the discretion of the assessor assessor.

The ratings of the individual evaluation areas are the weighty element of the "Protocol" as they determine the level of environmental compatibility of the work examined. The next step is represented by the attribution of a minimum threshold necessary for each area to define the ideal characteristics of a project with sustainability characteristics. Each Administration will have the opportunity to correct the weight of each requirement to fit the local reality, having in each case a set of common standards parameters.

From an analysis of the votes given to each assessment area, can derive a set of considerations that are usually condensed into graphs.
We set out below, the first items of the spreadsheet with the values of the "weights" placed on the Italian context:
Vote of the assessment multiplied by the weight of the weighted vote of the same area =
Sum of the weighted votes of the areas of the building = weighted vote
Environmental quality and external
Air pollution
Water pollution
Light pollution
Integration with the natural and built environment
Consumption of resources
thermal insulation
Passive solar systems
Domestic hot water production
Electricity (non-renewable)
Net consumption of drinking water
Re-use of existing structures
Use of materials (...?)
Recyclability of materials

3. environmental loads
CO2 emissions
Management of stormwater
Solid waste from construction and demolition
4. Indoor environment quality
natural lighting
Sound insulation of facade
Sound insulation of technical systems
Air temperature in winter
Figure 1 spreadsheet ITACA

It can be seen from the excerpt of the table as a great importance has been given, in terms of incidence and characterization, to the source of pollution linked to emissions and visual impact.
Before making any criticism, we have to start from some logical considerations: the eco-sustainable objective is, without any doubt, to minimize not only the consumption but also above all the production of energy. It is not surprising that you do not exclude that coming from renewable sources; in fact, even this type results with zero emissions, we can not similarly consider the chain of generation of the devices attached to them. For example we can just think of the increasingly frequent "fields" of photovoltaic panels that are real mutilation of the primary sector.

So, regardless of the intention to be insensitive to the issue of pollution, it would seem oxymoronic and deviant from the aim of the energetic certification to leave so little space to the factor "building envelope," based on common and indispensable features for each analysis. If you were considering a system of maximum efficiency energy production entirely renewable, what would be the advantage of a building envelope of poor performance? The dissipation of energy would require the production of increasing amounts going to frustrate all the premises and basic concepts of the brandished green-building.

So excluding or overshadowing the factor related to intrinsic basic features of the structure could be compared to groped for a drink while having a fridge while keeping it open. We now move on to the other party.

As mentioned at the beginning, ITACA direct competitor in the field of Italian energy certifications appears to be CASAACLIMA. (Notes on the structure, history and operation) It is known as the "calling card" of CASACLIMA is the energy-house matter that is materialized in the issue of a certificate. The energy certificate immediately shows the extent of the heat demand of a building, and has two energy classifications: the first concerns the class of insulation of the building, depending on the quality of the plant. With the help of a table divided into coloured boxes, from green (low energy demand) to red (high demand), even beginners can understand if a building consumes much or little energy. The thermal index of heat is determined based on factors relevant from the point of view of energy, through a process of calculating unit based on the following factors:

- The quality of the building envelope including exterior walls, windows, roof and thermal bridges.
- Build quality (e.g. thermal bridges, air-tight)
  - The losses caused by the change of air. The heat gains through solar radiation, the body heat and the heat produced by electrical appliances.
  - The quality of the whole system from the generator to the distribution systems, and if present, the ventilation system.
  - The needs and the total energy for domestic hot water
  - The energy carrier as gas oil, natural gas or electricity.

The end result is a mathematical calculation objective expressed in kWh / m^2 according to which you assign the category of the building (from "G" up to "gold" in order of decreasing energy demand). Such generality, let space to considerations and comparisons. One can not help but notice and praise the effort made by CASACLIMA in trying to give a cut of objectivity to their protocol through the mathematics of the calculation of the requirements, limiting the use of energy and indirectly the emission of polluting gases. Worthy of note is certainly as much attention paid to the use of indirect heat from a careful study of solar orientation, allocating everything to minimize the "needs" of energy. Critical reason of this protocol might just lie in the indirect process of evaluation of the polluting factor: focusing on the energy balance we neglect the importance of using eco-friendly building materials, practice unavoidable in the context of building world today.

It would seem mandatory and consequential in this point in the discussion, to consider a simple practical example of certification related to the Italian case and analyzed in the two protocols known so far in the case, in order to clarify the terms of comparison.

(Notebook Protocol ITACA)
The specific building, located in the Campania region, presents thermo-physical structures, geometry, construction type and conditions of use that make it representative of Italian building of the '70s. The structure is framed, with a system of beams and reinforced concrete columns, infill of double lining of hollow bricks. There is no type of thermal insulation.

It is composed of 12 apartments, with a total area of 1,020 m² in plan, spread over 3 levels. The projected area is 340 m² and the gross volume is equal to 3,570 m³. The new project involves the construction of two apartments on the roof (200 m² → 700 m³, 20% existing volume). I will be applied, therefore, the requirements of the Protocol and ITACA CASACLIMA in succession to the additional volume expected.
Plaster
Planking - perforated interspace
external plaster
Flooring in brick
Base
screed slope
Gravel / cobble

FLOOR COVERING

Parete Verticale
$U = 0.94 \text{ W/m}^2\text{K}$

Solaio controterra
$1/R_{\text{TOT}} = 1.25 \text{ W/m}^2\text{K}$

Solaio di copertura
$U = 1.4 \text{ W/m}^2\text{K}$
Energy analysis in terms of conventional calculation

For the purposes of energy certification of a building, you need:

a) The execution of an energy audit aiming to determine the energy performance of the building, through data retrieval and application of a specific calculation method, and the identification of energy improvements, which are cost-effective. The manner of execution of the diagnosis may be different and commensurate with the level of complexity of the calculation method, used for the assessment of performance.

b) The classification of the building as a function of energy performance, its confrontation with the limits of the law and the potential for improvement;

c) The issue of the certificate.

Specifically, in the determination of the energy performance of a property, the Presidential Decree 59/2009 provides that, for all categories of buildings (as classified according to the intended use of Article 3 of Presidential Decree 26 August 1993 n. 412), in the case of new construction and in the case of renovation of existing buildings, we proceed, at the planning stage to the determination of energy performance for winter heating (EPI), and verifying that it is lower than the limit value given in the appropriate table given in the Annex to Legislative Decree 192/2005 and subsequent amendments.

Regarding the building object of study, an energy analysis was made in conditions of conventional calculation, which allows the assessment of the energy performance indicators, using standardized input. In particular it is suitable for the classification performance of a building, when we must break free from too specific conditions of use.

Using a commercial software, accredited by CTI and therefore subject to the procedures UNI TS 11300 Part 1 and Part 2, it was found that the energy demand in heating is equal to: 68.049 kWh, or the energy performance index for winter heating (EPI) of the building is equal to: EPI = 67.8.

The comparison with the local regulations (see tab. 1.1 and 1.2) shows that the building energy analysis is a Class G, or the class to which correspond the highest energy consumption and, therefore, economically disadvantageous.
The results of the analysis should be compared with the limit values (the EP lim), calculated according to Table 1.3 of Annex C of D. Decree 311/2006, as the building in question is in the class E1 (residential buildings, pursuant to art. 3 of Presidential Decree 26 August 1993, n. 412).

The limit values (Table 1.3) are expressed as a function of climate zone in which the property is situated under investigation (as identified by art. 2 of Presidential Decree 26 August 1993, n. 412) and the aspect ratio of building S / V, where:
- S (m²) is the surface which delimits to the outside (i.e. towards environments not equipped with heating) the heated volume V;
- \( V \) (m\(^3\)) is the gross volume of the heated parts of the building, which is defined by the surfaces bounding it.
For values of \( S / V \) in the range of 0.2 to 0.9, and similarly for degree days (DD) to the intermediate climatic zone limits shown in the table, we proceed by linear interpolation.
With regard to the volume expansion of the present case, the \( S / V \) ratio for the two penthouses hypothesized, is equal to 0.58 m\(^{-1}\).

As the City of Naples located in a climatic zone C (1034 GG), interpolating from Table 1.3, it appears that the EPlim, only with reference to volume expansion, is equal to 36.11 kWh/m\(^2\) a.
The results of the analysis carried out have shown, therefore, that the energy requirements of the building exceed the limit imposed by the law, and therefore that the building is not up to standard.

Application of the Protocol ITACA

Below is the operationalization of the Protocol Itaca Campania synthetic building under study.
As mentioned above, the method of evaluation consists of a scoring system, based on the design of a framework to hierarchical levels:

The Protocol Itaca Campania is divided into 5 areas, which include rating 15 criteria, grouped into 10 categories:

<table>
<thead>
<tr>
<th>Area di Valutazione</th>
<th>Categorie</th>
<th>Criteri</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area di Valutazione</td>
<td>Categorie</td>
<td>Criteri</td>
</tr>
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<td>Area di Valutazione</td>
<td>Categorie</td>
<td>Criteri</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Area di Valutazione</th>
<th>Categorie</th>
<th>Criteri</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Qualità del Sito</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Consumo di Risorse</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Carichi Ambientali</td>
<td></td>
</tr>
<tr>
<td>Categories</td>
<td>Criteri di cui si richiede verifica</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------------------------</td>
<td></td>
</tr>
<tr>
<td>1.1 Condizioni del Sito</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.2 LEVEL di Urbanizzazione del Sito</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Energia Primaria non rinnovabile prevista durante il ciclo di vita</td>
<td>2.1.2 Trasmittanza termica dell’involucro edilizio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.1.4 Energia primaria per il Riscaldamento</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.1.5 Controllo della radiazione solare</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.1.6 Inerzia termica dell’Edificio</td>
<td></td>
</tr>
<tr>
<td>2.2 Energia da Fonti Rinnovabili</td>
<td>2.2.1 Energia termica per ACS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2.2 Energia Elettrica</td>
<td></td>
</tr>
<tr>
<td>2.3 Materiali eco-compatibili</td>
<td>2.3.1 Materiali da Fonti Rinnovabili</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3.2 Materiali riciclati recuperati</td>
<td></td>
</tr>
<tr>
<td>2.4 Acqua potabile</td>
<td>2.4.2 Acqua Potabile per Usi Indoor</td>
<td></td>
</tr>
<tr>
<td>3 Emissioni di CO2 evitate</td>
<td>3.1.2 Emissioni previste in fase operative</td>
<td></td>
</tr>
<tr>
<td>4.2 Benessere Termoigrometrico</td>
<td>4.2.1 Temperatura dell’Aria</td>
<td></td>
</tr>
<tr>
<td>4.3 Benessere Visivo</td>
<td>4.3.1 Illuminazione naturale</td>
<td></td>
</tr>
<tr>
<td>4.5 Inquinamento elettromagnetico</td>
<td>4.5.1 Campi Magnetici a frequenza industriale</td>
<td></td>
</tr>
<tr>
<td>5.2 Mantenimento delle prestazioni in fase operativa</td>
<td>5.2.1 Disponibilità della Documentazione tecnica degli edifici</td>
<td></td>
</tr>
</tbody>
</table>

Categories criteria, which require verification
Conditions of the Site 1.1.2 Level of Urbanization Site
Primary non-renewable energy expected during the life cycle 2.1.2 Thermal transmittance of the building envelope
2.1.4 Primary Energy for Heating
2.1.5 Control of solar radiation
2.1.6 Thermal inertia of Building
Renewable Energy 2.2.1 Thermal energy for ACS
2.2.2 Electricity
Eco-friendly materials 2.3.1 Materials from Renewable Sources
2.3.2 Recycled materials recovered
2.4.2 Drinking Water Drinking Water for Indoor Use
CO2 emissions avoided 3.1.2 Projected emissions during operational
Wellness Thermohygrometric 4.2.1 Air Temperature
Healthy Sight 4.3.1 Natural Lighting
4.5.1 Magnetic Fields Electromagnetic pollution at industrial frequency
Performance is maintained during operation
5.2.1 Availability of technical documentation of buildings
We will refer to the hypothesis of application of the synthetic Protocol ITACA, trying to create a volumetric expansion equal to 20% of the existing airspace. Furthermore, the application of the Protocol will focus on interventions in designing and executing construction, calibrated on a significant financial commitment but not excessive. The following will be analyzed individually some of the criteria listed above.

Criterion 1.1.2 - Level of urbanization of the site

The intervention was assumed in the city of Naples in Eastern area, therefore, being semi-suburban high urbanization area; to the criterion 1.1.2 are awarded 3 points.

Criterion 2.1.2 - Thermal transmittance of the housing
For the Climatic Zone C, the current energy legislation (Annex C of Legislative Decree 311/2006) provides for the following maximum thermal transmittance for the horizontal and vertical boundary surfaces:

1. Vertical walls: 0.34 W/m2K
2. Flat or inclined: 12.38 W/m2K
3. Windows including frames: 2.6 W/m2K

With about 10/12 cm of thermal insulation (polystyrene, polyurethane, rock wool) located outside of ordinary masonry (brick and concrete floors and walls plank hollow bricks), you will get around UWALL to 0.30 W/m2K. Similarly, low-e double-glazing windows with argon filled, they get UWINDOW equal to 1.8 W/m2K. Easily, so they are awarded 3 points.

Criterion 2.1.4 - Primary energy for heating

The new volume will have an energy performance rating for space heating amounted to 28.5 kWh/m2, compared to the limit established by law (equal to 36.11 kWh/m2). The relationship between the two is equal to 0.79, and this allows the acquisition of 15.3 points.
Criterion 2.1.6 - Thermal inertia of Building

<table>
<thead>
<tr>
<th>Material</th>
<th>Spessore (m)</th>
<th>Massa sup. (kg/m²)</th>
<th>U (W/(m² K))</th>
<th>f_a (attenuazione)</th>
<th>Y_PERIODICA (W/(m² K))</th>
<th>Sfasamento (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spessore</td>
<td>0.33</td>
<td>322</td>
<td>0.358</td>
<td>0.274</td>
<td>0.098</td>
<td>9.30</td>
</tr>
</tbody>
</table>

Criterion 2.2.1 - Thermal energy for ACS
With YIE of 0.10 W/m2K (low but quite ordinary, as visible in the example of the masonry shown on the previous page), compared to a legal limit of 0.12 W/m2K, you get a 17% reduction. Similarly to the covering floor, defining a structure with a value of less YIE of 15/20% compared to that of the law (0.20 W/m2K), 1:13 points are acquired.

Criterion 2.2.1 - Thermal energy for ACS

<table>
<thead>
<tr>
<th>CRITERIO 2.2.1</th>
<th>Energia termica per ACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA DI VALUTAZIONE</td>
<td>CATEGORIA</td>
</tr>
<tr>
<td>2: Consumo di risorse</td>
<td>2.2 Energia da fonti rinnovabili</td>
</tr>
<tr>
<td>ESIGENZA</td>
<td>PESO DEL CRITERIO</td>
</tr>
<tr>
<td>Incoraggiare l’uso di energia prodotta da fonti rinnovabili per la produzione di ACS.</td>
<td>nella categoria nel sistema completo</td>
</tr>
<tr>
<td>INDICATORE DI PRESTAZIONE</td>
<td>UNITÀ DI MISURA</td>
</tr>
<tr>
<td>Percentuale di energia primaria per ACS coperta da fonti rinnovabili.</td>
<td>%</td>
</tr>
<tr>
<td>SCALA DI PRESTAZIONE</td>
<td>in centro storico</td>
</tr>
<tr>
<td>NEGATIVO</td>
<td>&lt;20</td>
</tr>
<tr>
<td>SUFFICIENTE</td>
<td>20</td>
</tr>
<tr>
<td>BUONO</td>
<td>26</td>
</tr>
<tr>
<td>OTTIMO</td>
<td>30</td>
</tr>
</tbody>
</table>

Considering a new surface of 200 m2, for a total of 10 people is required to satisfy that 50% of the needs of ACS, about 6/7 m2 of flat solar panels. The decision not to further increase the solar surface is connected to technical-economic reasons. In fact, on an annual basis, an increase of solar integration over 50% would induce a summer cover more than 100% (converted to thermal energy and dissipated without use). Therefore 0 Points are acquired.

Criterion 2.2.2 - Electricity
Considering again the presence of 5 persons for each new apartment, for a total of 10 people, and by estimating an average consumption of 1000 kWh per person, converting from renewable sources to 25% of total demand means installing 2.1 kWp.

This requires 15 m² of net area of monocrystalline panels, 40/45 m² of gross area, considering a suitable distance between the parallel rows. A further area employment does not seem plausible, because the underlying apartments would not be allowed the same thing. Therefore, they are acquired 0 points.

Criterion 2.3.1 - Materials from renewable sources
With the use of materials from renewable sources in recurring production cycles, for a total percentage of 10% (with reference to buildings over 2 floors), you gain 3 points. Using selected producers (ANAB ICEA CONSORTIUM); 3:57 points are acquired.

Criterion 3.1.2 - Projected emissions during the operational phase
The building has a total primary energy demand estimated at around 72% of that required by a standard building according to the law for 2010. An EPI 20% lower than the limit to 2010, solar integration, the adoption of systems for drinking water saving (including the warm) and the significant presence of photovoltaic systems, would allow a drastic reduction of total energy demand and therefore of climate-altering emissions. They are therefore acquired 1.87 points.

Criterion 4.2.1 - Air temperature
The use of commercial technologies, widespread and low-cost systems such as radiator heating systems and split-system for summer cooling does not result in acquisition of points. The rating is equal to 0.

Below is a summary table containing the scores assigned to each criterion, scores weighed and the final result.
The overall score obtained by the application of the synthetic Protocol ITACA Campania to the case under study, is equal to 1.75. Application of the synthetic Protocol ITACA Campania, therefore, it appeared that the implementation of these measures allows obtaining a total score of 1.75. Since the final score of this case was superior to 1.5, it can be stated that all the requirements on demand by the Regional Guidelines are met.

Application of the Protocol CASACLIMA

You will pass, to the application of the provisions of CASACLIMA considered at the same volume at the start. The energy standard of the building, which is object of certification, is identified by two main parameters:

- Energy efficiency of the housing
- Overall efficiency

in turn calculated as the sum of specific factors (listed below) related to the housing and plant efficiency.

Energy efficiency of the envelope

The program provides users Procasaclima 2013 spreadsheets APTI to measure transmittance and emissions of each element both vertical and horizontal housing unit in question:
Figura 1 - stralcio foglio di calcolo

Figure 2 - excerpt spreadsheet

Going then to discern for each element are obtained the following data:

Outside vertical wall:

<table>
<thead>
<tr>
<th>Material</th>
<th>(24h)  dgn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmittance of U [W/m²K]</td>
<td>0.29</td>
</tr>
<tr>
<td>Internal heat loss [W/m²K]</td>
<td>15.87 0.00</td>
</tr>
<tr>
<td>External heat loss [W/m²K]</td>
<td>2.44 0.00</td>
</tr>
<tr>
<td>Transmittance of periodic U [W/m²K]</td>
<td>0.02</td>
</tr>
<tr>
<td>Solar factor</td>
<td>14.42</td>
</tr>
<tr>
<td>Insulation Y2 [W/m²K]</td>
<td>3.01</td>
</tr>
<tr>
<td>Solar factor of attenuation [-]</td>
<td>0.07</td>
</tr>
<tr>
<td>Solar factor of shading [-]</td>
<td>0.62</td>
</tr>
<tr>
<td>Total factor</td>
<td>7.99</td>
</tr>
<tr>
<td>Pu [MJ/m²]</td>
<td>724.0 988.3</td>
</tr>
<tr>
<td>GVP [kg CO₂eq/m²]</td>
<td>51.2 63.8</td>
</tr>
<tr>
<td>GVP processed [kg CO₂eq/m²]</td>
<td>51.40 63.39</td>
</tr>
<tr>
<td>AP [g SO₂eq/m²]</td>
<td>0.15 0.20</td>
</tr>
<tr>
<td>ICC [-]</td>
<td>39 51</td>
</tr>
</tbody>
</table>

quantità di materiali | 6 |
quantità di materiali certificati | 0 |
quantità di materiali regionali | 6 |
Roof coverings:

Going to the sum of the contributions of the glass surfaces, you get an average thermal transmittance of the housing equal to 0.80 W/m²K. Considering the heat balance (including losses due to ventilation and transmission) you get a return envelope in the winter period amounted to 28.5 kWh/m².

By comparing the results obtained with the parameters of Casaclima for the performance envelope you fall into category A.

Overall efficiency

The second parameter estimated from Casaclima involves the analysis of the emissions related to the use of plant in terms of its performance, focusing on the annual production of carbon dioxide. In this case the use of a good insulation and the support of the installation of renewable energy sources (solar panels) allowed a lower primary energy needs (72% compared to a normal building) that quantitatively speaking corresponds to annual fuel consumption per square meter of 10.23 kg of diesel fuel. Bearing in mind that for every pound of fuel oil are produced 3.34 of carbon dioxide, you can easily determine how the object in question produces 33.13 pounds of CO₂ per square meter per annum corresponding to a category "b" for Casaclima. It can be seen compared to ITACA there is more attention to obtain the numerical specific parameters rather than come back to the regional restrictions.

Conclusions

The work consisted in analyzing the building envelope of the same building through two different protocols used in Italy, from which are deduced the following considerations:

PROTOCOL ITACA: contemplates and evaluates the use of building materials, emphasizing those coming from renewable sources, to produce a score that exceeds the minimum limits imposed by
regional regulations. In this study case ITHACA gives a final rating of (1.75 / 5), just enough value in the rating scale.

CASACLIMA: assign a final grade based on mathematical relationship between energy demand and availability of the building, trying to reward the lowest differential. The process followed by the latter leads to neglect the environmental aspect in which it is intended a marginal role through the inclusion of "Brand casaclima more," not mandatory in order to obtain the final documentation, giving, however, a category of Excellence (category A).

This means that between the two protocols, with the same input, the most importance to the building envelope is given by CASACLIMA. This is because it evaluates in a quantitative way the building envelope, while ITHACA does so in a qualitative manner. The discrepancy found with the results of the work done, highlights how the approach with different protocols leave space to interpretation of the concept of certification of its quality, without objective guarantees for the end user. Just user, subject less informed in most cases, may be subject to decisions, which, although supported by protocols in force, are different from the initial request to take advantage of eco-sustainable living.

References
ACEN, 2012, Protocollo ITACA Campania: Linee Guida regionali Metodologie applicative
THE EFFECT OF LEED CERTIFIED RESIDENTIAL BUILDINGS ON HOUSEHOLD FINANCES IN FLORIDA?: LITERATURE REVIEW

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Abstract:

LEED (Leadership in Energy and Environmental Design) certification is touted to produce buildings that are “green” in terms of energy efficiency, however a study on energy use in LEED certified commercial buildings gave mixed results and in another study no reduction at all. Both studies concentrated on a database of commercial buildings, which is plentiful, though little research has been produced which examines consumption patterns in residential buildings. According to USGBC homes with LEED certification are resource-efficient consuming between 20-30% less energy that a home built to conventional standards. However, literature on these claims is scanty and has not included the possible economic costs of health implications due to affected indoor air quality.

What literature is available on the performance of LEED certified building energy use claims it is 25-30% better than the national average, though the report has been criticized for a lack of robust methodology as it relies on voluntary submissions and hence creates a biased sample; the comparisons were not on apple for apple basis as they used median energy use intensity (EUI) versus mean EUI for the conventional buildings. The study used the database that came from the NBI study and found the LEED mean EUI to be from 18-39% lower than matching non-LEED buildings. However, other authors used the same database and came to different conclusions suggesting a need for further study and analysis of the results. The report argued that LEED certification did not on average produce buildings that lower energy consumption both at the source and at the production point, though it acknowledged that they consumed less on-site energy but to the tune of 10-17%.

Introduction:

Of course, there have many debates about the legitimacy of LEED certification actually contributing to a more “sustainable” building, and while perhaps the intentions of the USGBC providing a third party rating system to which many building owners and builders aspire to build in accordance with, the issue seems to lie in the incentive and structure of the point based system. Many builders often look to LEED certification simply as a means to “gain tax credits, attract premium rents, and project an image of environmental responsibility.” (Navarro). The problem is the broad scope of the checklist and point system allows for a gap between the design and construction of the building and how it actually performs. Point accumulation often takes avenues through secondary material sources such as bamboo flooring while paying little attention to the actual optimization of energy usage. While it is obviously important to take renewable, sustainable materials in to account when designing and building, one should not neglect the features of a building, which continue to affect its post occupancy performance. One such example is the Federal Building in downtown Youngstown, Ohio which according to environmental assessment last year failed to qualify for the Energy Star label granted by the EPA which ranks buildings after reviewing a year’s worth of utility bills (Navarro). The building gained LEED certification by racking up points for items such as native landscape design while ignoring structural and mechanical energy-saving features according to a study done by the General Services Administration, which owns the building (Barnaby, et al). One major culprit for the poor post occupancy EPA scoring was a completely inefficient cooling system.
This, it seems, turns out to be a very large contributing factor to energy consumption. How efficiently buildings are heated and cooled can have a great impact on the finances required for this energy consumption. Previous schools of thought were to overdesign for this situation, installing energy intensive, larger than necessary units to accommodate for any situation, and sealing a building tightly as possible to the outdoors (also known as airtight construction), perhaps as a result in the lack of confidence of heating and cooling load calculations. However, there are numerous problems which can occur when a building becomes sealed off to the outside world and excess sensible capacity increases not only initial costs but results in performance problems including poor humidity control, excessive power demand, and noisy operations (Barnaby, et al, 2005). Correct calculations of heating and cooling loads are vital to building performance as having a properly sized system will have lower overall installation cost, perform better, operate more efficiently, and impose less demand on utilities (Barnaby, et al, 2007).

There are many avenues for calculation of these loads, and one Barnaby and Wilcox compared the measured and calculated residential cooling loads using two different methods in their experiment. The purpose of the experiment was to compare loads calculated with the Manual J 8th Edition (MJ8) and the ASHRAE Residential Heat Balance (RHB) method. The MJ8 is a component based procedure which utilizes formulas and tables that specify load contribution per unit area of a wide range of residential construction assemblies and takes into account design conditions and surface orientation (Barnaby, et al, 2007). However, the MJ8 makes assumptions about when the peak loads will occur and thus is limiting in some aspects. The RHB method 24-hour procedure, which can be performed any day of the year and can undertake any design condition. Hourly loads are calculated via energy balances and the design load is simply the peak of the overall daily profile (Barnaby, et al, 2007). One ideal capability of RHB is the ability to model temperature swing, which allows the space temperature to temporarily exceed the nominal set point temperature. Each house had identical construction and was fitted with windows, which allowed for interchangeable glazing. Two of these houses had south-facing primary fenestration and the other two had west-facing fenestration. Both MJ8 and RHB residential cooling load calculations assumed the worst case scenario of solar gains and therefore yielded conservative results for the overall cooling load estimates with high solar exposure. MJ8 loads were consistently conservative while the RHB loads became increasingly conservative as solar exposure increased. Xiao (2006) identified inter-room heat transfer via air flow and partition conduction as a weak spot in the RHB algorithms. An additional issue is that the design day is assumed to be repeated indefinitely when in reality residential buildings have a day-to-day variability.

While accurate calculations are vital to efficient mechanical systems, alternatives to using mechanical air conditioning might be explored as well as a means of sustainability. Passive systems work to remove heat from a building to a natural heat sink or by preventing heat from entering the building via external heat sources (Samuel, et al, 2013). It is important to note that the practicality of these passive techniques is often limited by the local climate. Nocturnal radiation cooling works best in arid regions, though is limited in the fact that is only operates at night therefore the net cooling period is less than 11 hours per day and the daytime load must be transferred using thermal storage systems. Geothermal cooling via earth sheltering or earth tunnel cooling takes advantage of the earth’s stable ground temperature at a certain depth to keep the building cool. However, drawbacks are challenges like moisture penetration and mold growth. Hydrogeothermal cooling takes advantage of cool ground water circulating through pipes to cool spaces. Thermal insulation and shading are other options, as well.

It is important to think about these alternatives as a possibility as some studies show that mechanically ventilated air added to “tight” homes may be adversely impacting resident health, building durability, comfort, and energy usage by raising indoor humidity levels. As sealing off the building to outside air requires the implementation of a mechanical air system, theoretically these
mechanical systems would have the potential to improve indoor air quality by removing any air contaminants within the system and decreasing humidity. However, research has shown that in hot humid climates ventilation with outside air may increase interior moisture levels and thus produce effects such as building failure, occupant discomfort, and poor indoor air quality (Moyer 2001, Cummings, et al. 1991). It has been recorded that buildings adopting the technique of added mechanical air systems to homes in hot humid climates results in longer periods of elevated interior relative humidity relative to conventional houses without dedicated ventilation systems (Rudd 2003). The study found that a correctly sized air conditioning system coupled with a dehumidifier to pre-condition outside air provided the best interior humidity control with only a slight increase in energy usage.

It is important to take these issues discussed into consideration when moving forward with research in regards to indoor air quality and alternative methods to cooling and heating. Not only is the health of the occupants of great priority, an adequate and appropriate system, which will not place financial burdens on the occupants, is just as important, as well.

References


Chapter 6: User Behavior and Choice

USING POST OCCUPANCY AND SIMULATION BASED APPROACH FOR RETROFITTING DEPRIVED COMMUNITY HOUSING IN THE UK

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Abstract
Houses in deprived communities will frequently suffer from poor standards of thermal comfort and energy performance. They are hard to heat in winter and consequently burn more fuel and produce higher CO₂ emissions than any equivalent energy efficient dwellings. As a result, occupants can become trapped in fuel poverty and may also experience health problems. Therefore, applying energy efficiency measures to poor quality housing does not guarantee that the maximum potential savings from the measures will be accomplished. This study has been undertaken as part of the BIG Energy Upgrade (BEU) project, which aims to deliver a new approach to housing retrofitting and energy efficiency within a minimum of ten of the most deprived communities across six local authorities within Yorkshire and the Humber region in the UK. The paper is investigating the procedures by which energy efficient measures for such properties are installed, quantified and assessed throughout a post occupancy monitoring programme and a series of computer simulation studies. This will represents an innovative approach and has the aim of ensuring that as much of the theoretically achievable energy savings are actually realised in practice. As a consequence, residents will have the best chance of perceiving what difference the energy efficiency interventions have had on the quality of their home environment.

Keywords: indoor environment, energy efficiency, deprived communities, post occupancy evaluation, computer simulation.

Introduction
The impacts of climate change are still on going and the trend of further change is deemed unavoidable due to greenhouse gas emissions across the world. In the UK, particularly for central England, the temperature has increased by about 1°C since the 1970s (Jenkins, et al 2010). The UK Climate Projection 2009, also known as UKCP09, provided an opportunity to quantify the climate change impacts on building performances (DEFRA, 2009). In order to tackle warming climate in future, the UK government has set very ambitious targets with the Climate Change Act 2008 in place for reduction of at least 34% in greenhouse gas (GHG) emissions by 2020 and of at least 80% by 2050, against the 1990 baseline. This commitment requires carbon reductions to be made by all industries, particularly the housing sector, because the existing housing stock produces 27% of all UK CO₂ (DTI 2007).

In the BIG Energy Upgrade, the aim is energy innovation of deprived community housing in Yorkshire and the Humber region in the North East England, UK. Houses in deprived communities will frequently suffer from poor standards of thermal comfort and energy performance. Hence, these community homes are hard to heat in winter and consequently burn more fuel and produce higher CO₂ emissions than any equivalent energy efficient dwellings. As a result, occupants can become trapped in fuel poverty and may also experience health problems. Therefore, applying energy efficiency measures to poor quality housing does not necessarily guarantee that the maximum potential savings from the measures can be accomplished. Many studies have demonstrated that a combination of poor constructional detailing, inefficient services, faulty installations and inappropriate
controls as well as the lack of resident/user awareness and feedback can combine to give disappointing energy savings compared against the predicted targets.

In this study, the focus is on the most deprived communities across six local authorities within Yorkshire and the Humber region in the country, and the investigation is underway using a post occupancy monitoring programme and a series of computer simulation studies to assess the procedures by which energy efficient measures for such properties are installed and quantified. Thus, this will represent an innovative approach and has the goal for ensuring that as much of the theoretically achievable energy savings are actually realised in practice.

**Methodology**

For the study to deliver a new approach to housing retrofitting and energy efficiency improvements within the most deprived communities across six local authorities, as well as for residents/users to have the best opportunity to learn what difference the energy efficiency interventions have had on the quality of their home environments, a group of researchers and experts from the Building Environments Analysis Unit (BEAU) at the University of Sheffield have been assigned to undertake two main tasks: (1) monitoring of indoor environment, and (2) performance simulation studies for investigating the procedures by which energy efficient measures for such community homes are installed, quantified and assessed. Moreover, the study would identify and eliminate reasons for underperformance in the upgraded homes from different communities through building monitoring and dynamic simulation analysis for predicting and analysing the complexities of building environmental performance.

In the study, three case study homes have been selected for this investigation. These homes are from the same region and represent areas of South Yorkshire (Barnsley), West Yorkshire (Kirklees) and Humberside (North East Lincolnshire), and have been coded as follows: B1, K1 and NEL1. The use of computer simulations in this instance is particularly helpful for retrofit options and refurbishment studies in order to perform parametric analyses in which the relative impact of individual parameters can be assessed. The impact of different energy efficiency measures would be estimated using computer models, via predicted performance criteria established.

Furthermore, the study presents a research into how the refurbished properties might perform in response to climate change by using future weather files based on UK climate projections as this would be vital for those communities that are least able to heat their homes in winter and may currently be most at risk of not being able to keep their homes cool in the warming summers of the future.

**Case Study Homes**

Table 1 shows the selected case study homes that are used in the studies carried out for both post occupancy monitoring of indoor environmental conditions and for computerised dynamic simulations in order to predict the impact of retrofitting on energy consumption and thermal performance.

The reason for selecting these three case study homes was mainly considered because of the construction types used in the dwellings investigated from this region, which are also common to other regions in the country. These are summarised as British Iron Steel Federation (BISF) ¹  Steel framed wall, Cavity wall and Solid wall construction homes.

<table>
<thead>
<tr>
<th>Table 1: General information of case study homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-1</td>
</tr>
</tbody>
</table>

¹ In 1944 the Interdepartmental committee on Housing Construction to identify the most promising for immediate development assessed various non-traditional house construction systems. The British Iron and Steel Federation (BISF) steel framed house was one of those selected and a programme was planned for the construction of 30,000 three-bedroom two-storey semi-detached houses in England and Wales (BRE 2002).
### Table 2: Retrofitting strategy and expected installation costs

<table>
<thead>
<tr>
<th>Measure</th>
<th>Construction</th>
<th>Installation Costs (£)</th>
<th>Target (U-value, Airtightness and Efficiency)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insulation Measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Wall</td>
<td>Cavity wall</td>
<td>450 ~ 500</td>
<td>0.3W/m²K</td>
</tr>
<tr>
<td></td>
<td>Solid (internal)</td>
<td>5,500 ~ 8,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solid (external)</td>
<td>9,400 ~ 13,000</td>
<td></td>
</tr>
<tr>
<td>Loft</td>
<td>0 to 270 mm</td>
<td>approx. 300</td>
<td>0.16W/m²K</td>
</tr>
<tr>
<td></td>
<td>up to 300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground Floor</td>
<td>530</td>
<td></td>
<td>0.25W/m²K</td>
</tr>
<tr>
<td>Windows</td>
<td>approx. 2,500</td>
<td></td>
<td>1.5W/m²K</td>
</tr>
<tr>
<td>Airtightness</td>
<td>Draught Proofing</td>
<td>200</td>
<td>5m³/(hm²) @ 50Pa</td>
</tr>
<tr>
<td></td>
<td>Front Doors</td>
<td>1,200</td>
<td></td>
</tr>
<tr>
<td>Heating System</td>
<td>New Boiler</td>
<td>2,300</td>
<td>over 90%</td>
</tr>
</tbody>
</table>

Table 3, on the other hand, shows the each case study home pre refurbishment (referred to as the ‘base case’); considering existing features and selected retrofitting features. Both case study homes K1 and NEL1 had external wall insulation measure installed and the case study home B1 had multiple measures installed such as cavity filling, topping up loft insulation, fitting of double glazing and replacing of boiler.

### Table 3: Detail of construction and retrofitting measures

<table>
<thead>
<tr>
<th>Case Study Home</th>
<th>Base Case Features</th>
<th>Selected Retrofitting Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>Elements Fabric U-value (W/m²K)</td>
<td>Elements Fabric U-value (W/m²K)</td>
</tr>
<tr>
<td>Loft Insulation</td>
<td>0.43</td>
<td>-</td>
</tr>
</tbody>
</table>
### Simulation Scenarios

In the study, computer simulation scenarios focused on three sensitivity studies such as retrofitting, energy efficiency measures and climate change. In order to carry out the simulation studies, a dynamic computer simulation package, DesignBuilder (version 2.2.5) has been used (DesignBuilder 2013), which is approved software by the UK government and was adopted to use EnergyPlus energy simulation software (version 4.0) with a built-in calculation method for thermal analysis and energy performance evaluation of the selected case study homes. The simulation scenarios used in the study are as follows:

- Study-A considers the effect of retrofitting on heating energy consumption. Each case study home with selected retrofitting measures has been tested through Study-A.
- Study-B considers the effect of various energy efficiency measures on heating energy consumption and cost effectiveness. Based on the EST's ‘Best Practice Standard for Refurbishment’ guidance (see Table 2), Study-B has been adopted to each case study home considering retrofitting/improvement measures in order for the analysis of cost effectiveness.
- Study-C considers the effect of climate change on heating, cooling and thermal comfort. UKCP09 2050s High Emission scenario has been selected to establish the impact of climate change on energy consumption and thermal comfort.

### Indoor Environment Analysis and Results:
In the study, the first section considered post occupancy monitoring findings as indoor environment analysis within the three selected case study homes (B1, NEL1, K1) respectively. The recommended standards and guidelines are provided by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and the Chartered Institution of Building Services Engineers (CIBSE), and have been considered for the analysis in this section (CIBSE 2006; CIBSE 2008; ASHRAE 2013).

Figure 1 shows the daily indoor air temperature (°C) profile of the living room and the bedroom in B1 (Barnsley) dwelling. The temperature in the living room is fluctuating around 22°C and the bedroom temperature is above 17°C. In comparison with the standard guidelines, it is clear that the living room swinging around the CIBSE recommendation for the range of internal temperatures (22-23°C) in the living room and also comply with the standard guideline of internal temperatures (17-19 °C) in the bedroom.

![Figure 1: Indoor temperature of the living room and the bedroom in B1 dwelling](image)

Figure 2 shows the level of relative humidity RH% for the living room and the bedroom in B1 (Barnsley) dwelling and they do both agree with the standard guidelines for these two rooms (40-70%).
Figure 2: Indoor relative humidity of the living room and the bedroom in B1 dwelling

Figure 3 shows the indoor CO$_2$ levels of the living room in B1 (Barnsley) dwelling. It can be seen that the level is under the ASHRAE recommended value for indoor space (1000ppm), which indicates the availability of fresh air within the space.

Figure 4 shows this direct (positive) relation between CO$_2$ and indoor temperature in B1 (Barnsley) dwelling. The results may indicate that the warmer space has lack of air ventilation rates and
therefore, the CO₂ levels are higher, and it also reflects the dilemma of achieving proper ventilation and indoor thermal comfort.

Figure 4: Correlation of indoor CO₂ against indoor temperature of the living room in B1 dwelling

Figure 5 shows the daily indoor air temperature (°C) of the living room and the bedroom in NEL1 (North East Lincolnshire) dwelling. The temperature in the living room is under 22°C and the bedroom temperature is above 17°C. In comparison with the standard guidelines, it is clear that the living room did not comply with the CIBSE recommendation for the range of internal temperatures (22-23°C) in the living room, however it does comply with the standard guideline of internal temperatures (17-19°C) in the bedroom.
Figure 5: Indoor temperature of the living room and the bedroom in NEL1 dwelling.

Figure 6 shows the level of relative humidity RH% for the living room and the bedroom in NEL1 (North East Lincolnshire) dwelling and they do both agree with the standard guidelines for these two rooms (40-70%).

Figure 6: Indoor relative humidity of the living room and the bedroom in NEL1 dwelling.
Figure 7 shows the indoor CO$_2$ levels of the living room in NEL1 (North East Lincolnshire) dwelling and it can be seen that the level is under the ASHARE recommended value for indoor space (1000ppm), which indicates the availability of fresh air in the space.

![Living room CO2 [PPM]](image)

Figure 7: Indoor CO$_2$ levels of the living room in NEL1 dwelling

Figure 8 shows this direct (positive) relation between CO$_2$ and indoor temperature in NEL1 (North East Lincolnshire) dwelling. The results may indicate that the warmer space has lack of air ventilation rates and therefore, the CO$_2$ levels are higher, and it also reflects the dilemma of achieving proper ventilation and indoor thermal comfort.

![Indoor temperature vs. CO2](image)
Figure 9 shows the daily indoor air temperature (°C) of the living room in K1 (Kirklees) dwelling. The temperature in the living room is above 22°C. In comparison with the standard guidelines, it is clear that the living room did comply with the CIBSE recommendation for the range of internal temperatures (22-23°C) in the living room. The same figure also shows the levels of CO₂ are under the ASHRAE recommended value (1000ppm) most of the time with some peaks above it.

Figure 10 shows this direct (positive) relation between CO₂ and indoor temperature in K1 (Kirklees) dwelling.
Simulation Studies and Results:
In the study, the second section considered computer simulation scenarios also focusing on three sensitivity analysis as retrofitting, energy efficiency measures and climate change within the three selected case study homes (B1, NEL1, K1) respectively. The simulation studies and scenarios are presented as Study-A, Study-B and Study-C as described in Methodology section.

Study-A Evaluations
In Study-A simulations, the heating demand has been reduced in the case study homes as expected for post retrofit. After retrofitting, the most dramatic heating energy demand decreased for the case of B1 dwelling, which was required less than 20% of the base case. However, this is quite obvious and predictable due to the fact that B1 dwelling was improved with most of its building fabric’s thermal properties and at the same time has been benefitted from a more efficient heating system by replacing its boiler (see Table 3). The least heating energy demand decreased for the case of NEL1 dwelling which was reduced by around %30 of the base case while the case of K1 dwelling required almost as less as 50% of the base case (see Figure 11).
Both in K1 and NEL1 cases, their existing external walls have been installed with external wall insulations. However, there is a significant difference between K1 and NEL1 dwellings as their external wall constructions are two very different structures such as K1’s external wall is made of a BISF steel frame which is a lightweight structure while in the case of NEL1, the external wall is an uninsulated solid wall which is a heavyweight structure. Building materials that are heavyweight store a lot of heat so are said to have high thermal mass. Materials that are lightweight do not store much heat and have low thermal mass. As a result, lightweight structure has less thermal mass than heavyweight structure that means when heating is required, the lightweight structure responses in shorter timeframe than the heavyweight structure, and at the same time, it is quickly cooled down when compared with the heavyweight structure.

In the base case, the heating energy demand difference between K1 and NEL1 cases is almost 30%. However, after retrofitting, the difference is reduced to around 7%. From the results, it can be seen that lightweight structure with better insulation has better heating saving performance than heavyweight structure due to the fact that lightweight structure does not need to heat the building and at the same time has less heat losses through building fabric. However, heavyweight structure does still need to heat the building first rather than the internal spaces.

**Study-B Evaluations**

In Study-B, dynamic simulations have been carried out for the base case model and for the range of retrofitting options as listed in Table 2 in order to undertake analysis of cost effectiveness through various retrofitting/improvements measures. As can be seen in Figure 12, in terms of heating energy savings, each case study home has a different priority energy efficiency measure applied; for instance, the most energy efficient retrofitting option for K1 dwelling is an external wall insulation, for B1 dwelling is a boiler replacement and for NEL1 dwelling is a front door replacement and draught proofing.

In the study, the term of ‘cost effectiveness’ is defined as how much cost is required to save 1kWh of heating energy consumption. As a result, lower number means more cost effective for the particular measure applied describing ‘cost effectiveness’ for that retrofit and improvement. In Figure 12, blue bars show the cost effectiveness applied for that particular measure which does not match with the most heating saving measure as shown with red bars. For example, the most energy efficient measure for K1 dwelling is external wall insulation while the most cost effective measure is front door replacement and draught proofing for the same dwelling.
On the other hand, the EST standard represents an improved base case home as the EST best practice standard, and this could be the best way to save heating energy consumption even though it may not necessarily be the most cost effective option as shown in the studies. From the study, it can be confirmed that the local authorities have selected the most energy saving measures for their homes and retrofitting, however, this is not necessarily accomplished with the most cost effective way.

![Graph K1](image)

![Graph B1](image)
Study-C Evaluations
In Study-C simulations, the heating demand decreased while the cooling demand and therefore the overheating hours increased through the climate change scenarios. Thus, global warming has an impact on heating and cooling demand, and thermal comfort (see Figure 13). In terms of heating energy demand, heating energy saving by climate change is fixed between around 27% in the case of NEL1 to around 35% in the cases of K1 and B1, and the savings have been made without improving thermal properties of the case study homes' building fabric.

On the other hand, in terms of cooling energy demand, the findings showed an opposite trend that means less heating savings in the case study homes while also showing less cooling demand such as in the cases of NEL1 and B1. Heavyweight structure showed better performance than lightweight structure for cooling energy consumption such as in the cases of NEL1 and K1, and even better when adapted to the climate change scenario in the case of NEL1 after retrofitting this dwelling due to both thermal mass and less heat gains from external sources like direct and indirect solar gains.

In terms of thermal comfort and overheating\(^2\), the findings showed that retrofitting case study homes would have brought overheating problems than when compared with the base case except the case of NEL1 due to its main construction type which is containing high thermal mass as a heavyweight structure. However, having thermal mass would be less efficient in bedrooms. This could explain that during daytime the bedroom space would be heated by direct solar gains and the heat would be stored in the thermal mass while then the stored heat will be exposed to internal spaces during night time where windows in the bedroom would unlikely to be opened due to reasons like security.

The study showed that better performance in heating energy consumption in the case study homes confirmed less benefit for cooling energy demand, and again high risk of overheating due to less heat losses through building fabric.

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\(^2\) The CIBSE Guide A shows the criteria for thermal comfort and overheating in the UK. Accordingly, overheating or thermal discomfort is confirmed when the internal operated temperature is over 28°C in the living room and is over 26°C in the bedroom for more than 1% of the occupied hours (CIBSE 2006).
Figure 13: The impact of climate change on heating, cooling and comfort for K1, B1 and NEL1
Conclusions
The study aimed to investigate the procedures by which energy efficient measures for such properties are installed, quantified and assessed throughout a post occupancy monitoring programme and a series of computer simulation studies. This research represents an innovative approach and has the aim of ensuring that as much of the theoretically achievable energy savings are actually realised in practice, and as a result, residents have the opportunity to receive feedback on potential impact of what difference the energy efficiency interventions have had on the quality of their home environment.

The retrofit has definitely improved the indoor environment in the selected case study homes however even though the improvements were beneficial, the indoor environment did not change significantly as can be seen with the study findings of indoor temperature profiles and relative humidity levels. They mostly comply with the recommended standards specified by ASHRAE and CIBSE. On the other hand, the CO$_2$ levels determining air quality within the living spaces of deprived community homes have remained mostly around similar levels although the airtightness levels have fairly improved in the investigated dwellings due to external wall insulations regardless of the construction type. Moreover, there was a proportional relation between indoor temperatures and CO$_2$ levels that reflected the dilemma of achieving proper ventilation and indoor thermal comfort at the same time, which can be one of the main conclusions from the research.

Accordingly with the simulation studies, energy efficiency measures like external wall insulation has helped reduction on heating energy demand in the case study homes regardless of their construction type. However, after retrofitting, it has been observed that lightweight structure with better insulation has better heating savings and thermal performance when compared with heavyweight structure because of the fact that a lightweight structure does not require as much heat as a heavyweight structure due to its high thermal mass. The study findings revealed that the local authorities have selected the most energy saving measures for retrofitting of their properties, however, this is not necessarily accomplished with the most cost effective way.

The studies also showed that with the effects of climate change, the heating demand would decrease while the cooling demand and the overheating hours would increase through the scenarios applied. Thus, global warming has an impact on heating and cooling demand, and thermal comfort. Furthermore, considering retrofitting for future and cooling energy demand, the findings showed that heavyweight structure has better performance than lightweight structure for cooling energy consumption. The study showed that better performance in heating energy consumption in the case study homes confirmed less benefit for cooling energy demand, and again high risk of overheating due to less heat losses through building fabric.

Acknowledgment
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Chapter 7: Renewable Energy and Technology

WINDOW THERMAL PERFORMANCE OPTIMIZATION IN GOVERMENTAL HOUSING PROGRAM IN ABU DHABI, UAE
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Abstract

This paper stems from a study that aims at the optimization of the window thermal performance in a typical house within the Emirati Family Housing Program. A survey of the newly constructed houses revealed the same window design for all houses orientation disregarding windows critical heat gain impact under the extreme hot climate of the United Arab Emirates.

Through a survey, the 5-bedroom villa emerged as the dominant type in this housing program. Thereafter, its thermal performance in relation to orientation was tested using HEED, an energy analysis software. The results indicated variable annual energy consumption per orientation with the highest rates of consumption being for the west oriented units. Thereafter, two scenarios of optimized alternatives with thermally efficient window’s components were tested. The first included thermally improved glazing (Double Tinted Squared Low E) and framing material (Vinyl) while the second introduced additional external shading (Automated Slatted Blinds). The results indicated an improvement in building thermal performance with annual energy savings ranging between 6-11%. Of more relevance to designers, similar thermal behavior was reached for all orientations.

Keywords: Orientation, Window Thermal Performance, Optimization, Housing, Hot Climate.

Introduction

Achieving energy efficiency in building has become a prime objective as it addresses international scale challenges such as global warming, air pollution and resources depletion. Globally the main drivers behind these inefficiencies are the human activities including the building sector where unprecedented rates of energy consumption are noted (Smith, 2005). The residential sector is one of the main energy consumers for its’ lighting and cooling needs (Freidman, 2012).

The United Arab Emirates (UAE) has experienced a rapid development process that followed the discovery of oil during the 1960’s. The high revenues of oil enabled the government to act as a housing and services provider for UAE citizens. Several housing programs emerged aiming at the provision of individual detached houses to nationals; a high energy consuming model that contributes to the country high ecological footprint (Clair, 2009). Detached houses, as a skin loaded building, feature a large envelop area that is subject to high solar radiation, making them the most energy demanding type of houses based on their cooling needs (Clair, 2009).

The governmental housing projects within the UAE have shown the allocation of typical houses design in different orientations to suit master planning goals. This allocation has been done with no adaption of the window design to the changing orientations of standard units.
In present times, windows are no longer considered weak components in the building envelop since the on-going improvements in thermal efficiency. The development has offered alternative glazing and framing materials that can respond to excessive heat gain through windows while maintaining the basic window functions. Incidentally, the adaptation of window design to climate can be obtained through the adequate specification of these advanced types of materials.

Consequently, this research aims to first check the impact of orientation on the existing houses then investigates window specifications that offer optimum thermal performance equally for all orientations.

**Housing in the UAE and Climatic Challenge**

UAE’s climate imposes a serious challenge to both housing designers and owners alike. The design challenge is in adapting the intended design to the extreme hot climate of the UAE, while the owner has the challenging task to alleviate the high running energy cost of properties.

The high summer temperatures in summer that range (27 and 38°C) are always accompanied by high humidity along the coastline. The UAE climate of the UAE is referred to as ‘tropical semi desert and desert climate ‘in the east, and ‘semi deserts and desert climates’ in the west (Troll & Paffen, 1980).

Vernacular houses in the UAE showed a high adaptation to the climatic context. However, newly constructed modern housing prototypes, which reproduced international architectural styles and construction methods, have hardly shown any adaption to the climate or local culture (Al-Sallal et al, 2012).

The residential sector accounts for a significant amount of newly constructed detached houses, or about 65% according to National Statistics Center (Abu Dhabi Government, 2010). The dependency on active cooling systems resulted in excessive energy consumption for cooling, that reached 39% of the total electricity consumption (RSB, 2013).

In 2003 and for the first time in the UAE, the Government of Dubai adopted regulations that impose insulation and glazing requirements for new buildings that lead to energy saving (AlNaqbi et al, 2012). In 2010, the Urban Planning Council in Abu Dhabi has established ESTIDAMA, the local sustainability framework. ESTIDAMA aims at achieving sustainability and energy conservation in buildings through the provision of guidelines for newly constructed buildings (AlNaqbi et al, 2012).

The governmental intervention in the housing sector coincided with the discovery of oil during 1960’s. The high revenues of oil enabled the government to act as the main housing provider for the citizens. Since that time the government has offered housing programs for the local citizens at both federal and local levels.

Housing has experienced a major development in typology and size over the last few decades. As a response to the local families evolving requirements, the size of houses in government programs have has increased from about 100m² in 1960’s to about 400 m² in the 2000’s.

During the last two decades, the government has launched a number of housing programs. The most recent one was in Abu Dhabi, the Emirati Housing program. These housing programs come in form of large number of detached houses with related services.

The Emirati Housing Program aims at providing 13,000 houses until 2017 in the form of communities and neighborhoods in cities of the Emirate of Abu Dhabi Emirates (UPC, 2011). Projects aim at the accommodation of cultural values and environmental adaptation through the design and construction of modern, high quality, sustainable homes that reflect Emirati heritage and traditions, as well as meeting Estidama requirements (UPC, 2011).
Al Falah community; the research case study is one of the Emirati Family Housing Program projects. It is located near the city of Abu Dhabi and includes 4,800 detached units (Aldar, 2009).

**CASE STUDY; AL FALAH COMMUNITY**

Al Falah community is designed to provide alternative housing options and facilities for the Emirati citizens. The project consists of five residential villages with approximately five thousand residential detached units organized in nine different designs in terms of sizes and architectural styles (Table 1)(G.H.M, Nov.2009).

<table>
<thead>
<tr>
<th>Village</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of villas</td>
<td>1,036</td>
<td>1,012</td>
<td>1,010</td>
<td>7,30</td>
<td>1,044</td>
</tr>
</tbody>
</table>

The diversity in design aims at providing multiple choices for local families to meet different family sizes and personal preferences. Villas are located in plots of a little over a 1000m² (30 mX35 m), and surrounded by 2.5 m high boundary walls (G.H.M, Nov.2008).
As stated earlier, houses at Al Falah have nine different designs varying in terms of size and architectural style. There are three different sizes of villas: 3, 4 and 5-bedroom, villas. (Table 2) (GHM, Nov. 2009).

The review of available design and construction data has revealed that only general sustainability measures were implemented in the Al Falah house design. That included the use of materials with low-heat transmittance (with low U values), the selection of efficient HVAC equipment and the selection of water efficient fixtures.

Table 2: Villa Classification by Size and Architectural Style at Al Falah Community

<table>
<thead>
<tr>
<th></th>
<th>THREE BEDROOM VILLA</th>
<th>FOUR BEDROOM VILLA</th>
<th>FIVE BEDROOM VILLA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANDALUCIA</strong></td>
<td><img src="ANDALUCIA.jpg" alt="Image" /></td>
<td><img src="ANDALUCIA.jpg" alt="Image" /></td>
<td><img src="ANDALUCIA.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>GULF</strong></td>
<td><img src="GULF.jpg" alt="Image" /></td>
<td><img src="GULF.jpg" alt="Image" /></td>
<td><img src="GULF.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>HERITAGE</strong></td>
<td><img src="HERITAGE.jpg" alt="Image" /></td>
<td><img src="HERITAGE.jpg" alt="Image" /></td>
<td><img src="HERITAGE.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>MODERN</strong></td>
<td><img src="MODERN.jpg" alt="Image" /></td>
<td><img src="MODERN.jpg" alt="Image" /></td>
<td><img src="MODERN.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Number of stories</td>
<td>1Story</td>
<td>2 Stories</td>
<td>2Stories</td>
</tr>
<tr>
<td>Floor Area</td>
<td>293.15 m²</td>
<td>356.96 m²</td>
<td>418.38 m²</td>
</tr>
<tr>
<td>Percentage</td>
<td>20% of total villas No.</td>
<td>30% of total villas No.</td>
<td>50% of total villas No.</td>
</tr>
</tbody>
</table>
METHOD

Based on the design and construction data of dominant five-bedroom villa, Al Falah a model design was selected for window optimization process. The selection was done based on size dominance. The five-bedroom villa (Figure 2&3) was selected as it accounts for about 50% of total villas. Moreover, since it has the largest size as the rest are three and four bedrooms villas, it is estimated that it is the most energy-demanding design.

![Figure 22: Typical Ground Floor Plan for the Five-Bedroom Villa](image)

![Figure 23: Base Case Model Perspective; Al Falah Typical Five-Bedroom Villa (Modern Type)](image)

The impact of orientation on the thermal performance of the existing design has been tested using Home Energy Efficient Design (HEED 4.0 build 34) software. HEED is a building energy analysis tool that evaluates the building overall thermal performance. It was developed at the University of California in Los Angeles (UCLA). HEED is validated against the ASHRAE/BESTEST Standard 140 and the HERS BESTTEST Standard.

Case Study; Existing Conditions

Table 3 summarizes the specifications of the existing conditions for the five-bedroom villa (base case):
<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Location</td>
<td>Abu Dhabi 24.42°N, 54.65°E</td>
</tr>
<tr>
<td>Area</td>
<td>Total Area (GF+FF)</td>
<td>402.36 m² (4331 ft²)</td>
</tr>
<tr>
<td></td>
<td>Floor Area (Footprint)</td>
<td>212.56 m² (2288 ft²)</td>
</tr>
<tr>
<td></td>
<td>Overall dimensions of the floor plan</td>
<td>17* 15.85 m (56 * 52 ft.).</td>
</tr>
<tr>
<td>Envelop Construction material</td>
<td>Windows</td>
<td>Double tinted low reflective glass with Air Gap</td>
</tr>
<tr>
<td></td>
<td>Walls</td>
<td>Insulated concrete panels. (20cm thick concrete panel with 6cm polystyrene insulation) R=11; Calculated using Opaque (Version 2) software based on the existing construction detail.</td>
</tr>
<tr>
<td></td>
<td>Roof</td>
<td>Hollow core concrete slab with water proofing and heat insulation layers R=18; Calculated using Opaque (Version 2) software based on the existing construction detail.</td>
</tr>
<tr>
<td>Ratio of Glazing per Façade</td>
<td>Front Façade</td>
<td>26.55%</td>
</tr>
<tr>
<td></td>
<td>Right Side Façade</td>
<td>13.4%</td>
</tr>
<tr>
<td></td>
<td>Left Side Façade</td>
<td>9.03%</td>
</tr>
<tr>
<td></td>
<td>Rear Façade</td>
<td>16.2%</td>
</tr>
<tr>
<td>Air Conditioning System</td>
<td>Package Unit</td>
<td>Seasonal Energy Efficiency Rate (SEER)=13</td>
</tr>
<tr>
<td>Indoor Temperature</td>
<td>Lowest indoor comfort degree= 21.1 C (70F)</td>
<td>According to California Residential Code</td>
</tr>
<tr>
<td></td>
<td>Highest indoor comfort degree= 23.88C (75F)</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>Illumination= 21.5 Lux (2foot candle)</td>
<td>Colors range between white and cream (construction documents: ALDAR,2009)</td>
</tr>
<tr>
<td></td>
<td>Wall/ceiling reflectance=70%</td>
<td></td>
</tr>
</tbody>
</table>
The impact of orientation on the base case was tested using HEED software. The annual electrical energy consumption, cooling loads and lighting loads for each cardinal orientation of the existing design are presented in Table 4.

Table 4: The Base Case Annual Energy Consumption, Cooling loads and Lighting Loads per Orientation

<table>
<thead>
<tr>
<th>Power Usage Kwh</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td><strong>Total Annual</strong></td>
<td>46,087.18</td>
</tr>
<tr>
<td><strong>Electrical Energy</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cooling Loads</strong></td>
<td>29,455.98</td>
</tr>
<tr>
<td><strong>Lighting Loads</strong></td>
<td>1,677.42</td>
</tr>
</tbody>
</table>

The first observation highlights a variable load for each orientation, highlighting the impact of window design on the total energy used. The higher ratio of glazing for the main façade is therefore directly affected by the change of orientation.

The base case testing has revealed a similar energy consumption rates when the model is oriented either to the north or to the south. The west-facing model had the highest energy consumption rate. However, the east oriented model had the lowest consumption rate. The recorded difference between the highest and the lowest consumption rates is 8.85%. This reduction in annual electrical energy consumption refers to the reduction in cooling loads as it is reduced by 10.65% when rotating building form west to face east.
This reduction in cooling loads with the main façade orientated east can be easily explained because the east elevation receives the least amount of solar radiation. This radiation strikes the east during the morning hours, when temperature is still low. During the day, the east façade heat gain happens through heat transmission from the hot ambient air. The transmitted heat was mitigated because of insulated wall panels and insulated glass panels used for windows (double glazing). On the other hand, when the building is facing west, it starts to receive direct solar radiation during the afternoon until evening when the temperature is at its highest levels in addition to the transmitted heat from ambient hot air.

**Window Thermal Optimization**

The second step of experimental works handles the thermally optimized window alternatives and their impact on overall window building energy performance. The thermal optimisation of window design can include different strategies such as the reduction of glazing, include shading devices. However, these strategies would have an impact of the building architectural style and appearance while the intention in this study is to reach the optimum thermal performance with no confliction with the existing architectural style. The window thermal optimization process went into a single component optimization process, (see alternative variables in tables 5&6), in which individual components of the window were optimized. As a result, two scenarios of thermally optimized windows were generated. The selection of alternative materials was done based on thermal properties and availability in market.

<table>
<thead>
<tr>
<th>Glass Type</th>
<th>U Value</th>
<th>SHGC</th>
<th>Tvis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinted double pane glass (Existing Design)</td>
<td>0.81</td>
<td>0.45</td>
<td>0.57</td>
</tr>
<tr>
<td>Tinted double pane Low- E glass</td>
<td>0.69</td>
<td>0.39</td>
<td>0.53</td>
</tr>
<tr>
<td>Tinted double pane Low- E squared glass</td>
<td>0.67</td>
<td>0.25</td>
<td>0.38</td>
</tr>
<tr>
<td>Tinted double pane reflective glass</td>
<td>0.81</td>
<td>0.16</td>
<td>0.09</td>
</tr>
</tbody>
</table>

**Figure 24: The Base Case Annual Energy Consumption, Cooling loads and Lighting Loads according to Orientation**

Table 5: Thermally Improved Glass Alternatives
<table>
<thead>
<tr>
<th>Variable</th>
<th>U Value</th>
<th>SHGC</th>
<th>Tvis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinted double pane glass in aluminum frame</td>
<td>0.81</td>
<td>0.45</td>
<td>0.57</td>
</tr>
<tr>
<td>(Existing Design)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tinted double pane glass in vinyl frame</td>
<td>0.51</td>
<td>0.38</td>
<td>0.49</td>
</tr>
</tbody>
</table>

The first scenario was generated by assembling the vinyl frame with squared Low-E double tinted glass. Table (7) and figure (6) present the results of Scenario 1. Significant savings were obtained (about 6-11%). Moreover, similar thermal performance independently from orientation was achievable, since the difference between different orientations was found to be light and ranges between 1-3%.

<table>
<thead>
<tr>
<th>Variable</th>
<th>North</th>
<th>South</th>
<th>East</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Kwh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base case</td>
<td>46,087.18</td>
<td>46,048.50</td>
<td>43,200.68</td>
<td>47,393.95</td>
</tr>
<tr>
<td>Tinted, Double, Squared, Low-E+ Vinyl Frame</td>
<td>41,407.96</td>
<td>41,429.77</td>
<td>40,551.88</td>
<td>41,839.04</td>
</tr>
<tr>
<td>Reduction</td>
<td>10.15%</td>
<td>10.03%</td>
<td>6.13%</td>
<td>11.72%</td>
</tr>
</tbody>
</table>

As result of using glazing units with multi-coating such as the squared doubled Low-E glass, the increase in lighting loads was expected. However, this increase in lighting loads did not affect the overall improved performance, reaching significant savings of about 11% due to the significant saving in cooling loads.
The second scenario of window optimization was to integrate vinyl frame with Low-E glass with external shading in the form of automated slatted blinds. The modified model was simulated to evaluate energy performance for the four main orientations.

### Table 8: Total Annual Electrical Energy Consumption (Scenario 2)

<table>
<thead>
<tr>
<th>Variable</th>
<th>North</th>
<th>South</th>
<th>East</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Kwh</td>
<td>Total Kwh</td>
<td>Total Kwh</td>
<td>Total Kwh</td>
</tr>
<tr>
<td><strong>Base case</strong></td>
<td>46,087.18</td>
<td>46,048.50</td>
<td>43,200.68</td>
<td>47,393.95</td>
</tr>
<tr>
<td><strong>Vinyl Frame +Low E Glass+ Slatted Blinds</strong></td>
<td>41,136.40</td>
<td>41,046.99</td>
<td>40,439.36</td>
<td>41,107.56</td>
</tr>
<tr>
<td><strong>Reduction</strong></td>
<td>10.74%</td>
<td>10.86%</td>
<td>6.40%</td>
<td>13.26%</td>
</tr>
</tbody>
</table>

Savings ranged from 6.5% to 13.26% with similar consumption for all orientations and was achievable in Scenario 2 (Table 8 & Figure 7). The saving is due to the reduction of heat gain achieved by blocking direct solar gain with shading and reducing transmitted and radiated heat via Low-E glass and vinyl or wood frames. The savings were achieved by reducing the cooling loads as a result to heat gain reduction.
CONCLUSION

This research has investigated the thermal optimization of windows characteristics in relation to orientation in a sample governmental housing project. This target enables flexibility in housing planning and, at the same time proposes energy savings strategies.

The thermal performance of the dominant type, about 402 m$^2$ of built up area, 5 bedroom houses, has been initially tested in relation to the cardinal orientation. The west orientation consumed annually 9.7% more than the east orientation. Subsequently, more efficient glass and frames were identified, and then two optimization scenarios were generated and tested.

The first scenario included optimizing glazing and frame by using double squared Low-E tinted glass and vinyl for frames. A saving of 6 to 11.7% from total annual energy consumption was deemed achievable along with similar consumption rates for all orientations.

The second scenario included optimized glass, frames and a shading device. 6.5 to 13% energy savings were deemed achievable with no measurable change in consumption rates when orientation varied. However, the use of automated slatted blinds as a shading device is associated with higher maintenance and operational costs.

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ASHRAE, 2005, ASHRAE Fundamentals Handbook,
CLAIR, P, 2009, Low-Energy Design In The United Arab Emirates– Building Design Principles, PEDP.
EFFECT OF LIVING WALLS ON ENERGY AND INDOOR ENVIRONMENT IN HOT-HUMID CLIMATE

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Abstract

Older buildings are especially vulnerable to temperature and humidity increases due to effects of climate change. Many countries have responded by changing polices that affect how new buildings are constructed leaving a large pool of poorly performing existing buildings. There has been an increase in the use of living plants both for aesthetics as well as energy performance in buildings. This paper presents a study of the potentials in energy reduction and improvements in indoor environment quality by installing a temporary living wall on the west faced a test box of 4'-0" x 4'-0" x 4'-0" during the month of October 2013 at University of Miami, constructed as described later in the paper. The results revealed a remarkable reduction in indoor temperature and potential air-conditioning energy reduction in buildings.

Keywords: indoor environment, living walls, energy savings, Passive cooling; Energy conservation; Thermal comfort; Retrofit

Introduction

The use of living walls is especially critical in the urban or semi-urban context where the existence of natural vegetation is the minimized. In the evolution of cities and buildings, the ratio of natural vegetation to hardscape is compromised. Therefore the use of green roofs and living wall systems can be used to mimic the microclimate of native vegetative ecologies and decrease energy requirements to keep a comfortable interior temperature in hot and humid climates. Green roof are specialist constructions that support plant growth and consists of vegetation, substrate, filter membrane and a drainage layer (Tabares-Velasco and Srebric, 2009). Similar interest as increased on the use of green facades that have plants growing on them because they offer ecological and environmental benefits such as the reduction of heat flux, heat island effects in urban areas as well improving the air quality (Ottele, Van Bohemen and Fraaij, 2010).

There are three different systems of green walls: "Green Facades Systems" GFS, "Living Walls Systems" LWS and "Bio-wall System" BWS (Francis and Lormier, 2011). The GFS have vines rooted at the base of the wall in a container or in the ground soil and are trained to climb the wall naturally or through wiring devices; in LWS, the plants are rooted on the wall it self, hence the wall
section will contain soil content and a drainage system and finally the BWS, where either a living wall and or vines are implemented in the interior of the wall. For this experiment, we are using a modified version of Living Wall System constructed with wooden frames with shelves for potted plants and test its impact on solar radiant heat transfer and compare this to that of a wall without plants.

**Literature Review**

Green facades and roofs have been used in building historically since the Hanging Walls of Babylon, and by 3rd BCE the Romans had started training grape vines (Vitis species) on garden trellises and on villa walls (Sharp, 2008). The benefits of GFS and LWS has been attributed to the existence of a microclimate of temperatures that are lower than the surrounding air but with slightly higher humidity levels (Pérez *et al.*, 2011). Research on air temperatures differences between areas under the shade of trees and adjacent non-shaded ones in Miami, Florida revealed on average of 3.6 ºC lower in the former (Parker, 1983).

The vegetation used in the GFS and LWS affect the microclimate through processes of shading, evapotranspiration and the urban breeze cycle (Miller, 1997; Pérez *et al.*, 2011). The conditions within the wall system was influenced by the size, species, health and location of the vegetation (Donovan & Butry, 2009; Sawka *et al.*, 2013). It would be expected that the larger, denser leaf structure will be more effective than those that are sparse, and a study by Wong *et al.* (2009) revealed that GFS with a 50% coverage and a shading coefficient of 0.041 reduced the thermal transfer value of glazed facade by 40.68%.

The reduction in heat flux through the building envelope results in lowers indoor temperatures and air conditioning demand. Dunnet & Kingsbury (2004) point out that a reduction of indoor temperatures by 0.5º C is equivalent to 8% reduction in electricity demand for air conditioning.

Living wall systems provide insulation layers to the building envelope because of trapped air between the plants and the wall. In addition it acts as radiant barrier at night thereby reducing heat loss in comparison to bare walls. They also help in reducing the effect of urban heat island by reducing solar energy absorbed through the process of transpiration.

Little work has been carried on effect of LWS on indoor environmental conditions of building in hot and humid climate zone of Florida. This study in particular looked at the effect of LWS on west facade of an experimental wood box built as described later in the methodologies section. The questions of interest were:

- What are the differences between ambient air temperature and Relative Humidity close to the outside wall surface of facade with LWS in comparison with one without?
• What are the differences between ambient air temperature and Relative Humidity close to the inside wall surface of facade with LWS in comparison with one without?

• What is the percentage reduction in heat flux and simulated energy demand for cooling the box assuming the wall is built to typical specification required by the Florida Building Code? (U-value of 0.0769 K·m$^2$/W)

Miami located in the southern tip of the East Coast of Florida and has a highly humid and hot climate. According to United States Department of Agriculture, USDA, it is designated in Zone 10b of the plant hardiness indicating the average annual extreme minimum temperatures are typically fall between 1.7 to 4.4 °C. The coldest month in Miami is January with average overnight temperature of 15.6°C while the warmest month is July with average daily high temperature of 32.2 °C. The dew points in Miami varies between 10.6°C which is agreeable to the human body to 24.4°C which is uncomfortable.

**Methodology**

The experimental work was aimed at looking at the microclimate of living wall systems and its performance in mitigating the transfer of heat flux through walls in hot and humid climate of South Florida. The experiment was carried out using two boxes of 1200mm x 1200mm x 1200mm without a window or typical door (Figure 1). One of the boxes was left bare to act as a reference, while other was fitted with a LWS. The construction of the walls, floor and ceiling of the box consisted of 50x100mm timber framing, 12.7mm thick marine plywood sheathing on exterior, 75mm thick fiberglass butt insulation, but without drywall/ plasterboard on the inside and the R-values of the assembly materials are indicated in table 1 below.

<table>
<thead>
<tr>
<th>Wall/ floor/ roof component</th>
<th>R (SI)-value W/K m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Air film</td>
<td>0.03</td>
</tr>
<tr>
<td>12.7mm Marine sheathing plywood</td>
<td>0.11</td>
</tr>
<tr>
<td>75mm Fiberglass Butt Insulation</td>
<td>2.63</td>
</tr>
<tr>
<td>Inside Air Film</td>
<td>0.12</td>
</tr>
<tr>
<td>50 x 100 mm wood stud</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Total Wall Assembly R-Value 2.89 W/K m$^2$ without considering studs, however the model construction had a stud density of 12% total 1/R value = (0.88)*1/2.89 + (0.12)*1/0.8 = 2.2 W/K m$^2$

$U = 1/R_T = 1/2.2 = 0.4545$ W/m$^2$K
The goal of the work was to investigate the potential impact of living walls on energy consumption of buildings as a retrofit strategy by placing a self-structured living wall system adjacent to the building. A modified green-façade (which acted as the LWS) was attached to the West façade of box 2, while box was left bare. Ambient radiant temperatures and humidity levels were recorded in the interior, the exterior surfaces and at the air gap between the LWS and the bare wall. Two kinds of sensors were used: Extech Temperature Data logger model TH10, with overall logging range of -40°C to 70°C with an accuracy of ±2°C; the CO2Meter CM-0018 1% carbon dioxide, temperature and relative humidity Data Logger, with overall logging range of ± 20 ppm ± 1 % of CO₂ measured value, ± 3 % accuracy; temperature range of -40 to 60°C with accuracy of ± 0.4°C at 25°C; relative humidity range of 0 – 100% RH non-condensing and accuracy of ± 3% RH.
Figure 3: Sensors Used (CO2Meter CM-0018 on LHS and Extech Data logger TH10 on RHS)

The data was logged over 2-day period and an average value used to determine the approximate temperature behavior.

The LWS system consisted of a mixture of well-grown Coleus and Salvia planted in in pots placed on wooden shelves. The plants were watered daily to keep them moist and had fairly large leaves, which would provide effective shading of the wall all year round, as they are annuals. A black textile material with antifungals was used as backing to avoid developments and growth of molds. 3 TH10s and CM-0018 were used per box and placed as indicated in Figures 1 & 2. The exterior ambient air conditions were obtained from the local weather station at the University of Miami.

TH10 were attached on both the inner and outer center of the west wall and one at the inner corner. The data logger on inner corner was placed to take into account thermal bridging effect at edges. For the LWS, the data logger was placed in the middle of the plant layer on a surface shaded with leaves. In addition ambient indoor temperature and relative humidity was logged by suspending CM-0018 at center of the box. The loggers were set to collect data at an interval of 5 minutes for a total of 50 readings.

**Results and Discussion**

In the experimental setup, no air conditioning was installed on the two test boxes that were both monitored for temperature changes. Figures 4, 5, 6 & 7 represent the comparisons of the logged temperature data of the exterior wall surface, interior wall surface and ambient indoor temperature for both boxes. It was noticed that the maximum differences in $T_{surf,in}$ between the bare box and one
with LWS was 3.6°C and the box with LWS had little fluctuations in peak high temperatures. The surface temperature difference between the exterior surface and the interior surface of LWS was 11.5°C while of the bare wall system it was 7.3°C, indicating benefits in reducing the solar radiant heat flux by the use of a LWS. The average daily amplitudes of outside surface temperatures, inside surface temperatures for bare wall, LWS and ambient indoor for box with LWS during the duration of the experiment were 12.4°C, 3.5°C, 1.4°C and 3.5°C respectively. The maximum registered inside surface temperature for bare wall and LWS were 28.4°C and 25.7°C respectively revealing that the LWS was able to provide both reduced indoor surface temperature and ambient air temperatures.

Figure 4: Log Data for Box 1: without Green Plantings
Figure 5: Log Data for Box 1 with Green Wall (plantings)

Figure 6: Comparison Data at center of box without plantings vs with plantings
References

3, 2013).
BIM and Energy Simulation Analysis for Renewable Energy Strategies

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Abstract
In this research, the centre for design research in the city of Lawrence, KS has been selected as a case study and has been studied for its operational performance with the application of BIM. This building has been built based on Zero Net Energy (ZNE) construction regulation to address the method of designing and constructing houses that has negligible effect on the environment and can comply with the framework of the green initiatives such as Leadership in Energy and Environmental Design (LEED) rating system. The main objective of this research is to address the discontinuities between current BIM and energy modeling tools with the focus on renewable energy features within the model. This research compares the results from the simulation model and the real building performance to give recommendations about the optimization of building performance and consideration of new factors for building performance enhancement. In this study, two different BIM processes have been conducted for the energy modeling: object-oriented geometric information modeling (e.g., envelop, doors, windows, walls, zones, etc.) with a BIM tool (Revit, Sketch-Up) and 3D building energy modeling (e.g., materials, heat resistance, location, weather data, renewables, etc.) with an energy simulation tool (EnergyPlus). EnergyPlus was evaluated in this study for inclusion of renewable sources in the site. This research has fulfilled the following objective: to examine different design alternatives to help to select the most environmentally friendly and energy-efficient strategy for the selected case study.

Keywords: BIM, Energy Modeling, EnergyPlus, LEED, ZNE

Introduction
The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased, reaching figures between 20% and 40% in developed countries, and has exceeded the other major sectors: industrial and transportation (Perez-Lombard, Ortiz et al. 2008). In the United States buildings consume close to 40% of all energy used and account for 40% of global CO2 emissions (Schlueter and Thesseling 2009). Growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings, assure the upward trend in energy demand will continue in the future. For this reason, energy efficiency in buildings is a prime objective for energy policy at regional, national and international levels.

In addition, the rising cost of energy and growing environmental concerns have pushed the demand for sustainable building facilities with minimal environmental impact through the use of environmental sensitive design and construction practices (Azhar, Brown et al. 2009). In efforts to alleviate resource depletion and environmental damages, the Architecture, Engineering, and Construction (AEC) industry has adopted Integrated Project Delivery (IPD) as a highly collaborative building procurement process supported by some prominent technological solutions and tools, such as the United States Green Building Council (USGBC) Leadership in Energy and Environment Design (LEED) rating system and Building Information Modeling (BIM) (Garzone 2006).

LEED is a green building certification system which encourages a building or community to be designed with consideration of environmental impact, energy savings, and human comfort (Gowri 2004). A LEED rating rewards designers for using strategies that can improve performance in metrics such as CO2 emissions reduction, water efficiency, energy savings, indoor environmental
quality, and other environmental impacts. Although LEED does not guarantee most efficient performance of a building or community, it is one method to help towards this goal (Todd, Crawley et al. 2001).

Building Information Modeling (BIM) represents the development and use of computer-generated building model to support the planning, design, construction and operation of a facility. This technology helps architects, engineers and constructors collaborate and visualize what is to be built and identify potential design, construction or operational problems in a simulated environment (Azhar and Brown 2009). Linking the building model to energy analysis tools allows for evaluation of energy use and can reduce the costs associated with traditional energy use patterns during building operation.

BIM can support the study of alternatives more quickly, to achieve LEED certification, and make timely decisions (Patel 2012). Despite the LEED certification process for the new construction, it is required to evaluate the building performance during its operation phase and recertify the building under LEED points. In cases when LEED certified buildings do not perform as expected in the filing period, building performance needs to be analysed and optimized during operation (Newsham, Mancini et al. 2009). Buildings can apply for recertification as frequently as each year but must file for recertification at least once every five years to maintain their LEED for Existing Buildings: Operations & Maintenance status (Council 2008).

This research addresses the discontinuities in data exchange between current BIM and energy modeling tools when dealing with renewable energy features in a LEED-rated building. Alternative renewable energy scenarios are evaluated to make recommendations for the optimization of building performance and its capacity to achieve Zero Net Energy (ZNE), in terms of energy consumed vs. energy generated during building operation.

**Project Description**

The University of Kansas has built an innovative research project in the city of Lawrence, KS. The Centre for Design Research (CDR) is considered as a green and sustainable facility. The group involved in the design and construction engaged in research to address the required specifications and materials that should allow for a Zero Net Energy (ZNE) scenario.

The new Centre for Design Research building, located on the historic Chamney Dairy Farm in Lawrence, Kansas, is a response to the emerging culture and support of sustainability at the University of Kansas (Figure 1).

In congruence with the centre’s mission, which is to provide a location for interdisciplinary work between multiple schools, the new building provides a facility that aids in the education of the university and community on sustainable strategies, material innovation and building efficiency. The design for the new building implements sustainable strategies to maximize the potential of existing resources, minimize environmental degradation, create an environment that is safe, comfortable and efficient and provide an iconic representation of sustainability for the University of Kansas.

The Centre achieved LEED® Platinum status recently (January, 2013) where several sustainable systems have been implemented and it includes features such as rainwater collection and reuse, a living wall, real time display of energy usage, wind turbines, solar collectors, electric vehicle charging stations, plants on the rooftop to soak up rain and insulate the building (Figure 1). In addition, high efficiency window types were implemented to reduce solar heat gains during summer months and heat losses during winter months and to eliminate the glare effects in both summer and winter. To make the facility more efficient and sustainable, a wind turbine and solar panels have been selected as the energy producing resources for this project.

In order to receive LEED certification, building’s performance was measured in several key areas: sustainable site development, water savings, energy efficiency, materials selection, indoor
environmental quality, and innovation. Data was collected during the design of the building; materials used and construction methods were documented during construction, and verified by a third-party organization after the building is in operation.

Figure 27: CDR Facility & Roof Garden with PV Panels

Research Methodology & Scope
This study will compare the results from the analysis of a BIM model to the real building performance in the operation phase. To fulfill this objective, the CDR building was selected as a case study. The model of this building was simulated in the BIM software and the energy consumption of the building was calculated accordingly with the consideration of different options (Figure 2). Also, the renewable energy sources were considered in the model and the energy consumption was calculated in this regard. The real energy consumption was calculated based on the available data from the energy companies and also the amount of energy generation, which is produced by the renewables. The following research tasks were performed:

1- Simulation and energy analysis to give recommendations about the optimization of building performance and consideration of new factors for building performance enhancement;
2- Measurement of the performance of renewable energy sources onsite (Solar Energy), in the current situation (2 years) and recommendation for addition/removal or modification of PV panels.

This research is based on simulation method. In this approach, the CDR was simulated in the Revit and sketch-Up software and the model was exported to the energy analysis program. EnergyPlus program was evaluated to analyse the facility and selection of the most optimum retrofit plan.

Figure 28: CDR Revit Model

The energy consumption of CDR and the generated energy by the renewables were calculated and the retrofit plan (PV panels addition or replacement), lighting, HVAC and equipment schedule change were proposed to the CDR current performance enhancement and to correlate with CDR LEED certification rating or even enhancing its energy performance to the net-zero energy level. Figure 3 presents the procedure and work plan approach.
Building Performance Analysis Software

EnergyPlus is a whole-building energy analysis software program being developed by the U.S. Department of Energy. Based on the Heat Balance Model, the program performs a comprehensive simulation of the building envelope, fenestration, HVAC systems, and day lighting (Crawley, Lawrie et al. 2001). EnergyPlus is a fully geometric model intended for annual energy simulations. EnergyPlus also includes solar components for simulating photovoltaic (PV) and solar thermal hot-water systems (e.g., solar collectors). The active solar models in EnergyPlus can be used to analyse low or zero-energy buildings that often utilize renewable energy resources to accomplish their energy-saving goals.

In this study the amount of energy consumed at the CDR was compared to the amount of energy is generated by the renewable energy (PV panels) with the consideration of different scenarios and proposing the best retrofit plan to the CDR performance enhancement. In order to conduct this study, the CDR building model was simulated in the Revit and room-bounding objects (Figure 5) were modified next. After verifying analytical volumes the gbXML file was exported using Green Building Studio™ program (Figure 4). gbXML file was Imported to Ecotect™ software and Input Data File (IDF) was Exported to Energyplus. Finally, the IDF editor was used to verify the geometry and application of retrofit plans on the model.

![Figure 29: The Procedure & Work Plan](image)

**Building Base Case, Current Performance & Retrofit Scenarios**
Different building performance scenario (Base Case, Current Performance) and retrofit plans (Retrofit 1, 2, 3) were proposed (Table 1, 2) and EnergyPlus (V8.0) software was used to evaluate the building performance in each scenario. The important part of the research is the evaluation of energy consumption in comparison to the energy generation in regards to the renewable energy.

a) Base Case

In this case, the CDR building is simulated as its primary performance that qualified the facility for the LEED platinum certification. The amount of the PV panels and their efficiency to generate the energy and the amount of energy consumption by the HVAC system, lighting and equipment's are calculated in the model (Table 3, 4).

b) Current Performance

This case presents the performance of the facility at its current situation and after 2 years of performance in the operation phase. Based on the available literature discussed earlier in the paper, the generated energy by the PV panels reduce over time and PV panels undergone degradation which is almost 1% a year. In order to consider this factor and calculate the amount of energy generation and comparison to the energy consumption, the rate of degradation was applied to the PV panel’s efficiency and energy analysis was applied accordingly. The facility current schedule for lighting, HVAC and equipment were obtained by consultation of facility managers and used as an input for energy analysis.

c) Retrofit 1

The area of PV panels is similar to the building base case but the degraded PV panels were replaced with the new panels to increase the energy generation by the facility. In order to reduce building energy consumption and after discussion with facility manager and staff, the schedule for lighting, HVAC and equipment allocated based on building use during the weekdays, weekend and holidays.

d) Retrofit 2

Other than degraded PV panels replacement with the new ones, the amount of panels were doubled in this case to evaluate the energy generation by the panels and the influence of PV location on energy generation amount. In this scenario, all the PV panels were located on the facility roof and the reason for increasing PV panels in a bulk scale is firstly because of availability of space in the facility roof area and secondly, the price of PV systems in the United States (i.e., the cost to the system owner) has dropped precipitously in recent years, led by substantial reductions in global PV module prices (Goodrich, James et al. 2012). In this case, similar to the retrofit 1 plan, the facility schedule updated in the case of HVAC operation, lighting control and equipment use.

e) Retrofit 3

In order to evaluate the PV location and its influence on energy generation, the PV panels were located both on the roof and south façade of the CDR facility. The degraded PV panels were replaced with the new ones and there area was doubled. The PV panels were located on the roof and south façade of the facility. Similarly, the building HVAC schedule, equipment and lighting were modified to evaluate the best-case scenario for energy consumption reduction.

Table 9: IDF Editor for Schedule Upgrade (Weekdays)
Life Cycle Assessment of PV Panels
The ability to accurately predict power delivery over the course of time is of vital importance to the growth of the photovoltaic (PV) industry. Two key cost drivers are the efficiency with which sunlight is converted into power and how this relationship changes over time. An accurate quantification of power decline over time, also known as degradation rate, is essential to all stakeholders—utility companies, integrators, investors, and researchers alike. Financially, degradation of a PV module or system is equally important, because a higher degradation rate translates directly into less power produced and, therefore, reduces future cash flows (Short, Packey et al. 1995). Technically, degradation mechanisms are important to understand because they may eventually lead to failure (Meeker and Escobar 1998).

Based on the research by National Renewable Energy Laboratory (NREL), degradation rates is almost 1%/year for single and tandem junction modules although the continuous research time rarely exceeded 1 year, implying that some of this was the initial light-induced degradation (DeBlasio, Waddington et al. 1987, Hahn, Berry et al. 1990). In this research nearly 2000 degradation rates, measured on individual modules or entire systems and show a mean degradation rate of 0.8%/year and a median value of 0.5%/year. The majority, 78% of all data, reported a degradation rate of <1%/year. Thin-film degradation rates have improved significantly during the last decade, although they are statistically closer to 1%/year than to the 0.5%/year necessary to meet the 25 year commercial warranties.

RESULTS
Due to the fact that the PV panels efficiency reduce over the time and in order to balance the amount of energy consumption and energy generation at the CDR with the focus on renewables and enhance the building performance towards the net-zero energy construction, various retrofit plans was considered and each of them evaluated to propose the best solution for this building.
Table 11: Base Case & Current Performance. (a) Site Energy. (b) Utility Use per Floor Area. (c) Electric Loads.

<table>
<thead>
<tr>
<th>Site and Source Energy</th>
<th>Base Case</th>
<th>Current Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Site Energy (GJ)</td>
<td>130.1</td>
<td>150.2</td>
</tr>
<tr>
<td>Energy Per Total Building Area [MJ/m²]</td>
<td>714.09</td>
<td>892.03</td>
</tr>
<tr>
<td>Total Source Energy (GJ)</td>
<td>361.1</td>
<td>381.1</td>
</tr>
<tr>
<td>Energy Per Total Building Area [MJ/m²]</td>
<td>1929.41</td>
<td>2013.10</td>
</tr>
</tbody>
</table>

Table 12: PV Panels Energy Generation (Base Case & Current Performance)

Table 13: Energy Use Summary of CDR

<table>
<thead>
<tr>
<th>Energy Use Summary</th>
<th>Base Case</th>
<th>Current Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACILITY (J)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>6.80E+10</td>
<td>6.88E+10</td>
</tr>
<tr>
<td>February</td>
<td>5.50E+10</td>
<td>5.59E+10</td>
</tr>
<tr>
<td>March</td>
<td>5.55E+10</td>
<td>5.71E+10</td>
</tr>
<tr>
<td>April</td>
<td>4.99E+10</td>
<td>5.02E+10</td>
</tr>
<tr>
<td>May</td>
<td>5.02E+10</td>
<td>5.22E+10</td>
</tr>
<tr>
<td>June</td>
<td>5.54E+10</td>
<td>5.78E+10</td>
</tr>
<tr>
<td>July</td>
<td>5.79E+10</td>
<td>6.02E+10</td>
</tr>
<tr>
<td>August</td>
<td>6.14E+10</td>
<td>6.33E+10</td>
</tr>
<tr>
<td>September</td>
<td>5.57E+10</td>
<td>5.74E+10</td>
</tr>
<tr>
<td>October</td>
<td>5.34E+10</td>
<td>5.45E+10</td>
</tr>
<tr>
<td>November</td>
<td>5.54E+10</td>
<td>5.62E+10</td>
</tr>
<tr>
<td>December</td>
<td>6.51E+10</td>
<td>6.58E+10</td>
</tr>
</tbody>
</table>

Figure 32: Base Case and Current Performance Energy Comparison

After consideration of facility base case and current performance, the energy consumption increase, reduced renewables generation and cost overrun is evident (Table 3, 4, 5; Figure 6, 7). In order to enhance the facility performance and meet the near zero net energy criteria, retrofit plans were introduced and applied to the CDR facility.

Based on the obtained results from the facility base case and current performance scenarios, it is evident that the facility energy consumption was increased since its LEED platinum certification whereas, its energy generation rate was decreased since that time. In order to retrofit the facility and improve its energy performance, the three retrofit plans were introduced and discussed in this paper with the respective energy consumption and generation in each scenario. Based on the obtained results, all considered retrofit plans have an influential effect on facility energy performance and
based on the long-term goals and available funding, the potential plans should be applied accordingly to improve facility performance (Figure 7).

Figure 33: Base Case, Current Performance and Retrofit Plans Comparison. (a) PV Electricity Generation. (b) Energy Use Summary. (c) Carbon Equivalent. (d) CO₂ Emission. (e) Electricity Consumption of HVAC. (f) Cost of Savings. (g) Energy Savings

**Life-Cycle Cost (LCC) of PV Panels Addition**

Based on the report by NREL (Goodrich, James et al. 2012), the design, and therefore cost of PV systems for commercial rooftops varies significantly based on pre-existing building features and roof
materials. However, the analysis results in a total installed price for a benchmark 2010 commercial PV system of $1.99/W_{P, DC}. The CDR roof surface is 75.86 ft. (Length) X 25.85 ft. (Width). Doubling the number of PV panels on the roof top by consideration of current facility PV types (250 W_{p}) and the size of PV panels (65 X 40 in) will require the addition of 20 extra PV panels on the rooftop. The estimated cost for installation of each extra PV panel with the consideration of NREL report, will be around 498.69 $ and the whole plan will cost 9974 $ to the facility. However, based on the cost estimation of electricity, the proposed plan will save 1.42 $/ft² of the facility which in total will cost 2806 $/ year saving in the electricity. The predicted plan will be paid back in 3.5 years and return on investment (ROI) in the case of PV panel’s addition is equal to 3.5.

One of the main issues that need to be emphasized is the very low points in the LEED checklist for the renewable energy, which is 7 points if the building has 13% of renewable energy onsite (Table 6). The CDR facility will obtain these 7 points whether the renewables perform in the optimum way or degraded after some years of use because of high percentage of renewables onsite in this building facility (17% of PV panels). Therefore, One of the main areas of the research for future, is the assessment of the LEED checklist in the evaluation of building performance and allocation of more points to renewable energy onsite and introduction of new pointing system for renewables efficiency in addition to their amount onsite. The upgrade of LEED criteria or introduction of new green initiatives in the case of renewables should be the direction for the future research.

Table 14: LEED Renewable Points

<table>
<thead>
<tr>
<th>PERCENTAGE RENEWABLE ENERGY</th>
<th>POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>1</td>
</tr>
<tr>
<td>3%</td>
<td>2</td>
</tr>
<tr>
<td>5%</td>
<td>3</td>
</tr>
<tr>
<td>7%</td>
<td>4</td>
</tr>
<tr>
<td>9%</td>
<td>5</td>
</tr>
<tr>
<td>11%</td>
<td>6</td>
</tr>
<tr>
<td>13%</td>
<td>7</td>
</tr>
</tbody>
</table>

The other direction of research in the case of CDR or any existing LEED certified building, would be the retrofit plan such as the assessment of openings (windows, skylight) and evaluation of the type of glazing (U factor, SHGC) and their size and direction in the relation to the energy consumption or savings of the facility.

Conclusions
In this research, the centre for design research in the city of Lawrence, KS was selected as a case study and was studied for its operational performance with the application of BIM. This facility is LEED platinum certified building and the main objective of this research was to evaluate the LEED certified buildings during their operation phase with recommendation of possible retrofit plans to enhance their performance. This research compared the results from the simulation model and the real building performance. The influence of renewables on energy consumption/generation was the main focus of this research and therefore, the EnergyPlus (V 8.0) was used as the main tool in this study for broad inclusion of renewables.

Based on the obtained results and comparison of them with base case and current performance of building, the retrofit plans have direct impact on energy reduction, CO₂ emission reduction and higher energy generation through renewable energy. With regards to the cost benefit analysis, retrofit plans reduce electricity bills annually in the facility. As it described in the LCC analysis, the payback period for retrofit 2 and 3 is 3.5 years with the consideration of energy savings of facility annually.

In conclusion, irrespective of retrofit plans capability to increase energy generation by the facility, it does not have any affect on building certification process and in order to motivate the facility owners
and introduce the financial benefits of achieving higher LEED certified building to reduce the tax returns, increase return on investment (ROI) and reduce energy bills, it is required to upgrade the LEED checklist accordingly.

References
STUDY ON THERMAL PERFORMANCE OF NATURALLY VENTILATED DOUBLE-SKIN FACADE

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Abstract

As a passive way of building energy conservation, naturally ventilated Double-skin façade (DSF) is widely used in climates with hot summers and cold winters. However, due to the complicated air flow and heat transfer in DSF, economical and practical methods suitable for evaluating thermal performance of naturally ventilated DSF are still lacking. One computational fluid dynamics (CFD) simulation can only obtain the performance of a DSF at one point, which means a large amount of simulations are required to reach an assessment of one certain type of naturally ventilated DSF. In this paper, a new evaluation method is proposed. By separating indoor heat gain through DSF into two parts – solar heat gain and heat gain caused by temperature difference between indoor and outdoor, which significantly reduces the amount of CFD simulations. Two sets of CFD simulations were performed for validation. The novel assessment method showed good computational accuracy and was applied to obtain Integrated Solar Heat Gain Coefficient (ISHGC) for cooling season, which was a more proper assessment indicator for DSF. And the proposed assessment method was adopted in comparing multiple naturally ventilated DSF with varied structures. The comparison results could be applied in DSF optimization.

Keywords: Naturally ventilated double-skin facade, assessment method, assessment indicator, computational fluid dynamics, optimization design.

Introduction

Naturally ventilated double-skin facade (DSF) has attracted a lot of attention and been widely applied in commercial buildings (Poirazis 2004). Well-designed naturally ventilated DSF is able to not only meet the requirements of indoor thermal comfort, but also potentially contribute a large amount of energy saving. Therefore, the performances of naturally ventilated DSF in shading and heat transfer should be analyzed and optimized. However, DSF is different from the conventional building envelopes, so that the assessment method should be different from the conventional.

Multiple assessment indicators of DSF were proposed in previous researches. H. Manz (Manz 2004:127-136), S. K. Chou et al (Chou 2009:2275-2281) adopted total solar energy transmittance (TSET), which was the ratio of the total energy through DSF to the total solar irradiation on the DSF. In the work of D. Saelens et al (Saelens 2003:167-185), thermal performances of DSF were evaluated by combined heat transfer coefficient and heat venting efficiency, which was the ratio of the heat brought out by ventilation to the total solar irradiation on the DSF. While A. Fallahi et al believed that SHGC (Solar Heat Gain Coefficient) and annual building load should be applied to study the performance of DSF (Fallahi 2010:1499-1509).

However, the complicated heat transfer in DSF, including turbulent convection, radiation and heat conduction cannot be described completely by heat venting efficiency. Thus, annual building load, which is influenced by multiple factors other than DSF, is unable to evaluate DSF distinctly.
Although SHGC, TSET and integrated heat transfer coefficient are proven to be effective in measuring the thermal performance of DSF, the three coefficients change under different meteorological conditions and are difficult to calculate. One CFD simulation can only provide one result under one certain condition, which implies that a much bigger amount of simulations are required to reach an assessment of the whole cooling season.

Therefore, it is necessary and valuable to design an economical and practical assessment method suitable for naturally ventilated DSF. In this paper, a new method is proposed to do fast calculation of thermal performance in any meteorological condition and obtain IHSGC for cooling season. By separating indoor heat gain through DSF into two parts – solar heat gain and heat gain caused by temperature difference between indoor and outdoor, this new assessment method can significantly reduce the amount of CFD simulations. The proposed assessment method was further verified by two sets of results of CFD simulations.

**Proposed Assessment Method**

In this section, a novel assessment method of naturally ventilated DSF is proposed. Indoor heat gain through DSF was divided and analyzed separately. Formulas were derived for each part of the heat flow to approach the proposed assessment indicator, ISHGC for cool supply season.

**Energy flow of DSF**

Energy flow of DSF, which contains reflection, transmission, absorption, convection heat transfer, heat venting, etc., is complicated as shown in the **Figure 34**.

![Figure 34 Energy flow of DSF](image)

DSF affects the indoor cooling load in three aspects, which are transmission of direct and diffuse solar radiation, free convection heat transfer between internal facade and indoor air, and long-wave radiation heat exchange between internal facade and indoor objects.
The long-wave radiation heat exchange is relatively small compared with the other two heat transfer ways, and can therefore be ignored (Baldinelli 2009:1107-1118). Accordingly, the elements of cooling load are reduced to transmission and convection heat transfer as shown in the Equation 1.

\[ \Phi = \Phi_{\text{trans}} + \Phi_{\text{conv}} \]  

(1)

The convection heat transfer is affected by both the solar radiation and the air temperature difference between indoor and outdoor, so that the convection heat transfer can potentially be divided into two parts according to the two different causes.

Assume that the air temperature in the cavity has a linear distribution and the convective heat transfer coefficient of internal facade is homogeneous, then we get the following Equation 2.

\[ \Phi_{\text{conv}} = k_i F (t_c - t_{in}) = k_i F (t_{out} - t_{in}) + k_i F (t_c - t_{out}) \]  

(2)

Where \( t_c = \frac{(t_{co} + t_{out})}{2} \).

In Equation 2, \( (t_{out} - t_{in}) \) is the air temperature difference between indoor and outdoor, so \( (t_c - t_{out}) \) can be regarded as the temperature rise caused by radiation. In this way, the convection heat transfer is divided into two parts according to different causes, as shown in Equation 3 and 4.

\[ \Phi_{\text{conv},\text{td}} = k_i F (t_{out} - t_{in}) \]  

(3)

\[ \Phi_{\text{conv},\text{rad}} = k_i F (t_c - t_{out}) = k_i F (t_{co} - t_{out})/2 \]  

(4)

\( \Phi_{\text{conv},\text{rad}} \) is the convection heat transfer caused by radiation. And \( \Phi_{\text{conv},\text{td}} \) is the convection heat transfer caused by temperature difference between indoor and outdoor. Therefore, indoor heat gain through naturally ventilated DSF is divided into three parts.

\[ \Phi = \Phi_{\text{trans}} + \Phi_{\text{conv},\text{td}} + \Phi_{\text{conv},\text{rad}} \]  

(5)

Among the three parts, \( \Phi_{\text{conv},\text{rad}} \) and \( \Phi_{\text{trans}} \) are caused by radiation, while \( \Phi_{\text{conv},\text{td}} \) is caused by temperature difference. Divide Equation 5 by \( F \), and Equation 6 for average heat flux can be obtained.

\[ q = q_{\text{trans}} + q_{\text{conv},\text{td}} + q_{\text{conv},\text{rad}} \]  

Such an algorithm is featured by conciseness and clear physical meanings. Transmission and temperature difference between indoor and outdoor have barely no affect in causing free convection inside the cavity, so that \( \Phi_{\text{trans}} \) and \( \Phi_{\text{conv},\text{td}} \) are separated from natural ventilation in DSF. Thus, the ability of heat venting of DSF reflects on \( \Phi_{\text{conv},\text{rad}} \) alone. Under the same meteorological condition, DSF with a smaller \( \Phi_{\text{conv},\text{rad}} \) has a superior effectiveness in heat venting.

**Proposed assessment indicator**

According to Section 0, indoor heat gain through DSF is separated into two parts—heat gain caused by solar radiation (\( \Phi_{\text{conv},\text{rad}} \) and \( \Phi_{\text{trans}} \)), and heat gain caused by temperature difference (\( \Phi_{\text{conv},\text{td}} \)). The thermal performance of naturally ventilated DSF can be evaluated based on two different causes.

The convective heat transfer coefficient of internal facade \( k_i \) can be adopted as the indicator of heat gain caused by temperature difference between indoor and outdoor.

As for the evaluation of heat gain caused by solar radiation, there is a conventional assessment indicator SHGC for single-skin facade (Shameri 2011:1468-1475).

\[ \text{SHGC} = \frac{\Phi_{\text{conv},\text{rad}} + \Phi_{\text{trans}}}{F \cdot h} \]  

(7)

However, DSF has complicated natural ventilation and energy flow, so that the value of SHGC varies under different meteorological conditions. SHGC indicator should be reformed to meet the requirement of DSF assessment. Sum up the daytime heat gain during the whole cooling season, and then divide it by the sum of solar irradiation received by the outer surface of external facade during the same period. Thus, Integrated Solar Heat Gain Coefficient (ISHGC) can be obtained.
ISHGC = \frac{\int (\Phi_{\text{conv,rad}} + \Phi_{\text{trans}}) dt}{F \int j_h dt} \quad (8)

This indicator describes the multiple forms of heat transfer rates, which implies the dynamic ventilation behavior, and reflects the thermal performance during the whole cooling season. Therefore, ISHGC is an ideal assessment indicator for natural ventilated DSF.

To have a better description of thermal performance, two new indicators are derived.

ISHGC_{\text{conv,rad}} = \frac{\int \Phi_{\text{conv,rad}} dt}{F \int j_h dt} \quad (9)

ISHGC_{\text{trans}} = \frac{\int \Phi_{\text{trans}} dt}{F \int j_h dt} \quad (10)

The two indicators above represent the levels of \( \Phi_{\text{conv,rad}} \) and \( \Phi_{\text{trans}} \), respectively. Combined with convective heat transfer coefficient of internal facade \( k_i \), full characterization for thermal performance of DSF is obtained.

**Calculation of each part of \( \Phi \)**

By separating into three parts, each part of indoor heat gain is possible to be measured respectively. By conventional methods from heat transfer theory, \( \Phi_{\text{trans}} \) and \( \Phi_{\text{conv,td}} \) can be calculated. However, \( \Phi_{\text{conv,rad}} \), which relates to free convection inside the cavity, is not easy to estimate. In this paper, a novel method to estimate this part of heat transfer is proposed. Thus, with a small number of CFD simulations, \( \Phi \) and \( q \) can be measured.

**Calculation of \( \Phi_{\text{trans}} \)**

\( \Phi_{\text{trans}} \) can be calculated based on radiation intensity, DSF structure and optical properties of each surfaces of DSF. Considering the properties of different surfaces, the short-wave radiation received by internal facade is separated into three parts to approximate \( \Phi_{\text{trans}} \), which are diffuse radiation, direct radiation and once-reflected radiation. Radiation reflected multiple times by different surfaces is relatively small and can be ignored. Figure 35 shows the ranges of the three different kinds of radiation.
Figure 35 short-wave radiation received by internal facade

From the geometrical relationship in the figure above, following three equations can be obtained.

\[
H_{\text{diff}} = \begin{cases} 
D \tan A' & , D \tan A' < H \\
H & , D \tan A' \geq H
\end{cases} \quad (11)
\]

\[
H_{\text{dir}} = H - H_{\text{diff}} 
\quad (12)
\]

\[
H_{\text{re}} = \begin{cases} 
6 - D \tan A' & , H \leq D \tan A' < 2H \\
0 & , D \tan A' > 2H
\end{cases} \quad (13)
\]

The radiation intensities of the three parts mentioned earlier can be calculated by solar diffuse and direct radiation intensity, solar attitude angle, and optical properties of each surface. The common types of inner blind include cloth curtain, venetian blinds and so on. The transmittance of inner blind can be treated as constant value. Besides, the transmittance of internal and external facade, and the reflectivity of the bottom of DSF are treated as constant.

Thus, the radiation intensity are measured as Equation 14, 15, and 16.

Diffuse radiation intensity.

\[
\overline{J_{\text{trans,diff}}} = J_{h,\text{diff}} r_{e} r_{b} r_{t} \quad (14)
\]

Direct radiation intensity.

\[
\overline{J_{\text{trans,dir}}} = J_{h,\text{dir}} r_{e} r_{b} r_{t} \quad (15)
\]

Once-reflected radiation intensity.

\[
\overline{J_{\text{trans,re}}} = J_{h,\text{dir}} r_{e} r_{b} r_{t} \rho_{b} \quad (16)
\]

In Equation 14, 15 and 16, the transmittance of structures should be considered in calculating area-averaged values. By the above 6 functions, \(\phi_{\text{trans}}\) under any meteorological condition can be calculated.

\[
\phi_{\text{trans}} = \overline{F_{\text{trans}}} \quad (17)
\]

Where,
Calculation of $\Phi_{\text{conv},td}$

$\Phi_{\text{conv},td}$ is the heat transferred when the temperatures between the internal facade are indoor and outdoor temperature respectively. With given temperatures of indoor and outdoor, $\Phi_{\text{conv},td}$ can be estimated by convective heat transfer coefficients, heat conductivity coefficient and thickness of internal facade, as shown in Equation 19 and Equation 20.

$$k_i = \frac{1}{\frac{1}{h_{ii}i} + \frac{1}{h_{io}}}$$  \hspace{1cm} (19)

$$\Phi_{\text{conv},td} = k_i F_i (t_{out} - t_{in})$$  \hspace{1cm} (20)

Calculation of $\Phi_{\text{conv},rad}$

$\Phi_{\text{conv},rad}$ is caused by solar radiation, and is related with solar radiation intensity. This mathematical relation can be used to reduce the workload of calculation. It is obtained by following steps.

According to Equation 4, mean cavity temperature $\bar{c}$ is the only unknown. Therefore, the key point in calculation of $\Phi_{\text{conv},rad}$ is the relationship between $\bar{c}$ and solar radiation intensity.

Assuming the cavity is in steady-state heat transfer condition. Based on the energy flow described in Section 0, the heat balance in the DSF cavity can be formulated as Equation 21.

$$F \bar{c}_e \frac{J}{\rho} = (t_{co} - t_{out})cG + k_e F(\bar{c}_e - t_{out}) + k_i F(\bar{c}_e - t_i) + F_{\text{trans}}$$  \hspace{1cm} (21)

The left side of the equation is the heat gain of the cavity, which is solar radiation transmission through external facade. The right side is the heat losses of the cavity, including heat venting, convection heat transfer through external and internal facade, and solar radiation transmission through internal facade.

Substituting Equation 14 and 15, and take $(\bar{c}_e - t_{out})$ as $\Delta t$, Equation 22 can be obtained.

$$F \bar{c}_e \frac{J}{\rho} = 2cG\Delta t + (k_e F + k_i F)\Delta t + k_i F (t_{out} - t_{in}) + F_{\text{trans}}$$  \hspace{1cm} (22)

Assuming that structure of DSF and physical properties of each surfaces are constant, then the variables except $G$, $\Delta t$ and $t_{out}$ are constant. The relation between $G$ and $\Delta t$ is derived as follow.

Since the two DSF openings are on the same surface, the wind pressures of inlet and outlet are approximately equal, which means there exists only thermal pressure ventilation in DSF cavity. According to the basic principles of thermal pressure ventilation, the pressure differential between inlet and outlet is described Equation 23.

$$\Delta p = \frac{\rho g H \Delta t}{T}$$  \hspace{1cm} (23)

Due to the resistance of inner blind and heating effect of various surfaces, the airflow inside the cavity is turbulent flow and in the region of quadratic resistance law. Thus, ventilation quantity fits Equation 24.

$$G = \sqrt{\frac{\Delta p}{\rho}} = \sqrt{\frac{\rho^3 g H \Delta t}{T S}}$$  \hspace{1cm} (24)

By substituting Equation 24 into Equation 22, Equation 25 is derived.

$$F \bar{c}_e \frac{J}{\rho} = 2c \sqrt{\frac{\rho^3 g H}{T S} \Delta t^{1.5}} + (k_e F + k_i F)\Delta t + k_i F (t_{out} - t_{in}) + F_{\text{trans}}$$  \hspace{1cm} (25)

Equation 25 describes the relationship between $J$ and $\Delta t$. According to the simulation results from Z. Zeng’s work, heat venting occupies a vast majority (mostly more than 70%) of total heat gain.
inside the cavity (Zeng 2012:1-6). In that case, convection heat transfer in Equation 25 can be ignored. Thus, \( J_h \) is proportional to \( \Delta t^{1.5} \). In other words, \( \Delta t \) is proportional to \( J_h^{2/3} \).

Set the proportionality factor as \( \alpha/k_i \) and obtain Equation 26.

\[
k_i (T_c - T_{out}) = \alpha J_h^{2/3}
\]

(26)

Substituting Equation 26 into Equation 4, the relation between \( \Phi_{\text{conv,rad}} \) and \( I_h \) is measured as Equation 27.

\[
\Phi_{\text{conv,rad}} = \alpha F J_h^{5/3}
\]

(27)

\( \alpha \) is named Radiation Conversion Index, which represents the average level of convection heat flux through internal facade converted from \( J_h \). Theoretically, when Equation 27 is validated, \( \alpha \) of a certain type of DSF can be obtained by one single simulation. With a determinate \( \alpha \), it is possible to calculate \( \Phi_{\text{conv,rad}} \) under any given meteorological condition without simulation study.

Thus, all of the three parts of indoor heat gain are obtained. And two sets of CFD simulations of two different kinds of DSF were performed for validation in authors’ unpublished works. The computational accuracy of the proposed method was proved to be acceptable. It is practical to divide the indoor heat gain into three parts and calculate them separately. Furthermore, all the parameters needed in calculation could be obtained without simulations, except \( \alpha \), which could be fitted with a small number of CFD simulations. Thus, the thermal performance of DSF was able to be estimated quickly in any meteorological conditions.

**Modeling**

The assessment method was adopted in optimization design of DSF. In the following section, CFD model settings and the modeling of the different kinds of DSF are described.

**Computational Domain**

To emulate the influence of atmosphere, atmosphere section was added into the computational domain of the CFD models.

The computational domain and the basic DSF structure are shown in Figure 36.
Besides, the orientation of the DSF is set as south, for the models are to simulate DSF at the Northern Hemisphere and southward is the most common orientation of DSF (Gratia 2007:199-211).

**Physical Properties**

Physical properties of facade, blind, and other surfaces were set as Table 15. Radiation properties were set separately by short-wave (0.1-3µm) and long-wave (3-100µm).

**Table 15 Thermal and solar optical properties settings**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Material</th>
<th>$\delta$ (mm)</th>
<th>$\tau_S$</th>
<th>$\varepsilon_S$</th>
<th>$\tau_L$</th>
<th>$\varepsilon_L$</th>
<th>$\lambda$ (W/m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External facade</td>
<td>Glass</td>
<td>10</td>
<td>0.7</td>
<td>0.1</td>
<td>0</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Internal façade</td>
<td>Glass</td>
<td>20</td>
<td>0.7</td>
<td>0.1</td>
<td>0</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Blind</td>
<td>Fabric</td>
<td>20</td>
<td>0.1</td>
<td>0.6</td>
<td>0</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Sky</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Other surfaces</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0.7</td>
<td>0</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

**Radiation Conditions for CFD Simulation**

To fit the radiation conversion index $\alpha$, CFD simulations are required. Theoretically, only one result under one radiation condition is enough to calculate $\alpha$. However, considering both the accuracy and the computing time, 3 radiation conditions were adopted in the CFD simulations in this study, shown in Table 16.
The above three sets of radiation conditions cover the southward solar radiosity values under common meteorological conditions. Simulation results obtained under the above three conditions, can provide a more accurate value of $\alpha$.

### Turbulence Model, Near-wall Treatment and Mathematical Calculation

The turbulence model adopted the standard two-layer $k$-$\epsilon$ model, which combines standard $k$-$\epsilon$ model with the two-layer approach and can work with either low-Reynolds number type meshes ($y^+ \sim 1$) or wall-function type meshes ($y^+ > 30$). The two-layer all $y+$ wall treatment, which employs a blended wall law to estimate shear stress and can give good results for both coarse meshes ($y^+ > 30$) and fine meshes ($y^+ \sim 1$), was applied as the wall treatment model.

The steady state mode, finite volume method, second-order upwind convection scheme and SIMPLE solution algorithm were applied in the simulations. The commercial CFD code of STAR-CCM+ 4.04.011 was used in the mathematical calculations (CD-adapco JAPAN Co. Ltd. 2009). Accuracy of the method has been validated by experimental data according to Zeng’s work (Zeng 2012:1-6).

### Optimization Design of Naturally Ventilated DSF

Multiple naturally ventilated DSF with varied structures were simulated. And ISHGC of all the DSF were calculated and compared. The simulation location was set as Beijing, China. The optimization design results can be widely applied in climates with hot summers and cold winters.

### Hourly Meteorological Conditions

Considering the common type of office building in Beijing, the typical cooling season is approximately from May 15th to September 15th. And the typical cooling supply hour, which is also the typical working hour, is defined as 8:00am to 6:00pm.

Some of the meteorological conditions were obtained from report of hourly parameters of typical meteorological year of Beijing. From the report, outdoor temperature, southward direct and diffuse radiosity were adopted in the CFD simulations in this study.

Converting solar altitude angle, $A'$, could be calculated according to the coordinate of Beijing and some simple geographical principles (not explained here due to the length of this paper).
Optimization Design of Blind Position

Inner blind is a critical shading device of naturally ventilated DSF. Blind is made of low-transmission high-reflection material. On one hand, inner blind reflects part of solar radiation energy out of the facade; on the other hand, it heats up ambient air by absorbing radiation energy. In this way, thermal pressure drives hot air out of the DSF cavity and heat is ventilated out of the facade. Eventually, the indoor heat gain is reduced.

The structure settings of DSF are as follow:
1) The widths of the DSF cavities are 80cm;
2) The heights of the DSF are 3m;
3) The slits between blinds and the top and bottom are 10cm;
4) 5 positions of Inner blind for comparison, the distances between blind and external facade are set as 10cm (innermost), 20cm (inner), 40cm (middle), 60cm (outer), and 70cm (outermost) respectively;
5) Both inlet and outlet on external facade are 10cm wide, plain openings, no shading.

By applying the proposed assessment method, hourly indoor heat gain are calculated. Thus, ISHGC of each models are obtained. Besides, blind position has no effect on ISHGC, which are 0.0969 uniformly. ISHGC are shown in Figure 37.

![ISHGC of different blind position models](image)

For the whole cooling season in Beijing, ISHGC of outermost model is 1.7% larger than that of innermost model. It can be concluded that Blind position has barely no effect on convection heat transfer though internal facade.

Optimization Design of Cavity Width

Cavity width is another critical parameter of DSF designing. It has a direct influence on ventilation resistance of DSF, so that it may have a significant influence on heat venting performance. Meanwhile, as the cavity width increases, the shading effect of the top of DSF gets stronger and solar transmission heat gain gets smaller.

However, economic considerations also have an important impact on designing decisions. Larger cavity means less usable area and less rental income. Therefore, it is necessary to study the thermal performance of DSF with different cavity width by adopting the proposed assessment method and indicator.
The structure settings of DSF are as follow:
1) 6 kinds of widths of cavity: 20cm, 40cm, 60cm, 80cm, 100cm, and 120cm;
2) The distance between blind and internal facade is 10cm;
3) Other structure parameters are the same as those of the previous section.

Firstly, CFD simulations of 3 different radiation conditions are finished. Figure 38 shows the velocity magnitude distribution inside the DSF cavities. The velocity of the air flow in the middle of cavities is no more than 0.4m/s.

By applying the proposed assessment method, hourly indoor heat gain are calculated. Then ISHGC are obtained as shown in Figure 39.

We can come to following conclusions from the above 2 figures.
1) Cavity width mainly influences the short-wave transmission heat gain. A wider cavity can provide a better shading effect, which means the direct radiation area is smaller on the internal facade; 

2) Cavity width has barely any impact on convective heat gain. In other words, heat-venting performance of DSF is not sensitive to cavity width. The ventilation volumes of different width are approximately equal. From Figure 38, it can be found that the velocities between blind and internal facade stay close to 0.4m/s. However, the velocities between blind external facade are obviously different, which results in similar ventilation volume; 

3) For the whole cooling season in Beijing, wider cavity leads to less indoor heat gain. ISHGC of 20cm cavity is 12.3% larger than that of 120cm cavity. Nonetheless, the amount of energy saving is rather small compared with the economic value which 100cm could bring. Therefore, 20cm cavity is recommended.

**Optimization Design of Ventilation Opening**

Ventilation openings are main resistance components of naturally ventilated DSF. Its size, shape and location, all influence the resistance coefficient of DSF cavity and heat venting effect directly. However, there is a dilemma between beautiful appearance and energy conservation. Besides, dustproof performance should also be considered. For these reasons, optimization of ventilation opening is important.

Optimization design of ventilation opening is separated into two parts – opening size and opening shape. Here are the structure settings of opening optimization:

1) When comparing the sizes of openings, all models adopt plain opening, which refers to no component at the opening. 4 different width of opening: 5cm, 10cm, 15cm, and 20cm. Both openings (inlet and outlet) have the same size;

2) When comparing different opening shapes, all the widths of openings are set as 10cm. 3 compared shapes: board, bafflers, and plain opening, as shown in Figure 40. Among them, opening angle (angle between board and facade) of board is generally smaller than 45°, while opening angle of bafflers normally can be any angle;

3) Other structure parameters are the same as those of the previous section.

![Figure 40 Three shapes of ventilation openings](image)

Figure 41 shows the ISHGC of different opening size models.

![Figure 41](image)
Conclusions can be obtained from the above figure:
1) Larger opening leads to smaller area shaded by external facade and larger indoor transmission heat gain.
2) Larger opening leads to smaller resistance coefficient, which enhances heat venting and lower the cavity temperature, eventually decreases the convective heat gain. Besides, convective heat gain reduces significantly when the width increases to 10cm from 5cm.
3) For the whole cooling season in Beijing, opening size has a major impact on indoor heat gain. However, ISHGC of openings larger than 10cm are close. For the consideration of appearance, 10cm opening is recommended.

Figure 42 shows the ISHGC of different opening shape models.

From the Figure 42, we can come to following conclusions:
1) Different opening shapes barely influence transmission heat gain;
2) Different opening shapes have significant impact on convective heat gain, and the impact is
mainly shown in opening angle. Convective heat gains of 90° bafflers and plain opening are close, which means 90° bafflers have very tiny impact on resistance of DSF cavity.

3) For the whole cooling season in Beijing, ISHGC is smallest with 90° bafflers. And with 30° board and 45° board, ISHGC increase 16.2% and 6.8% respectively. And when adopting 30° bafflers, 60° bafflers and plain opening, ISHGC increase 15.3%, 2.8% and 3.0%, respectively. Therefore, baffler opening is recommended. And it is better to keep the opening angle over 60° in summer.

Conclusions

A novel assessment method and indicator ISHGC were proposed. ISHGC describes the multiple forms of heat transfer, implies the dynamic ventilation behavior, and reflects the thermal performance during the whole cool supply season. It is practical to apply the proposed method and indicator in the thermal performance analysis and design assistance for naturally ventilated DSF.

Optimization design were done by adopting the proposed assessment method and ISHGC. Results are shown as follow:
1) Optimization design of blind position
Blind position has barely any influence on heat venting performance of naturally ventilated DSF
2) Optimization design of cavity width
Heat venting performance of DSF is not sensitive to cavity width. The ventilation volumes of different width are approximately equal. For areas similar to Beijing, 20cm cavity is recommended.
3) Optimization design of ventilation opening
When adopting plain opening, larger opening leads to larger transmission heat gain and smaller convective heat gain. For areas similar to Beijing, openings with width over 10cm are recommended. Considering rainproof and dustproof requirements, bafflers opening and board opening are more commonly used, instead of plain opening. Opening angle has a major impact on resistance coefficient, which results in larger convective heat gain. Bafflers opening is recommended. And it is better to keep the opening angle over 60° in summer.

Nomenclature

- $c$: the heat capacity of air, J/(kg·K)
- $F$: DSF area, m²
- $G$: ventilation quantity, m³/s
- $h$: convective heat transfer coefficient, W/(m²·K)
- $H$: distance between inlet and outlet of DSF, m
- $J$: radiosity, W/m²
- $k$: overall coefficient of heat transfer, W/(m²·K)
- $\Delta p$: pressure differential between inlet and outlet of DSF, Pa
- $q$: area-averaged heat flux, W/m²
- $Q$: heat gain in cool supply season, MJ/m²
- $S$: resistance coefficient of DSF, (m·kg)⁻¹
- $t$: centigrade temperature, °C
- $T$: absolute ambient temperature, K

Greek Symbols

- $\alpha$: Radiation Conversion Index, W¹/³/m²³/³
- $\delta$: thickness, m
- $\epsilon$: emissivity
- $\theta$: incident angle, degree
\( \lambda \) thermal conductivity, W/(m·K)
\( \rho \) ambient air mass density, kg/m\(^3\)
\( \tau \) transmittance
\( \phi \) heat transfer rate, J/s

Subscripts
b blind plain
c cavity
c\( o \) outlet of cavity
c\( \text{conv} \) convection
e external facade plain
h horizontal direction
i internal facade
ii internal surface of internal facade
in indoor
io external surface of internal facade
l long-wave
out outdoor
rad radiation
s short-wave or southward
t\( d \) temperature difference
trans transmission

References


THERMAL EFFECTIVENESS OF GREEN ROOFS ON NZE BUILDINGS

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Abstract
The research deals with the experimental assessment of the thermal performance of a green roof compared to other passive cooling technologies (roofs with ventilated cavities or with a reflective covering), under temperate climate in Italy. All roofs are installed on a highly insulated building, in order to understand whether their performance is inhibited by the low thermal transmittance necessary to meet the building energy saving regulations in Europe. Green roofs are also recognized as a fundamental strategy that dense urban areas can deploy to mitigate the Urban Heat Island effect, thanks to their high albedo.

Roofs albedo and thermal transmittance were experimentally evaluated. The measurement results show that the passive cooling property of a green roof is not only due to its albedo, but also to combined effects of soil insulation, evapotranspiration and radiative shading of the plant canopy. In summer, a reduction of the surface temperatures has been recorded on the upper part of the soil substrate where temperatures turn out to be lower than those of the external air, and also on the roof soffit because of the thermal inertia of the soil substrate. In winter, the soil substrate of the green roof acts as a natural insulating material, providing further thermal resistance to the roof.

Keywords: Green Roof, NZEB, Urban Heat Island, albedo, passive cooling.

Introduction
In a building market that is moving towards Nearly Zero Energy Buildings (NZEB), there is an ever-increasing interest in energy saving techniques and environmental sustainability. Consequently, numerous researches have been carried out on the potential benefits of using green roofs on buildings.

Green roofs can be employed for reducing energy consumption for heating in winter as well as for cooling in summer (Castleton et al., 2010; Eumorfopoulos and Aravantinos, 1998), but they can also be used for reducing the Urban Heat Island (UHI) effect of big metropolitan areas (Rosenfeld, 1995; Takebayashi and Moriyama, 2007).

The culture substrate of green roofs could act as a natural insulating material with low thermal conductivity and high thermal mass, while the vegetation is useful for reducing solar heat gains due to its high albedo and to the evapo-transpiration phenomena that take place on it (Ayata et al., 2011; Lazzarin et al., 2005; Palomo del Barrio, 1998; Takakura, 2000).

Numerous studies have been carried out on the energy performance of green roofs under warm and temperate climates, but most of them analysed the performance on buildings with high thermal transmittance.

Santamouris et al. (Santamouris et al., 2007) presented an experimental investigation of the green roof system efficiency in a Greek school and performed simulations to calculate both the cooling and heating load for the summer and winter period. The energy performance evaluation showed a significant reduction of the building’s cooling load during summer (for the whole building in the range of 6–49%), while the influence of the green roof system in the building’s heating load was found insignificant.
Parizotto and Lamberts (Parizotto and Lamberts, 2011) analyzed the thermal performance of a green roof in both summer and winter by comparing it with other low insulated roofs with ceramic and metal cladding. The green roof was installed on top of an experimental single-family house in the city of Florianopolis (Brazil), which has temperate climate. Results in summer showed that the green roof performed better than other kinds of roofs. It led to reduced external surface temperatures and better indoor comfort; it reduced thermal flux by up to 97% compared to a metal clad roof, and increased outgoing heat flux by up to 49%. Moreover, the green roof gave excellent performance in winter too. Even though the vegetation in the roof reduced solar heat gains, insulation of culture substrate contributed to reducing the outgoing thermal flux by up to 52% compared to a metal clad roof.

Even if the above-mentioned studies agree on the overall efficiency of the green roof in terms of both energy saving and environmental comfort, the benefits found are linked to specific cases. In particular, our knowledge about the influence that the installation of a green roof on a highly insulated slab could have on its thermal performance is still limited.

In fact, some studies underline that the use of high insulation in roofs could limit the potential of some cooling strategies on the covering. D’Orazio et al. (D’Orazio et al., 2010) have previously shown that an increase in roof insulation thickness decreases the passive cooling potential due to traditional construction methods of roofs (ventilation, inertia, radiative properties).

Other studies demonstrate that green roofs, although being efficacious especially in terms of solar heat gains in summer, can find their potential limited if they are associated to highly insulated roofs. Zinzi and Agnoli (Zinzi and Agnoli, 2012) analysed the performance of cool and green roofs on non-insulated (U = 1.4 W/m²K) and moderately insulated (U = 0.6 W/m²K) slabs with the help of Energy Plus software. They were able to obtain savings in consumption compared to traditional roof coverings by up to 13.9% in the case of non-insulated ones and up to 7.8% in the case of moderately insulated ones.

Simulations carried out by Theodosiou (Theodosiou, 2003) on the basis of the analytical model by Palomo-Del Barrio (Palomo del Barrio, 1998) confirm that increasing the insulating layer in the roof reduces the capacity of the green layer to draw out the stored heat during the day at nighttime because it reduces heat flux that passes through the system.

More numerous are the studies that show environmental benefits (UHI reduction) in the use of materials with specific optical properties or vegetated envelopes (Takebayashi and Moriyama, 2009, 2007; Takebayashi et al., 2012). In fact, such materials reach lower temperatures when they are exposed to solar radiation. Consequently, they reduce heat transfer to the adjacent air thereby contributing to the decrease in temperature on an urban scale.

Since roofs represent about 20-25% of the urban surface, their whole conversion into green or cool roofs could lead to many environmental benefits on an urban scale (Akbari and Levinson, 2008). The experiment described in this paper would give a contribution to the research, by providing results on the thermal performance of a green roof also compared to other types of roofs installed in a NZE building.

Materials and methods
The in-situ monitoring was carried out on a real-scale experimental building near Ancona (Italy, 2064 DD). The building was 8.20 x 10.50 m, totalling 82.30 m² with a volume of around 250 m³. The roof was divided into modules of the same width (1.50 each) and same length of 6 m on the south slope and 3 m on the north slope, in order to obtain a similar size as that of real roofs.
This research focused on four different kinds of roofs installed in the building: two ventilated clay tiles and copper roofs (respectively named LV6_A and MV6_A), a green roof (MNV_GR), and a roof with a reflective covering (MV6_RS) (Figure 1).

The green roof installed had a culture substrate with medium–low thickness (15 cm) and low and evergreen vegetation of the “officinalis” type for which very little maintenance is required. Table 1 shows the materials that constitute the roof.

An automatic drip irrigation system was installed on the green roof in the summer season, which automatically turned on at 6 a.m. every morning for one hour. External weather conditions were recorded every 10 minutes throughout the summer and winter of 2011 by means of a 12-bit datalogger (Elog Lsi-Lastem) to which instruments were connected in order to measure global radiation (DPA 153 Lsi-Lastem), temperature and relative humidity of the air outside (DMA 572.1 Lsi-Lastem), speed and wind direction (DNA 021-024-027 Lsi-Lastem), and rainfall (DQA030 Lsi-Lastem). Thermal data on the roof stratigraphies were also observed in the same period by means of five 12-bit dataloggers (Elog LSI-Lastem) connected to:

• Thermal resistances (PT100 Lsi-Lastem) for measuring temperatures within the different layers of the roof coverings (surface of the insulation, surface of the covering, slab, ground, air cavities);
• Probe for measuring temperature and moisture content in the planted roof soil (DISACC4825 Lsi-Lastem).

The accuracy of the probes is +/-0.15°C. All the probes and measurement connections were calibrated beforehand, and the calibration results were noted to correct the recorded values. In order to measure the albedo of roofs, the protocol developed by Sailor et al. (Sailor et al., 2006) was followed. A system of two coupled radiometers (DPA 153 Lsi-Lastem) was assembled: one facing the sky to measure the incident global radiation and the other one towards the roof surface to detect the amount of reflected radiation. The inclination of the instrumentation was then adjusted to 17°, the same as the roof’s pitch (Figure 2).
Table 17: Thermophysical properties of the materials composing the green roof.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation and soil substrate</td>
<td>0,150</td>
<td>Lapillus, Compost</td>
<td>0,17 (dry) 0,33 (saturated)</td>
<td>582</td>
<td>1000</td>
</tr>
<tr>
<td>Filter sheet</td>
<td>0,001</td>
<td>Polypropylene</td>
<td>0,220</td>
<td>910</td>
<td>1900</td>
</tr>
<tr>
<td>Drainage, storage and ventilation element</td>
<td>0,002</td>
<td>Polyethylene</td>
<td>0,380</td>
<td>950</td>
<td>2300</td>
</tr>
<tr>
<td>Air (inside the drainage element)</td>
<td>0,023</td>
<td>Air</td>
<td>Thermal Resistance = 0,16 W/m²K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retention Felt</td>
<td>0,004</td>
<td>Polypropylene</td>
<td>0,220</td>
<td>910</td>
<td>1900</td>
</tr>
<tr>
<td>Roof covering</td>
<td>0,001</td>
<td>Copper</td>
<td>380</td>
<td>8900</td>
<td>382</td>
</tr>
<tr>
<td>Osb board</td>
<td>0,015</td>
<td>OSB</td>
<td>0,130</td>
<td>630</td>
<td>2200</td>
</tr>
<tr>
<td>Insulation</td>
<td>0,120</td>
<td>EPS</td>
<td>0,035</td>
<td>25</td>
<td>1470</td>
</tr>
<tr>
<td>Roof Slab</td>
<td>0,050</td>
<td>Fir wood</td>
<td>0,120</td>
<td>550</td>
<td>2700</td>
</tr>
</tbody>
</table>

Figure 44: Placement of the instrumentation for the albedo measurements on roofs, composed by two coupled radiometers: one facing the sky to measure the incident global radiation and the other one towards the roof surface to detect the amount of reflected radiation.
The albedo of the roof is represented by the ratio of total reflected radiation to incident electromagnetic radiation. Radiation measurements were carried out during four days of clear sky in the month of September. For the incident radiation, only the values which were greater than 100 W/m² were considered, to avoid the occurrence of errors and dispersions of results.

In the winter period, the thermal transmittance of the roofs compared to a reference roof (another roof installed in the building, with the same stratigraphy but without the ventilation and the vegetation layer) was evaluated. The assessment was based on the average method as defined by ISO 9869: 1994 regulation (ISO 9869, 1994), starting from the coefficient of heat transfer of the outside and inside air film as defined by the UNI EN ISO 6946:2008 regulation (UNI EN ISO 6946, 2008).

Results: Assessment of roof coverings albedo

The scatter plot in Figure 3 show the values of incident and reflected radiation, measured for the four monitored roofs MNV_GR, MV6_A, LV6_A, and MV6_RS. The lines that interpolate the points show a linear trend. The slope of these lines represents the value of albedo: 0.66 for the roof with reflective sheeting MV6_RS, 0.31 for the clay tile roof LV6_A, 0.13 for the green roof MNV_GR, and 0.09 for the copper roof MV6_A. The value of albedo for the reflective sheathing appears to be comparable with those proposed in the literature, where the range varies between 0.65 and 0.80.

Concerning the green covering, the value of the resulting albedo is slightly lower than the other data found in the literature (Sailor, 2008; Takebayashi and Moriyama, 2007). However, it is important to consider that the passive cooling property of a green roof is not only due to its albedo, but also to a combined effect of soil insulation, evapotranspiration and radiative shading of the plant canopy.

The solar radiation flux coming into the system is a net contribution after solar reflection and absorption of the greenery, according to the eq. (1).
Where:
\( R_n \) is the solar radiation entering the system (W/m\(^2\));
\( R_e \) is the incident global solar radiation (W/m\(^2\));
\( R_r \) is the reflected radiation (W/m\(^2\));
\( R_g \) is the radiation absorbed by the greenery (W/m\(^2\)).

The fraction of the incident radiation \( R_n \) entering a green roof depends on the LAI (Leaf Area Index), that is the ratio between the green area and the underneath soil area, and on the short-wave extinction coefficient \( k_s \).

The exponential law developed by the Palomo del Barrio model (Palomo del Barrio, 1998) clearly illustrates this relationship in eq. (2):

\[
R_n = R_e^{-k_sLAI}
\]

Where:
\( k_s \) is the short-wave extinction coefficient;
LAI is the Leaf Area Index.

In our experimental roof, we assumed a LAI of 4 and a \( k_s \) of 0.29 (values proposed for similar vegetation characteristics in by Palomo del Barrio (Palomo del Barrio, 1998)). We measured the incident (\( R_e \)) and reflected (\( R_r \)) radiation on the Green Roof. In Table 3 mean measured values during the monitoring period are reported. \( R_n \) was calculated by the eq. (2); \( R_g \) by the eq. (1).

**Table 18** Results of calculation of the radiation entering the system \( R_n \) (W/m\(^2\)) and the radiation absorbed by the greenery \( R_g \) (W/m\(^2\)). The incident global solar radiation \( R_e \) (W/m\(^2\)) and the reflected radiation \( R_r \) (W/m\(^2\)) are the mean measured value during the monitoring period. LAI and \( k_s \) are assumed by considering values proposed for similar vegetation characteristics.

<table>
<thead>
<tr>
<th>( R_e ) (W/m(^2))</th>
<th>( k_s )</th>
<th>LAI</th>
<th>( R_n ) (W/m(^2))</th>
<th>albedo</th>
<th>( R_r ) (W/m(^2))</th>
<th>( R_g ) (W/m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>527.82</td>
<td>0.29</td>
<td>4</td>
<td>165.46</td>
<td>0.13</td>
<td>68.62</td>
<td>293.74</td>
</tr>
</tbody>
</table>

It is possible to normalise to 100 incident energy units, the energy exchanges in the canopy. We found in percentage that the greenery reflected 13 units and it absorbed 56 units, calculated as residual term after the transmitted fraction of Eq. (2). The solar radiation entering the system can be then estimate as 31% of the incident global solar radiation. This result is independent to the fact that the green roof was wet or dry, in agreement with Lazzarin et al. (Lazzarin et al., 2005).

**Results: Thermal performance of the roofs**

Summer thermal analysis was carried out in the month of September 2011. Figure 4 shows external surface temperatures of the roofs with respect to the external air temperature and total radiation on a bright day (22/09/2011) in the period considered.

As it can be observed, the surface temperatures on the upper side of the substrate of the green roof (MNV_GR) during the day are actually lower compared to the external air temperature and reach a maximum of 23.60°C against an external temperature of 24.70°C. On the contrary, the covering temperatures of the other roofs are undoubtedly higher, with maximum temperature that arrives up to 59.50°C for the roof with copper covering (MV6_A) and goes down to 47.65°C for the ventilated clay tile roof (LV6_A) and 43.42°C for the reflective sheathing (MV6_RS). The green roof surface temperature is also delayed in time compared to external air temperature because of the thermal inertia of the substrate. Water accumulation during the irrigation phase in the early morning (at 6 a.m.) also contributes to cool the roof.
Figure 5 shows the temperatures on the soffit of the wooden slabs on the same day. It can be seen how the differences between the temperatures are rather low in terms of absolute value because of the high insulation of the slabs.

Figure 46: Roofs covering surface temperature trend (°C) on a bright day (22/09/2011).

Figure 47: Roofs slab surface temperature trend (°C) on the day in question (22/09/2011).
However, the green roof (MNV_GR) is able to guarantee a lower internal surface temperature, which is also considerably attenuated and delayed in time compared to the other roofs. In particular, the difference in the surface temperatures of the green roof was observed to be up to 2°C compared to the temperature of the other ventilated roofs.

The temperature of the roof with the reflective sheathing (MV6_RS) is comparable to that of the other two ventilated roofs in the daytime phase, while it decreases during night-time hours, for phenomena of undercooling due to the low emissivity of the reflective material.

**Results: Assessment of the roofs thermal transmittance**

The assessment of the roofs thermal transmittance was carried out during winter period. Summer evaluation was not included because during this season quasi-steady conditions are rarely obtained due to the very high solar radiation.

Results can be seen in Figures 6 and 7 and summarized in Table 3, which also includes a comparison with theoretical values. The estimate was carried out throughout the monitoring period (Figure 6) and also specifically on days without any rainfall (27-29/01) in order to highlight the influence of the volume of water in the substrate on thermal transmittance values (Figure 7).

![Figure 48: In situ thermal transmittance assessment for the green roofs compared to the reference roof, throughout the monitoring period (21-26 January 2011).](image)

The experimental thermal transmittance value of the reference roof turned out to be quite similar to the theoretical one. As regards the roofs LV6_A and MV6_A, their theoretical U-value is the same because of the calculation method defined by UNI EN ISO 6946 for ventilated roofs. This value differs from the experimental one by a maximum of 5.83% for the LV6_A during the analysis period.

As regards the green roof (MNV_GR), the experimental value calculated during the entire measurement period differs from the theoretical one by 7.48%. This means that the theoretical transmittance overestimates the insulating properties of the green roof. However, the calculation carried out in the days without any rainfall shows an opposite result: the experimental thermal
transmittance turns out to be lower than the theoretical one (-10.09%). In fact, in those days, the dry culture substrate guarantees better performance in terms of insulation.

![Figure 49: In situ thermal transmittance assessment for the green roofs compared to the reference roof, on days without any rainfall (27-29 January 2011).](image)

In general the green roof MNV_GR guarantees lower experimental U-values compared to all other roofs. During the entire measurement period its experimental U-value differs from the roof LV6_A one by a 15.32%, during the days without any rainfall by a maximum of 28.82%.

Table 19: Results of the thermal transmittance assessment and comparison with theoretical values calculated by UNI EN ISO 6946. It can be noticed that theoretical U-value for ventilated roofs is the same because the thermal resistances of the air cavity and all the superior layers were disregarded, while a thermal resistance of the outside air film of 0.10 m²K/W was considered, according to UNI EN ISO 6946 calculation method.

<table>
<thead>
<tr>
<th>roof type</th>
<th>dynamical U-value whole period [W/m²K] (ISO 9869)</th>
<th>theoretical U-value [W/m²K] (UNI EN ISO 6946)</th>
<th>difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference roof</td>
<td>0.245</td>
<td>0.244</td>
<td>0.27%</td>
</tr>
<tr>
<td>MV6_A</td>
<td>0.256</td>
<td>0.247</td>
<td>3.58%</td>
</tr>
<tr>
<td>LV6_A</td>
<td>0.261</td>
<td>0.247</td>
<td>5.83%</td>
</tr>
<tr>
<td>MNV_GR</td>
<td>0.227</td>
<td>0.211</td>
<td>7.48%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>roof type</th>
<th>dynamical U-value dry period [W/m²K] (ISO 9869)</th>
<th>theoretical U-value [W/m²K] (UNI EN ISO 6946)</th>
<th>difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference roof</td>
<td>0.241</td>
<td>0.244</td>
<td>-1.32%</td>
</tr>
<tr>
<td>MV6_A</td>
<td>0.241</td>
<td>0.247</td>
<td>-2.42%</td>
</tr>
<tr>
<td>LV6_A</td>
<td>0.244</td>
<td>0.247</td>
<td>-1.10%</td>
</tr>
<tr>
<td>MNV_GR</td>
<td>0.190</td>
<td>0.211</td>
<td>-10.09%</td>
</tr>
</tbody>
</table>
Conclusion

Preliminary measurements of the in-situ albedo of roof covering materials show that green roof reaches a quite low value. However, the passive cooling property of a green roof is not only due to its albedo, but also to a combined effect of soil insulation, evapotranspiration and radiative shading of the plant canopy. Experimental results confirm that the plant canopy reflects 13% of incident global solar radiation and absorbs 56%, so that the solar radiation entering the system can therefore be estimated as 31% of the incident global solar radiation.

The in-situ monitoring of roofs confirmed a significant reduction in the external covering temperatures by increasing the albedo of the roofs, but also highlighted how the differences in the external temperatures become "flattened" internally. In winter, the culture substrate of green roofs acts as a natural insulating material, providing further thermal resistance to the roof.

Green roofs could be effectively adopted for the mitigation of the Heat Island effect. They also show a good potential even in NZEB, for their passive cooling ability due to the evapotranspiration phenomena of the vegetation and the storage capacity of the substrate.

References


Abstract
Every tradition has developed a building system that is regarded as a sustainable or eco-friendly product. In the Middle Eastern hot and dry climate, besides local construction materials, we find the emphasis is demonstrated by the use of common elements such as inner courtyards, lattice windows, and wind captures all of these play a foremost role in the creation of spaces that have the advantage of providing sustainable microclimate changes, enjoyment, and local identity. The elements of the traditional house were successful in cooling the building for longer hours during the day and providing human comfort in the hot summer; modern architecture lacks these characteristics. This study searches for a way to create a wall cooling system that can be applied to future building designs. A wall cooling system embodies natural applications for sustainable architecture; it stretches toward nature to learn a further new lesson of support interior space with a cool environment in regions that are confronted with a hot and hostile climate. Additionally, it searches for traditional elements that help in supporting the proposed method so that it incorporates nature and traditional house cooling systems. This study has five components: 1. Aerodynamic behavior toward a fixed object with an example from windcatcher towers and Nigerian traditional houses. 2. Water cooling systems as a lesson from the Middle East. (The concept of cool walls designed by Mey Kahn and Boaz Kahn as an inspiration from Mashrabiea and Jara is well considered in this study.) 3. Self-shading walls 4. The cactus plant's properties. 5. Walls combining all previous ideas.

Keywords: Self-cooling wall, self-shading wall, wind capture, aerodynamic behavior, decorative wall

Introduction
In his book “Design with Nature”, McHarg (1992) has directed our attention to the place of nature in our world. Nature is an inspiration for thought. Rushing for sustainable living world, countries have inevitably become more comprehending of the need for the balance of man-nature relationship. Similarly, design in nature is another good angle that highlight how the constructional law governs evolution in biology, physics, technology, and social organization (Bejan and Zane 2012). “Man is that uniquely conscious creature who can perceive and express. He must become the steward of the biosphere. To do this he must design with nature” (McHarg 1992: 5). It is a convivial indication of our integration with nature. Indigenous peoples around the world sensitively developed their way of life to preserve nature. Our ancestors had followed similar step while evolving their traditional physical environment along with cultural aspects (Lynch 1981), climate, and natural resources (Rapoport 1969). The product insured aptness to geographical characters. Keeping in mind the possibility of designing with nature, a possible question would inquire how much a design has natural elements that reflect our traditional built environment? The cover page of the proceeding of “Terra 2008: The 10th International Conference on the Study and Conservation of Earthen Architectural Heritage” posted a picture of mud structure from Nigeria that share two main architectural elements of the Arab Gulf countries. Beside the brutal exposure of the earthen construction material, the structure has grid-like ribbed elevations with systematic distribution of short horizontally projected wooden posts (Rainer, et. Al 2008) (Figures 1 and 2). Looking at both Figures, one may question how earthen structure fits into the hostility of the arid environment? The study digs deep into the concept of traditional mud structure in Arabic Gulf Countries.

Nature and Design
The previously proposed two questions impulse the search for a plant that belongs to arid environment with basic design that resembles the traditional architecture presented in Figures 1 and 2. The cactus plant shown in Fig. 3 is best fit the criteria. Cactus is a spiny plant adapted to survive in hot, dry climates. “It depends upon taking in precious water. Water intake that begin from the available soil moisture by its fibrous roots continues with a cactus plant's storage units being located in the stem”. [2] Researches go on describing the physical parts (roots, leaves, areoles, spine, flower, stems, taxonomy), photosynthesis and metabolism, and phylogeny. Regarding the function of spines and thorns researches limited their use only to protect the fleshy stems (which contain water) of the cactus from predators. This study goes beyond the common approach to includes the plant ability to reduce the heat impact that itself, the aim of the study will be explored in traditional mud structures.

![Fig. 1. Earthen structure, Nigeria and Fig. 2. Wind catcher tower in Dubai. Fig. 3 illustrate cactus Plants.][1]

The similarity between the Nigerian and Arab Gulf traditional structure presented by the projection of both the ribs and wall beams and by horizontally projected wooden sticks that also resemble the pattern presented in the cactus plant shown in Fig. 3. Ribs and wall beams strengthen the structure and at the same time work collectively as a shading devise or self-shading wall. The percentage of the wall shading depends upon the pattern itself and on the sun angle. By looking at both Figures 1 and 2, the average shading may range from 5 to 50 percent. The application of self-shading wall is considered in modern sustainable architecture that applies adjacent screen walls or attaching a screen wall to the southern wall. Many examples are found in the case of Sultan Qaboos University, Muscat, Oman.

Mud walls act as an analogue to cactus plants' water storage in the stem, and similarly helps keep the heat away from the inner space. Usually the temperature inside the structure is 5 to 7 centigrade less than the temperature outside. That is good enough to make space during hot days with the temperature ranging between 30 to 45 Centigrade tolerable. The typical thickness of the mud wall is 80 cm, which is what makes it a good insulator. Also, such a wall works as a cooling system because it stores the moisture and maintains the lower temperature of the night. During the day, when the outer surface is exposed to heat, the moisture evaporates, causing the wall to cool I call this process the Terracotta jara effect. Terracotta jara is widely used in the Middle East to cool down water. Terracotta not only makes the jara surface moist, but also keeps the water contained. It is place where there is air current for better results. Fig. 4 represents a model that summarizes the similarity between the cactus plant and traditional earthen structure in the Arabic Gulf Region.
The study will analyze four parameters:

I. Windcatchers  
II. Aerodynamic behavior  
III. Self-Shedding Walls  
IV. Jara and water cooling  
V. New proposed system for self-cooling wall in hot-arid climate Regions

I. Windcatcher

Because of the compact structures, the cool air passes above the buildings without going through the lower levels (Mansour 1995). Traditional earth architecture direct windcatcher, particularly the prevailing wind, to the advantage of the inner spaces as a result of the negative and positive air pressure. The main function of this windcatcher is to channel the wind into the house and moderate the climate inside by providing airflow inside, if it is not cold, at least the airflow provides cooling effect. Al-Wakil and Siraj (1989) summarizes the advantage of windcatchers in three functions: a- Provide air circulation and replacement; b- Provide convective cooling; c- Provide evaporative cooling.

There are three main systems that are registered in that regard: wind-tower (Baggadeer), windcatcher (Malkaf), and geo-cooling system.

Wind-Tower (Baggadeer): It is used in architecture in the Arabic Gulf, Iran, Pakistan, and Afghanistan.

- The square plan layout in Fig. 5 shows the wind-tower as a main traditional element. The tower height is 15 m (45 ft.) for two-story building, and 8 m (24 ft.) for one-story building. The base has the height of 2 m max. while its side is around 2.33x2.33 m (7x7 ft.) (Fridoni 1995). (Fig. 6)
- The inside void is divides into four identical volumes by two
diagonal crossed walls. The air penetrating the tower from the wind direction straight down into the room where the continually open-base of the tower is located.

- The identical opening of its four elevations with vertical dividers that vary in numbers. The height of the tower is 3-5 m and 3-2 arched openings for the four elevations.

- On the elevation of the tower vertical and horizontal wooden spikes are projected out with the length of 30-40 cm. Some people refer to the spikes projected out of walls as a functional element, holding the roof from both sides. They are long wooden beams placed next to each other, covering the whole span. They act as carriers for the roof, holding it from the top. Furthermore, if the householder wanted to extend the existing span of any room in the house, it can be done easily by adding new wooden beams to the existing projected ones and connecting them together. As a result, the room span will increase and the roof will carry more load. This shows the importance of these wooden beams in the past as a structural roof system.

**Windcatcher, Malqaf**

It is one direction windcatcher stand above the roof level facing the prevailing wind. It is mostly located on the outer walls where a gap in the wall creates a channel allow the air to flow from the roof down into the house. According to Attia and De Herde (2009), the idea of the malqaf has been presented by Egyptians in the houses of Tal Al-Amarna through is represented in wall paintings of the tombs of Thebes (1300 B.C.). Fig.s 7 and 8 illustrate the location of malqaf and the airflow. The malqaf dispenses with the need for ordinary windows to ensure ventilation and air-movement in addition to enhancing indoor environmental quality. The malqaf is also useful when filters are integrated within the shaft; in reducing the sand and dust, which is so prevalent in the winds of hot arid regions (Fathy 1986).

**Geo-Cooling Channels, wind-assisted temperature gradient system.**

It is a qanat in the ground, which works as an earth-to-air heat exchanger. (Fig. 9 and 10) A wind-tower is also used along with the ground sub-surface channel used to provide the inner space with cool air from the earth as the airflow move upward due to temperature gradient. Cold water body may be used in the ground to magnify the geo-cooling effect by the water vapor. The level of the ground channel is between 1.5 to 3 meters. The ambient earth temperature is typically 10 to 23 °C (50-73 °F ) [5]

![Fig. 7: A typical windcatcher or malqaf used in traditional Persian/Arabic architecture. (Al-Wakil, and Siraj 1989)](image1)

![Fig. 8: Advanced wind-catcher system or malqaf. [3]](image2)
II. Aerodynamic

Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a solid object. [6] The following is a literature review that introduces three concepts that will help illustrate the airflow through natural cooling system in traditional Arab region.

1. Venturi Effect

Venturi Effect that is defined as the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe (Fig. 11). It is also called a jet effect; as with a funnel the velocity of the fluid increases and when it crosses sectional area decreases, with the static pressure correspondingly decreasing. Bernoulli's equation (1) is used in the special case of incompressible flows, such as the flow of water or other liquid, or low speed flow of gas, the theoretical pressure drop at the constriction is given by: [7]

$$p_1 - p_2 = \frac{\rho}{2} \left( v_2^2 - v_1^2 \right)$$

where $\rho$ is the density of the fluid, $v_1$ is the (slower) fluid velocity where the pipe is wider, $v_2$ is the (faster) fluid velocity where the pipe is narrower (as seen in the Fig 11). This assumes that the flowing fluid (or other substance) is not significantly compressible - even though pressure varies, the density is assumed to remain approximately constant. [7]

Similarly to the Venturi Effect, the case shown in Fig. 12 illustrates asymmetry of a wing shape, making air travel faster over the top rather than the bottom. That explains the wind flow channel effect, where an opening in a building or street that demonstrates airflow travels faster than the original velocity. [7]
Fig. 13. A vortex is created by the passage of an aircraft wing, revealed by smoke. Vortices are one of the many phenomena associated with the study of aerodynamics. [8]

**Vortex Airflow:**
As mentioned in the introduction, the cactus plant protects itself with spines spread partially or completely around its body. Although the question ignored by studies is if these spines serve a function climatically. This research assumes that the air moves around the spine creating a local vortex. So the focus is on aerodynamics of the horizontal projected spines. The advanced study of aircrafts shows that wind behavior around an aircraft's wing creates the vortex motion by "the difference in pressure between the upper and lower surface of the wing (Fig. 13). The high pressure air below the lower surface of the wing moves around the wingtip towards the lower-pressure region on the upper surface, creating the vortex" [8]. Presumably the case is similar to a spike projected out of a solid wall and windcatcher. The difference is that the craft wing is moving while for a spike, the wind is facing a fixed object. Velocity is another parameter to consider here, requiring a lab experiment to determine the speed and angle where the vortex will take place.

3. **Airflow in Traditional Arab Gulf Architecture:**
The study concern has three directionality: wind face a solid wall or standing object, wall with windows, and wind face walls with projected pole (spick).

- **Solid object:** Before hitting the wall surface, the air moves with a certain constant *acceleration*, as shown in the following equations. The speed of the air will hit the wall...
Fig. 14: Dimensional flow of wind and solid object (Taranath 1998).

Fig. 15: Wooden spicks create vortex flow of wind that gives possibility air to flow inside the open surface (barrier) and will start creating airflow either side of the object (equations 2 and 3, and Fig. 14). The maximum lateral wind loading and deflection are usually observed along wind direction, the maximum acceleration of a building loading to possible human perception of motion or even discomfort may occur in across wind direction (Taranath, 1998).

Equations for constant acceleration: [9]

\[
\begin{align*}
  v &= v_0 + at \\
  x &= x_0 + v_0 t + \frac{1}{2}a t^2
\end{align*}
\]

Where,
- \( v \): Final velocity
- \( v_0 \): initial velocity
- \( a \): acceleration
- \( x_0 \): initial distance
- \( x \): traveled distance
- \( t \): time taken

Wall with windows: In respect to Venturi Effect, there are two different approaches where the air changes its velocity and move faster. First, There is a window inside the wall itself, so the air will start moving faster while entering the building in a higher velocity. For example, if the air was moving with a velocity 1-2 m/s, when it will enter in this window three to four times faster than the original velocity. It can reach 3-6 m/s. Second, if there are two rows of buildings standing opposite to each other and a narrow street in between, the air will move inside this narrow path with increased velocity. The air speed will be much less than of the airflow penetrate an opening in a building. If the air is moving with a velocity of 1-2 m/s, then it will enter this street with a speed of 2-4 m/s. The two sides of buildings create a barrier for the air. (Brown 2012)

b. Walls with projected pole (spick): In case there is a spike around an opening, the air involves in vortex motion around it. The cyclized air will increase the airflow around the opening. It is assumed that the nearby opening will suck the vortex air if it faces an air current; otherwise the spike will change the direction of the air current through the vortex motion and consequently will increase the possibility to have airflow entering the nearby opening. (Fig. 15)

Inside the building, the cold fresh air will replace the hot stale air, which has lighter weight causing it to move upward. In the case windcatcher, one or two openings facing the will let the air inward while the rest will let the air outwards. The performance of the windcatcher depends greatly on the position, orientation and size of the inlet and outlet opening in relation to the wall ratio. (Fathy 1986). In the case of Malqaf, another opening the roof is usually located parallel to the first opening (Bordo 1987). In the case of Arab traditional houses, the hot air will also find its out through windows or doors that are directly into the inner courtyard. The malqaf and windtower are most efficient and useful when filters are

Fig. 16. The projected columns and beams create self-shading wall.
integrated within the shaft; thus reducing the sand and dust so prevalent winds of hot arid regions (Fathy 1986).

III. Self-shedding walls
Self-shading walls are found in three different wall systems: First, walls with recessed openings, exemplified by the work of Le Corbusier in his project le Habitat, as screens of self-shading cells that provide a considerable amount of opening and at the same time, proposed a control of sunlight penetration. Second, a solid wall with a veneer: a solid wall where the veneer is a screen wall with a thickness of about 10 cm and the size varies as the designer wishes. In some cases a veneer screen wall provides shade up to 60% of the elevation. (Fig. 16) Third, a screen wall shadowing the elevation: The gap between the elevation and screen wall is varied depending on the screen wall design and the designer concept, with an average of 10 to 30 cm. This gap allows the air to circulate and screen to protect the elevation from direct sunlight exposure. The material can be metallic or masonry.

IV. Jara and Water Cooling
This section presents the main concept of the study. Jaras are terracotta containers used for water storage. When filled, it sucks up water that will evaporate once exposed to airflow. The temperature of the water will drop to cool 5 to 10 degree less than the surrounding temperature. The faster the wind speed, the colder the water will be. This is evident when truck drivers, for example, hang out their jara, or even metal container draped with a wet cloth. The speed of the vehicle will cause the water to cool despite the summer heat in the Middle East. Both Mey Kahn and Boaz Kahn take the jara concept further to application inside the house. The screen is a pipe formed in a decorative way; filled with water. The airflow will go through the screen cooling the water that, in return, will work as cooling device. They called it ECOoler (Fig. 17). As stated on his Internet site: “It's a very smart concept of combining to old traditional design. Just thinking about it is making me feel a lot cooler. I do believe that this is a very workable design concept and if further developed would really help promote natural and passive cooling methods in a structure.” [10]

V. New proposed system for self-cooling wall in hot-arid climate Regions.
In this final section, the concluding question is that how can all of these previous studies help develop a new self-cooling wall system? Here we have two scenarios to merge the previous studies in one coherent self-cooling wall: First, a windcatcher can be built out of terracotta with inner channels filled with water that are connected to a pipe net inherited inside an inner wall. The original function of the windcatcher is still applied with an additional advantage: the fresh air moving downwards will pass the wet terracotta and consequently will cool down. As a result, the reduction of the inner space temperature will be higher than the original method. Is it possible to apply geo-cooling channels to the advantage of the proposed self-shading wall? In reference to this method used in the mouth airbrush tool, my application is that if the exit side of the geo-cooling channels is placed at the base of the wind-catcher, its flowing air entering the inner space will suck
the outer air from the wind-catcher downwards, resulting in doubling up the current circulation inside the building.

Second, the screen wall is made of terracotta and has a depth of at least 5 to 10 cm (2-4 in) with inner channels filled with water. This channel is connected with an inner wall (metallic being a good option for fast temperature exchange). The screen wall works as a self-shading wall. It is better to have at least a 10 cm (4 in) gap between the outer wall and the screen wall, this will help to increase the air circulation as well as the evaporation of the water of the screen wall surface (Fig. 18). So Figure 18 does not show spicks in the structure, it is possible to add them to the nodes of the screen walls to capture the tilt and side wind.

In both cases a natural cooling of the inner space is the result of self-cooling walls. Just like a radiator in a car, where a fan cools down the water to return back to the hot engine to keep it at an acceptable temperature. If the water movement between the outer channel and the inner channel was slow, a small pump may be applied between both walls. The surface-water evaporation in scenario one and two will cause reduction of water in the pipe system; therefore, a supplement water tank will be connected to the pipe system to keep the water level in the pipe constant.

![Fig. 18. The three main layer wall consists of: a screen wall that allows the wind to penetrate it’s opening, resulting in the evaporation of the water of the wet surface of the terracotta screen wall. A gap followed by an outer wall with cavity and insulation board, then the inner wall with an imbedded pipe net to cool the building.](image)

**Conclusion**

This research went through various concepts to understand the architecture of hot, arid environments, resembling the cactus plant. As the cactus plant is adapted to hot-arid climates, its structure and form play a great role in its survival. Two prominent aspects are focused on in this research, the self-shading and the spines, both of which are addressed in the earth architecture of the hot-arid area of the Middle East and nearby regions. Projected column-beam structures create a self-shading like the use of lattice windows, *Mashrabiya*, helping the reduction of the exposure to sunrays. The self-shading wall resembles the folds of the cactus plant. Additionally, there are a number of cases where good airflow is demonstrated in traditional architecture through a number of elements; two of which are wind catchers and spikes. Finally, the ECOoler helped understanding the traditional Middle Eastern use of *jara* to cool down water.
The proposed self-cooling wall is meant to be sustainable, energy efficient, and a pleasant architectural element. The reduction of sun exposure is one way to reduce the heat imposed on building elevations, and the screen wall will help to transfer cool water to the inner wall surface. The study introduces an idea that has been partially tested as the discussion of different concepts, such as aerodynamics, windcatchers, screen walls, jaras, and spikes; all of which ensure the application of the proposed self-cooling wall. However, there are still short comings of the research which require further work to answer the following questions:

1- With the low speed of airflow around the spike with an air current of a different angle, what would be the appropriate vortex speed?
2- In respect to various wind speeds, what would be the degrees of the heat reduction inside the structure after the application of the self-cooling wall?
3- In the wind-tower case, what would be the exact reduction of the temperature after the application of the windpipe system in the proposed terracotta structure?

References


Internet References


DEVELOPMENT OF A VIRTUAL WATER FLOW METER USING PUMP HEAD AND MOTOR POWER

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Abstract
Water flow rates are key controlled variables of a hydronic heating, ventilation and air conditioning system and can have significant impact on overall system performance and efficiency when not optimized. However, space limitations and expensive installation costs prohibit physical flow meter installations. The objective of this paper is to develop a virtual water flow meter using the pump-motor system performance. Virtual water flow meters can be integrated into system controls as real-time correction and calibration tools for optimal operation. Generally the water flow is propelled by a pump driven by a motor, and hence the water flow rate is related to other measurable variables such as pump head and motor power. Theoretically, a virtual water flow meter can be developed to virtually obtain the water flow rate from measured pump head and motor power along with projected motor and pump efficiency models. Because variable frequency drives have been widely installed in heating, ventilation and air-conditioning systems, a comprehensive motor efficiency model is needed to project motor efficiency under variable frequency and voltage. At the same time, an in-situ pump efficiency curve needs to be projected through a calibration process corresponding to actual pump head measurement. This paper explores a theoretical model of virtual water flow meters in order to identify the relationship of pump water flow rate with measurable pump head, motor power, and power frequency and voltage; then demonstrates a procedure to implement a virtual water flow meter and validate the virtual pump water flow meter through an experiment.

Keywords:

Introduction
In current heating, ventilating and air-conditioning (HVAC) industry practice, the control and performance monitoring of equipment and systems are often limited by the number of physical sensors installed. The costs of hardware and installation are usually cited as the reason for not installing more sensors. Virtual sensors may provide a lower-cost alternative to physical sensors. Several studies of virtual sensors developed for HVAC systems were summarized by Song et al. (2012, 2013). Wang et al. (2013b) recently carried out an investigation on development of a virtual airflow meter using calibrated motor and fan efficiencies (2012), where the procedure to implement the virtual airflow meter was introduced and the accuracy of the developed virtual fan airflow meter was validated through an experiment.

Water flow measurements in hydronic systems are critical for operation, control, and fault detection of chilled water plants. Subdividing various systems into primary / secondary (P/S) loop via a hydraulically dependent interconnection has long been a standard solution for central chilled-water plants. Having real-time, accurate flow rate data from such systems is a critical parameter for establishing optimized system operation. Faulty or inefficient operations can lead to substantially higher energy consumption in properties. In addition to helping achieve optimized chiller plant operation available waterflow measurements in hydronic HVAC systems can enhance the operating efficiency of multiple other system components, including modulating water valves and air handling units by detecting faults more easily and consequently implementing self correcting strategies against such faults.
Water flow rate is often determined by use of pressure based meters such as Pitot tube, Orifice plate or Venturi meter, (ASHRAE 2009). However, valves, bends and fittings close to the waterflow measurement devices can cause errors. Long, straight pipe sections should be installed upstream and downstream of the flow measurement devices to assure fully developed flows. These conditions are hard to be satisfied in actual systems. For existing systems, high retrofit cost may prohibit installing a new water flow meter; similarly the quantity to meters necessary in order to gather enough data for various system components and stages renders such installations cost prohibitive. In addition, because flow measurement accuracy decreases as the flow rate decreases in variable volume systems, the accuracy of water flow measurements from traditional meters is not reliable at lower flow rates.

Pumps are essential components installed in hydronic HVAC systems and measurable flow rates are critical parameters used when establishing optimized control strategies for chilled water plants with primary and secondary loops. Since water flow rate, measurable pump head and motor power determines pump performance, theoretically the flow rate can be determined by either measureable pump head, measured motor power, or both. This concept parallels studies previously carried for fans and air flow studies. Liu (2002) proposed a fan airflow station that determines airflow rate using a measured fan head associated with an in-situ fan head curve.

The virtual pump/fan flow meter works under the same principle. Figure 1 shows a pump head curve (a solid line) and a pump power curve (a dashed line) under a fixed pump speed. The approach of this pump-head-curve-based water flow station is marked by (a) in Figure 1. The accuracy of pump-head-curve-based water flow stations depends on the slope of the pump head-water flow curve. In other words, the errors of the pump head measurement can cause unacceptable errors with the pump water flow measurements if the pump head curve is flat, shown as the approach marked (b) in Figure 1. Unfortunately, the pump head curve always has a flat section under a certain water flow range. Therefore, the water flow measurement may have poor accuracy within a certain water flow range.

Figure 1(a): Pump head and pump power water flow stations.
To eliminate the error caused by the flat section of a pump head curve, a pump-power-curve-based pump water flow station was developed by Wang and Liu (2007). The pump-power-curve-based pump water flow station determines the pump water flow rate using pump power calculated from measured motor power with projected motor efficiency, shown as the approach marked (c) in Figure 1(a) and Figure (b). In general, the pump power curve is steep in the water flow range where the pump head curve is flat. Similar to pump-head-curve-based water flow stations, the accuracy of pump-power-curve-based pump water flow stations also significantly depends on the slope of the pump power-water flow curve.

Since the pump power or the motor mechanical output power is not measurable by a power meter and has to be obtained from the measurable motor electrical input power, motor efficiency has to be applied in order to obtain the pump power measurement from the measurable motor input power. The U.S. Department of Energy's (DOE) Industrial Technologies Program (ITP) developed the MotorMaster+ motor system management software, which can access motor performance data such as motor efficiency and power factor at 25%, 50%, 75% and 100% rated loads under the rated frequency for nearly 30,000 industrial electric motors (DOE 2008). Due to the lack of motor efficiency data under variable frequencies other than the rated frequency, DOE (2008) suggested that motor input power can be used as the only variable to determine the efficiencies under variable frequencies, based on the published efficiency under the rated frequency for National Electrical Manufacturers Association (NEMA) Design A and B motors. This simplified motor efficiency model is followed in the exploration of both pump-power-curve-based and pump-power-head-based water flow stations in this study.

Several experiments have been conducted on the motor efficiency under variable frequencies (Domijan et al. 1997, Gao et al. 2001, Burt et al. 2008). The results show that the motor efficiency is impacted not only by motor power, but also by power frequency. According to motor theory, power frequency, voltage, and motor power impact motor efficiency. Comprehensively, motor efficiency can be accurately estimated using the motor equivalent circuit theory if the parameters of the circuit are given. Wang et al. (2013a) successfully developed a method to determine the equivalent circuit parameters based on the published motor efficiency and power factor at four power levels under the
rated power frequency and voltage. The completion of the comprehensive motor efficiency model provides an opportunity to develop a more accurate virtual water flow meter based on the pump-power-head-based water flow station; the same model was previously explored for the development of a virtual air flow meter by Wang & Liu (2012).

In this paper, a virtual water flow meter is developed based on measured motor power and pump head with projected motor and pump efficiency models. The pump head is measured using a pressure differential transducer. The motor power is directly obtained through a VFD analog output or calculated from a direct power measurement. The comprehensive motor efficiency model is applied to project the motor efficiency from measured motor power, voltage and frequency using the motor equivalent circuit theory. Then the pump efficiency model is projected through a calibration process. The detailed theory and implementation regarding the virtual water flow meter is introduced in the paper along with an experiment on the development and validation of the virtual water flow meter.

THEORY

VFDs are widely used in primary and secondary loops of Hydronic HVAC system plants to adjust motor and pump speed to match the variations of water flow demand. Figure 2 shows an electrical configuration of a pump-motor-VFD system.

![Figure 2: Electric configuration of a pump-motor-VFD system](image)

The motor and pump sustain mechanical energy losses. The useful work (HQ) imparted into water can be determined by the motor input power (Wmotor) along with both motor and pump efficiencies since the motor input power (Wmotor), input frequency and voltage are normally is available in the VFD panel, which is an important by-product of VFDs. With reliable motor input power, the useful work can be expressed as:

$$H \cdot Q = W_{motor} \cdot \eta_{motor} \cdot \eta_{pump}$$

(1)

Since the pump head is easily measured using a differential pressure sensor, the pump water flow rate can be obtained using Equation (2) if the motor and pump efficiencies are known.

$$\frac{Q}{W_{motor}} = \frac{\eta_{motor} \cdot \eta_{pump}}{H}$$

(2)

For a pump without a VFD installed on its motor, a power meter has to be installed. According to Equation (2), motor and pump efficiencies will be applied in the development of virtual water flow meters.

Motor efficiency is related to motor power loss. For three-phase induction motors, motor losses include the resistance loss in copper rotor windings (or rotor loss) and copper stator windings (or stator loss), the magnetic energy dissipated in the motor's iron components (or core loss), the mechanical loss of moving parts (or friction loss) and the stray loss (IEEE 2004, Wang et al. 2013a).

Motor equivalent circuit theory can be applied to determine the motor losses and motor efficiency under different frequencies and voltage. A motor equivalent circuit is defined by six circuit parameters: stator winding resistance, rotor winding resistance, stator leakage reactance, rotor leakage reactance, magnetizing reactance and core loss resistance. The loss of stator and rotor winding resistance corresponds to the copper losses and the loss of core loss resistance corresponds to the core or iron loss, while friction and windage losses are excluded from the rotor mechanical output.
power. The stray load loss is complicated and can be excluded from the rotor mechanical output power (IEEE4) or represented by a resistance (Kueck et al. 1996, Wang et al. 2013a). Wang et al. (2013a) successfully developed a method to estimate these six parameters based on the published motor efficiency and power factor for four load levels under rated frequency. Motor efficiency can be expressed as a function of power voltage (V) and frequency (f) as well as motor input power (Wmotor) for a given motor if these six circuit parameters are known.

\[ \eta_{motor} = \eta_{motor}(f, V W_{motor}) \]  \hspace{1cm} (3)

**Pump efficiency**

Conventionally a pump efficiency-water flow curve is given under full or design speed by manufacturers. Since the pump speed always varies in a variable flow system with a VFD, the affinity laws for pump are applied to eliminate motor speed impact. Based on the affinity laws, a pump working at points with the same ratio of the head to the flow square (H/Q^2) has constant efficiency no matter what the speed is, i.e., pump efficiency is a unique function of the ratio of the head to the flow square (H/Q^2).

In fact, the measured pump head is different from the pump head defined in the manufacturer's pump curve. Therefore, an in-situ pump efficiency curve needs to be obtained through calibrations with measured pump water flow rate (Q) and head (H) as well as pump power or motor output power (Wpump), which is calculated by measured motor input power (Wmotor) and projected motor efficiency.

\[ \eta_{pump}(Q+H) \]  \hspace{1cm} (4)

Then the pump efficiency can be regressed as a polynomial function of the ratio of the head to the flow square (H/Q^2) through the calibration.

\[ \eta_{pump} = \eta_{pump}(H/Q^2) \]  \hspace{1cm} (5)

With projected motor and pump efficiency models, defined by Equations (3) and (5), the pump water flow rate (Q) is related to the measured motor input (Wmotor) and the measured pump head (H), as well as the measured power frequency (f) and voltage (V). The basic equation of the virtual water flow meter can be expressed as:
Virtual water flow Meter Implementation

According to Equation (6), motor input power, pump head, and motor and pump frequencies are needed for the virtual water flow meter. Motor input power and pump head are directly measureable inputs, but motor efficiency and pump efficiency are indirectly calculated. Motor efficiency can be calculated in real time based on measured motor input power, power frequency and voltage once the six circuit parameters are determined by the given motor manufacturer’s information. The preferred pump efficiency applied in Equation (6) is in-situ pump efficiency, which corresponds to actual head measurements and needs to be obtained through a calibration process, rather than pump efficiency obtained from manufacturer’s pump curves. Therefore, the pump efficiency calibration requires a temporary water flow measurement device such as an ultrasonic water flow meter.

The entire implementation process is illustrated in the flow chart in Figure 4. Overall, four permanent measured inputs, including pump head, motor input power from the VFD, motor frequency and motor voltage, and one temporary input, i.e., water flow measurements, are needed. Since the power frequency is always an input signal to the VFD, and most VFDs have a capacity to provide the motor input power and voltage signals through analog output channels, ideally only one permanent physical sensor for pump head measurement is needed for the virtual water flow meter implementation.

EXPERIMENTS

The experiments were conducted on a pump-motor-VFD system in a chilled water booster plant located at the Richter Library Building at University of Miami Coral Gables Campus. The chilled water booster loop utilized is an 8” main pipe fed by two pumps with alternating duty cycles. During the experiment system was set to operate continuously using one pump only without duty cycling. The pump in use is rated with a flow rate of 600 US gpm at 80 ft. of head. The motor in use is rated at 20 hp (24.3 kW). The motor information is introduced in Table 1 in a later section. Data was
collected from the VFD installed on the 20 hp motor of the chilled water pump as the VFD frequency was modulated by the plant controls parameters.

Real-time monitoring and data collection was established at the experiment site as follows. The intended design was to obtain the motor input power and frequency from two analog output channels by two data loggers and obtain the motor input frequency from one analog input channel, at the VFD. In addition, a conventional externally installed ultrasonic waterflow station was installed on the chilled water pipe for the pump efficiency curve calibration and virtual flow measurement validation. Data gathered from the water flow meter were stored and downloaded. In addition to the noted variables and external data loggers, a differential pressure transducer was installed at pump discharge for pump head measurements.

**Pump efficiency calibration**

Two separate experiments were conducted from April 24th to May 2nd and May 3rd to May 17th 2013. The first experiment is used to calibrate the pump efficiency model or Equation (5), and the second experiment is used to validate the virtual water flow meter. The calibration on the pump efficiency model needed a wide range of the ratio of the head to the flow square, which should cover all possible ratios of the head to the flow square for the validation.

As shown by the dashed lines in Figure 4, the inputs needed to obtain an in-situ pump efficiency curve are motor efficiency, motor input power, pump head and water flow rate. Motor efficiency is an indirectly calculated input from motor frequency, motor voltage and motor input power.

The published motor data are listed in Table 1 and the estimated circuit parameters are listed in Table 2. Then the motor efficiency can be projected based on actual motor frequency, motor voltage and motor input power.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>AO-Smith</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>BH4J01f</td>
</tr>
<tr>
<td>Motor type</td>
<td>NEMA Design B</td>
</tr>
<tr>
<td>Size (HP)</td>
<td>20</td>
</tr>
<tr>
<td>Speed (RPM)</td>
<td>1800</td>
</tr>
<tr>
<td>Full load speed</td>
<td>1766</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>460</td>
</tr>
<tr>
<td>Load (%)</td>
<td>25% 51% 75% 88% 100% 115% 124% 148%</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>43% 56% 76% 79% 80% 81% 82% 82%</td>
</tr>
<tr>
<td>Power factor (%)</td>
<td>89% 93% 93% 93% 93% 93% 92% 91%</td>
</tr>
</tbody>
</table>

**Table 2.** Calculated equivalent circuit parameters.

<table>
<thead>
<tr>
<th>Parameter (ohm)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stator winding resistance</td>
<td>0.27623</td>
</tr>
<tr>
<td>Stator leakage reactance</td>
<td>1.56348</td>
</tr>
<tr>
<td>Magnetizing reactance</td>
<td>21.93410</td>
</tr>
<tr>
<td>Core loss resistance</td>
<td>721.59211</td>
</tr>
<tr>
<td>Rotor winding resistance</td>
<td>0.20668</td>
</tr>
</tbody>
</table>
Both pump water flow rate and pump head measurements are required to calculate the pump efficiency and the ratio of the head to the water flow square. Figure 7 shows the measured pump water flow rate and head during the calibration.
Then the pump efficiency can be derived from the measured pump head and water flow rate in Figure 7 and measured motor power and projected motor efficiency in Figure 6 by Equation (4). Figure 8 shows the pump efficiency versus the ratio of the pump head to the pump water flow square.

The pump efficiency curves in Figure 8 can be regressed as a second order polynomial expression of the ratio of the pump head (in inch of water) to the pump water flow (in 1,000 gpm) square in two different ratio ranges for accurate results.

\[
\begin{align*}
\eta_{pump} &= \eta \left( \frac{H}{Q} \right) = \\
\eta_{pump} &= \begin{cases} 
-0.000010758 \cdot (H/Q^2) + 0.0036738 \cdot (H/Q) + 0.33645, & H/Q^2 < 200 \\
-0.00000027119 \cdot (H/Q) + 0.000026428 \cdot (H/Q) + 0.65254, & H/Q^2 \geq 200
\end{cases}
\end{align*}
\] (6)
Virtual water flow meter validation

The virtual water flow meter has been developed using Equation (2) as well as the projected VFD efficiency the projected motor efficiency by Equation (3), and the projected pump efficiency by Equation (6) following the same procedure previously developed by Wang et al. (2013b). As in the case of air flow meter study, the basic equation is an implicit expression of the water flow rate due to the flow-related pump efficiency. Therefore, the trial and error method has to be applied in the flow rate calculation.

Figure 9 compares the water flow rate measured by the ultrasonic water flow meter installed at the experiment site and the developed virtual water flow meter in a two-week period. A close-up figure by reducing the time period from two week to 12 hours is also shown with Figure 10.

Figure 9: Comparison of measured water flow and calculated water flow.

Figure 10: Close-up comparison of measured water flow and calculated water flow over 12 hour period.
Figure 11: Comparison of measured water flow and calculated water flow.

Figure 11 presents the level of agreement between actual measured water flow rate versus calculated water flow using the developed virtual water flow meter. The experimental results show that the water flow rate determined by the virtual flow meter agrees well with the result from the installed ultrasonic water flow meter. The coefficient of determination or R-square for the entire validation period is 0.9681.

CONCLUSIONS

The theory of virtual water flow meters with comprehensive motor efficiency and pump efficiency models is demonstrated. As previously developed by Wang et al. (2013b) for virtual air flow meter development study, the water flow rate can be virtually determined based on measured motor power, voltage and frequency, and pump head as well as the projected motor and pump efficiency models.

In order to further validate the referenced model, a virtual water flow meter was also experimentally tested and developed on a chilled water pump. The water flow determined by the developed virtual water flow meter agrees well with the water flow meter measurement as indicated by the R-square of 0.97 for instant measurement.

NOMENCLATURE

\[ f = \text{VFD output frequency, Hz} \]
\[ V = \text{VFD output voltage, V} \]
\[ H = \text{pump head, inch of water or Pa} \]
\[ Q = \text{pump water flow, gpm or m}^3/\text{s} \]
\[ W = \text{VFD input power, kW} \]
\[ W_{\text{motor}} = \text{VFD output or motor input power, kW} \]
\[ \eta_{\text{pump}} = \text{pump efficiency} \]
\[ \eta_{\text{motor}} = \text{motor efficiency} \]
\[ \eta_{\text{VFD}} = \text{VFD efficiency} \]
ACKNOWLEDGMENTS
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REFERENCES


Chapter 8: Building and Material Technology


Saman Babaieidarabadi, Francisco De Caso, Diana Arboleda, & Antonio Nanni

Abstract
Addressing sustainability of the built stock can be achieved by extending the design life of structures by implementing rehabilitation technologies and moving away from the existing demolish-rebuild culture, which equate to high levels of carbon footprint and higher costs to the end-user. The upgrade and rehabilitation of infrastructure through strengthening using externally bonded Fiber Reinforced Polymer (FRP) systems has become an accepted practice in the construction industry. Nevertheless, FRP systems are not widely used to rehabilitate homes due to issues comprising of: economics (high cost of the polymeric resins), technology (lack of fire resistance), and the environment (recyclability and in fire events resins release toxic fumes). As sustainable construction turns its focus towards natural and compatible systems, the idea of a novel resilient strengthening system of fabric-reinforced cementitious matrix (FRCM) is a candidate fulfilling these requirements. With this overarching objective, and taking into account that the use of unreinforced masonry (URM) structures has been implemented for the past millennia and are still widely used today in many homes, this paper addresses the use of FRCM as a system for masonry wall strengthening to improve the innate deficiency in flexural capacity, failing in a brittle manner when subject to out-of-plane loads generally caused by wind or earthquakes. This paper reports the experimental results of eighteen concrete block and clay brick walls strengthened with different amounts of FRCM when subject to an out-of-plane uniformly distributed pressure. An analytical approach is proposed following the well-established procedure in ACI 549 (2013) to compute the flexural capacity of the strengthened walls analyzed as simply supported members and neglecting the arching effect. Finally, the experimental and analytical results are compared, and design limitations as per ACI 549 (2013) are discussed.

Keywords: Fabric-reinforced cementitious matrix, flexural capacity, masonry walls, out-of-plane loading, strengthening.

1.0 Introduction
Masonry is one of the oldest construction materials. For thousands of years masonry was the predominant building material until modern materials such as concrete and steel appeared in the nineteenth century. Masonry buildings comprise a large percentage of the world’s built stock; as such, it is an important target for repair and rehabilitation methods aimed at extending the design life of such structures. Masonry is a building technology that meets many of the attributes of sustainable construction. Therefore, efforts devoted to the improvement of existing masonry structures in terms of safety and performance can help users, practitioners and ultimately society in meeting the goals
of a cultural shift from demolish-rebuild, towards economical, technologically and environmentally sound acceptable building solutions.

Unreinforced masonry (URM) walls exhibit low strength and show a brittle failure mode when exposed to in plane and out-of-plane loading. Retrofitting of URM walls with common externally applied techniques such as adhering organic based composites or fiber-reinforced polymer (FRP) composite systems, and installation of FRP bars in the mortar joints, known as near surface mounted (NSM) bars, have been effective on improving the performance of the masonry structures in terms of strength, stiffness, and pseudo-ductility. Nevertheless, significant margins exist to advance externally-bonded composite rehabilitation technologies by addressing the issues posed by the use of organic polymer matrices including: high initial cost, lack of fire resistance, lack of reversibility, environmental and health related, where production relies on hazardous toxic constituents requiring high energy inputs.

More environmentally-benign solutions are desired consistent with the growing demand for sustainable construction materials and systems (McGraw 2009, Bank 2010), this is reflected in the increasing number of green building projects on existing buildings through the United States Green Building Council’s (USGBC) Leadership in Energy and Environmental Design (LEED). Water-based inorganic binders (i.e., cement-based) are of interest as potential sustainable matrices for composite systems due to compelling properties, including non-toxic, recyclable, well known and used product in the construction industry, with high thermal stability, resistance to ultraviolet (UV) radiations and aggressive environments (Foden et al. 1996, De Caso et al. 2009). Cement-based matrices embedding glass, carbon, aramid FRP bars and crack stitching are alternative techniques, have been initially used for external strengthening of the masonry structures (Morbin 2002, Secondin 2003, Nanni 2003, Tumialan et al. 2003, Li et al. 2005, Galati et al. 2005, Hrynyk et al. 2007, Myer 2011, Babaeidarabad et al. 2013). In this study, retrofitting of URM walls with a novel fabric-reinforced cementitious matrix (FRCM) composite is investigated. FRCM is a composite material consisting of one or more layers of dry fibers in the form of open mesh or fabric applied to URM walls through cement-based matrices. FRCM system should not be confused with the use of FRP reinforcing grids embedded in concrete or mortar. A fabric consists of primary direction and secondary direction strands connected perpendicularly where polymeric coatings may be applied to the fibers only to increase the long-term durability and to prevent problems attributed to handling and installation (Loreto et al. 2013). This paper presents a comprehensive experimental testing program on eighteen concrete block and clay brick URM walls strengthened with two different schemes of FRCM reinforcement fabric and subjected to out-of-plane uniform distributed pressure. Additionally, this research program implements an analytical model as per ACI 549 (2013) to calculate the flexural moment capacity of FRCM strengthened walls for design considerations and compare with experimental results.

2.0 Experimental Program

2.1 Test Specimens

Eighteen masonry wall specimens made of concrete masonry block and clay brick with dimensions of 1422x1220x92 mm (56x48x3.63 in) were constructed in a running bond pattern by a professional mason and tested under out-of-plane loading. According to the test and calculation protocols of AC434 (2013), the URM walls were externally strengthened by applying two levels of FRCM reinforcement, 1-ply and 4-ply. URM walls are strengthened only on one side to enhance the flexural strength of the sections by acting as external tension reinforcement. Specimen identification throughout this paper is shown in the “A-B-C” format; where: “A” denotes the method of loading (O for out-of-plane loading); “B” denotes the base masonry material (CMU for concrete block and CL for clay brick); and “C” denotes the number of fabric reinforcement layers (Control for 0, 1 ply for 1, or 4 plies for 4). Three repetitions were tested in each configuration. Test specimens are summarized in Table 20.
2.2 Material Characterization

The nominal dimensions of each concrete block and clay brick units used in the construction of the wall specimens were 102x203 x406 mm (4x8x16 in) and 102x68x203 mm (4x2 2/3x8 in) respectively. A type M mortar was used to fabricate all the walls, with a compressive strength of 22 MPa determined by testing 50-mm mortar cubes in accordance with ASTM C109 (2012). Masonry prisms were constructed with three standard concrete blocks/clay bricks, one on top of the other. The prisms were tested in accordance with ASTM C1314 (2012), having an average compressive strength of 19 MPa and 24 MPa for CMU and clay brick prisms, respectively (Babaeidarabad et al. 2013). FRCM strengthening material was composed of a sequence of one or four layers of cement-based matrix reinforced with dry-fiber fabrics. The fabric consisted of a balanced network with carbon fiber toes disposed along two orthogonal directions at a nominal spacing of 10 mm. The equivalent nominal fiber thickness was 0.048 mm in both primary and secondary directions. Arboleda et al. (2012) performed tensile coupon testing in order to characterize the FRCM mechanical properties with results reported in Table 21. Specimens were tested in accordance with AC434 (2013) using clevis-type grips to allow the fiber slippage control failure. The mechanical properties of the masonry prisms and the FRCM coupons were used as the basis of the analytical work.

2.3 Test Setup

The wall specimens in this program were loaded by means of an air bag applying horizontally distributed pressure with a maximum pressure of 0.14 MPa (20 psi) connected to an air compressor. The air bag was placed between the URM test specimens and a reaction wall providing a support to the system. URM walls were tested in one cycle due to their innate low flexural strength capacity; while strengthened walls were tested in three cycles of loading and un-loading, where the last cycle was continued towards failure. Four dywidag rods and steel channel/tube box sections on the top and bottom of the wall were used to anchor the wall specimen to the reaction wall in order to create a close-loop system. FRCM was cut just below the supports of the strengthened walls in order to prevent the continuity of FRCM at the boundary to simulate the condition of field applications where FRCM cannot continue beyond the slabs (or beams) below and above the wall. Additionally, in order to capture the full flexural capacity of the strengthened walls and avoid pre-mature shear failure at the supports, steel rods with a nominal diameter of 6.35 mm and length of 406 mm were embedded at a depth of 6.35 mm within the substrate to increase the shear capacity without affecting on the flexural capacity. Out-of-plane displacement of the wall specimens was measured using three wire displacement transducers (WDTs) located at the supports and mid-height of the wall specimens. Applied pressure was measured with a pressure transducer connected to the air bag outflow and the data acquisition system. The loads at the support were measured using two load cells on top and two load cells on the bottom. All data was gathered using a National Instruments data acquisition system operating LabVIEW™ software with a frequency of 10 Hz. Test setup configuration details including instrumentation used in this experimental program is shown in Figure 50.

3.0 Test Results and Discussions

3.1 Maximum Load Capacity

Experimental test results in terms of maximum flexural bending moment capacity and failure mode of all masonry walls are presented in Table 22. It can be clearly observed that FRCM strengthening technique increases the moment capacity of URM walls. Furthermore, with increasing number of reinforcing fabric layers, the flexural strength of the walls increased. Flexural strength enhancement is defined as the ratio between the average maximum moment capacity for each set of walls and the
control one. Strength enhancements were calculated to be 2.7 and 7.8 for concrete block walls, and 2.8 and 7.5 for clay brick masonry walls using 1-ply and 4-ply, respectively.

3.2 Crack Pattern and Failure Modes

- **Unreinforced Masonry**
  The unreinforced concrete block and clay brick masonry wall specimens failed in flexural mode as expected after developing flexural cracks formed primarily at the mortar joints at the mid-height which continued to open as the load increased, as shown in Figure 51 (a and d).

- **Masonry Wall Strengthened with 1-Ply FRCM**
  The 1-ply FRCM strengthened concrete block and clay brick masonry wall specimens showed flexural failure as expected by rupturing of the fibers at FRCM occurring at mid-height. Figure 51 (b and e) shows the typical crack patterns and failure modes of masonry with 1-ply FRCM at failure.

- **Masonry Wall Strengthened with 4-Ply FRCM**
  The URM clay brick wall specimens strengthened with 4-ply FRCM experienced shear failure due to the high level of FRCM flexural reinforcement, shifting the failure mode. Shear failure was characterized by development of fine vertical cracks in the masonry substrate near the supports that progressed at a slope of approximately 45°. Shear failure preceded flexural failure indicating that the level of strengthening was excessive, as shown in Figure 51 (f)(enhanced crack lines). CMU walls strengthened with four plies reached the maximum loading capacity of the air bag and ultimate failure of the wall was not reached.

4.0 Analytical Approach

According to MSJC (2011), the nominal flexural capacity of unreinforced masonry walls is calculated in accordance with Equation 1:

\[
\phi_m M_n = \phi_m M_{cr} = \phi_m S f_r
\]

where \(\phi_m\), \(M_{cr}\), \(S\), and \(f_r\) are the strength reduction factor, cracking moment, section modulus of uncracked wall, and modulus of rupture, respectively. Following the recommendations of MSJC (2011), the allowable modulus of rupture, \(f_r\), for clay and concrete masonry with a type M mortar is taken as 0.43 MPa. In order to calculate the nominal flexural capacity of FRCM reinforced walls, the analytical model is developed as per the procedure established in ACI 549 (2013), with the following assumptions:

a) Plane sections stay plane;

b) The bond between the FRCM and the substrate masonry in addition to the fabric within the matrix is perfect;

c) A parabolic distribution is used for compressive stresses of the masonry. The stress block parameters, \(\beta_1\) and \(\gamma\), associated with such a parabolic distribution are taken as 0.7 for simplicity (Tumialan et al. 2003, Turco et al. 2003, Galati et al. 2005);

d) Failure modes are controlled either by the slip in the FRCM or crushing of the substrate masonry (ACI 549 2013);

e) The maximum compressive strain, \(\varepsilon_m\), for concrete masonry block and clay masonry are considered to be 0.0025 and 0.0035 mm/mm, respectively (Tumialan et al. 2003, Galati et al. 2003, MSJC 2011);
f) The tensile strength of the masonry is disregarded (Tumialan et al. 2003; Galati et al. 2005; MSJC 2011; ACI 549 2013); and,
g) FRCM has a bi-linear elastic behavior up to failure controlled by slip.

Following the recommendation of ACI 549 (2013), the ultimate tensile strain for FRCM design considerations, $\varepsilon_{fu}$, is the average minus one standard deviation derived from tensile test conducted as per AC434 (2013) (see Table 21). The effective tensile strain level in FRCM at failure, $\varepsilon_{fe}$, is limited to the ultimate tensile strain at failure level, $\varepsilon_{fu}$, expressed in Equation 2:

$$\varepsilon_{fe} = \varepsilon_{fu} \leq 0.012$$

(2)

The effective tensile stress level in the FRCM attained at failure, $f_{fe}$, is calculated in accordance with Equation 3:

$$f_{fe} = E_f \varepsilon_{fe}$$

(3)

where $E_f$ is the tensile modulus of elasticity of the cracked FRCM.

The analytical flexural capacity of an FRCM strengthened masonry wall is determined in accordance with Equation 4:

$$\phi_m M_n = \phi_f M_f$$

(4)

where $M_n$ is representative of nominal flexural capacity, and $M_f$ is the contribution of FRCM reinforcement. In the analysis, the strength reduction factor, $\phi_m$, is assumed to be 1.0. $M_f$ is expressed in accordance with Equation 5, while Equation 6 shows the equilibrium in the section of the masonry wall (see Figure 52):

$$M_f = A_f f_{fe} (t_m - \frac{\beta c}{2})$$

(5)

$$A_f f_{fe} = \gamma_f f_m (\beta c) b_m$$

(6)

where $A_f$, $t_m$, $c$, and $b_m$ are the area of the fabric reinforcement by unit width, thickness of the masonry wall, distance from extreme compression fiber to neutral axis, and width of masonry wall considered in flexural capacity analysis, respectively. The effective tensile strain level in FRCM, $\varepsilon_{fe}$, and the compressive strain in the masonry, $\varepsilon_m$, are related in accordance with Equation 7:

$$\frac{\varepsilon_m}{c} = \frac{\varepsilon_{fe}}{t_m - c}$$

(7)

Analytical flexural capacity of each set of walls is presented in Table 22, where it is clear that the analytical results are significantly below the actual experimental results. This might be due to the arching mechanism effect, which is disregarded in the analytical approach, and experimentally can provide a considerable influence to the structural behavior of walls. Additionally, the analytical results might be lower due to safety factors as discussed in the next section.

5.0 Design Provisions

In accordance with ACI 549 (2013), the maximum force that can be transferred by the FRCM to the substrate masonry is limited to not exceed 87.6 kN/m (6000 lbf/ft.) in the strengthened walls when subjected to out-of-plane loading, expressed in accordance with Equation 8:

$$T = A_f E_f \varepsilon_{fe} < 87.6 k \frac{kN}{m} (6000 \frac{lbf}{ft})$$

(8)

Furthermore, the flexural strength reduction factor, $\phi_m$, as per ACI 549 (2013) is equal to 0.6 similar to the reduction factor recommended by the MSJC (2011) for URM walls subjected to flexural loads. Applying a strength reduction factor makes a section with low ductility attain a higher reserve of strength. It can be observed that applying the flexural strength reduction factor in the design provisions makes the difference between experimental and design values more noticeable as seen in Table 22, since the reduction factor for flexure is too conservative.
6.0 Conclusions

While masonry comprises a large percentage of the world’s built stock and is a building technology that meets many of the attributes of sustainable construction, few alternatives exist to the current demolish-rebuild culture in industry. This paper has presented an alternative economical and resilient design life extension solution for the masonry stock, which is to retrofit with a novel fabric-reinforced cementitious matrix strengthening system (FRCM).

From the sustainability point, FRCM technology addresses economic, technological, and environmental issues, since it is a cement-based system. From a structural point, this technology significantly improves existing masonry structures in terms of safety and performance. Specifically, in terms of ultimate out-of-plane bending moment capacity, depending to the amount of FRCM strengthening, flexural strength of retrofitted URM walls can be dramatically increased, providing added safety and life extension to URM wall structures. The flexural enhancement was calculated to be 2.7 and 7.8 for concrete block masonry and 2.8 and 7.5 for clay brick wall, using 1-ply and 4-ply carbon FRCM, respectively. Flexural failure was observed in most of the experimental tests as expected, where the failure mode shifted to shear failure when wall structures are over reinforced with FRCM. Therefore, a minimal amount of reinforcement, a designer can fully engage and utilize the FRCM system for flexural strengthening.

A sectional analysis according to the methodology proposed by ACI 549 (2013) and MSJC (2011) is used to predict flexural capacity of the masonry wells. Calculated results underestimate the experimental results, since arching mechanism is disregarded in the calculations. Similarly, by applying a strength reduction factor, $\phi_m$ as per ACI 549 (2013), design flexural capacity results are conservative which is expected to yield safe structural designs.

7.0 Acknowledgements

The authors acknowledge the National Science Foundation (NSF) for the support provided to the Industry/University Center for Integration of Composites into Infrastructure (CICI) at the University of Miami under grant IIP-0933537 and its industrial member Ruredil S.p.A., San Donato Milanese, Italy. The authors also thank Titan America Inc., Medley, FL for their support to this project. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.
8.0 Notation

- \( A_f \) = area of fabric reinforcement by unit width, mm\(^2\)/mm (in\(^2\)/in)
- \( A_n \) = net cross-sectional area of masonry wall, mm\(^2\)/mm (in\(^2\)/in)
- \( A_v \) = area of shear reinforcing, mm\(^2\) (in\(^2\))
- \( b_m \) = width of masonry wall considered in flexural analysis, mm (in)
- \( c \) = distance from extreme compression fiber to neutral axis, mm (in)
- \( C \) = compression force provided by masonry, kN (kip)
- \( E_{f}^* \) = tensile modulus of elasticity of the un-cracked FRCM specimen, MPa (ksi)
- \( E_{f} \) = tensile modulus of elasticity of the cracked FRCM specimen, MPa (ksi)
- \( E_m \) = modulus of elasticity of masonry wall, MPa (ksi)
- \( f_{m}^c \) = compressive strength of masonry, MPa (psi)
- \( f_{fe} \) = effective tensile stress level in FRCM attained at failure, MPa (ksi)
- \( f_{fu} \) = ultimate tensile strength of FRCM, MPa (ksi)
- \( f_r \) = modulus of the rupture, kPa (psi)
- \( f_y \) = yield strength of dowel bars, MPa (ksi)
- \( H \) = height of the wall, mm (in)
- \( h_{eff} \) = clear height of the wall, mm (in)
- \( I_{cr} \) = cracked moment of inertia of the strengthened wall, mm\(^4\) (in\(^4\))
- \( I_n \) = un-cracked moment of inertia of the wall, mm\(^4\) (in\(^4\))
- \( L \) = length of the wall, mm (in)
- \( M_{cr} \) = cracking flexural strength, kN-m (lb-ft)
- \( M_f \) = contribution of FRCM, kN-m (lb-ft)
- \( M_n \) = nominal flexural strength, kN-m (lb-ft)
- \( N_u \) = axial force applied to masonry, kN (kip)
- \( p_u \) = ultimate lateral uniform pressure, kPa (psf)
- \( S \) = section modulus of un-cracked wall, cm\(^3\) (in\(^3\))
- \( s \) = spacing between shear reinforcing, mm (in)
- \( T \) = tension force provided by FRCM, kN (kip)
- \( t_m \) = thickness of the wall, mm (in)
- \( T_{max} \) = maximum force in the FRCM transferred to the masonry per unit width, kN/m (lb/ft)
- \( V_n \) = nominal shear strength, kN (kip)
- \( W_u \) = ultimate lateral unit load, kN/m (lb/ft)
- \( \beta_1 \) = ratio of depth of equivalent rectangular stress block to depth to neutral axis
- \( \gamma \) = multiplier of \( f_{m}^c \) to determine intensity of the equivalent block stress for masonry
- \( \delta_u \) = mid-height deflection for un-reinforced and strengthened wall, mm (in)
- \( \varepsilon_{m}^c \) = maximum compressive strain in masonry associated to peak \( f_{m}^c \), mm/mm (in/in)
- \( \varepsilon_{fe} \) = effective tensile strain level in FRCM composite material attained at failure, mm/mm (in/in)
- \( \varepsilon_{fu} \) = ultimate tensile strain level in FRCM, mm/mm (in/in)
- \( \omega_r \) = calibrated reinforcement ratio
- \( \rho \) = the ratio between area of reinforcement and net area of URM walls

Table 20: Test matrix

<table>
<thead>
<tr>
<th>Specimen Code</th>
<th>Strengthening Material</th>
<th>Masonry Type</th>
<th>Repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-CMU-Control</td>
<td>0 ply of FRCM</td>
<td>Concrete Block</td>
<td>3</td>
</tr>
<tr>
<td>O-CMU-1</td>
<td>1 ply of FRCM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-CMU-4</td>
<td>4 ply of FRCM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-CL-Control</td>
<td>0 ply of FRCM</td>
<td>Clay Brick</td>
<td>3</td>
</tr>
<tr>
<td>O-CL-1 ply</td>
<td>1 ply of FRCM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-CL-4</td>
<td>4 ply of FRCM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 21: Mechanical properties of carbon FRCM coupons

<table>
<thead>
<tr>
<th>FRCM Property</th>
<th>Symbol</th>
<th>Units</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>COV [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of elasticity (cracked)</td>
<td>$E_f$</td>
<td>GPa</td>
<td>69</td>
<td>13</td>
<td>19</td>
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<tr>
<td>Ultimate tensile strength</td>
<td>$f_{fu}$</td>
<td>MPa</td>
<td>802</td>
<td>34</td>
<td>4</td>
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<tr>
<td>Ultimate tensile strain</td>
<td>$\varepsilon_{fu}$</td>
<td>mm/mm</td>
<td>0.0052</td>
<td>0.0011</td>
<td>21</td>
</tr>
<tr>
<td>Fiber area by unit width</td>
<td>$A_f$</td>
<td>mm$^2$/mm</td>
<td>0.05</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(Note: 1.0 GPa = 145.03 ksi; 1.0 MPa = 0.145 ksi; 1.0 mm/mm = 1.0 in/in; 1.0 mm$^2$/mm = 0.039 in$^2$/in)

Table 22: Experimental, analytical, and design results

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Experimental Results</th>
<th>Analytical Results</th>
<th>Design* Flexure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Moment $M_u$ kN.m</td>
<td>Average Moment $M_{u,ave}$ kN.m</td>
<td>Failure Mode</td>
</tr>
<tr>
<td>OP_CMU_Control-1</td>
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<td>2.37</td>
<td>F</td>
</tr>
<tr>
<td>OP_CMU_Control-2</td>
<td>2.32</td>
<td>2.37</td>
<td>F</td>
</tr>
<tr>
<td>OP_CMU_Control-3</td>
<td>2.63</td>
<td>2.37</td>
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<td>2.32</td>
<td>F</td>
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<tr>
<td>OP_CL_Control-2</td>
<td>2.57</td>
<td>2.32</td>
<td>F</td>
</tr>
<tr>
<td>OP_CL_Control-3</td>
<td>2.27</td>
<td>2.32</td>
<td>F</td>
</tr>
<tr>
<td>OP_CL_1</td>
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<td>6.39</td>
<td>F</td>
</tr>
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<td>6.20</td>
<td>6.39</td>
<td>F</td>
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<tr>
<td>OP_CL_1</td>
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<td>6.39</td>
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<td>17.46</td>
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<td>OP_CL_4</td>
<td>16.94</td>
<td>17.46</td>
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<tr>
<td>OP_CL_4</td>
<td>17.81</td>
<td>17.46</td>
<td>F</td>
</tr>
</tbody>
</table>
(Note: 1.0 kN.m = 737.56 lb.ft; 1.0 kN = 0.23 kip; Slenderness ratio (h/t) = 13.2; F = Flexural failure; S = Shear failure; *ϕ factors and other limits apply)

Figure 50: Test Setup

Figure 51: Failure mode of wall specimens: OP-CMU-Control (a); OP-CMU-1 (b); OP-CMU-4 (c); OP-CL-Control (d); OP-CL-1 (e); and OP-CL-4 (f)
Figure 52: Stress and strain distributions in the wall section

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STABILIZATION OF SANDY LOAM SOIL HOUSING BRICKS WITH BAGGASE ASH

Salim, R.W., Ndambuki, J.M. and Adedokun, D.A.

Abstract

Sugarcane Bagasse Ashes SCBA is solid waste material, which is generated as a combustion by-product from boilers of sugar and alcohol factories. The sugarcane industry produces large amounts of sugarcane bagasse, which is composed mainly of sugar, fibrous material and water. SCBA are considered a non-biodegradable waste hence poses a detrimental effect on the environment. Previous researches carried out indicate that, of the large volume of SCBA produced in the developing countries, only 2% is being recycled. The application of SCBA in the stabilization of soil bricks has been explored over the years and has yielded a positive result in improving its compressive strength and water resistance. However the effectiveness of SCBA as a stabilizer is dependent on the type of soil. In our research, we investigated the characteristics of sandy loam soils mixed with 3, 5, 8 and 10% by weight of SCBA. The result shows improvement in the compressive strength and water absorption of sandy loam bricks between 5-10% by weight of SCBA. The availability of SCBA as a waste material and its positive impact on the compressive strength of soil brick, if maximized would lead to cheap and affordable housing in developing countries.

Keywords: SCBA, sugarcane bagasse ash, compressive strength, stabilization, water absorption

1. INTRODUCTION

Sugar Cane Bagasse Ash (SCBA) is obtained as a combustion by-product from boilers of sugar factories and it contains mainly silica (Cordeiro et al, 2008). The total SCBA generation in Kenya is estimated to be about 1.6 million tons per year with a potential of about 2.6 million tones out of which the factories recycle only 25% as a renewable energy (Onchieku et al, 2012). Many developing countries produce large amount of SCBA with limited recycling for soil amendment. Larger percentage of it is disposed to open landfills (Tantawy et al, 2012). The high production and low utilization rates leads to the challenge of its disposal as SCBA is non biogradable (Faria et al, 2012)

SCBA is however known to have a pozzolanic property, which poses economic advantages and environmental enhancing potentials (Keogh, 1978). Previous researches carried out on partial replacement of cement with SCBA showed that SCBA had positive effect on the strength and durability of concrete (Srinivasan and Sathiy, 2010; Ganesan et al, 2007). With success recorded in the use of SCBA in concrete, researchers have been investigating the suitability of SCBA in the stabilization of soil. Onyelowe (2012) observed an increase in the bearing properties of lateritic soil
with an increase in SCBA. This was also supported by Alavez- Ramirez et al (2012) who concluded that an addition of 10 % lime and 10 % SCBA significantly improves the durability and mechanical properties of compacted soil blocks.

In this present study, SCBA was used in the stabilization of compacted sandy loam soil bricks and the samples were tested for compressive strength and water absorption.

2. Materials and Methods

The Sandy loam soil used in this research was obtained at the Eldoret area of western Kenya after which the determination of its particle size distribution was performed using the wet sieve method recommended by BS 1377 part 2 (1990). The Maximum dry density was obtained by the proctor compaction test according to BS 1377 Part 4 Section 3. The liquid and plastic limits of the soil were obtained using the method prescribed in BS 1377 part 2(1990). Sieve analysis was performed on the soil according to BS 13377 part 2 (1990).

The SCBA used was obtained based on previous study (Keogh, 1978). Sample was obtained from the Lubao Jagerry sugar factory in Kakamega county of Kenya, East Africa.

2.1 Mixture Proportion and Sample preparation

The soil preparation for the brick making process involved sieving the soil through the 2.0 mm sieve. 6 Kg weight of soil and bagasse ash percentages by weight as shown in Table 1 were measured and homogeneously mixed by hand. The mixing process lasted for 10 minutes to ensure an even distribution of SCBA in the mixture. Water content up to the optimum moisture content was gradually added to the mix of soil and bagasse ash. Additional 1% water beyond the optimum moisture content was added afterwards to allow for the hydration of bagasse ash according to ACI (1992). Experimental mixture proportions are summarized in Table 2. After the mixing process, the soil/bagasse mixes were poured into a steel mold with dimension 285 X 145X 95 mm, after which they were pressed to form the brick. Curing was done under mulching using bagasse fibers for one week and was air-dried until the test dates. This is shown in Figure 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Percentage of stabilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEBA-0</td>
<td>0</td>
</tr>
<tr>
<td>CEBA-3</td>
<td>3</td>
</tr>
<tr>
<td>CEBA-5</td>
<td>5</td>
</tr>
<tr>
<td>CEBA-8</td>
<td>8</td>
</tr>
<tr>
<td>CEBA-10</td>
<td>10</td>
</tr>
</tbody>
</table>
Table 2 Mixes of Brick (kg)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Soil</th>
<th>SCBA</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEBA-0</td>
<td>6.0</td>
<td>-</td>
<td>2.04</td>
</tr>
<tr>
<td>CEBA-3</td>
<td>5.82</td>
<td>0.18</td>
<td>2.04</td>
</tr>
<tr>
<td>CEBA-5</td>
<td>5.70</td>
<td>0.3</td>
<td>2.04</td>
</tr>
<tr>
<td>CEBA-8</td>
<td>5.52</td>
<td>0.48</td>
<td>2.04</td>
</tr>
<tr>
<td>CEBA-10</td>
<td>5.4</td>
<td>0.6</td>
<td>2.04</td>
</tr>
</tbody>
</table>

Figure 1 Curing setup in the laboratory

Mechanical properties

Mechanical testing was carried out to determine the compressive strength of the brick in accordance with the Kenyan Bureau of Standards (KS02-1070, 1993). The tests were carried out after 14, 21 and 28 days of molding the bricks.

Rate of Water Absorption

Water absorption is a measure of water absorbed in a masonry unit for a particular laboratory test. It is not a measure or description of porosity or permeability of a masonry unit. It is an indicator of rain penetration.

The water absorption test set up was an improvised method where a hole was bored on the block equal in diameter to a measuring cylinder of diameter 2.2 cm. The cylinder was filled with water and inverted in the hole as shown in Figure 2. The rate of water absorption was measured at a regular interval as function of the height drop in the cylinder. The water absorption experiment was performed for the blocks stabilized with 8 and 10% SCBA after 28 days of curing.
3. Results

The characteristics of the soil used are presented in table 3 and figure 3. It could be seen that the soil is a fine grained soil with its optimum moisture content suggesting that it contains organic silt (Food and Agricultural Organization of the United Nation, 2006)

<table>
<thead>
<tr>
<th>Property</th>
<th>Liquid Limit ($w_L$)</th>
<th>Plastic Limit ($l_P$)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Atterberg limits</td>
<td></td>
<td></td>
<td>50.7</td>
</tr>
<tr>
<td>Grain size distribution (%)</td>
<td>Gravel (&gt; 2000 µm)</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sand (63-2000 µm)</td>
<td></td>
<td>99.5</td>
</tr>
<tr>
<td></td>
<td>Silt and clay (&lt;63 µm)</td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Surface area normalized</td>
<td>Optimum water Content (%)</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>proctor test</td>
<td>Maximum Dry Density (Kg/m$^3$)</td>
<td></td>
<td>1221</td>
</tr>
</tbody>
</table>
The results of the compressive strength carried out on the brick at different percentage bagasse ash stabilization are presented in Table 4 and Figure 3.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 days</td>
</tr>
<tr>
<td>CEBA-0</td>
<td>2.05</td>
</tr>
<tr>
<td>CEBA-3</td>
<td>2.162</td>
</tr>
<tr>
<td>CEBA-5</td>
<td>2.16</td>
</tr>
<tr>
<td>CEBA-8</td>
<td>2.35</td>
</tr>
<tr>
<td>CEBA-10</td>
<td>2.73</td>
</tr>
</tbody>
</table>

From Figure 4, it is apparent that the compressive strength of concrete increased with an increase in the Bagasse ash content in the brick. When compared to the control at 14 days after molding, the bricks which were stabilized with 3% and 5% SCBA indicated a 5% increase in compressive strength, while the 8% SCBA stabilized brick increased in compressive strength by approximately 15% while the 10% SCBA stabilized brick showed the highest increase in strength by 33%. Figure 4 also shows that the compressive strength of all bricks tested including the control, increased with an increase in the days of curing as well, as with an increase in the SCBAs content. After 28 days of curing, the brick with the highest Bagasse ash content (10%) showed the highest increase of 65%.
when compared to the control. This is largely due to the progressive densification of the soil / SCBA matrix as a result of hydration and pozzolanic reactions (Alavez-Ramirez et al, 2012).

Figure 4 Plot of compressive strength of bricks at different % bagasse stabilization

The results for the water absorption test are presented in Table 5. It shows the change in volume of water in the measuring cylinder with respect to the duration of the soil's exposure to water.

Table 5 Rate of water absorption

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>Volume (ml) 8%</th>
<th>Volume (ml) 10%</th>
<th>Water absorption rate (ml/min) 8%</th>
<th>Water absorption rate (ml/min) 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>31</td>
<td>21</td>
<td>2.07</td>
<td>1.40</td>
</tr>
<tr>
<td>30</td>
<td>33</td>
<td>23</td>
<td>1.10</td>
<td>0.77</td>
</tr>
<tr>
<td>45</td>
<td>35</td>
<td>24</td>
<td>0.78</td>
<td>0.53</td>
</tr>
<tr>
<td>60</td>
<td>36</td>
<td>26</td>
<td>0.60</td>
<td>0.43</td>
</tr>
<tr>
<td>75</td>
<td>38</td>
<td>27</td>
<td>0.51</td>
<td>0.36</td>
</tr>
<tr>
<td>90</td>
<td>39</td>
<td>29</td>
<td>0.43</td>
<td>0.32</td>
</tr>
<tr>
<td>105</td>
<td>40</td>
<td>31</td>
<td>0.38</td>
<td>0.30</td>
</tr>
<tr>
<td>120</td>
<td>42</td>
<td>32</td>
<td>0.35</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Figure 5 Average water absorption rate per time

Figure 5 shows that the average water absorption rate of the bricks is inversely related to the time of exposure and bagasse ash content. With an increase in curing time, the rate of water absorption reduces and with an increase in bagasse ash, the rate of water absorption reduces. Since the lower the water absorption capacity of a brick the higher its durability (Kerali, 2001), the brick which was stabilised with 10% bagasse ash is seen to be more durable than that stabilized with 8% bagasse ash.

4. Conclusion

Based on the results obtained, the following conclusions can be drawn

(i) All the bricks had a compressive strength higher than 2 N/mm² at 14 days curing, which is indicative that Sandy loam soil is suitable for the production of bricks

(ii) The un-stabilized bricks exhibited the lowest marginal increase in compressive strength of 0.25 N/mm² between 14 and 28 days of curing, while the bricks stabilized with 10% SCBA had the highest marginal increase in compressive strength of 1.07 N/mm² between 14 and 28 days of curing.

(iii) 10 % SCBA had lower water absorption than the 8% SCBA; hence it is more suitable for stabilization of sandy loam soil as it will yield a higher compressive strength and lower water absorption.

5. References


