Towards A Unified Cost Optimal Methodology for Designing Low Energy Buildings in the Mediterranean Sea Region

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Abstract: - The increasing sustainability problems our world faces because of the thoughtless energy consumption and emissions production puts an increasing pressure for immediate and drastic energy saving measures. Although the consumption of energy – through appropriate legislation - is constantly decreasing in the industrial and transportation sector the building’s sector doesn’t seem to follow this trend. This fact is indeed worrying and has its roots mainly in the land development model followed the last 50 years and the way people manage their private fortune. In this context, the development of methodologies for designing cost optimal Low Energy Buildings is very important. If countries located in the same region and facing common problems and challenges coordinate their actions and develop unified methodologies this will help achieve the targets faster. This paper presents part of the common research work performed in this direction by two research teams in Cyprus and Egypt. The authors have investigated systematically a representative two storey building with respect to its energy and financial performance and have concluded to a proposal for the characteristics of the Low Energy Building. This proposal is not intended to be an exclusive design; however it will serve as a starting point for the design of Low Energy Buildings and as a reference case with respect to other designs.

Key-Words: - Cost Optimal, Design Methodology, Low Energy Building, Mediterranean

1 Introduction
In designing Low Energy Buildings, it is important to appreciate that the underlying purpose of the building is neither to save - nor use - energy [1]. Rather, the building is there to serve the occupants and their activities. An understanding of building occupancy and activities can lead to building designs that not only save energy and reduce costs, but also improve occupant comfort and workplace performance [2]. As such, Low Energy Building design is a vital component of sustainable, green design that also helps the occupants’ needs to be assessed and a project budget to be respected.

A Low Energy Building should be carefully sited and its programmed spaces carefully arranged to reduce energy use for heating, cooling, and lighting. However, this is frequently not possible due to various reasons such as building density, installation constraints, land aesthetics, etc. A study has taken place to develop methodologies and tools to improve the energy performance of buildings in use [3], including identifying the best energy saving opportunities in HVAC system retrofits and standard reporting methods for the energy performance of buildings in support of the “Unified Methodology for Designing Low Energy Buildings”. A number of stakeholders have argued that the design can be controlled by legislation [4]; in particular the tightening of the Building Regulations will ensure that energy efficiency standards for future buildings and major refurbishments are continually improved through the establishment of minimum standards. Following a first tightening of the building code around 2013 and a second tightening in 2020, new
buildings will have higher energy efficiency. Ahead of regulation, some form of incentives will be needed to stimulate front running Nearly Zero Energy Buildings. This could be achieved by offering benefits on building rights and tax relief for energy efficiency measures and for including on-site renewable energy generation [5].

In the present paper an investigation regarding a typical two storey house located in Egypt and Cyprus will be presented. The investigation includes a detailed study of various energy saving measures with respect to the thermal and economic performance achieved. A sensitivity analysis regarding the influence of various passive building measures with respect to their stochastic nature has been performed and evaluated. The result of this study is a proposal for the cost effective Low Energy House Design that can serve as a reference case for the Mediterranean region.

2 Problem Formulation

The specification of the Low Energy Building design problem presented in the current paper is based on the results of a field study regarding the most influential factors for acquiring a Low Energy Building, performed during the BECET project [6]. The field study has been realized with the method of written questionnaires. More than 100 people with different characteristics have participated in the study. The most important findings of the study are the influence a) of the aesthetic part, b) the initial investment cost for acquiring the building and c) the reliability of the proposed solutions. Neither, of the three aforementioned factors are usually taken into consideration and only the thermal performance of the building is assessed.

Aim of this study is to present a proposal for a cost effective Low Energy House Design that may serve as a reference case for energy labeling schemes or for funding purposes. In this context, a “typical” two storey house has been investigated. “Typical” means that it is a house that is not optimally sited due to various constraints and has a plan typically found in praxis. Low Energy means that it has to be a house that consumes 75% less energy compared to the uninsulated and unprotected case.

2.1 Consideration of climatic conditions

The study has compared the climatic conditions of different zones in Cyprus and Egypt. Cyprus has 4 climatic regions: Z1 the coastal region, Z2 first inland region, Z3 the second inland region and Z4 the mountain region. For Egypt, only a part of the climatic zones have been selected: Z1 (Alex, El- Arish), Z2 (Cairo), Z5( Ghardagha), Z6( Heights, Santa Catrene).

Tables 1 & 2 present the heating and cooling degree days for each zone. It is shown that the average temperature almost coincides for the Cypriot and the chosen Egyptian zones especially in summer (cooling season), while it is slightly less in Cyprus than Egypt in winter time (heating season). The number of heating and cooling months is the same in zone 1 for both of the countries. For the other zones there is an increase by one month for cooling and decrease by one month for heating compared to Cyprus. The total Heating Degree Days (HDD) in Egypt is less than Cyprus because Egypt is slightly hotter than Cyprus.

2.2 Design variables – Scenarios

The study considered wall, roof and floor constructions with different insulation levels: U- values ranged from 2.3 W/m²·K for the un-insulated buildings, U- values for regulation is 0.85 W/m²·K for based insulated buildings, 0.55 W/m²·K for well insulated buildings and 0.35 W/m²·K for very well insulated buildings. Different window types have been evaluated: single glazed, double glazed with metal and plastic frame, as well as triple glazed windows. The study included the comparison of shading devices and low e-glazing for solar protection. The considered air condition types were terminal units, split units and package units for both peak and normal operations. Natural ventilation has been evaluated for 0.5 and for 1.5 air changes per hour due to its stochastic behavior. The study regarded typical lighting and internal loads with respect to values found in the energy code for every space type.

More information for the regulation based insulated buildings are found in Table 3, which summarizes the U- value and OTTV (overall thermal transmission value) given by Egyptian and Cypriot energy code for residential buildings (7) for the selected climatic Zones.

3 Results & Discussion

3.1 Thermal load comparison

The study evaluated the thermal performance of the reference case for various scenarios by using ASHRAE CLTD method, as described in the previous paragraph. Fig.1 & Fig.2 illustrate the results for the insulated building case for the cooling season (July) and for the heating season (January) for Lefkosia and Larnaca (Cyprus) and for Cairo and Alexandria (Egypt).

The results show that for the same building when located in the Egyptian cities the cooling loads are slightly higher than when located in Cypriot cities. The differences in cooling loads between all cities are decreased for the insulated scenario. Furthermore, the
results are the closest to each other for Cairo & Alexandria for the un-insulated case and Alexandria & Nicosia for the insulated case. The comparison of the heating loads shows that Larnaca needs more heating than other cities, while this need becomes very small when thermal insulation is applied. The least difference is between Alexandria and Nicosia; even without using thermal insulation (they almost coincide), while the other differences are also small especially when thermal insulation is applied.

An evaluation of the envelope loads and internal loads for the three building envelope types at both normal and peak operation given by Egyptian Team using HAP software program has been performed and some of the results are illustrated in Fig. 3. It can be observed that the envelope load is decreasing with thermal insulation, while the internal load is increasing. This is because thermal insulation doesn’t allow the internal heat to be transferred through the envelope. In this case the internal load is large and may reach values up to 73 W/m². The analysis shows that there is definitely a contra dictionary behavior between the envelope and internal loads, with respect to the insulation level. A possible and realistic solution is to improve the efficiency of the sources that cause the internal loads such as lighting and the electrical equipment as well as design customized heat removal mechanisms for certain areas e.g. kitchen.

The mechanical equipment used for heating and cooling has a significant effect on the thermal load. A comparison is given also by using HAP to show this effect. The thermally insulated case has been investigated for different air conditions types at normal and peak operations. The numerical results show that the package units outperform with respect to the rest of the cases Fig.4.

3.2 Energy consumption comparison
The energy consumption of the reference building in Cyprus has been evaluated with the national accepted toll iSBEM-CY. The corresponding energy rating is given in Fig. 5 for Lefkosia (Cyprus). For the un-insulated case the consumption is about 308 KWh/m²/y with a rating level C, for the medium insulated case the consumption is about 249KWh/m²/y with a rating level B, for the insulated case the consumption is about 76KWh/m²/y with a ratio of 0.27 of the base case realized rating level A. The comparison of selected studied cases with the Egyptian energy code is given in Fig. 6, which shown that using insulation and applying efficient energy lamps confirmed with the indication given in the energy code. The end use energy has been evaluated using Visual DOE software for different energy consumption items in Alexandria. This is shown in Fig.7. The OTTV index for the considered building materials and glasses is 37.5 W/m² and is confirmed by the Egyptian Energy code (Table 3).

Additionally, a critical analysis regarding the building energy consumption under partial and continuous HVAC operation has been conducted. Two scenarios have been considered a) HVAC is operated according to a determined time schedule and b) HVAC is operated according to the adaptive thermal comfort criterion (ASHRAE 55-2004). The difference, in cooling energy consumption between the two cases is significant. A 34% reduction in the consumption of energy can be expected. The temperature profiles for the operative temperature and the building envelope temperatures for such a case are shown Fig.8. It is obvious that the energy reduction comes from the decreased time the HVAC equipment is used and the reduced temperature set point. It is evident therefore that Low Energy Buildings should be evaluated with based on hourly analyses. However, this need is not currently reflected on the national energy performance assessment methodology.

3.3 Techno-economical evaluation
A cost-benefit analysis has been performed for the most promising cases. The analysis included not only the energy consumption and the investment cost for the energy saving measures but also the cost of the HVAC equipment. A series of base cases has been determined and qualitatively distinguished as low, medium and high insulated. For each one a motive of three cases has been developed alternating each time the glazing and shading characteristics. Some of the results are shown in Fig.9. (peak thermal evaluation) & Fig. 10 (financial evaluation)

The House of Quality methodology [6] has been used for the evaluation of the different design alternatives and the selection of the best case has been done with respect to the weighted average method. The financial criteria considered in this study are shown in Fig.11 & Fig. 12.

3.4 The proposed Low Energy Building Design
The proposed Low Energy Building Design has the following characteristics:
- U-Value:
  - External Wall:  0.55 W/m²K
  - Roofs: 0.46 W/m²K
  - Partitions: 2.3 W/m²K
  - Floor to ground: 1.4 W/m²K
  - Floor: 0.55 W/m²K
- Openings
  - Double glazed glass with thermal insulating frame, U=2.7 W/m²K
  - Low e-glass or automatic shutters. SHGF < 0.65
• Openings area < 25% of floor area
• Lighting
  - Usage of energy efficient lamps
• Ventilation:
  - 3 L/s For Bed and Living Room
  - 14 L/s for kitchen and bathrooms.
• Air conditioning system
  Packaged system with high COP (40% better than A class threshold) and with intelligence characteristics (occupancy sensor)

4 Conclusion
An introducing a concept for facing the energy crisis by integrating and collaborating efforts of neighbor countries with similarities in climatic condition is an important action that could accelerate the introduction and effectiveness of energy saving measures in the building sector. An example is given by Cyprus and Egypt which joined their efforts to propose a Low Energy Building Design solution for both countries.

The research teams investigated a representative for both countries case study. The investigation considered various energy saving measures and has led to the proposal of a commonly accepted solution. The influence of various uncertain variables has been assessed. The resulting concept is summarized in reducing consumption energy by 75%, imposing minimum internal loads 5 W/m$^2$ and resulting in pay back periods less than 4 years. This is realized by selecting appropriate thicknesses of thermal insulation, efficient lamps, insulating glass and ventilation strategies.

Future steps for the joint research carried out are towards achieving Zero Energy Buildings and putting a Unified Cost Optimal Methodology for Designing Low Energy Buildings in the Mediterranean Sea Region.

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References:

<table>
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<tr>
<th>Heating Degree Days &lt; 20°C</th>
<th>Cooling Period Duration in months</th>
<th>Average Temperature Heating Period</th>
<th>Average Temperature Cooling Period</th>
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<tbody>
<tr>
<td>Z1 1049</td>
<td>4</td>
<td>14.2°C</td>
<td>25.8°C</td>
</tr>
<tr>
<td>Z2 1231</td>
<td>4</td>
<td>13.2°C</td>
<td>27.3°C</td>
</tr>
<tr>
<td>Z3 1339</td>
<td>4</td>
<td>12.6°C</td>
<td>26.8°C</td>
</tr>
<tr>
<td>Z4 2033</td>
<td>2</td>
<td>11.6°C</td>
<td>25.2°C</td>
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Table 1: Heating and cooling degree days and the average seasonal temperature in Cypriot Climatic Zones

<table>
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<tr>
<th>Heating Degree Days &lt;18.3°C</th>
<th>Average Heating Period Temp</th>
<th>Cooling Period months &gt;24</th>
<th>Average Cooling Period Temp.</th>
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<tbody>
<tr>
<td>Z1 469</td>
<td>16.1°C</td>
<td>4</td>
<td>25.9°C</td>
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<tr>
<td>Z2 344</td>
<td>15.9°C</td>
<td>7</td>
<td>25.8°C</td>
</tr>
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<td>Z3 142</td>
<td>17.7°C</td>
<td>7</td>
<td>29.4°C</td>
</tr>
<tr>
<td>Z4 330</td>
<td>14.1°C</td>
<td>4</td>
<td>25.7°C</td>
</tr>
</tbody>
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Table 2: Heating and cooling degree days and the average seasonal temperature in some Egyptian Climatic Zones

<table>
<thead>
<tr>
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<tr>
<td>Egypt</td>
<td>Z1 0.46</td>
<td>2.1</td>
<td>0.87</td>
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<td>45</td>
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<td></td>
<td>Z2 0.37</td>
<td>1.5</td>
<td>0.74</td>
<td>1.12</td>
<td>22</td>
<td>40</td>
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<tr>
<td></td>
<td>Z3 0.35</td>
<td>1.2</td>
<td>0.9</td>
<td>1.40</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Z4 0.5</td>
<td>0.83</td>
<td>0.83</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cyprus</td>
<td>Z5 0.75</td>
<td>0.85</td>
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Table 3: The U-Value and OTT-Value for walls and roofs
Fig. 1: Comparison of cooling loads for different cities and insulation levels

Fig. 2: Comparison of heating loads for different cities and insulation levels

Fig. 3: Variation of cooling load and internal load for different building envelope masses

Fig. 4: Variation of thermal load for different air condition types

Fig. 5: Nominal energy consumption of the proposed building

Fig. 6: Heat loss (W) due to alternative building thermal mass with reflective glass and ventilation rate ach=1.5
Fig. 7: End Use Energy for different items for insulation case.

Fig. 8: Temperature profile for intermittent HVAC operation (inside air temperature denoted with red color)

Fig. 9: Thermal losses and Cooling Loads

Fig. 10: Approx. Total Cost with Central Heating and Non-Inverter AC units

Fig. 11: Interest in investing in energy saving measures with respect to initial cost of building (expressed as a percentage of the total cost of the building)

Fig. 12: Interest in investing in energy saving measures with respect to initial cost of building