BUILDING ENERGY PERFORMANCE SIMULATIONS OF THE RESIDENTIAL HOUSES IN MEDITERRANEAN CLIMATE: CASE STUDY FOR BODRUM, TURKEY

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ABSTRACT
This work results from the doctoral thesis, where residential houses in Bodrum have been analyzed energetically using the simulation software DesignBuilder. Bodrum is a characteristic city in the Mediterranean zone, and obtains optimum conditions for energy efficient design. It is under the influence of the Mediterranean climate, has hot and arid summers and mild and rainy winters.

The results have been evaluated in order to optimise the thermal behaviour of the houses for future settlements. Prototypes according these evaluations have been developed. Finally, significantly reduced energy demand values like 13.11 kWh/m²a for cooling, and 11.32 kWh/m²a for heating have been achieved.

Keywords: Residential house, Mediterranean climate, energy simulation, passive measures

INTRODUCTION
Energy simulation software are useful tools for designing buildings in this century. They provide significant contribution dealing with climate mitigation and adaptation in regard to energy responsible planning. Architects should use energy simulation tools for dealing with better support by decision-making and energetically optimization in building design.

There were several researches about overall energy saving methods for residential buildings in countries around the Mediterranean region like in Jordan (Tahat et al., 2002) and in Tunisia (Znouda et al., 2007). Furthermore, there are various researches about energy simulations focusing on various particular passive energy saving measures for the same climatic region: for instance, a research about reversible windows from Italy (Gugliermetti et al., 2007), thermal mass from Cyprus (Kalogirou et al., 2002), plant coverage (Kontoleon et al., 2010) and air tightness (Sfakianaki, et al., 2008) from Greece, etc. Various simulation methods and tools have been used by these researches in order to optimize building energy performance. According to the lack of researches in Turkey about these topics, the necessity to show design and energy standards in the housing sector lead to prepare this research.

The major factors, which affect energy consumption, heat gain and heat loss, are primarily at building level. They can be classified in seven main categories, which have been simulated: openings, external wall, roof, shading element for the roof, openings, and as vegetation, form-mass, orientation, and an additional basement floor. Non-typical components in the settlements of Bodrum have also been simulated to estimate their potential contribution.

The effects on energy consumption of each mentioned criteria have been analyzed in terms of their thermal behaviour. According to the simulation results of the actual condition, the heating energy demand of the typical residential houses in the city exceeds 23 MWh annually, whereas it is over 8 MWh/a for cooling.

As conclusion, the aim was to reduce energy consumption with passive measures. The cooling energy demand of the existing houses varies between 42.79-60.75 kWh/m²a, and the heating energy demand between 118.18-125.31 kWh/m²a.
About Location

Weather characteristics in Bodrum

The energy consumption of a building is strongly related to the climate surrounding it (Lemke, 2008). Turkey’s geographic location is disadvantageous, because both summer and winter conditions vary strongly, which complicates the design solutions in regard to better comfort conditions and energy efficiency.

Bodrum is a small town in the west-southern part of Aegean Region in Turkey and its geographical coordinates are 37°2'18" North, and 27°25'45" East. According to the Meteorology Department of Republic of Turkey, the Aegean coasts of Turkey display a typical Mediterranean climate of hot summers and mild winters. Characteristics of local climate in Bodrum do not show significant differences from the common characteristics of Aegean-Mediterranean climate. Some important points are:

- Hot summers and moderately cold winters,
- Intense heat in the day-time in summer,
- Often intense cold at night in winter,
- Very high summer aridity.

These climatic values lead to enhanced importance of solar shading. Besides, site planning, orientation and formation of buildings, vegetation, interior ventilation, and building material become importance in regard to these characteristics.

<table>
<thead>
<tr>
<th>TEMP. °C</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Max.</td>
<td>15</td>
<td>15.1</td>
<td>17.4</td>
<td>20.9</td>
<td>25.9</td>
<td>31.1</td>
<td>34</td>
<td>33.7</td>
<td>30.2</td>
<td>25.6</td>
<td>20.1</td>
<td>16.3</td>
</tr>
<tr>
<td>Average Min.</td>
<td>8.2</td>
<td>7.8</td>
<td>9.4</td>
<td>12.5</td>
<td>16.4</td>
<td>20.6</td>
<td>23.2</td>
<td>23.1</td>
<td>20.2</td>
<td>16.6</td>
<td>12.6</td>
<td>9.6</td>
</tr>
<tr>
<td>Max in summer</td>
<td>42.3</td>
<td>44.2</td>
<td>45.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min in winter</td>
<td>-1.6</td>
<td>-4.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
</tbody>
</table>

Architecture in Bodrum

Beside typical Aegean architecture, Bodrum has its own characteristics of local architecture, and they are as follows:

- Dwellings are arranged in compact patterns to avoid intense solar radiation in summer period.
- Older settlements have high density, unlike the ones after tourism boom. Furthermore, the construction permit in Bodrum is restricted to 10% of the total area.
- Although they have generally clear geometrical forms, there is an enhanced diversity in building form in the recent years.
- Local building directives define 6.5-7 m as the maximum height of a house in Bodrum.
- The openings of the houses with such great thermal inertia are kept relatively small. In regard to view, the WWR of the related facade might be high.
- Flat roof is an obligation. They are mainly not insulated, and not accessible. The roofs are used as the place of DHW equipment.
- The external painting is also regulated by the building directives and must be white or in light colours to reject the solar radiation.
- The use of basement floor is because of economic issues neglected.
- They generally have no or insufficient thermal insulation.
- There is no heating system in the houses. Auxiliary devices are used for heating. Cooling is obtained by rational air conditioners.
SIMULATIONS

Simulation procedure

The simulations of the selected objects have been run by “DesignBuilder V1.8”, which provides a range of environmental performance data. It is based on EnergyPlus. They have been run in three ways:

• Cooling calculations to determine the size of the mechanical cooling equipment for the hottest day.
• Heating calculations to size the heating equipment required to meet the coldest winter design weather conditions.
• Building energy performance simulations based on EnergyPlus.

Furthermore, as mentioned in the European Passive Solar Handbook, the detailed approach of simulations requires reliable hourly and monthly weather data for the whole year (Goulding et al., 1992). The weather data that is used by the simulation software is supplied by DOE from the “U.S. Department of Energy: Energy Efficiency and renewable Energy”. This data has been optimized with the information from Turkish State Meteorological Service.

Simulation criteria

The major factors, which affect energy consumption, are mentioned in the introduction. The considered values of these factors during the simulations are summarized in the following sections.

Furthermore, in regard to the afore mentioned aspects, the materials are selected according to the following principles in order to run representative simulations: The materials, which are used frequently in Bodrum, were chosen and simulations run respectively. These materials have been varied in respect of different other criteria, e.g. dimensions, combination, etc.

Openings

Simulations of energy-based parameters of windows have been run by DesignBuilder using ASHRAE calculations. Since the energy efficiency of the window depends on many criteria, parameters have been utilized as inputs in the simulations of the whole building.

Windows performance values like performance parameters (U, SHGC, Vt), glazing components (layers, infill gas, coating, etc.), various frame types, and window design values like window to wall ration and orientation have been simulated. Simulations have been run on a combination of criteria, which are available and widely used in Turkey.

Following combination of the performance value has reached the optimum efficiency for both summer and winter conditions in Bodrum: 7-chamber window PVC profile with warm edge, 6-13-6 cm layers, Argon as infill gas, LowE at position 1. This combination for the windows has an U-value of 0.78 W/m²K and g-value of 0.47. The window to wall ratio (WWR) is 30%, 10%, 5%, and 10% for the south, west, north and east facades respectively.

Thermal insulation

Thermal insulation of a building envelope offers a major contribution toward enhanced energy efficiency. Placement, type, and thickness of the insulation material are three major factors with respect to insulating the building envelope. Simulations are run with many variations of thickness, the type and placement of the insulation material.

External wall: There are thermal and practical considerations for insulation: For instance, insulation placement on the outside of the external walls (Al Homoud, 2005). Furthermore, polystyrene rigid boards have been chosen as material according their wide usage in Bodrum.

The cost-performance ratio of XPS is better than EPS (Dombayci et al., 2006). According to the simulation results, XPS rigid boards with 0.3 W/mK has also better energetic performance in the region as well. Different combinations of the placement and thickness (between 2-12 cm) have been simulated. 6-8 cm XPS rigid boards placed below the outermost layer of the external walls has achieved the most efficient performance.

Roof insulation: Roof insulation is one of the most important criteria in regard to energy consumption of a building, because this surface is exposed through greatest direct solar radiation in Bodrum.

XPS rigid board as insulating material, installed in different layers of the roof has been simulated with two to ten cm thickness. According to the simulation results, six cm XPS rigid board placed below the accessible surface of the roof has the best performance on cooling load. Thicker insulation material performs slightly better on the cooling load, whereas it may increase the heating load. The highest reduction of the cooling requirement can be achieved.

Figure 3 Thermal insulation effect to existing buildings without any other measure
in the floor directly under the roof. The effect in the ground floor is not significant.

**Shading elements**

As in the case of Bodrum, or in other regions with hot summer periods, shading strategy plays an important role by the means of energy saving and reducing cooling energy demand. Simulations have been run for three architectural elements separately: window shading, local shading, and roof shading elements.

**Figure 4 Shading effect to existing buildings without any other measure**

**Local shading components:** Opaque exterior shades, which block beam radiation from entering windows, are simulated in terms of form, position, and thickness. The width of the simulated components varies between eight and 15 cm as well as the length between 15 and 45 cm. Other dimensions are neither architectural nor in terms of energy efficiency relevant. The shading component is divided into four segments and each of these segments are simulated separately and combined. Furthermore, eaves are frequently used in regions like Bodrum. Deep eaves for the south façade let the winter sun and avoid summer sun. The same principle is used by the prototype as balcony. Larger windows on the south façade, or on facades with sea-view can be seen often in the region. Therefore, elongated balconies above the first floor and an eave with the same principle above the second floor are used by the prototype.

**Window shading components:** Simulations have been run to determine the impact on the cooling load of dwellings in Bodrum. Window shading elements like blinds and rolls have been simulated for both the inside and outside placement of window. This as a singular measure has not a significant effect on reducing the cooling requirement. Combined with other shading measures, an enhanced efficiency could be obtained.

**Roof shading:** The important factor, which has not been considered in Bodrum yet, is roof shading. Simulations have been run on roof shading elements in order to prove their contribution to reducing the cooling load. Several designs have been tested distinguished by their shape and coverage area. Furthermore, operative roof shading elements, which may be beneficial, have been tested as well. Simulations showed that, shading elements can also permit solar penetration in winter, when correctly designed and used on south facades. Moreover, opaque shading elements perform two per cent better than operational systems. Furthermore, simulation results show that area-wide shading elements have the greatest energy efficiency.

**Figure 5 Shading illustration**
Form-mass

One of the most important factors, which influence the energy efficiency of a building, is the form of the building. Several simulations have been run in regard to the building form. From square to oblong shapes, various alternatives are simulated to identify an optimum form for housing settlements in Bodrum. According to the results, in hot-dry climates like in Bodrum, the perimeter to area ratio should be as low as possible. Another criterion in heat gaining is the height of a building. High apartment blocks are already not permitted in Bodrum.

Orientation

Givoni points out that, the amount of radiation received by the building is determined by orientation (Givoni, 1969). The orientation can provide profitable solutions for energy consumption and comfort standards (Karasu, 2010). Most of the buildings in Bodrum are, if possible, oriented to the see. This situation leads sometimes deviation from the optimum orientation.

The object has been simulated by changing its orientation in 45° segments. Simulations have been run for both actual and energetically optimized buildings.

Outputs show that there is no significant difference of heat loss of building elements like the roof, ceiling, partitions, and ground flour depending on orientation. The most important difference can be seen in the glazing and external wall. Southern directions give the best result for solar heat gain through glazing in the winter period, but also the worst performance in the summer period. These results show that orientation has a significant influence on the cooling load. But the benefits should be improved with the combination of other criteria.

Basement floor

A basement floor in a house in Bodrum is a critical factor in terms of energy efficiency. It may increase the heating load, whereas the cooling requirement decreases significantly. These effects depend on the energy performance of the house, with other words, to other passive measures. According to the simulation results, the more a house has enhanced energetic values, the less is the reduction of the cooling requirement through a basement floor, and vice versa by the heating requirement. Therefore, the seasonal occupancy plays an important role by taking the decision about the construction of a basement floor. The economic efficiency should be considered as well.

Especially by energetically optimized houses, the thermal effect of a basement floor on the upper floors can be neglected. The direct effect on the ground floor is more significant by not energetically optimized houses. In this case, the operative temperature in winter is up to 0.4 °C higher, whereas it is up to 0.6 °C lower. Compared with other measures, the effect of a basement floor is not significant.
RESULT ANALYSIS

The energy requirement of a house in Bodrum is significantly related to the construction methods that have been employed. Energy optimizations are strongly needed. Each of the passive architectural measures can reduce the energy requirement in a definite amount. The combination of the measures always showed a better performance when compared with separate installations. Thermal insulation of the building envelope has the largest impact on the energy requirement. Furthermore, the roof and windows should be protected from intense solar radiation during the summer period.

Finally, optimized architectural plan and quality might lead to enhanced efficiency of all other measures.

Prototype

Analyses proved the necessity of a prototype house which accords with basic design principles for dwellings in Bodrum. The explorative design developed by Karasu bases on the requirement analysis. It is called the Basic Bodrum House (BBH) and represents an optimum of a house in Bodrum in regard to energy consumption and may also be applicable to housing settlements in the same climatic zone within the Mediterranean Region. A Best-Case (BC) house with improved thermal quality has also been developed as an alternative.

Table 2 below shows the differences of the thermal characteristics of the existing house and developed houses. Beside enhanced thermal characteristics of the prototypes, the BBH and BC are architecturally optimized compared with the actual conditions. It means that criteria like orientation, form, WWR, thermal glazing, thermal insulation, etc., are optimized based on previous simulation results. Beside higher air tightness, the BC has lower U values in each building component, where the material choice has been kept the same.

Table 2
Prototype characteristics in comparison to the actual condition of the analyzed object

<table>
<thead>
<tr>
<th>DIMENSIONS M²</th>
<th>ACTUAL</th>
<th>BBH</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>total floor area</td>
<td>143.9x2</td>
<td>114.7x2</td>
<td>114.7x3</td>
</tr>
<tr>
<td>conditioned area</td>
<td>143.9x2</td>
<td>99.7x2</td>
<td>99.7x2</td>
</tr>
<tr>
<td>roof area</td>
<td>125.2</td>
<td>99.7</td>
<td>99.7</td>
</tr>
<tr>
<td>Window area</td>
<td>17.3/4.8/6.8/1.5</td>
<td>1.5/16.8/5.3</td>
<td>1.5/16.8/1.5/3.6</td>
</tr>
<tr>
<td>Window Ug</td>
<td>6.1</td>
<td>1.31</td>
<td>0.78</td>
</tr>
<tr>
<td>Solar heat gain coefficient SHGC</td>
<td>0.81</td>
<td>0.45</td>
<td>0.47</td>
</tr>
<tr>
<td>External wall Uw</td>
<td>1.84</td>
<td>0.39</td>
<td>0.20</td>
</tr>
<tr>
<td>Roof Ur</td>
<td>3.32</td>
<td>0.43</td>
<td>0.33</td>
</tr>
<tr>
<td>Air leakage in ac/h</td>
<td>2</td>
<td>0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

ENERGY REQUIREMENT

| Cooling kWh/m²a | 42.79 | 22.35 | 11.32 |
| Heating kWh/m²a | 118.18 | 39.51 | 13.11 |

According to the simulation results, the cooling and heating energy demand of existing houses in Bodrum can be reduced by up to 44 and 54 per cent in comparison to actual conditions. These have been achieved by up to 73 and 89 per cent in architecturally optimised houses for planned settlements in comparison with actual conditions of

Figure 8 Effect of a basement on operative temperature (in °C)

Figure 9 Prototype house for Bodrum (w/o scale)
existing houses. Finally, simulation results show that, energy demand values like 13.11 kWh/m²a for cooling, and 11.32 kWh/m²a for heating are achievable.

CONCLUSION
The purpose of this research has been to assess how and to what extent energy intensity in new and existing housing settlements in Bodrum can be reduced. Numerous factors, which influence the thermal behaviour of the buildings, have been analyzed. Following results are recommended:

• Architectural design and energy efficiency should be considered as a whole during the design phase, and building energy simulation tools are highly necessary.

• Complete insulation of the envelope has a better efficiency compared with separate implementations. Thermal glazing should be considered as an additional measure to thermal insulation.

• Increasing construction quality, which means better air tightness, is not a cost additive measure. However, its influence on the thermal behaviour of passive measures is significant. Therefore, its implementations should be standardised.

• Shading elements should be emphasized by the settlements. Roof-shading elements besides window shading provide a significant reduction of the cooling energy demand. Hence, they can be a part of Bodrum’s vernacular architecture.

LITERATURE


