ENVIRONMENTAL SUSTAINABILITY PERFORMANCE OF RESIDENTIAL BUILDINGS’ THERMAL RETROFITS

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ABSTRACT

Environmental sustainability is one of the greatest concerns of the world, and building sector has a considerable effect on achieving a sustainable environment because of the impacts associated with but not limited to the manufacturing of building materials, construction of the buildings, energy use in the operation period, and demolition and waste disposal. Thermal retrofitting of existing buildings is a measure in this sense which will reduce environmental impacts associated with energy use in the operation period, and also that will prevent impacts associated with construction of new buildings. In this respect, a research project was completed on thermal retrofitting of residential buildings in Istanbul (Turkey), and a database was built for selection of efficient retrofit alternatives. As a further study, using building types determined in this research, environmental sustainability performance of building retrofits in two other cities of Turkey with different climatic conditions, namely Ankara and Izmir, were studied in order to evaluate the effect of climatic conditions on environmental sustainability performance.

In the paper, the completed research project is briefly explained at first, methods and procedures of the current study and the results of three cities are then presented, and finally the efficiencies of retrofits are comparatively discussed for different cities.

Keywords: Environmental sustainability, retrofit, residential building, climate.

1 INTRODUCTION

Depletion of natural resources including both energy and others such as minerals or water, and pollution of environment caused by all kinds of human activities are two of the significant problems in the world. Taking necessary measures, first, for preserving current condition of the environment, and then, for reversing the harm we caused is a policy accepted all over the world. Buildings, as objects providing the necessary interior environment we need to perform our activities, and construction industry, which creates the necessary built-environment we need, have a considerable and widely accepted effect on achieving the aforementioned policy.

Considering that thermally retrofitting the existing (residential) buildings, rather than demolishing them to construct new ones, is a measure that will help both preserving natural resources and decreasing pollution caused by manufacturing, construction and space heating activities, various research studies had been made in building community. Some of them take the subject into account theoretically/strategically [1, 2, 3], and some others directly analyse performances of retrofitting alternatives [4, 5]. Similarly, a research project considering the case in Turkey was designed, and completed in 2011 by the authors [6]. One of the main objectives of the study was to evaluate both economic and environmental efficiency of
various thermal retrofit alternatives considering buildings' characteristics such as remaining service life, window to wall ratio (WWR) or plan type. A database was generated for Istanbul, as the output of the study that can be used either by the owners or constructors, for deciding on what type of thermal retrofits would be efficient for their building. Enlarging the database for different cities of Turkey was planned as well. Considering that climatic conditions affect buildings' energy consumption [7, 8, 9], initially, the environmental sustainability performance of thermal retrofits are being investigated for three different cities of Turkey, namely Istanbul, Ankara and Izmir. These cities are selected as they have the highest urban population in Turkey in the given order [10], and represent three of the four climatic regions defined in the mandatory Turkish Standard on thermal insulation of buildings [11], where Istanbul is primarily classified under Marmara type with a temperate climate as a transition region, Ankara is under terrestrial type with cold winters, and hot-dry summers, and Izmir is under Mediterranean type with hot-dry summers, and warm-humid winters [12]. Climate types of these cities according to different classification schemes can be found in [13].

In this paper, in relation with this further research study, brief information on the research project completed in 2011 is given initially for providing necessary background information. Methods and procedures used in the comparative evaluation of environmental sustainability performances at different cities are then explained, and findings are presented. Finally, effectiveness of these thermal retrofits is comparatively discussed for different cities.

2 THERMAL RETROFITTING OF RESIDENTIAL BUILDINGS IN ISTANBUL

In the research study, a method was developed for sustainability assessment of thermal retrofits, and a database was generated based on the use of predefined building types and predefined retrofit alternatives for detached residential buildings with natural gas fired central space heating system. For this purpose, 60 buildings with these characteristics, located at six different neighbourhoods of Istanbul were randomly selected, and information such as distances to other buildings, number of stories, number of apartments at one storey, and assembly of building elements was then gathered through field surveys and project analyses. As the result of this investigation, two main building types, namely Types A and B in terms of plan shape, and two sub-types for each of them in terms of the floor area of one storey were identified. For determining the thermal retrofits, material manufacturers and construction firms working on retrofitting were contacted for identifying the mostly preferred construction techniques and thermal insulation materials, which were identified to be the exterior application of either extruded polystyrene (XPS), expanded polystyrene (EPS) or stone wool (SW) at the exterior walls, and laying glass wool (GW) on the attic floor at the roofs. As additional retrofit alternatives; (i) replacement of single-pane wooden framed windows with double-pane windows of either wooden or PVC frame, (ii) thermally insulating the floor between heated apartments and the unheated basement, and (iii) thermally insulating the walls enclosing the staircase with the same materials used at the exterior walls were defined as well.

In the evaluation of environmental sustainability, life cycle assessment (LCA) method was used. Environmental impacts of buildings without any retrofit were determined considering the space heating energy required during their remaining lives. For the retrofitted cases, raw materials and energy required for the manufacturing of retrofit materials, and material transportation and construction energy were considered additionally [14]. In the evaluation of economic sustainability, life cycle cost (LCC) method was used, and costs associated with the aforementioned items for the environmental sustainability were considered. Energy consumption of building types were determined by EnergyPlus software, and environmental impacts were determined by SimaPro software and its Ecoinvent database.
In the determination of environmental and economic performances of retrofit alternatives, the same approach was used and ‘the total impact of a building type without any retrofit’ was compared with ‘the total impact of the same building type when retrofits are applied’ [15]. Equation used for determining environmental performance is given as an example in Equation (1). The overall performances of retrofit alternatives are then determined by Equation (2).

\[
NR_{ij} = \frac{(NI_i - NI_j) \times 100}{NI_i}, \quad \text{Equation (1)}
\]

\[
SP_{ij} = \frac{(NR_{ij} \times mn) + (CR_{ij} \times mc)}{100}, \quad \text{Equation (2)}
\]

Where, \(NR\) is environmental performance, \(NI\) is environmental impact (Ecopoints), and the indices \(i\) and \(j\) are building type and retrofit alternative planned to be used respectively in Equation (1), and \(SP\) is sustainability performance (-), \(NR\) is environmental performance (-), \(CR\) is economic performance (-), \(m\) is importance ratio (%) in Equation (2).

### 3 SUSTAINABILITY PERFORMANCE OF THERMAL RETROFITS IN DIFFERENT CITIES OF TURKEY

#### 3.1 Method and procedures

In the completed research project, as aforementioned, two main building types were determined through the field studies, which were Type A with a square-like plan and Type B with a rectangular plan, and there were two sub-types of each in terms of floor area. For the rectangular type, there were also two sub-types in terms of orientation of the building. Three different WWRs were determined for each building type, which were 10%, 20% and 30%. Service life of buildings was accepted to be 50 years, and buildings at the ages of 15, 20, 25 and 30 were studied. As the buildings at those ages were generally middle-rise buildings, buildings were accepted to have six stories, one of which was unheated basement. In the current study on evaluating the effect of exterior environmental conditions, the same building types determined for Istanbul were used, and one sub-type of each main type with a WWR of 20% for the ages of 15 and 30 were studied (Table 1). For the rectangular type, only the one, whose long side was oriented to north-south, was studied.

<table>
<thead>
<tr>
<th>Building type</th>
<th>Plan type</th>
<th>Long side facing</th>
<th>Floor area</th>
<th>WWR</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Square-like</td>
<td>N/A</td>
<td>210.25 sq.m</td>
<td>20%</td>
<td>15, 30</td>
</tr>
<tr>
<td>B1-1</td>
<td>Rectangular</td>
<td>North-South</td>
<td>231 sq.m</td>
<td>20%</td>
<td></td>
</tr>
</tbody>
</table>

In the completed research project, typical building element assemblies of existing buildings were determined by analysing their projects available at the archives of municipalities, and the thicknesses of thermal insulation materials were determined considering the information gathered from construction firms on generally applied thicknesses. In the current study, on the other hand, as performing field studies, project analyses and construction firms interviews at different cities would be time consuming, building element assemblies determined for the existing buildings at Istanbul are used for all other cities, and thermal insulation thicknesses are determined considering the U values defined for building elements in the mandatory Turkish Standard on thermal insulation of
buildings [11]. Therefore, computations associated with Istanbul were renewed considering the thermal insulation thicknesses determined. All buildings investigated during the field studies had reinforced concrete (R.C.) structural frame. Considering the thermal bridges at the structural members, necessary thicknesses for the thermal insulations were calculated taking into account the assembly at the location of R.C. beams rather than the one at infill walls. In addition, in this paper, impacts of retrofitting with two different thermal insulation materials, namely EPS and SW, and renewal of windows with double-pane PVC frame are presented only (Table 2).

Table 2. Information on the retrofitted building elements, except renewal of window system

<table>
<thead>
<tr>
<th>Building element</th>
<th>Assembly a (d; λ)</th>
<th>U value b - insulation material (m; d) c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical exterior envelope above ground</td>
<td>Exterior rendering (3; 1.4)</td>
<td>Istanbul: 0.60</td>
</tr>
<tr>
<td></td>
<td>Thermal insulation d</td>
<td>Ankara: 0.50 EPS/SW; 5</td>
</tr>
<tr>
<td></td>
<td>R.C. beam (25; 2.1)</td>
<td>Izmir: 0.70 EPS/SW; 4</td>
</tr>
<tr>
<td></td>
<td>Interior plaster (2; 0.87)</td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>Thermal insulation d</td>
<td>Istanbul: 0.40 GW; 8</td>
</tr>
<tr>
<td></td>
<td>R.C. floor slab (10; 2.1)</td>
<td>Ankara: 0.30 GW; 11</td>
</tr>
<tr>
<td></td>
<td>Interior plaster (2; 0.87)</td>
<td>Izmir: 0.45 GW; 7</td>
</tr>
<tr>
<td>Floor above unheated basement</td>
<td>Wooden parquet (2; 1.12)</td>
<td>Istanbul: 0.60 EPS/SW; 5</td>
</tr>
<tr>
<td></td>
<td>Cement screed (3; 1.4)</td>
<td>Ankara: 0.50 EPS/SW; 6</td>
</tr>
<tr>
<td></td>
<td>R.C. floor slab (10; 2.1)</td>
<td>Izmir: 0.70 EPS/SW; 4</td>
</tr>
<tr>
<td></td>
<td>Thermal insulation d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interior plaster (2; 0.87)</td>
<td></td>
</tr>
<tr>
<td>Projected floor</td>
<td>Wooden parquet (2; 1.12)</td>
<td>Istanbul: 0.60 EPS/SW; 5</td>
</tr>
<tr>
<td></td>
<td>Cement screed (3; 1.4)</td>
<td>Ankara: 0.50 EPS/SW; 6</td>
</tr>
<tr>
<td></td>
<td>R.C. floor slab (10; 2.1)</td>
<td>Izmir: 0.70 EPS/SW; 4</td>
</tr>
<tr>
<td></td>
<td>Thermal insulation d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interior plaster (2; 0.87)</td>
<td></td>
</tr>
<tr>
<td>Walls enclosing staircase</td>
<td>Interior plaster (2; 0.87)</td>
<td>Istanbul: 0.60 EPS/SW; 3</td>
</tr>
<tr>
<td></td>
<td>Thermal insulation d</td>
<td>Ankara: 0.60 EPS/SW; 3</td>
</tr>
<tr>
<td></td>
<td>Hollow clay brick (9; 0.45)</td>
<td>Izmir: 0.60 EPS/SW; 3</td>
</tr>
<tr>
<td></td>
<td>Interior plaster (2; 0.87)</td>
<td></td>
</tr>
</tbody>
</table>

Notes and abbreviations

a: Assembly either from top to down or exterior to interior.
b: Max. thermal transmittances (W/m²K) used in the calculations considering values in [11].
c: Thermal conductivity of EPS, RW and SW are taken as 0.035 W/mK.
d: Location of thermal insulation when retrofitted. Thicknesses for different cities are given in the cells of the same row.
d: Thickness (cm)  λ: Thermal conductivity (W/mK)  m: Thermal insulation material

3.2 Results

Annual space heating energy consumptions of building types with and without retrofitting are given in Figure 1 for different cities of Turkey. In order to understand the effect
of building orientation on heating energy consumption, building B1-2, whose long side is facing east-west, is studied as well. Analysis of heating energy consumptions shows that:

- Thermal retrofit of all building types decreases the energy consumption at all cities;
- Annual consumption is the greatest at Ankara followed by Istanbul and Izmir, when buildings of same type with same retrofitting conditions are compared with each other;
- Annual heating energy consumption of building B1-2 is always higher than that of building B1-1 at all cities.

![Figure 1: Annual space heating energy consumption of building types with and without retrofitting and located at different cities of Turkey.](image)

As the objective is to evaluate the effect of climatic conditions on the environmental performance of building retrofits, information on the exterior air temperature and solar radiation are given in Figure 2 for the cities considered. General analysis of these shows that:

- Monthly minimum exterior air temperature is always lower in Ankara than in other cities;
- Monthly global solar radiation on horizontal surface is always higher in Izmir than in other cities, during both summer and winter seasons.

Environmental performances of two buildings types retrofitted with two different insulation materials are given in Figure 3 for different cities of Turkey and for different building ages. Analysis of environmental performances shows that:
- Environmental performance is always higher when EPS is used, when compared with the use of SW at the same building;
- Environmental performance of a building at the age of 15 is always higher than the same building at the age of 30;
- Environmental performance of building A1 is always higher than building B1-1’s, except the ones located in Izmir, when buildings at the same age retrofitted with the same material are compared with each other;
- Both for buildings A1 and B1-1, the highest performance is achieved in İzmir followed by Istanbul and Ankara, when buildings at the same age retrofitted with the same material are compared with each other.

![Environmental Performance Chart](image)

Figure 3: Environmental performance of buildings types retrofitted with different insulation materials at various cities of Turkey.

As mentioned in Section 2, environmental performance used in this study is dimensionless, and reflects the percentage of performance gain (or loss in some cases). Therefore, environmental impact scores for different end point damage categories are given in Figure 4 for building A1 located in Istanbul as an example. Analysis of these scores shows that:
- Ecosystem quality impact is in negligible amounts for all cases;
- The highest impact occurs in relation with resource use followed by climate change and human health;
- The impact of building without any retrofit is always higher than the retrofitted ones for all damage categories;
- The impacts of a 30 years old building are lower than that of a 15 years old building, as the remaining life of the former one is shorter (i.e. 20 years) than the
latter (i.e. 35 years), and thus the amount of heating energy consumption during its remaining life is smaller.

4 DISCUSSION AND CONCLUSION

In general, it is observed that thermal retrofitting increases the environmental performance of residential buildings located at different cities of Turkey with different climatic conditions. These performance values range between 55-64 points, and the highest improvement is achieved in climate change and resource use categories.

Environmental performances of buildings in Istanbul and Ankara are similar to each other, although minimum air temperature of Ankara is lower than that of Istanbul, up to 18°C. As the mandatory Turkish Standard [11] defines different thermal transmittance values at these cities, where limit values are lower in Ankara, similar performance gains can said to be meaningful. In Izmir, on the other hand, environmental performances of buildings are higher than those of located in other cities, especially for building B1-1, although higher limit thermal transmittance values are defined for Izmir in the aforementioned standard. Maximum air temperature of Izmir is usually higher than others’, up to 30°C, especially during summer time, and the amount of solar radiation is also higher than others’ up to ca. 1100 Wh/m². As the summer time conditions are more severe in Izmir, it can be assumed that primary driver of the limit transmittance values in Izmir is the cooling loads occurring during summer. Therefore, increase in the sustainability performance is found meaningful as space heating energy consumption is only considered in this study.

Another significant variation observed in the results is the performance of building B1-1 at different cities. In Istanbul and Ankara, it has a lower performance than building A1’s, while it is the opposite in Izmir. Building B1-1’s long facades are facing north-south, and the annual energy consumption of its retrofitted state is the lowest in Izmir, while in building B1-2 with long facades oriented east-west, the annual heating energy consumption of its retrofitted state is the highest. Therefore, the increase observed in environmental performance of building B1-1 may be explained by high solar radiation in Izmir, and increased solar heat gain through south façade due to increased façade area. However, further analysis considering different WWRs and floor areas will be helpful to strengthen this assumption.

In conclusion, this initial study on understanding the effect of weather conditions on environmental performance of thermal retrofit of residential buildings showed that, in addition to heating energy consumption, which is important in the case of Istanbul and
Ankara, cooling energy consumption, which is especially important in the case of Izmir, should be also studied to make a holistic comparison among different climates.

REFERENCES