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A PERFORMANCE BASED METHOD FOR SELECTION OF THERMAL INSULATION MATERIAL: SOCIAL HOUSING CASE [1]

ISI YALITIMI MALZEMESİNİN SEÇİMİNDE PERFORMANSA DAYALI BİR YÖNTEM: SOSYAL KONUT ÖRNEĞİ

Burcu Çiğdem YILMAZ[1], Seden ACUN ÖZGÜNLER[2]

[1] İstanbul Technical University, Graduate School of Science Engineering and Technology, İstanbul / Turkey
[2] İstanbul Technical University, Faculty of Architecture, İstanbul / Turkey

ORCID ID: 0000-0001-5975-5115[1], 0000-0001-8786-4618[2]

Öz: Amaç: Bu çalışma, yüksek performanslı sosyal konut tasarımında ısı yalıtım malzemesinin seçimi için çok kriterli bir karar verme yöntemine dayanan bir yaklaşım önermektedir. **Yöntem**: Önerilen yaklaşım için, Türkiye'de ortak bir sosyal konut arketipi üzerinde çalışılmıştır. Bağımsız değişkenler ısı yalıtım malzemesinin türü ve kalınlığı, cam türü ve cam-duvar oranı olarak belirlenmiş ve alternatif senaryolarla arketipin performansını araştırmak için parametrik analiz metodu kullanılmıştır. İkinci olarak, yüksek performanslı bir bina için enerji, maliyet ve çevresel (gömülü enerji ve karbon emisyonu) performansları gibi karar verme kriterleri listelenmiş ve her bir alternatif için hesaplanmıştır. Arketipin enerji ve maliyet performans analizi Energy Plus dinamik bina enerji simülasyon aracı ile gerçekleştirilmiş, çevresel kriterler literatürden elde edilen değerler doğrultusunda elle hesaplanmıştır. Son olarak, sonuçlar arketip için en iyi alternatifleri belirlemek için önerilen bir çok kriterli karar verme yaklaşımı olarak önerilen Ağırlıklı Toplam Metodu (WSM) ile değerlendirilmiştir. **Bulgular**: Sonuçlar göstermektedir ki, önerilen yöntem içerisinde en yüksek enerji verimliliğine sahip senaryo çevresel kriterler hesaba katıldığında toplam WSM puanı ile alt sıralara düşmektedir. Bunun yanında, WSM puanı en yüksek olan senaryo ise düşük yaşam döngüsü maliyeti ile öne çıkmaktadır. **Sonuç**: Genel sonuç olarak, binalar için ısı yalıtım malzemelerinin seçiminde doğru karar vermede, farklı çevresel ve ekonomik özelliklerin hesaba katılmasının binalar için daha yüksek performans sağladığı kanaatine varılmıştır.

Anahtar Kelimeler: Bina Performansı, Enerji Verimliliği, Yaşam Döngüsü Maliyeti, Çevresel Etki, Karar Verme

Abstract: Aim: This study proposes an approach based on a multiple criteria decision-making method for the selection of thermal insulation material in the design of high performance social housing. **Method**: The proposed approach has been studied on a common social housing archetype in Turkey. Independent variables were determined as thermal insulation material type and thickness, glazing type and window to wall ratio (WWR) and parametric analysis method was used to investigate the performance of the archetype with alternative scenarios. Secondly, decision making criteria such as energy, cost, and environmental (embodied energy and carbon emissions) performances for a high performance building, were listed and calculated for each alternative. Energy and cost performance analysis of the archetype was conducted through the Energy Plus dynamic building energy simulation tool, where the environmental performances were calculated through values obtained from the literature. Finally, results were evaluated through the proposed Weighted Sum Method (WSM) as a multiple criteria decision making approach to determine the best alternatives for the studied archetype. **Results**: Results indicate that, when the environmental criteria are considered through the proposed methodology, the highest energy efficient case moves to lower positions with its overall WSM score. On the other hand, the best alternative of the WSM becomes significant with its low life cycle cost. **Conclusion**: The results indicate that proper decision making on the selection of thermal insulation materials for buildings, with different environmental and economic attributes, ensures higher performances for buildings.

Key Words: Building Performance, Energy Efficiency, Life Cycle Cost, Environmental Impact, Decision Making

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(1) ***Corresponding Author: Burcu Çiğdem YILMAZ, İstanbul Technical University, Graduate School of Science Engineering and Technology, İstanbul / Turkey , burcucigdemc@gmail.com, Geliş Tarihi / Received: 31.08.2018 Düzeltme Tarihi / Revision: 01.04.2019 Kabul Tarihi/ Accepted: 29.04.2019 Makalenin Türü: Araştırma ve Uygulama / Research and ApplicationÇıkar Çatışması / Conflict of Interest: Yok / None Ethics Committee Report Unavailable***

INTRODUCTION

Total world energy consumption has been rising rapidly and future projections indicate that a 28% increase in energy consumption is expected between 2015 and 2040[1]. Buildings, as one of the most significant consumers of energy, represent more than one-third of global energy consumption. Thus, buildings have a significant role on global warming, depletion of resources, and emissions. The high amount of energy consumption in buildings, mostly for heating, cooling and lighting spaces, has brought about the necessity of legislative strategies such as energy efficiency regulations, energy certification of buildings, refurbishment of existing buildings, etc. (Directive, 2002/91/EU: 1-7; Directive, 2010/31/EU: 1-23). The publication of European Directive (2002/91/EC: 1-7) represented a definitive answer in terms of building energy certification and reducing energy consumption in buildings through European Union countries. Adoption of the Directive (2010/31/EU: 1-23) (EPBD Recast), while targeting the increase of energy efficiency in buildings, has also accompanied new provisions such as cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building.

By the increasing actions on the energy efficiency of buildings, thermal insulation materials have become one of the key applications in promoting the energy efficiency as well as moisture and sound protection of today's structures (Korkmaz and Alacahan, 2014: 1-26). In accordance with the progress in the thermal insulation material industry and the material properties, the effect of thermal insulation on building energy performance has still been investigated in recent researches, (Aditya et al, 2017: 1352-1365; Tettey et al, 2017: 369-377; Simona et al., 2017: 393-399; Menyhart and Krarti, 2017: 203-218; Lucchi et al, 2017: 412-423; Lee et al, 2017: 1081-1088; Tettey et al, 2014: 1204-1207, Nematchoua et al, 2017: 170-182; Braulio-Gonzola and Bovea, 2017: 527-545; Altan Dombaycı et al, 2006: 921-928; Mohsen et al, 2001: 1307-1315). For instance, Aditya et al (2017: 1352-1365) presented a review on the recent developments of thermal insulation materials and discussed the potential reductions on energy consumption and emissions in buildings through the application of proper insulation materials. Tettey et al. (2014: 1204-1207) also highlight that as more stringent energy-efficiency standards are introduced and high performance buildings are built, more attention must be paid to the choice of building thermal insulation material. Nematchoua et al. (2017: 170-1827) point out the optimum levels for wall insulation in the studied tropical climate. Braulio-Gonzola and Bovea (2017:

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[1] https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf

527-545) studied the thickness optimization of envelope insulation materials and found out that 40% reduction in energy demand can be achieved by the optimum insulation compared to regulations.

Moreover, high performance buildings with high thicknesses of insulation material may lead to higher costs and may have a greater impact on the environment, when an integrated optimization approach is not considered. Yılmaz and Oral (2018: 122-132) studied the building stock energy retrofit and analysed a thermal insulation optimization between the U value of the wall, roof, floor and the energy savings. The calculated maximum effective thicknesses for all insulation applications were then used in the energy retrofit packages. Tubelo et al. (2018: 213-227) conducted a study to explore the cost-effective envelope optimization for social housings in accordance with thermal comfort improvement. They found out a 97% potential increase in thermal comfort by nearly 50% increase in cost, where more cost-effective with a significant increase of thermal comfort levels were also possible and were therefore considered to be a more adequate solution for the context. Mangan and Oral (2016: 362-376) evaluated the energy, economic and environmental performances of residential buildings through improvement measures such as insulation level, glazing, solar control, and so on. Thus, it is obvious that, determination of the optimized envelope solution for a high performance building is a multiple criteria decision-making problem, since the envelope parameters have a significant impact on energy, cost, and environmental performances of buildings.

Within the building typologies, social housings come into prominence with the requirements of lower investment costs for investors and lower levels of energy consumption for users. In addition, a higher level of environmental performance should also be considered in social housings to be a model for the public. This study proposes an approach for decision making on high performance social housing design. The study is unique by integrating the cost optimality in EPBD Recast (Directive, 2010/31/EU: 1-23) and the environmental criteria in a decision making model for Turkey. Particularly, housings as conditioned for 24 hours, require a proper level of thermal insulation. In this study, methodology is specified for a multiple criteria decision making on thermal insulation material selection and the impact of selection of the thermal insulation material on the performance of social housing is investigated.

RESEARCH METHOD

Building design, as a process of decision making involves multiple decision makers such as investors, landlords, designers, experts, and so on where each decision maker, from different points of view, targets the success of the project with different concerns. This paper proposes a multiple criteria decision-making approach for the selection of thermal insulation material in high performance social housing design. The methodology of the proposed approach is summarized in Figure 1. The main steps of the methodology are:

- Determination of the archetype for analysis,
- Parameterization of the archetype with determined independent variables,
- Building performance calculations in terms of energy, cost and environmental criteria,
- Multiple criteria decision-making.

The steps of the methodology are systematically explained in the following sections from 2.1 to 2.4.

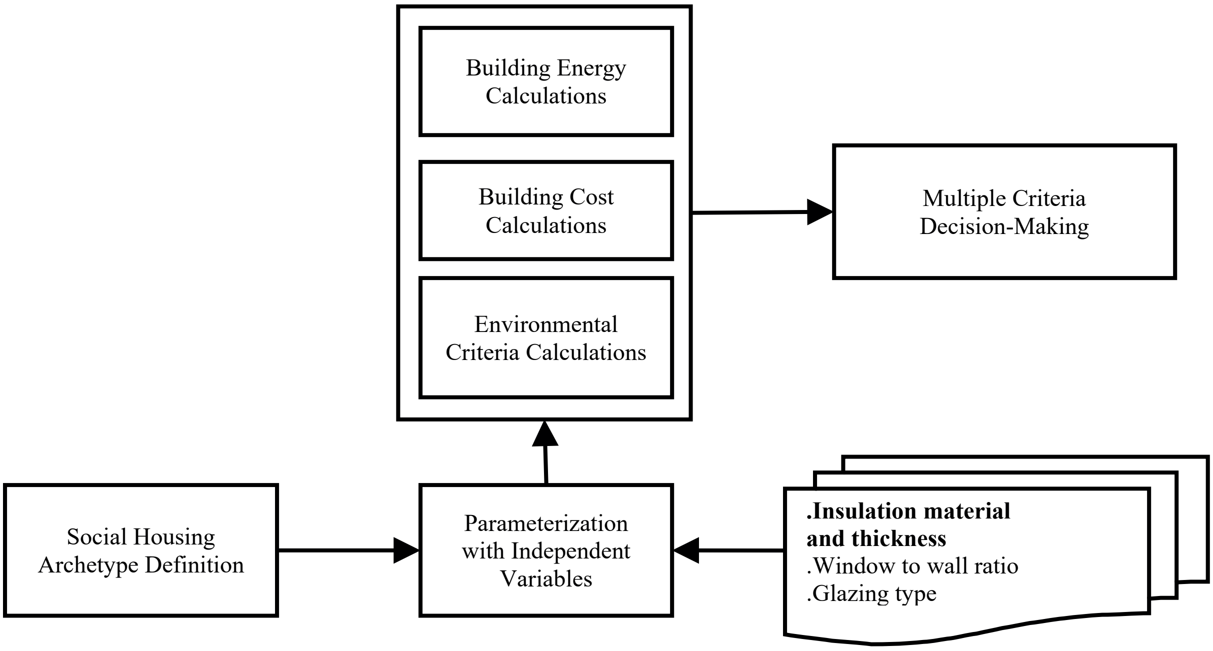

Figure 1. Flowchart of the Proposed Methodology

Description of the Social Housing Archetype

The case study building is an archetype of social housings which is commonly applied in Turkey. The archetype is composed of 11 residential floors. Each floor comprises 320 m^2 conditioned area (80 m^2 per apartment unit and 55 m^2 unconditioned area). Typical floor plan and thermal zoning of the typical floor is given in Figure 2.

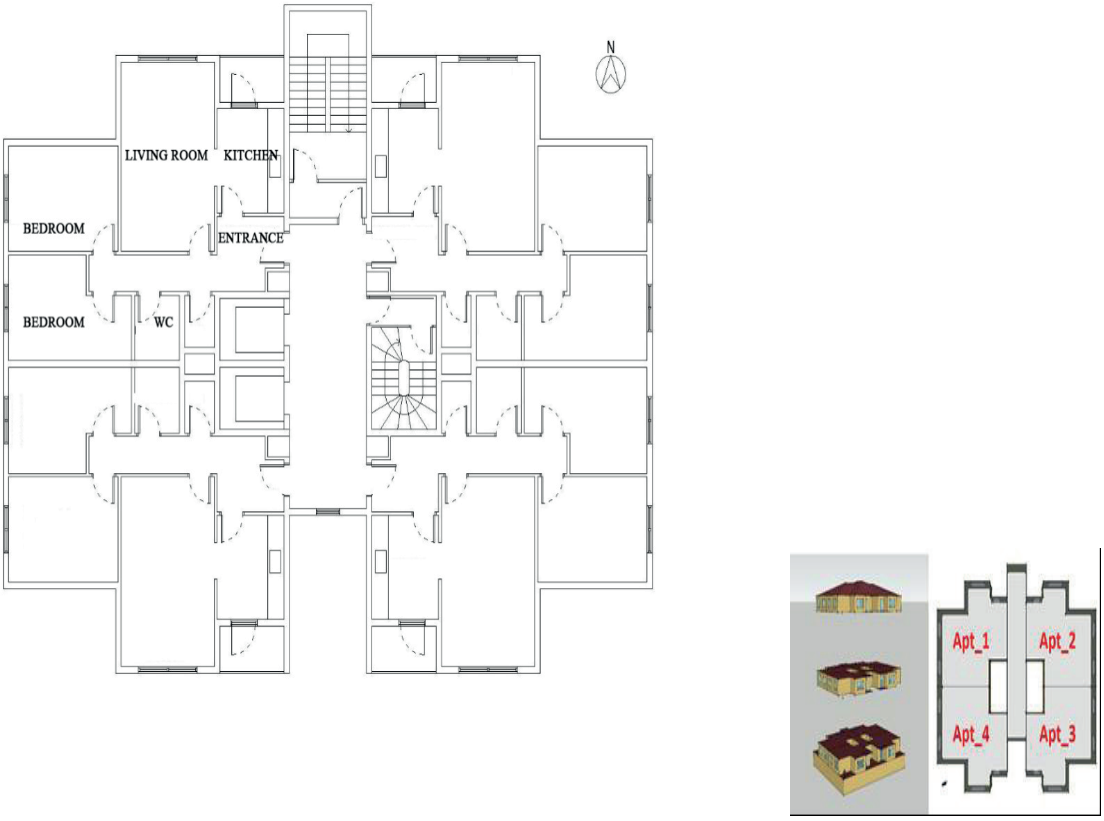

Figure 2. Typical Floor Plan of the Case Study Building (on the left) and the Thermal Zones of the Typical Floor (on the right)

The archetype was defined with the reference values for envelope elements in order to represent a base case. Reference values were obtained from the National Building Energy Performance Calculation Methodology – Reference Building Description document (BEP-TR, 2008: 1-11). Window and wall properties of the base case archetype are given in Table 1 and Table 2, respectively.

Table 1. Transparent Component Thermal and Optical Properties

Glazing type	U Value (W/m2K)	Solar heat gain coefficient (0-1)	Visible transmittance (0–1)
Exterior Window	2.40	0.70	0.80

Table 2. Opaque Component Thermal Properties

Opaque component	Material	Thickness (m)	Conductivity (W/mK)	U Value (W/m2K)
Exterior Wall	Plaster	0.020	0.970	Uextwall=0.57 [22]
	Insulation	0.060	0.035	
	Aerated brick	0.190	0.500	
	Gypsum plaster	0.020	0.970	

Determination of the Independent Variables

In this methodology, criteria for the evaluation of the thermal insulation material selection are the effect of the thermal insulation material on the life cycle energy consumption on life cycle building costs, and on the environmental performance.

The parameters of thermal insulation materials and the required considerations are well explained by Sezer (2016: 88-96) in four steps such as selection of insulation material, determination of insulation thickness, insulation type, and insulation application. Commonly applied thermal insulation materials, such as expanded polystyrene (EPS), extruded polystyrene (XPS), rockwool (RW), glasswool (GW), and cellular glass (CG) are investigated within the decision making approach. Properties of the investigated thermal insulation materials are given in Table 3.

Table 3. Thermal Insulation Material Parameters

Thermal Insulation Material Name	Thermal Conductivity (W/mK)	Density (kg/m3))	Specific Heat (J/kgK)	Thickness Alternatives (m)
Extruded Polystyrene (XPS)	0.032	30	1300	0.04, 0.08, 0.12, 0.16, 0.20
Expanded Polystyrene (EPS)	0.035	20	1250	0.04, 0.08, 0.12, 0.16, 0.20
Cellular Glass (CG)	0.035	90	900	0.04, 0.08, 0.12, 0.16, 0.20
Glasswool (GW)	0.040	60	1000	0.04, 0.08, 0.12, 0.16, 0.20
Rockwool (RW)	0.040	120	900	0.04, 0.08, 0.12, 0.16, 0.20

In addition to the variety of thermal insulation materials, a variation in other design parameters may also change the performance of the thermal insulation material in terms of energy, cost, and so on. Thus, other envelope parameters such as the window to wall ratio and glazing type are considered to be other independent variables in order to compose a whole approach for the envelope. Window glazing types that are investigated and their properties are given in Table 4. Window to wall ratios for the envelope are considered to be 30%, 40% and 50%. Orientation was not taken into consideration in this study as an independent variable. The orientation of the current case is as signified in Figure 2.

Table 4. Window Glazing Thermal and Optical Properties

Glazing type	U Value (W/m2K)	Solar heat gain coefficient (0-1)	Visible transmittance (0–1)
Glazing 01* (TS 825, 2008: 30)	2.40	0.70	0.80
Glazing 02	1.60	0.70	0.80
Glazing 03	0.60	0.60	0.70

* Reference Window

Calculation of the Dependent Variables

Dependent variables of the study are determined as the energy, cost and environmental performances varying according to the independent variables. It was assumed that these criteria can represent a decision making group which is composed of architects, mechanical engineers, contractors and investors. On the other hand, other criteria such as fire safety or structural strength were not considered in this study in order to limit the decision making perspective within the EPBD scope. The criteria that are included in this approach as dependent variables, and the methodology to calculate the effect of the material on these criteria, are explained in detail in the following section.

Methodology for Energy Calculations

Effect of the material selection on the energy performance of the building is calculated through the life cycle energy consumption of the case building for a 30 year life span. Energy consumption is calculated through the Energy Plus simulation tool, on an hourly basis, with 6 time steps per hour. Conduction transfer function algorithm is used for heat balance calculations, with TARP algorithm for inside and DOE-2 algorithm for outside surface convection calculations.

This study evaluates only the temperate dry climate region of Turkey. Temperate-dry climate region, which is represented by the capital city of Ankara was selected for this study. The temperate-dry climate region studied in this paper and its related information is given in Table 5.

Table 5. Temperate-Dry Climate Region

Climate region	City	Latitude (deg)	Longitude (deg)	Elevation (m)
Temperate-dry	Ankara	40.12	32.98	949

It is assumed that four people are living in each apartment unit. Average lighting power density is fixed to 6 W/m^2 for each apartment unit, with an additional 5 W/m^2 electronic equipment load. Since the building is a new construction, infiltration is considered to be low as 0.2 ach for apartment units and 0.5 for unconditioned zones such as the apartment hall.

In this study, it is considered that the case building is mechanically operated for heating and cooling through 24 hours. Set-point temperatures of the building are assumed as 20^{o}C for heating and 26^{o}C for cooling. Heating is provided by a central boiler. Cooling is provided by unit packaged terminal air conditioners, and ventilation is provided naturally, related with the occupancy schedule.

Methodology for Cost Calculations

Effect of the material selection on the cost performance of the building is calculated through the life cycle costs of the case building for 30 a year life span. Life cycle costs are calculated by the methodology presented in (CEN, 2007: 5-15).

(CEN, 2007: 5-15) introduces global cost (C_G) as given in Equation (1), as a sum of annual costs (C_a), such as operation, maintenance, replacement, (with reference to the beginning year) and investment costs (C_I). Moreover, residual value ($V_{T-f}(j)$) within the calculation period (T) is subtracted from the sum of all other costs. The present value factor ($f_{pv}(n)$) is used to transform the sum of first year to the n^{th} year annual costs to a current (today) value.

$$C_G(T) = C_I + \sum_{i=1}^{T}(C_{a(i)} \times f_{pv}(i)) - \sum_{j=1} V_{T-f}(j) \tag{1}$$

In order to calculate the present value factor by using Equation (2), the inflation rate (R_i) and the nominal interest rate (R) must be acquired to compute the real interest rate (R_R) as expressed by Equation (3) (CEN, 2007).

$$f_{pv}(n) = \frac{1-(1+R_R)^{-n}}{R_R} \tag{2}$$

$$R_R = \frac{R-R_i}{1+R_i} \tag{3}$$

In this methodology, only the envelope costs are considered for investment costs (C_I), in order to make a comparison between the scenarios due to changes in the independent variables. Envelope costs are evaluated in two parts as the wall and the windows. Figure 3 represents the opaque envelope component costs, in terms of Turkish Lira (TL) per m2, with different thermal insulation materials and thicknesses. Opaque component costs per m^2 were calculated based on the unit costs including the construction and labour costs. Window costs are calculated as 60 TL/m2, 75 TL/m2, and 125 TL/m2 for windows with glazing type 01, 02, and 03, respectively.

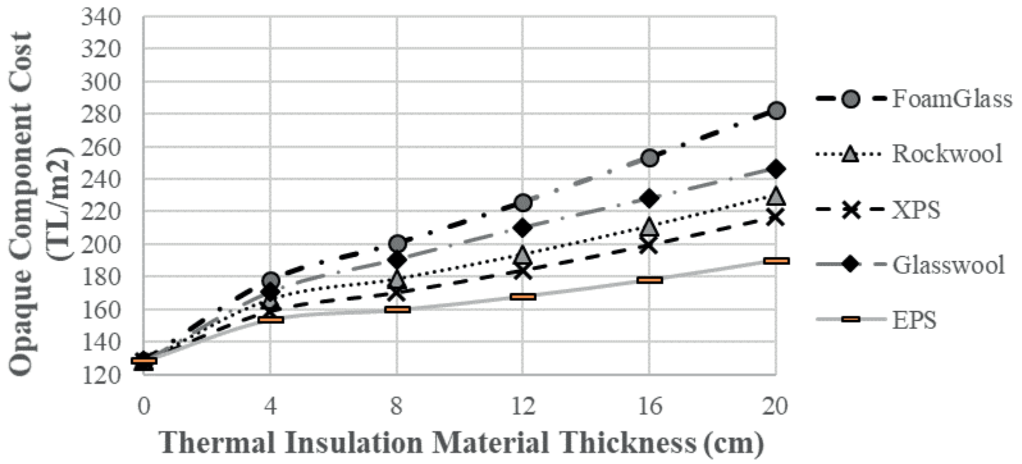

Figure 3. Building Opaque Wall Costs with Different Thermal Insulation Materials and Thicknesses

Methodology for Environmental Performance Calculations

The effect of the material selection on the environmental performance of the building is calculated through the embodied carbon (kg-CO^{2}e/kg) and embodied energy (MJe/kg) of the materials.

A literature review and technical data sheets are used to obtain information on embodied carbon and embodied energy levels of materials. Table 6 presents the embodied carbon and embodied energy levels of materials.

Table 6. Environmental Performance Values of the Thermal Insulation Materials

Thermal Insulation Material Name	Embodied Carbon (kgCO2eq/kg)	Embodied Energy (MJ.e/kg)
Extruded Polystyrene (XPS)[2]	5.37	70.80
Expanded Polystyrene (EPS)[3]	2.55	88.60
Cellular Glass (CG)2	0	27.00
Glasswool (GW)2	1.35	28.00
Rockwool (RW)2	1.05	16.80

Methodology for Multiple Criteria Decision Making on Alternatives

Decision making, as a cognitive process of selecting an option or multiple options among several alternatives, can be addressed as a problem-solving method within a situation. In other words, decision making is described as the study of identifying and choosing alternatives based on the values and preferences of the decision maker[4]. Since there may be several alternative choices to be considered, decision making focuses on selection of the one that best fits with the aim, objectives, and limitations.

Before taking the steps of a decision making process, it is important to identify the decision maker(s) and stakeholder(s) in the process, the structure of the problem, variables and the alternatives, and which model would best fit to the problem's situation. In a decision model where only one optimal solution is obtained, the result may not be satisfactory and explanatory from the points of view of multiple decision makers. It is also discussed by Wang et al. (2005: 1512–25) that, a mismatch between a specific optimization model and design practice may occur in terms of variables such that the exact thermal resistance value of a window may not exist in the market or a given time lag of a wall may not correspond to the solution of the designer.

Multi-criteria decision making (MCDM) methods deal with the process of making decisions in the presence of multiple objectives, (Pokehar et.al, 2004: 365-81). Objectives can be qualitative or quantitative, with the same or different levels of dependency. A MCDM can be either multi-attribute decision making (MADM) or multi-objective decision making (MODM). MADM problems are dis-

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[2] http://www.jackoninsulation.com/uploads/tx_wwdownloads/XPS_Foam_Insulation_Jakodur_plus_03.pdf

[3] http://www.greenspec.co.uk/building-design/embodied-energy/

[4] http://www.virtualsalt.com/crebook5.html

tinguished from MODM problems, which involve the design of a "best" alternative by considering the trade-offs within a set of interacting design constraints, (Baker, D., et al., 2002: 1-40). MADM is based on selecting the best alternative by ranking a finite number of alternatives, where MODM is expressed by a continuous function.

There are numerous MADM methods, representing different mathematical approaches. However, MADM methods have common characteristics such as there are multiple alternatives with multiple attributes. In addition, generally all MADM methods require information regarding the relative importance of each criterion. Many of the MADM methods have a complex mathematical structure so that there are difficulties in the application of such methods in the building sector where the stakeholders are not experts in the field of decision making. The weighted Sum Method (WSM) is the selected MCDM method for this study, due to its simplicity of application. WSM is a MADM ranking method, where the best alternative is selected by the sum of n number of criteria ranking weights within m alternatives. It can be expressed by the following equation, where a and w are the actual value and weight factor of the j^{th} criteria given for the i^{th} alternative, respectively.

$$A_{WSM} = Max \sum_{i}^{j} \left(a_{ij} w_j \right) \qquad (1)$$

In the methodology, all scenarios occurring by parameterization are calculated in terms of life cycle cost and primary energy consumption through the 30 years life span. Cost optimal point is determined through the EPBD methodology and the efficient frontier cases are obtained for each insulation material, which are the optimal alternatives that demonstrate the highest energy efficiency with the lowest cost. It is considered that the frontiers are the dominant cases of each insulation material alternative set, thus alternatives which are not frontier are eliminated in the methodology. Moreover, frontier alternatives beyond the cost optimal point are listed with high performance building design criteria as: investment cost, primary energy consumption, and environmental performance values for the multiple criteria decision making.

Another common characteristic of MADM methods is that, the attributes may have different units of measurements. In this case, in order to be compared with each other, all criteria values are normalized with a "min-max normalization" technique in order to obtain comparable data. The equation (2) used for the min-max normalization is given below. According to the equation, the difference between the value (x) and the minimum value of the data set is divided to the difference between the maximum and the minimum value of the data set and the normal. So that, the maximum value was normalized to 1, where the better alternatives have a value between 0 and 1.

$$x' = \frac{x-\min(x)}{\max(x)-\min(x)} \qquad (2)$$

Further, normalized values of criteria were summed in order to obtain the total score of the alternatives. In this step, weighting factors of each criteria were considered as equal. Finally, best alternatives are determined for the decision maker, in order to develop a building design with high performance. Steps of the decision making approach are represented as a flow chart in Figure 4.

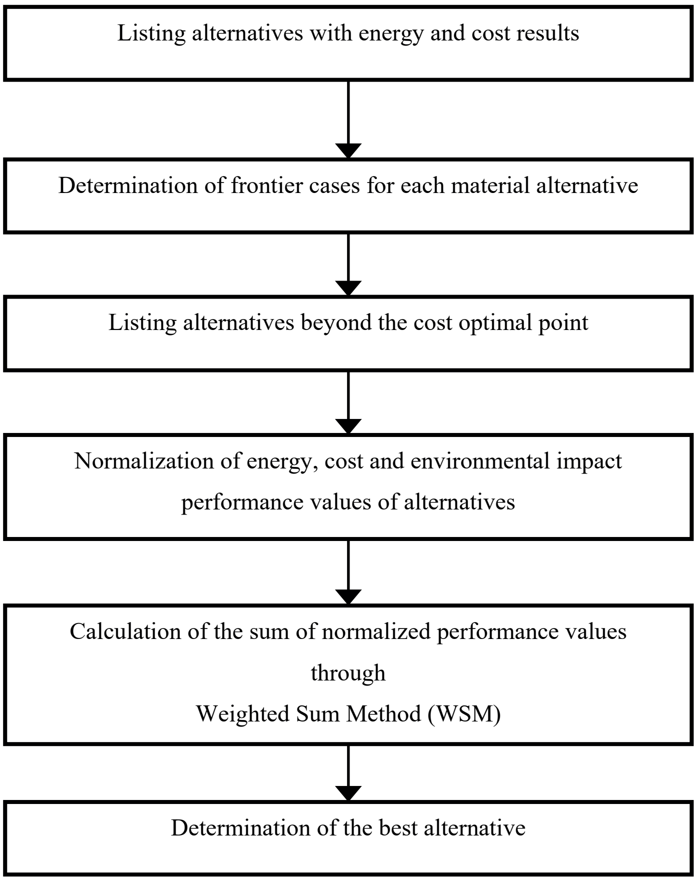

Figure 4. Methodology of the Decision Making Process

RESULTS

The analyses were done on a social housing archetype, considered to be situated in temperate-dry climatic region of Turkey. Five thermal insulation materials, five thickness variations, with three glazing types and three window to wall ratios were analysed resulting in a total of 225 scenarios.

Listing the 225 alternatives with energy and cost results are represented in Figure 5, below. The current requirement level (base case with reference values), cost optimal level and the highest energy efficiency levels are also marked in Figure 5, in order to determine the key values of the outputs. According to the results, primary energy consumption varies between 124.01 kWh/m^2.a and 170.62 kWh/m^2.a, where the life cycle cost varies between 588.5 TL/m^2 and 725.36 TL/m^2 for a 30 year life span. The cost optimal case has a 130.89 kWh/m^2 primary energy consumption and

588.5 TL/m^2.a LCC, where the energy efficient case has a 124.01 kWh/m^2.a energy consumption and 625.21 TL/m^2 LCC. Besides, the current requirement level has a 167.18 kWh/m^2.a energy consumption and 642.68 TL/m^2 LCC.

Properties of the cost optimal, highest energy efficient and current requirement levels are also highlighted in Figure 5. According to the results, the cost optimal and the highest energy efficient level have triple glazing with 12cm EPS and 20cm XPS, respectively. The cost optimal insulation level is determined as 12 cm for EPS and 8 cm for XPS, rock wool, glass wool and foam glass.

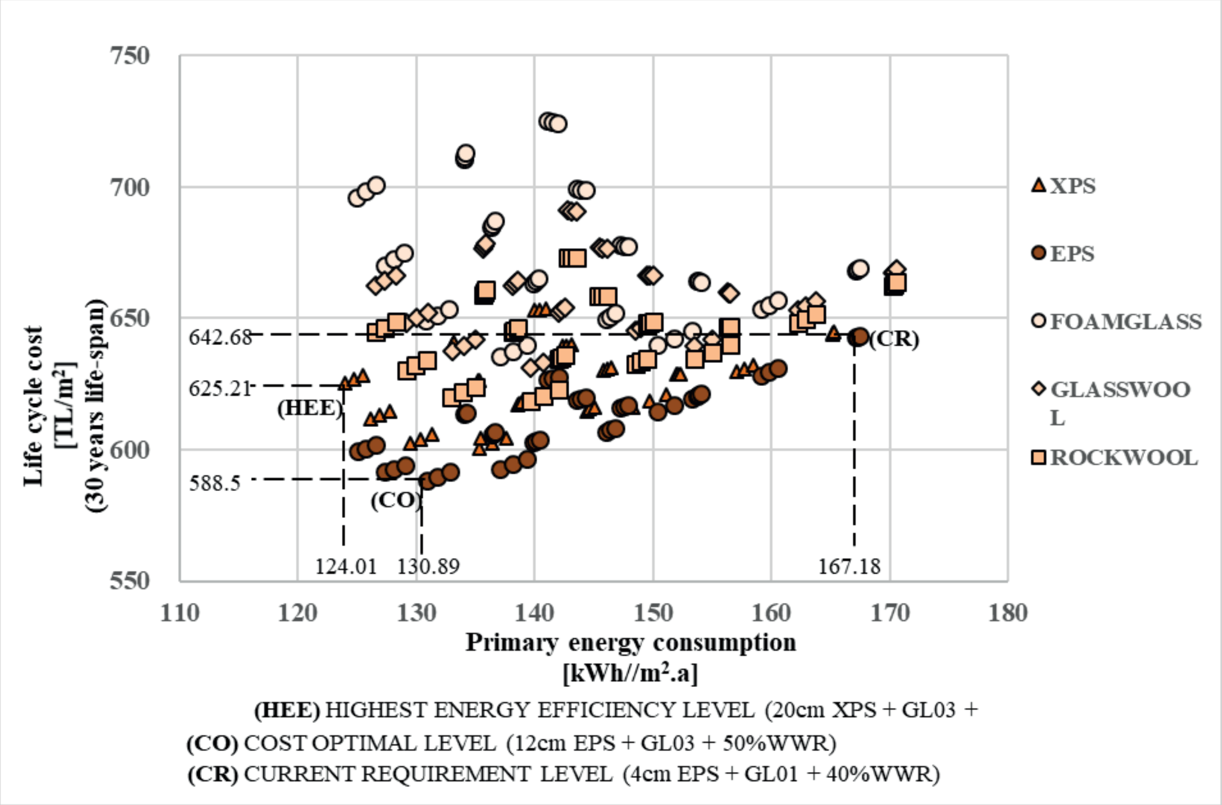

Figure 5. Primary Energy Consumption and Life Cycle Cost of 225 Alternatives

In the second step, the efficient frontiers of each insulation material are determined. The efficient frontiers are computationally determined within the two data fields (primary energy consumption and life cycle cost) as described below:

- the alternatives are sorted by life cycle cost and ranked by energy consumption.

- if the ranking of the alternative n is higher than the previous and highest rank so far, then it lies on the efficient frontier.
- if the ranking is less, then it does not lie on the efficient frontier.

Figure 6 represents the life cycle energy consumption and cost calculation results of 19 efficient frontier cases within the 225 alternatives.

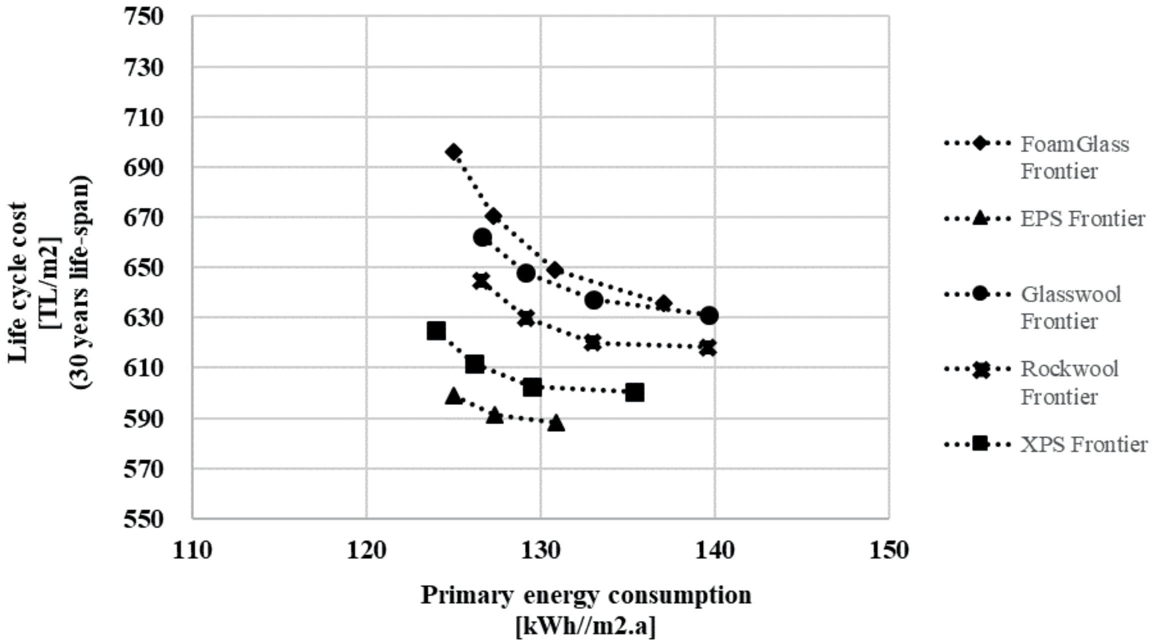

Figure 6. Primary Energy Consumption and Life Cycle Cost of Efficient Frontiers

According to the efficient frontiers, the primary energy consumption varies between 124.01 kWh/m^2 and 139.67 kWh/m^2. In comparison with the current requirement level, all frontiers occur above the requirement level. Moreover, the life cycle cost of the frontiers varies between 695.99 TL/m^2 and 588.49 TL/m^2. Thus, the alternatives that are selected through the efficient frontier method represent a wide range with a high performance in terms of either energy or cost. In the third step, frontiers are eliminated according to the cost optimal threshold level determined in the first step.

A total of 13 out of 19 frontiers, which are beyond the threshold (cost optimal point) are determined and listed in Table 7 below. According to Table 7, the selected frontiers have an insulation thickness between 12cm and

20cm with a variation of five insulation materials. Additionally, the U values of the frontiers vary between 0.15 W/m^{2}K and 0.31 W/m^{2}K. All cases have W03 window type and 50% window to wall ratio significantly.

In the fourth step, 13 alternatives were listed with decision making criteria as investment cost, primary energy consumption and environmental performance values. To compare with each other, all criteria values are normalized by the equation (2). Further, normalized values of criteria were summed in order to obtain the total score of the alternatives. In this step, weighting factors of each criterion was considered to be equal.

The results of the WSM are given in Figure 7, also showing the distribution of the performance criteria values. The total WSM score varies between 0.904 (best alternative) and 1.574 (worst alternative). It is clear that the order of the frontiers is significantly changed by the environmental performance effect. The frontiers are ordered according to the total WSM score in Figure 7.

Table 7. Independent Variables of Efficient Frontiers beyond the Cost Optimal Level

Alternatives	**Insulation Material**	**Insulation Material Thickness (cm)**	**Window Type**	**Window to Wall Ratio (%)**
1 F*	XPS	20	Window type 03	50
2 F	Foamglass	20	Window type 03	50
3 F	EPS	20	Window type 03	50
4 F	XPS	16	Window type 03	50
5 F	Rockwool	20	Window type 03	50
6 F	Glasswool	20	Window type 03	50
7 F	Foamglass	16	Window type 03	50
8 F	EPS	16	Window type 03	50
9 F	Rockwool	16	Window type 03	50
10 F	Glasswool	16	Window type 03	50
11 F	XPS	12	Window type 03	50
12 F	Foamglass	12	Window type 03	50
13 F**	Rockwool	12	Window type 03	50

*** U Value: 0.15 W/m^{2}K ** U Value: 0.28 W/m^{2}K**

Results indicate that, when the environmental criteria are considered with the proposed methodology, the highest energy efficient case (1F: 20cm XPS) moved to 4th position with its WSM score. On the other hand, the best alternative of the WSM (3F: 20cm EPS) becomes significant with its low life cycle cost.

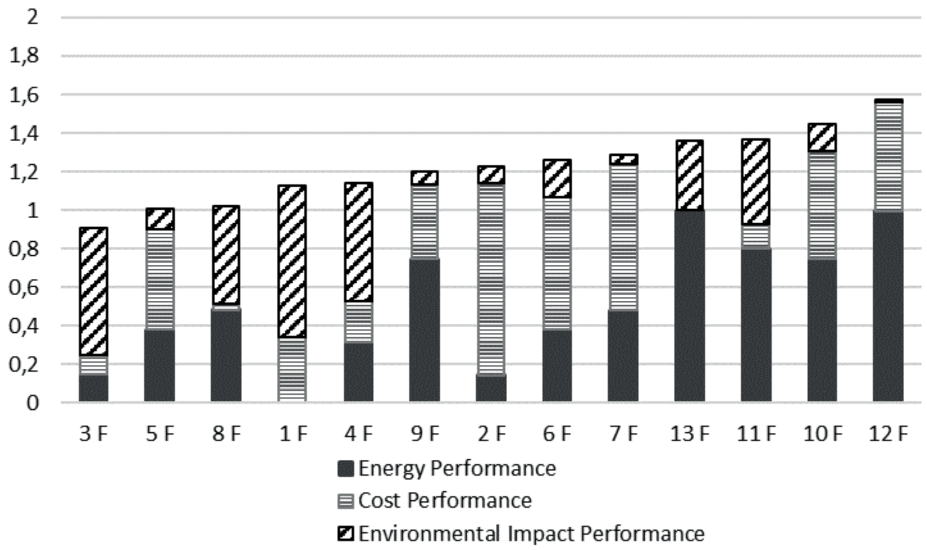

Figure 7. WSM Score Distribution According to the Performance Criteria

Within the 13 frontiers, when high energy performance is targeted, either the cost or the environmental criteria become significantly dominant, highlighting that if a high insulation level has a good environmental performance then it requires higher costs and if the cost performance is good then it has a high environmental impact. This indicates that, the methodology substantially affects the decision making by considering multiple criteria.

When the best alternatives of the decision making are analysed, it is observed that rock wool and glass wool occur frequently with mostly 12cm, 16cm and 20cm thicknesses. Moreover, foam glass insulation, which generated the highest frontier in the second step, comes into prominence by its environmental performance, as seen in Figure 7.

From another point of view, the 8F case (16cm EPS) is significant with the balance between the environmental and energy performance scores. Besides, this case is also significant with its low LCC (2nd lowest LCC case). Thus, 8F becomes significant by the harmony of three performance scores, in addition to its total WSM score. Since the total WSM score of the first three alternatives are close to each other, it can be determined that the 8F has a higher performance by its sub-scores balance.

In addition, prominent alternatives of the decision making commonly comprise window type 3, with 50% window to wall ratio, presenting the importance of the window type selection together with the opaque wall design. When high thickness of thermal insulation is considered, the cost of opaque walls becomes significant and should be evaluated with the whole envelope design.

CONCLUSION

Estimation of building performance might be essential in building projects where the indicators of building performance are crucial. Housings, which are buildings such as apartments or units assigned for residence, are one of the main cases, since the amount of housing stock within the whole building stock has a great amount. As analyzed, urbanization and social housings has an important impact on the embodiment of 'housings'.

The requirements of social housings such as low investment costs for states and low operating costs for low-income group occupancies signify the importance of performance estimation for social housings.

The results indicate that proper decision making in the selection of thermal insulation materials for buildings, with different environmental and economic attributes, ensures higher performances for buildings. The proposed approach influences the selection of the best alternative, which allows the personal preferences of the decision maker without digressing from the scope of EPBD.

The study was limited with 5 insulation materials and total 225 scenarios. An extension on the number of materials, so that the attributes, will enrich the results of the study.

It is clear that the methodology used in multiple criteria decision making and the weighting factors of the criteria are quite substantial and effective on the results of the decision. The study should be improved by assigning different weighting factors to decision making criteria, in order to identify the deviations due to the different weighting factors. Further studies can also be conducted with different decision making methods, and variations of the criteria and weighting factors can be analysed.

REFERENCES

ADITYA, L., MAHLIA, T.M.I., RISMANCHI, B., NG, H.M., HASAN, M.H., METSELAAR, H.S.C., MURAZA, O., ADITIYA, H.B., (2017). A review on insulation materials for energy conservation in buildings. Renewable and Sustainable Energy Reviews, 73, 1352-1365. doi:10.1016/j.rser.2017.02.034

ALTAN DOMBAYCI, Ö., GÖLCÜ, M., PANCAR, Y., (2006). Optimization of insulation thickness for external walls using different energy-sources. Applied Energy, 83, 921-928

BAKER, D., BRIDGES, D., HUNTER, R., JOHNSO,N G., KRUPA, J., MURPHY, J. AND SORENSON, K., (2002). Guidebook to Decision Making Methods, WSRC-IM-2002-00002, Department of Energy, USA, 1-40. http://emi-web.inel.gov/Nissmg/Guidebook_2002.pdf

BRAULIO-GONZOLA, M., BOVEA, M.D., (2017). Environmental and cost performance of building's envelope insulation materials to reduce energy demand: Thickness optimization. Energy and Buildings, 150, 527-545

BISWAS, K., SHRESTHA, S.S., BHANDARI, M.S., DESJARLAIS, A.O., (2016). Insulation materials for commercial buildings in North America: An assessment of lifetime energy and environmental impacts. Energy and Buildings, 112, 256-269

CEN [EUROPEAN COMMITTEE FOR STANDARDIZATION], (2007). EN ISO 15459:2007. Energy performance of buildings – Economic evaluation procedure for energy systems in buildings. Brussels: Belgium; 2007, p.5-15

DIRECTIVE 2002/91/EU. the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings, 1-7

DIRECTIVE 2010/31/EU. the European Parliament and the Council of 19 May 2010 on the Energy Performance of Buildings (recast), 1-23

KORKMAZ, M., ALACAHAN, N.D. (2014). Financial research of efficiency of insulation systems about heat, moisture and sound in physical protection of today's structures. International Refereed Journal of Design and Architecture, Issue: 01, vol.01, 1-26

LEE, J., KIM, J., SONG, D., KIM, J., JANG, C., (2017). Impact of external insulation and internal thermal density upon energy consumption of buildings in a temperate climate with four distinct seasons. Renewable and Sustainable Energy Reviews, 75,1081-1088

LUCCHI, E., TABAK, M., TROI, A., (2017). The "Cost Optimality" Approach for the Internal Insulation of Historic Buildings. Energy Procedia, 133,412-423

MAHLIA, T.M.I., IQBAL, A., (2010). Cost benefits analysis and emission reductions of optimum thickness and air gaps for selected insulation materials for building walls in Maldivs. Energy, 35, 2242-2250

MANGAN, S.D., ORAL, G.K., (2016). Assessment of residential building performances for the different climate zones of Turkey in terms of life cycle energy and cost efficiency. Energy and Buildings 110, 362-376

MENYHART, K., KRARTI, M., (2017). Potential energy savings from deployment of Dynamic Insulation Materials for US residential buildings. Building and Environment, 114,203-218

MOHSEN, M.S., AKASH, B.A., (2001). Some prospects of energy savings in buildings. Energy Conversion and Management, 42, 1307-1315

NEMATCHOUA, M.K., RICCIARDI, P., REITER, S., YVON, A., (2017). A comparative study on optimum insulation thickness of walls and energy savings in equatorial and tropical climate. International Journal of Sustainable Built Environment, 6, 170-182

POKEHAR, S.D., RAMACHANDRAN, M., (2004). Application of multi-criteria decision making to sustainable energy planning – A review. Renewable and Sustainable Energy Reviews 2004;8 :365-81

SEZER, F.Ş. (2016). Parameters that effect efficiency in heat insulation and a suggestion for system design for heat insulation applications in Turkey. International Refereed Journal of Design and Architecture, 09, 88-96

SIMONA, P.L., SPIRU, P., ION, I.V., (2017). Increasing the energy efficiency of builidngs by thermal insulation. Energy Procedia, 128,393-399

TETTEY, U.Y.A., DODOO, A., GUSTAVSSON, L., (2014). Primary energy implications of different wall insulation materials for buildings in a cold climate. Energy Procedia, 61, 1204-1207

TETTEY, U.Y.A., DODOO, A., GUSTAVSSON, L., (2017). Effects of different insulation matrials on primary energy and CO2 emissions of a multi-storey residential building. Energy and Buildings, 82, 369-377

TS 825 (2008). Thermal Insulation Regulation for Buildings. May 2008, p.30

TUBELO, R., RODRIGUES, L., GILLOTT, M., SOARES, J.C.G., (2018). Cost-effective envelope optimization for social housings in Brazil's moderate climates zones. Building and Environment 133, 213-227

TURKEY (BEP-TR) REFERENCE BUILDING DEFINITION GUIDELINE, (2008). Turkish Ministry of Public Works and Settlement, Building's Energy Performance of, Official Gazette, No: 27075, p.1-11

WANG, W., ZMEUREANU, R., RIVARD, H., (2005). Applying multi-objective genetic algorithms in green building design optimization, Building and Environment 2005;40:1512–25.

YILMAZ, Y., ORAL, G.K., (2018). An approach for an educational building stock energy retrofits through life-cycle cost optimization. Architectural Science Review, 61:3,122-132 doi:10.1080/00038628.2018.1447438

YLMEN, P., MJÖRNELL, K., BERLIN, J., ARFVIDSSON, J., (2017). The influence of secondary effects on global warming and cost optimization of insulation in the building envelope. Building and Environment, 118, 174-183

İNTERNET KAYNAKLARI

https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf (E.T. 16.10.2018)

http://www.jackoninsulation.com/uploads/tx_wwdownloads/XPS_Foam_Insulation_Jakodur_plus_03.pd (E.T. 16.10.2018)

http://www.greenspec.co.uk/building-design/embodied-energy/ (E.T. 16.10.2018)

http://www.virtualsalt.com/crebook5.html (E.T. 16.10.2018)