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ENERGY-SAVING RETROFITTING OF HOUSES IN COLD CLIMATES

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Abstract: Built environment is a problematic issue from an energy use perspective because an important part of total energy consumption in countries is usually caused by existing buildings. Current buildings stock constructed before 2000 in Turkey is mostly thermally poor and current standards related to energy efficiency in buildings are relatively not enough when compared with international examples. In this research, impacts of various energy efficient measures on heating for an existing detached two-storey house located in cold climate, Eskisehir-Turkey are analyzed to find possible energy saving rate by using DesignBuilder and EnergyPlus software. Firstly, energy consumption profile for base case is simulated then, effect of defined energy efficient measures on total heating energy consumption is investigated. Lastly, life cycle approach is applied to make an economic analysis and estimating payback period for energy efficient measures. As a result, the highest energy saving (37%) for heating was obtained by the application of thermal insulation on external wall, floor and ground floor and replacement of current windows. In addition, the payback period of energy efficient measures are more than 10 years; thus, the government should support energy efficient retrofitting of existing buildings in Turkey.
Keywords: Heating, energy efficient retrofitting, life cycle cost analysis, residential building.

SOĞUK İKLİMLERDEKİ KONUTLARIN ENERJİ ETKİN YENİLENMESİ

ÖZET: Enerji kullanımı açısından bakıldığında yapılı çevre sorunlu bir konudur çünkü ülkelerin toplam enerji tüketimlerinin önemli bir kısmı mevcut binalarda tüketilen enerjiden kaynaklanmaktadır. Türkiye'de özellikle 2000 yılından önce inşa edilmiş binaların çoğu yapı fiziği açısından zayıf ve binalarda enerji verimliliği ile ilgili standartlar yeterince uygulanmayabilmektedir. Bu çalışmada, 1980'li yıllarda Eskişehir'de inşa edilmiş yalıtımsız iki katlı konutun ısıtma enerjisi tüketimindeki değişim, çeşitli enerji etkin iyileştirme önerileri doğrultusunda, DesignBuilder ve EnergyPlus simülasyon (benzetişim) programları kullanılarak hesaplanmıştır. Öncelikle, konutun mevcut durumda m^2 başına tükettiği ısıtma enerjisi miktarı hesaplanmış, sonra enerji-etkin tasarım bağlamında önerilen yenileme önlemlerinin ısıtma enerjisi tüketimine etkisi incelenmiştir. Son olarak ise yaşam döngüsü yaklaşımı uygulanarak ekonomik analiz yapılmış ve enerji etkin önlemlerin geri ödeme süreleri bulunmuştur. Söz konusu araştırma sonucunda, ısıtma amaçlı en yüksek enerji tasarrufu (%37) dış duvarlara, giriş ve 1. kat zeminine ısı yalıtımı uygulandığında ve mevcut pencerelerin ısı kontrol (low-e) kaplamalı camlara sahip pencerelerle değiştirilmesi sonucu elde edilmiştir. Ayrıca uygulanan yaşam döngüsü analizi ile geri dönüşüm sürelerinin yaklaşık olarak 10 yıldan fazla olduğu görülmüştür. Bu nedenle yapı sahiplerini teşvik edici düzenlemeler (vergi indirimi, kredi kolaylığı, vb.) oluşturulabilir.
Anahtar kelimeler: Isıtma, enerji etkin yenileme, yaşam döngüsü analizi, konutlar.

INTRODUCTION

Nowadays, reduction of energy consumption and efficient use of energy is an important subject for most countries in the world. Building sector is one of the major fields where world total energy consumption takes place. As it is known, one of the objectives of the European Union is to reduce carbon dioxide emissions by 20% at least until 2020 (Saikku et. al., 2008). Therefore it is planned to reduce energy consumption rates in existing and newly constructed buildings with new regulations and by increasing interest in energy efficiency.

In Turkey, energy efficient measures are usually taken to prevent heat losses in buildings because of TS 825 Thermal Insulation Regulation in Buildings (TS-825) (2000) which is compulsory since 2000 but energy for space heating is still almost twice as much as the sum of other domestic energy consumption (cooking, hot water, freezing) (Kaynakli, 2008). Energy efficiency in buildings has started to be evaluated with a holistic approach with BEP TR (Building Energy Performance) application since 2011. Additionally, there are lots of existing buildings constructed before 2000 in Turkey that they do not have enough measures to reduce energy consumption. Thus, energy performance of existing buildings should be improved. In other words, retrofitting of existing buildings is essential and urgent issue. Buildings-stock mostly consists of residential buildings in Turkey. For that reason, retrofitting studies should be started from residential buildings and they can lead to a considerable reduction in total energy consumption in Turkey.

This study focuses on various energy efficient measures which can potentially be applied in cold climates in Turkey. Analyses of reduce energy demand of existing houses for heating by energy-saving retrofitting measures are the purposes of this study. Properly applied retrofitting measures can significantly reduce energy consumption. In addition, life cycle cost analysis was performed to predict payback periods for energy efficient measures.

METHOD

In this study, firstly an existing house is investigated from Eskisehir where heating season is longer than cooling season. Then geographical and climate features of Eskisehir are explained. Additionally, investigated house is introduced with termophysical features of building components. Indoor temperature and relative humidity are measured between 10 October 2010 and 3 March 2011 with HOBO data logger in three spaces of house. Then, they are shown with graphics. Furthermore, existing house is modeled by using DesignBuilder v2.04.002 program and assumptions are explained. Lastly, appropriate energy efficient measures are determined. Impact of them is calculated with DesignBuilder and life cycle cost analysis is made to estimate payback period of energy efficient measures.

Life Cycle Cost Analysis

The life-cycle cost analysis (LCCA) can be defined as follows: An economic assessment of alternative designs, construction or other investments, comparing the sum of all significant returns, initial costs, operating costs and maintenance costs over economic life of each alternative expressed in equivalent economic units.

Prior to beginning a LCCA, project alternatives need to be established. These alternatives should be distinctly different and viable solutions to the facility issue being addressed. The chosen alternative is the most reasonable and cost-effective solution to the project problem. A minimum of three different project alternatives should be incorporated into the LCCA. A brief description of each project alternative and the reason of this selection should be included in the LCCA. The life-cycle cost of a project can be calculated using the formula:

$$LCC = C + M + E + R - S \quad (1)$$

- The capital cost (C) of a project includes the initial capital expense for equipment, the system design, engineering, and installation. This cost is generally considered as a single payment occurring in the initial year of the project, regardless of how the project is financed.
- Maintenance (M) is the sum of all yearly scheduled operation and maintenance (O&M) costs. Fuel or equipment replacement costs are not included. O&M costs include such items as an operator's salary, inspections, insurance, property tax and all scheduled maintenance.
- The energy cost (E) of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used.
- Replacement cost (R) is the sum of all repair and equipment replacement cost anticipated over the life of the system.
- The salvage value (S) of a system is its net worth in the final year of the life-cycle period.

Future costs must be discounted because of the time value of money. Real discount factor can be found by using the formula:

$$\text{Real interest rate} = (1+\text{nominal interest rate}) / (1+\text{inflation rate}) \quad (2)$$

The formula for the future sum of Money (F) of a present worth (P) in a given year (n) at a real discount rate (i) is:

$$F = P*(1 + i)^n \quad (3)$$

Geographical and Climate Features of Eskisehir

Eskisehir (30°32' East longitude, 39°46' North latitude) is located in the north-west of the Central Anatolia in Turkey. It has a harsh and dry continental climate. Thus winters are snowy and summers are hot and dry. At the same time, there is a significant difference in temperature between day and night. The average annual temperature is 10.8°C. While January with 0°C is the coldest month of the year, July with 21.7°C is the hottest month of the year. The mean, lowest and highest recorded monthly air temperatures are shown in Figure 1 (Turkish State Meteorological Service, 2011). Other climate data belonging to Eskisehir are summarized in Table 1 (Kılıç and Öztürk, 1980; Devlet Meteoroloji İşleri Genel Müdürlüğü Bülteni, 1974).

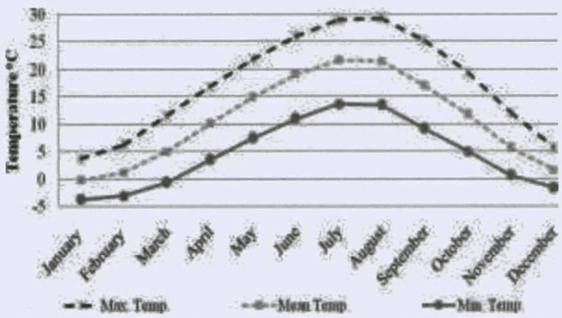

Figure 1. Monthly temperatures for Eskisehir (1975-2010)

Table 1. Monthly climate data for Eskisehir (1929-1970)

Months	Sunshine duration (h/day)	Solar radiation (MJ/m^2.day)	Relative humidity (%)	Mean wind speed (m/s)	Rainfall (mm)
Jan	2,45	5,1	80	3,0	43,6
Feb	3,38	8,2	78	3,0	38,3
Mar	4,58	12,5	71	3,3	38,5
Apr	6,49	16,4	63	3,2	34,7
May	8,53	21,5	63	2,8	45,1
June	10,5	23,9	59	2,7	36,6
July	12,3	24,7	54	3,0	12,1
Aug	11,3	21,8	54	2,9	4,7
Sep	9,15	17,5	59	2,5	18,4
Oct	6,48	11,3	66	2,0	22,2
Nov	4,29	7,0	75	2,1	29,4
Dec	2,32	4,3	81	2,7	50,0

Building Description

Existing house is two floors and ground floor was constructed between 1956 and 1957. Then first floor was added in 1980. Ground floor is approximately 70 m^2 and first floor is 100 m^2. House had not thermal insulation. External walls consist of plaster (3 cm), brick (19 cm) and plaster (2 cm) with U value of 2.015W/m^2K. Ground floor has a U value with 1.737 W/m^2K and roof has a U value with 4.129 W/m^2K. Windows compose of wooden frame and single glazing (6.121 W/m^2K). All U values for building components are not within the limits defined in TS-825, it was built before it became compulsory. The maximum U values shown in TS-825 for Eskisehir are 0.5 W/m^2K for external wall, 0.3 W/m^2K for roof, 0.45 W/m^2K for ground floor and 2.4 W/m^2K for window.

The examined house was renovated in 2004 by insulating the external wall with 4 cm XPS (U: 0.598 W/m^2K) and by insulating the roof with 10 cm glass wool (U: 0.365 W/m^2K). Despite of these measures, U values are still not within limits specified in TS-825. Existing windows were replaced by double clear glazing. In addition, entrance and balcony of first floor was closed after 2004, which is named as buffer zone (Fig. 3). No change was made in the ground floor. Original and renovated floor plans of house are shown in Figure 2.

The house is heated with natural gas by using floor standing boiler and no device is used for cooling in summer. Natural gas consumption rate in 2010 is indicated in Figure 4. It is clear that maximum energy demand for heating takes place in January. Natural gas is only necessary for hot water in summer.

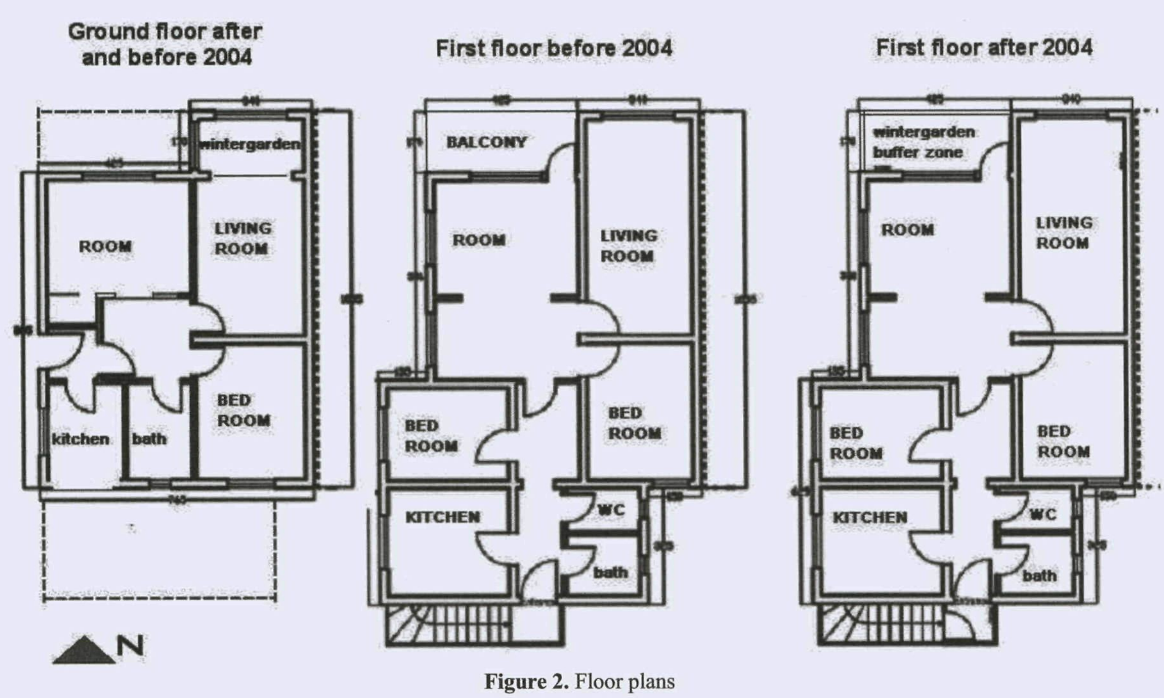

Figure 2. Floor plans

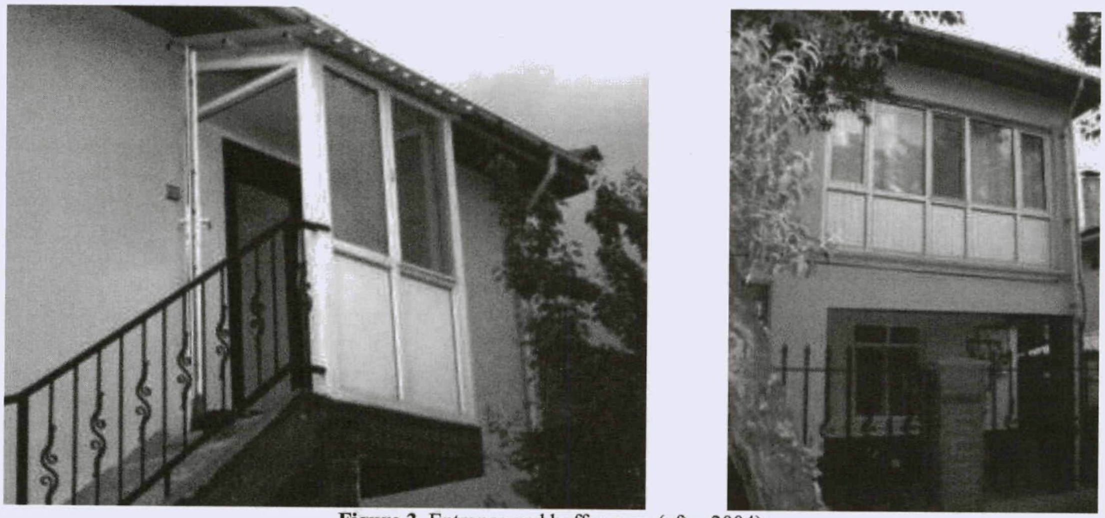

Figure 3. Entrance and buffer zone (after 2004)

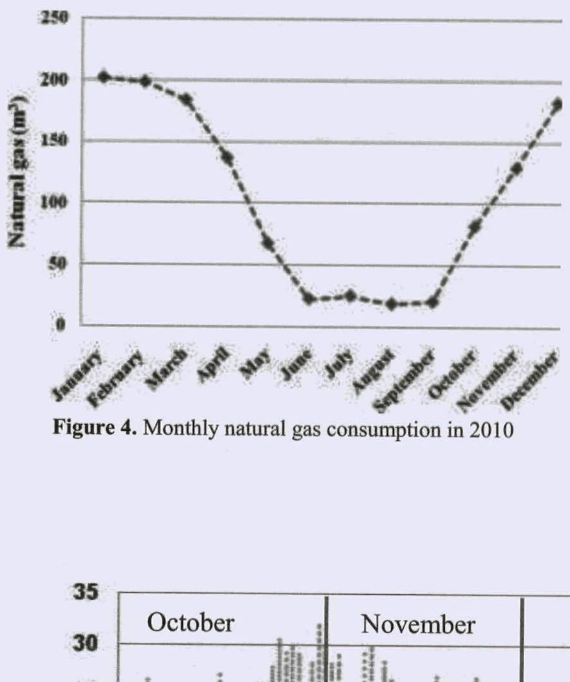

Figure 4. Monthly natural gas consumption in 2010

Evaluation of Indoor Temperature and Relative Humidity Measurements

Temperature and relative humidity were measured in entrance, living room, and buffer zone of first floor with HOBO RH/Temp/Light/External data logger during the five months (10 October 2010 – 3 March 2011) at intervals of 10 minutes. The measuring accuracy of HOBO data logger is ±0.7 °C for temperature and ±%5 for relative humidity.

Data loggers are placed on the walls at a height of 1.5 m from the ground. In addition, a data logger is used to measure outdoor temperature and relative humidity between 10 October 2010 and 2 January 2011. Thus, record times between indoor and outdoor measurements are the same. Living conditions in house during the measurement were not restricted to reflect real life situation. The measurements are shown in Figure 5 and 6.

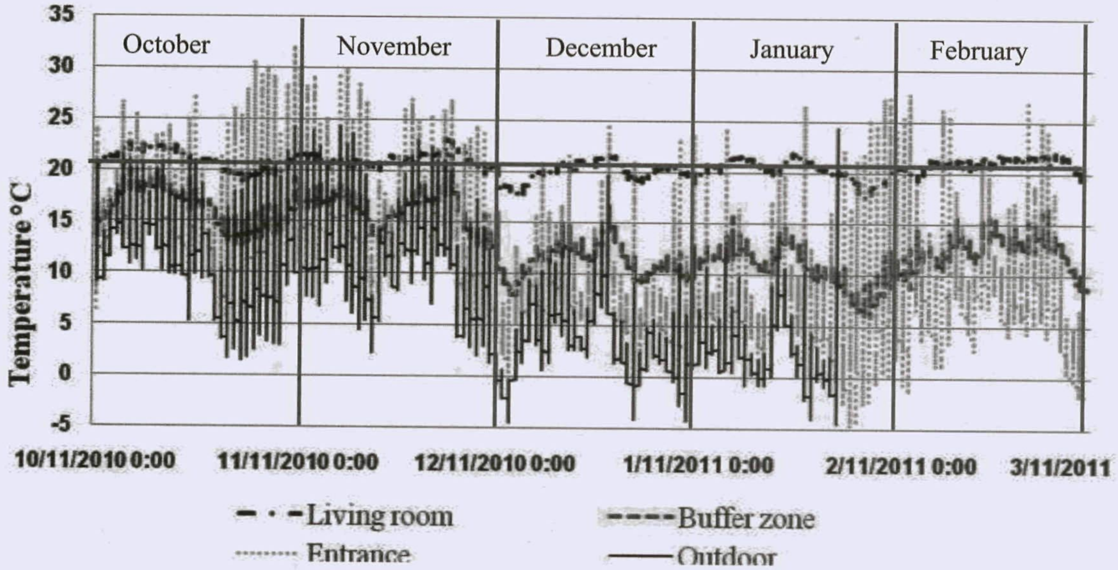

Figure 5. Measured indoor temperatures

It is clear from Figure 6 that temperature is different at each location. Minimum temperature fluctuation took place in the living room and temperature varies between 17.4 and 23.2°C. Thus the standard deviation is minimum in this place compared to others. Furthermore, temperature is usually within the comfort range in the living room. Temperature is lower than the 20°C in other spaces except the south facing entrance. High standard deviation and temperature fluctuation mostly occurs in entrance. Temperature varies between 6.1 and 21.7°C in buffer zone, -4.7 and 32.2°C in entrance and -4.5 and 24.4°C in outdoor. Average temperature is 20.7°C in living room, 13.3°C in buffer zone, 11°C in entrance and 7.7°C in outdoor. These results are also summarized in Table 2 by using statistical values.

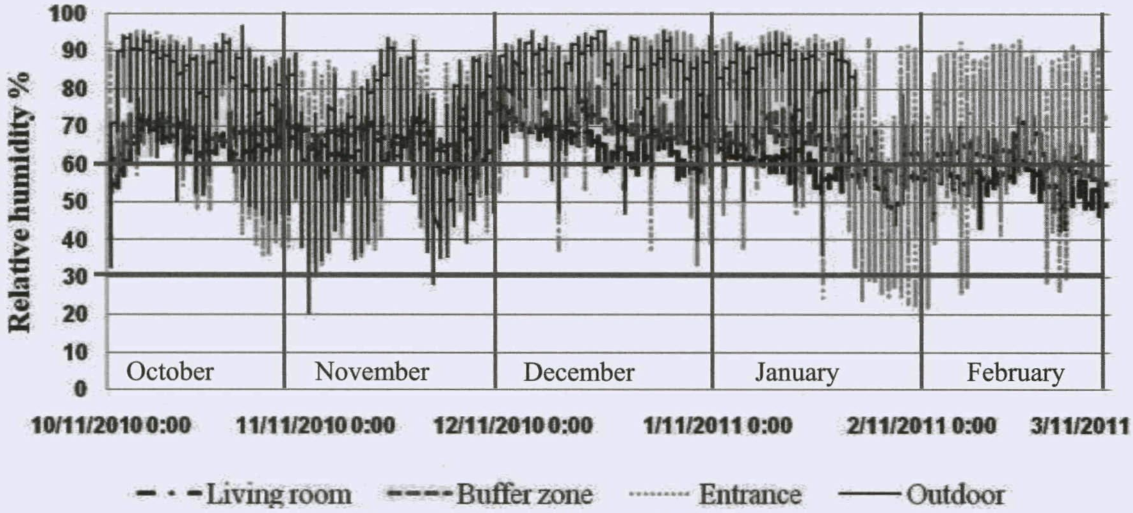

Figure 6. Measured indoor relative humidity

Relative humidity values are also different according to the measurement points. They vary between 42.7 % and 78.9 % in living room, 45.3 % and 86.2 % in buffer zone, 45.3 % and 86.2 % in entrance and, 18.6 % and 95.5 % in outdoor. Average relative humidity is 61.7 % in living room, 66.1 % in buffer zone, 69.2 % in entrance and 78.3 % in outdoor.

Table 2. Statistical values for temperature and relative humidity

Temperature	**Outside**	**Entrance**	**Buffer zone**	**Living room**
Minimum	-4.5	-4.7	6	17.4
Average	7.75	11	13.2	20.6
Maximum	24.4	32.2	21.7	23.2
Standard deviation	5.8	6.5	2.93	0.9
Relative humidity	**Outside**	**Entrance**	**Buffer zone**	**Living room**
Minimum	20.6	18.6	45.3	42.7
Average	78.3	69	66	61.7
Maximum	96.5	95.4	86	78.9
Standard deviation	13	14	4.45	5.72

Relative humidity fluctuation and standard deviation are the highest in entrance. According to ASHRAE Standard 55 – 2004 (2004) relative humidity values should be between 30 % and 60 % to provide thermal comfort in spaces. However, they are outside of this range. In December, relative humidity is usually over 60 % in house.

Creation and Validation of Thermal Model

Thermal model of current house was prepared by using DesignBuilder v2.04. DesignBuilder (DesignBuilder documentation, 2006) is a comprehensive user interface of EnergyPlus program. EnergyPlus (LBNL, 2011) is validated and powerful software to calculate energy consumption for heating, cooling, ventilating, lighting and carbon dioxide emissions.

A thermal model generated with DesignBuilder consists of different level. They are site, building, block, zone and surface. This organization is very helpful for users. For example, if a material of external wall is set in building level. This will be the default materials of all external walls for all blocks in the building. In block level, 3D model of a building can also be created. Examined house was divided into some thermal zones to prepare model. Thermal zones were constituted based on the original space division because there is no space in house. Firstly, existing house (no insulation) was modeled, than thermal model was updated depending on determined energy efficient retrofitting options. Also, non-insulated situation of current house was investigated. After 3D model was completed, necessary data about building components, the number of people living in house, site features, heating and cooling equipment and lighting devices were collected. At the same time each space was physically investigated. Then all data was integrated into the Design Builder. In this study, only the heating system and working hours were taken into account, for there is no equipment for cooling in house. Thermostat temperature for the heating system was set at 20°C and heating equipment works during all days in winter. Air infiltration rate was assumed as 1.5 air change rate per hour (ach) for first condition of house (no insulation). It was taken as 1 ach (air change rate) for thermal model of current house.

Building energy analysis programs are used for time dependent calculations. Therefore, they need hourly climate data. Climate data for Eskisehir was generated by using METEONORM (2011) program. It is a software providing hourly climate data for a location in the world.

Validation of thermal model is an essential and significant task to understand that results taken from simulation properly reflects current situation. In this research, indoor temperature of buffer zone is used for validation. Measured mean hourly indoor air temperature of a typical winter working day (3 January 2010) is compared with values taken DesignBuilder program (Fig. 7). It is clear that measured data is properly matching with simulated data. There is no considerable difference between them. Little difference should be considered as normal. It can be related to outdoor climate conditions because measured hourly climate data for one year was not available for Eskisehir.

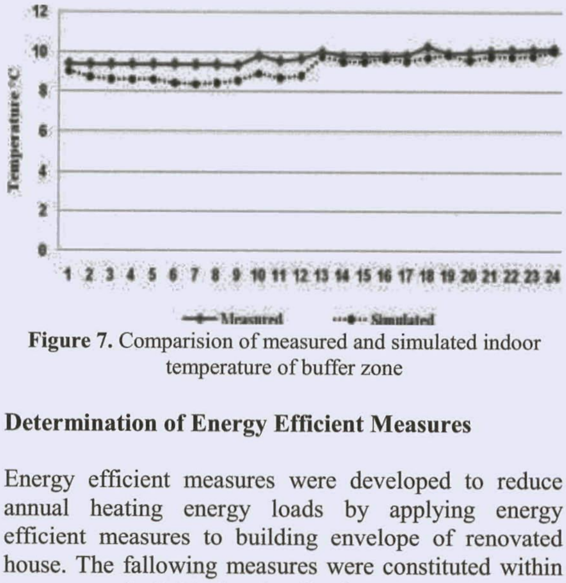

Figure 7. Comparision of measured and simulated indoor temperature of buffer zone

Determination of Energy Efficient Measures

Energy efficient measures were developed to reduce annual heating energy loads by applying energy efficient measures to building envelope of renovated house. The fallowing measures were constituted within two groups (individual and collective strategies):

Individual measures:

- Addition of 4 and 8 cm XPS on external wall.
- Addition of 6 cm XPS on ground floor.
- Addition of 4, 6 and 10 cm glass wool on roof.
- Addition of 6 cm XPS on floor exposed to outdoor conditions in first floor.
- Replacement of existing window with low-e (low emissivity) double glass-air (U: 1.772-SHGC (solar heat gain coefficient): 0.563) and low-e double glass-argon (U: 1,499-SHGC: 0.563).

Collective measures:

These were determined based on the results of individual measures. In other words, the individual measures were grouped to provide maximum benefit:

- Addition of 6 cm XPS on ground floor + 6 cm XPS on floor exposed to outdoor conditions in first floor.
- Addition of 6 cm XPS on ground floor + 6 cm XPS on floor exposed to outdoor conditions in first floor + 8 cm XPS on external walls.
- Addition of 6 cm XPS on ground floor + 6 cm XPS on floor exposed to outdoor conditions in first floor + 8 cm XPS on external walls + replacement of existing window with low-e double glass-air.

DISCUSSIONS AND RESULTS

Improvement of Thermal Insulation

As a result of simulations, it is seen that there are key differences between non-insulated and current situation of house in terms of annual heating energy loads. In current situation, annual heating load is less than 50% compared to non-insulated condition. At the same time, there are differences in annual heating loads consumed in ground and first floor. Approximately 10% more heating is needed on the ground floor.

Annual heating load can be reduced 8% in current house by adding 4cm XPS on external walls (Fig. 8). If 8cm XPS is added on external walls, annual heating loads may be less than 11% in house. The most important reason of this reduction is to decrease heat transfer from indoor to outdoor in winter with improvement of thermal insulation.

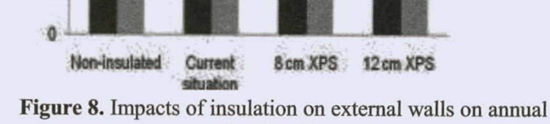

Figure 8. Impacts of insulation on external walls on annual heating load

It is clear that there is no considerable impact of increasing roof insulation on annual heating loads (Fig. 9). It may be concluded that existing insulation thickness is enough for roof. In other words, 10 cm glass wool is optimum thickness to prevent heat losses in buildings for Eskisehir in winter.

There is no insulation on ground floor. Thus, insulation thickness providing minimum limit shown in TS-825 was determined and its influence on annual heating load was calculated. The annual heating load decreased 25% compared to current situation by adding 6 cm XPS on ground floor (Fig. 10). In addition, it is seen that insulation in ground floor also decreased 2.5% annual heating load in first floor. It can be stated, that insulation on ground floor can affect heating energy loads in other floors. Especially in locations which have a long heating season, energy conservation is very important. Therefore, heat losses from building envelope should be minimized. 6 cm XPS was added on first floor exposed to outside. As a result of this, annual heating load reduced 15% in first floor. It also decreased 1.3% annual heating load on ground floor (Fig. 11).

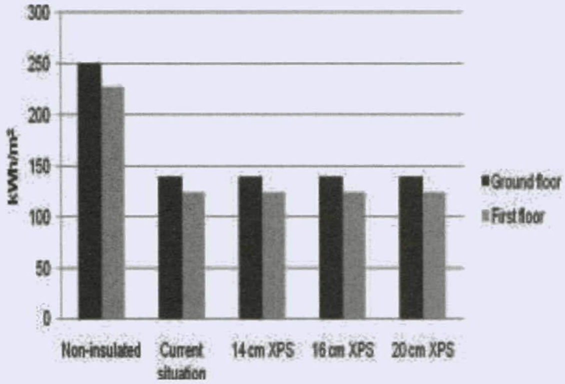

Figure 9. Impacts of insulation on roof on annual heating load

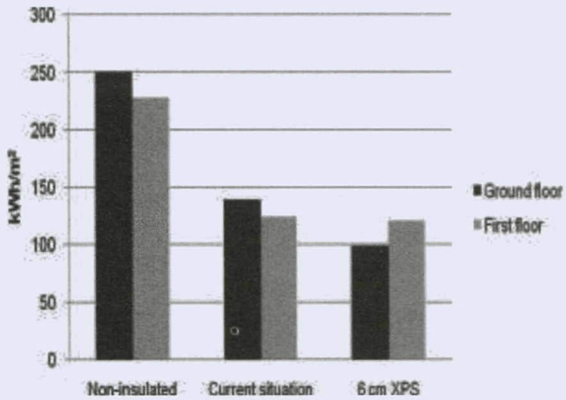

Figure 10. Impacts of insulation on ground floor on annual heating load

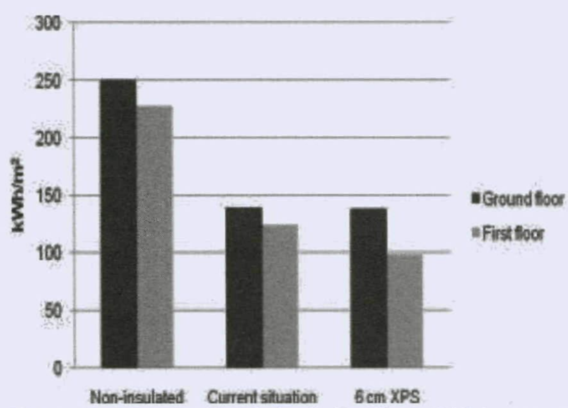

Figure 11. Impacts of insulation in first floor which is open to outside on annual heating load

Replacement of Existing Windows

Annual heating loads can be reduced by changing windows with energy efficient ones. Double clear window is used in current house. Annual heating load can be 3% less with replacement of windows with low-e double glass-air (Fig. 12). If argon gas is used instead of air in window annual heating load can be 4% less. For that reason, energy efficient windows should be preferred in buildings which especially have high window to wall ratio.

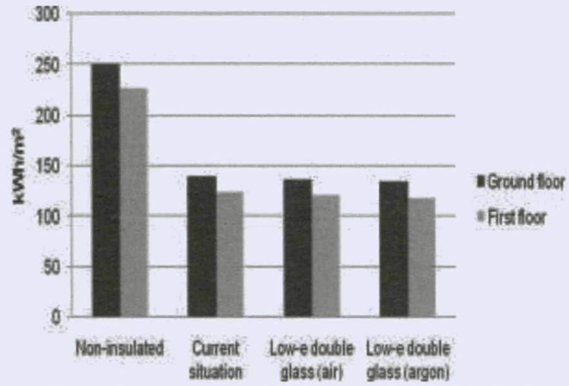

Figure 12. Impacts of windows on annual heating load

Grouping of Individual Measures

Individual measures mentioned above are grouped in three different ways. Firstly, 6 cm XPS was applied on ground floor and open parts of first floor to outside. Consequently, annual heating loads decreased 29.1% in ground floor and 23% in first floor. Secondly, in addition to first measurements, 4 cm XPS was implemented on external walls. Annual heating loads decreased 39.1% in ground floor and 31% in first floor thanks to extra improvements. Lastly, in addition to previous measurements, windows were replaced with low-e double glass-air and annual heating loads decreased 41% in ground floor and 34% in first floor (Fig. 13). It is possible to generate lots of different energy efficient groups, but in this study individual measures which are easy to implement and mostly affects energy consumption were grouped.

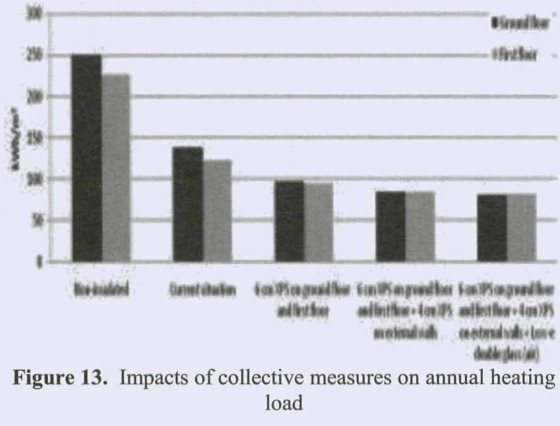

Figure 13. Impacts of collective measures on annual heating load

Life Cycle Costs for Energy Efficient Measures

Various scenarios are provided in this economic evaluation that use a life cycle cost (LCC) analysis to compare energy efficient measures. The analyzed energy efficient measures are non-insulated (case 1), current situation (case 2), 6cm XPS on ground floor and first floor (case 3), 6cm XPS on ground floor and first floor + 4 cm XPS on external walls (case 4), 6cm XPS on ground floor and first floor + 4 cm XPS on external walls + low-e double glass (air) (case 5). The main objective of this economic assessment is to investigate which case is economically feasible. In order to, identify the least cost feasible option for the alternatives a life-cycle costing analysis is carried out.

The input data and assumptions used for the economic analysis are tabulated in Table 3. Also, the analysis period is for 20 years, operation and maintenance costs, replacement costs and salvage value are assumed to be zero for all alternatives.

To compare alternatives, the net present value of 20-year life-cycle costs, life-cycle savings, and cumulative life-cycle savings were computed for each alternative, as shown in Table 4 and 5. Case 3 was found to have highest net present value of life-cycle saving, and lowest pay-back period. Case 3, 4, 5 have very similar life-cycle savings to each other. Payback period is 7 years, 8 years, and 8 years for Cases 3, 4 and 5 respectively. As a result we can say that Case 3 is the economically best alternative.

Table 3. The input data and assumptions

Scenarios	Total energy consumption per year (kWh)	Total energy cost per year (TL)	Initial cost (TL)
Case 1ground floor	16601.2037		
Case 1 first floor	23069.4269		
TOTAL	39670.6306	2854.36	0
Case 2ground floor	9229.408762		
Case 2 first floor	12544.7404		
TOTAL	21774.15	1566.65	9552.8
Case 3ground floor	6470.99461		
Case 3 first floor	9662.639422		
TOTAL	16133.634	1160.81	13710.82
Case 4ground floor	5647.78668		
Case 4 first floor	8634.260637		
TOTAL	14283.047	1027.67	17548.85
Case 5ground floor	5398.55289		
Case 5 first floor	8260.144446		
TOTAL	13658.6973	982.74	18866.42
Annual interest rate (%)	14 %		
Annual inflation rate (%)	10.43 %		
Natural gas cost	0.765564 TL/Sm^3		

Table 4. Energy costs and life-cycle costs of all scenarios

Year	Case 1	Case 2	Case 3	Case 4	Case 5	LCC-Case 1	LCC-Case 2	LCC-Case 3	LCC-Case 4	LCC-Case 5
1	2854.3	1566.65	1160.81	1027.67	982.74	2854.30	11119.45	14871.63	18576.49	19849.16
2	2946.58	1617.3	1198.34	1060.90	1014.51	2946.58	1617.30	1198.34	1060.89	1014.51
3	3041.84	1669.59	1237.08	1095.19	1047.31	3041.84	1669.59	1237.08	1095.19	1047.31
4	3140.19	1723.57	1277.08	1130.60	1081.17	3140.19	1723.56	1277.08	1130.61	1081.17
5	3241.71	1779.29	1318.36	1167.15	1116.13	3241.71	1779.29	1318.36	1167.15	1116.12
6	3346.51	1836.81	1360.99	1204.89	1152.21	3346.51	1836.81	1360.99	1204.89	1152.21
7	3454.71	1896.20	1404.99	1243.84	1189.46	3454.70	1896.20	1404.99	1243.84	1189.46
8	3566.40	1957.50	1450.41	1284.06	1227.92	3566.40	1957.50	1450.41	1284.05	1227.92
9	3681.70	2020.79	1497.30	1325.57	1267.61	3681.70	2020.79	1497.30	1325.57	1267.61
10	3800.73	2086.12	1545.71	1368.42	1308.60	3800.73	2086.12	1545.71	1368.42	1308.60
11	3923.60	2153.56	1595.68	1412.67	1350.90	3923.60	2153.56	1595.68	1412.66	1350.90
12	4050.45	2223.19	1647.27	1458.34	1394.58	4050.45	2223.19	1647.27	1458.34	1394.58
13	4181.41	2295.06	1700.53	1505.48	1439.66	4181.40	2295.06	1700.53	1505.48	1439.66
14	4316.59	2369.26	1755.51	1554.16	1486.21	4316.59	2369.26	1755.51	1554.16	1486.21
15	4456.15	2445.86	1812.26	1604.40	1534.26	4456.14	2445.86	1812.26	1604.40	1534.26
16	4600.21	2524.94	1870.85	1656.27	1583.86	4600.21	2524.94	1870.85	1656.27	1583.86
17	4748.94	2606.57	1931.34	1709.82	1635.07	4748.94	2606.57	1931.34	1709.82	1635.07
18	4902.47	2690.84	1993.78	1765.10	1687.93	4902.47	2690.83	1993.78	1765.10	1687.93
19	5060.97	2777.83	2058.24	1822.16	1742.50	5060.97	2777.83	2058.24	1822.16	1742.50
20	5224.59	2867.64	2124.78	1881.08	1798.83	5224.59	2867.64	2124.78	1881.07	1798.83

Table 5. Life-cycle savings and cumulative life–cycle savings of all scenarios (LCS: Life-cycle savings, CLCS: Cumulative life-cycle savings)

Year	LCS(1-2)	LCS(1-3)	LCS(1-4)	LCS(1-5)	CLCS(1-2)	CLCS(1-3)	CLCS(1-4)	CLCS(1-5)
1	-8265.15	-12017.30	-15722.20	-16994.90	-8265.15	-12017.30	-15722.2	-16994.90
2	1329.28	1748.24	1885.69	1932.07	-6935.87	-10269.10	-13836.5	-15062.80
3	1372.26	1804.76	1946.65	1994.53	-5563.61	-8464.33	-11889.9	-13068.30
4	1416.62	1863.11	2009.58	2059.01	-4146.99	-6601.22	-9880.27	-11009.20
5	1462.42	1923.34	2074.55	2125.58	-2684.57	-4677.88	-7805.72	-8883.66
6	1509.70	1985.53	2141.63	2194.30	-1174.88	-2692.35	-5664.09	-6689.36
7	1558.51	2049.72	2210.86	2265.24	383.63	-642.63	-3453.23	-4424.12
8	1608.90	2115.98	2282.34	2338.48	1992.528	1473.35	-1170.89	-2085.64
9	1660.91	2184.39	2356.13	2414.08	3653.44	3657.75	1185.239	328.44
10	1714.61	2255.02	2432.30	2492.13	5368.05	5912.76	3617.541	2820.58
11	1770.04	2327.92	2510.94	2572.70	7138.09	8240.68	6128.48	5393.28
12	1827.27	2403.18	2592.12	2655.88	8965.35	10643.86	8720.597	8049.15
13	1886.34	2480.88	2675.92	2741.74	10851.70	13124.74	11396.52	10790.89
14	1947.33	2561.08	2762.43	2830.38	12799.02	15685.82	14158.95	13621.27
15	2010.28	2643.88	2851.74	2921.89	14809.31	18329.71	17010.69	16543.16
16	2075.28	2729.36	2943.94	3016.35	16884.58	21059.07	19954.63	19559.51
17	2142.37	2817.60	3039.12	3113.87	19026.95	23876.67	22993.75	22673.38
18	2211.63	2908.69	3137.37	3214.54	21238.59	26785.36	26131.12	25887.92
19	2283.14	3002.73	3238.80	3318.47	23521.72	29788.09	29369.92	29206.39
20	2356.95	3099.81	3343.51	3425.75	25878.67	32887.90	32713.43	32632.15

CONCLUSIONS

In this study, impacts of various energy efficient measures for a detached two-storey house located in Eskisehir were investigated. General results can be summarized as follows but it is noted that they are mostly valid in cold climates:

- Prevention of heat losses from building envelope is important to reduce energy consumption for heating.
- Increasing of insulation thickness cannot reduce so much energy consumption for heating and it should not be forgotten while determining insulation thickness.
- Increasing of insulation after a certain thickness on external wall or roof can not so much reduce annual heating load.
- Insulation on ground compared to insulation on external wall has a great effect on annual heating loads in ground floor.
- Windows are one of the important parameters for affecting heating loads in buildings.
- Buffer zones at suitable places can be used to an energy efficient measure.
- In Turkey, there are lots of existing buildings which were not constructed according to TS-825. Thus, retrofitting of these buildings based on minimum conditions defined in TS-825 can lead to approximately 50 % reduction in annual heating loads in cold climates.
- Payback periods of energy efficient measures can be more than 10 years. Thus people should be supported to reduce payback periods by government.

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