MODELING THE USE OF ALTERNATIVE ENERGY SOURCES AND TECHNOLOGIES TO REDUCE ENERGY CONSUMPTION OF A SINGLE DETACHED HOUSE AT ANKARA, TURKEY

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ABSTRACT

In this study, hourly energy consumption model of a single detached house in Ankara is developed using ESP-r. Natural gas is used for space heating, cooking, and water heating in this two-story 4500 square feet four-bedroom home. Hourly electricity and daily natural gas consumption of the dwelling are monitored for one year. The hourly space heating demand model is developed using the hourly climate, building envelope, and occupants' energy consumption behavior data. The estimated hourly heating energy demand of the dwelling is then compared with the actual measured heating demand to determine the performance of the model. Various energy saving scenarios are applied to the model to determine the amount of reduction in total energy consumption, associated emissions, and fuel expenditure. As for renewable energy scenarios, photovoltaic panels to generate electricity, ground source heat pump for space heating, and solar panels for domestic hot water generation are applied to the hourly model. Scenarios based on improving wall and roof insulations, and window glazing are also applied to the model for heating demand reduction analyses. These scenarios are evaluated based on annual energy demand, associated CO_2 emissions, and fuel expenditure savings. The pay-back periods for each scenario are also calculated to determine the most appropriate scenario for this single detached dwelling to reduce annual energy consumption, CO_2 emissions, and fuel expenditures.

KEYWORDS

ESP-r, building energy simulation, residential energy consumption.

INTRODUCTION

The residential energy consumption has a significant share in total energy consumption of most countries, e.g. in US it is about 22% (US DOE 2015) and in Turkey it is about 30% (ETKB 2015). With the increase in the number of dwellings in Turkey, residential energy consumption and associated CO_2 emissions is increasing. Turkey Statistical Institute declared that in 2014 the total number of residential buildings is increased by

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12%, whereas single detached dwelling numbers are increased by 6% compared to 2013 (TUIK 2015).

Energy savings at homes can be obtained by improvements made in the physical structure of the dwelling or by providing the energy demand with renewable energy sources. In addition, after the completion of the Payback Period (PBP), homeowners are provided an increase in the fiscal value of dwelling.

In the open literature, there are many studies on modelling the energy demand of buildings and determining the energy savings of various energy efficiency based scenarios. In the studies conducted on using renewable energy sources the factors affecting the performance of systems are examined (Chow and Chan 2004, Chow et al. 2003, Thevenard 2005, Eke and Senturk 2013, Lee et al. 2014, Huang et al. 2015), and energy savings (Maurer and Kuhn 2012, Koyunbaba et al. 2013, Karkare et al. 2014) and decrease in CO_2 emissions (Good et al. 2007, Syed et al. 2009, Nikoofard et al. 2014) are also calculated. In addition, studies on determining the energy savings obtained by the interaction of the building with the sun (Florides et al. 2000, Sailor 2008, Appelfeld et al. 2012, Tavares et al. 2014) and studies on examining the effect of changes in the physical structure of the building materials are also conducted (Parker 1998, Florides et al. 2000, Høseggena et al. 2008, Sozer 2010, Yildiz and Arsan 2011, Friess et al. 2012, Dias et al. 2014).

The majority homes in Turkey are apartments, however in recent years there is a significant increase in the number of single detached homes which have higher energy consumption intensity than those of the apartments. Due to this reason in this study a single detached dwelling is selected. The main objective of this study is to evaluate appropriate energy saving scenarios for this single detached dwelling based on building envelope improvements and use of renewable energy technologies. In this paper, first general background information about the subject is given. Then, the methodology used, the application of scenarios and economic analysis are presented. Finally, results, discussions, general conclusions, and recommendations of the study are provided.

METHODOLOGY

In this study, space heating energy consumption of a single detached house constructed in 2007 in Ankara, Turkey, has been modeled. The dwelling is 700 m^2, where the heating area is 500 m^2. Energy for space heating, DHW, and cooking is met by a boiler fueled by natural gas (NG). Design heating demand of the dwelling is 188 GJ/year.

Model Development

Hourly heating demand model of the dwelling is developed using ESP-r building energy simulation software. A survey was conducted to the occupants to collect data on the architecture and construction material and heat gain. Hourly meteorological data of a nearby weather station are obtained for 2013. The daily NG consumption of the dwelling is monitored for 2013. In order to determine the NG consumption for heating in dwelling, the estimated NG consumption values for cooking and DHW are subtracted from monitored total NG consumption. In the next step, technical data of the scenarios are provided from various sources. In addition, 2013 hourly electricity consumption of the dwelling is monitored to be used in the photovoltaic panel (PVP) scenario.

After providing the necessary data, hourly heating demand model of the dwelling is developed by using the ESP-r. First, total heat gain data are input into the ESP-r. Then three control loops for heating system is designed (rooms at 22°C, bathrooms at 24°C, basement at 15°C). Finally the air-flow network defined. To determine the amount of air entering through the windows by natural ventilation, a specific area of the window opening is defined in ESP-r. The calibration of the model is conducted by assigning a window opening area in which the monitored and estimated heating demand of the dwelling are closest to each other.

Application of Scenarios and Determining the Reductions in CO2 Emissions

The scenarios applied to the model are summarized in Table 1.

Table 1. *Scenarios applied to the model*

Scenario Type	*Scenario*	*Scenario Code*	*Current State*	*Suggested Improvements*
Physical Improvement Scenarios	Window	S.1-a	12 mm, air filled, double glazing	16 mm Argon filled, double glazing
		S.1-b		16 mm Argon filled, triple glazing
	Insulation	S.2-a	80 mm polystyrene foam insulation on wall (k=0.04 W/mK)	90 mm polystyrene foam (k=0.04 W/mK)
		S.2-b		80 mm XPS (k=0.35 W/mK)
		S.2-c		90 mm XPS (k=0.035 W/mK)
		S.2-d	No roof insulation	100 mm XPS (k=0.035 W/mK)
	Window + Insulation	S.3	12 mm air filled, double glazing, 80 mm polystyrene foam on wall (k=0.04 W/mK), No roof insulation	16 mm, Argon filled, triple glazing, 90 mm XPS on wall (k=0.035 W/mK), 100 mm XPS on roof (k=0.035 W/mK)
Renewable Energy Scenarios	PVP	S.4	No PVP	PVP on the roof
	SHDW	S.5	No SDHW	SDHW on the roof
	GSHP	S.6	No GSHP	GSHP System

As shown in Table 1, in physical improvement scenarios, the improvement of current state presented is thought to be changed with suggested improvements. The amount of energy saved and reduction in associated CO_2 emissions with the obtained energy savings of each scenario is calculated by using natural gas emission factor of (NGEF) of 2.14 kg-CO_2/m^3 of NG.

In case of addition of PVP to the southeast and southwest-facing roof of the dwelling, electricity to be generated is estimated by ESP-r. Suitable area for PVP addition at the roof is 45 m^2. The amount of the electricity generated by the PVP is taken as the amount of electricity saved. Also reduction in CO_2 emissions with the obtained energy savings is calculated by using electricity emission factor (EEF) of 0.446 kg-CO_2/kWh.

In GSHP scenario, GSHP with 50 kW capacity and COP of 4.3 is defined as the heating system. After application of GSHP to the model, energy savings to be obtained and reduction in CO_2 emissions is calculated by using NGEF.

For SDHW scenario, daily monitored NG data during September is used based on the assumption that the amount of NG consumed in this month is only for DHW and cooking. The NG consumption for cooking is estimated to be similar to that of another dwelling that consumes NG for only cooking. This estimated average daily NG consumption for cooking is then subtracted from daily NG consumption during September to determine the NG consumption for DHW. Finally, by using 100 cm underground soil temperature data, the amount of DHW consumed is calculated. The price quote of required SDHW system that can produce appropriate amount of DHW for the households is obtained from a local company. A SDHW system consists of 10 panel collectors with 18 m^2 total area is estimated to provide adequate amount of DHW. The amount of DHW can be generated by the SDHW system and consequently the amount of energy savings and reductions in CO_2 emissions are calculated.

Economic Analysis

For the economic analyses, costs of scenario applications and current structure of the dwelling, electricity and natural gas tariffs, and interest rates are obtained. Since future electricity and natural gas tariffs are required for the calculation of PBPs of the scenarios, the electricity price of the last eight years and NG price of the last decade data are used to develop forecasted prices, respectively. In order to calculate PBP, first net cash flow (NCF) is determined for each year. Finally net present value (NPV) is calculated for each year and PBP is calculated as the year where NPV becomes positive.

RESULTS AND DISCUSSION

The space heating demand of the dwelling is estimated as 141 GJ by ESP-r for 2013 in which the heating degree-day for Ankara is 2563ºC-days. Since the heating area of the dwelling is 500 m^2, heating demand per heating area is found to be 0.28 GJ/m^2. Natural gas equivalent of 141 GJ heating demand with 98% efficiency boiler is found to be 3753 m^3 of NG. The total heating cost of the dwelling based on 2013 natural gas price (Baskent Dogalgaz 2015) is calculated as 1328 USD and CO_2 emissions associated with this natural gas consumption for heating is calculated as 8058 kg-CO_2.

Based on the NG monitoring data, 6729 m^3 natural gas was consumed for heating, DHW, and cooking in 2013. Out of 6729 m^3, 135 m^3 was used for cooking and 2059 m^3 was used for DHW and 4535 m^3 was consumed for space heating. The monitored NG consumption for heating is 782 m^3 higher than the estimated value. The difference between these two values could be due to the high NG usage of the occupants after unexpected temperature fluctuations during the transition months in spring and autumn.

The NG equivalent of the estimated daily heating demand and monitored daily NG consumption for space heating during 2013 are shown in Figure 1. The error analyses conducted between the estimated and actual NG data shows that the average regression coefficient (R^2) and the mean absolute percentage error (MAPE) are 0.95 and 24%, respectively. As seen here, the R2 value is found to be reasonable (max. value is 1), however the MAPE is higher than expected. Due to the low NG usage in transition months (April, October, and November) the difference between the monitored and estimated NG consumption is high in terms of percentage which results in high MAPE.

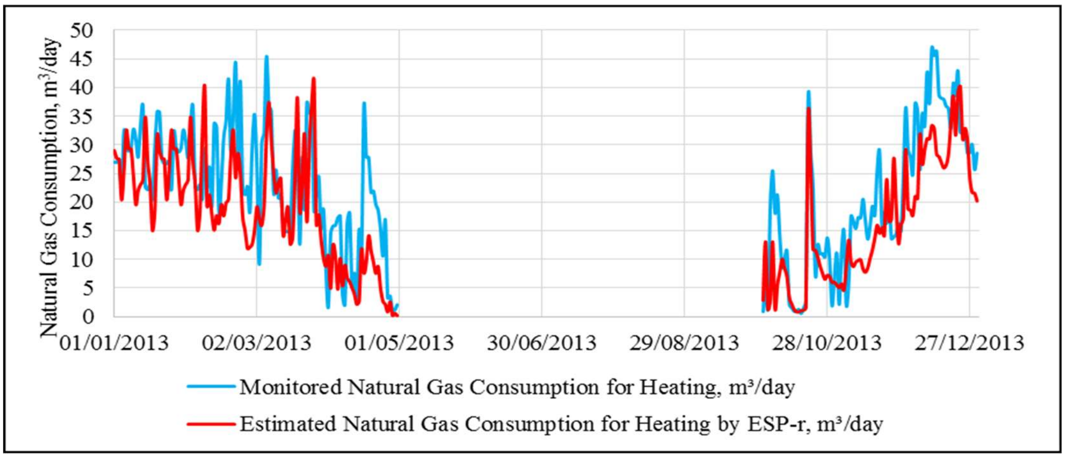

***Figure 1**. Daily heating demand for 2013 estimated with ESP-r simulation and monitored daily consumption of natural gas for space heating*

After the hourly model is validated using 2013 actual climate data, the model is run using the normal climate data of Ankara obtained from USDOE (US DOE 2015) to determine the heating demand for scenario analyses. The annual heating demand of the dwelling is estimated as 182 GJ/year based on the normal weather data in which the heating degree-day for Ankara is 3307 ºC-days. The energy savings, reduction in CO_2 emissions, and PBP of the scenarios listed in Table 1 are calculated by taking the nominal rate as 0.65 and these results are presented in Table 2.

***Table 2**. Overall Scenario Results*

Scenario Code	*Scenario Description*	*Energy Savings, GJ/year*	*Investment Cost, USD*	*PBP, year*	*CO_2 Reduction, kg/year*
S.1-a	Window Glazing	22	417	1	1259
S.1-b		27	512	5	1546
S.2-a	Insulation	2	44	23	114
S.2-b		4	76	>40	229
S.2-c		5	107	>40	286
S.2-d		51	967	4	2919
S.3	Window + Insulation	84	1593	7	4809
S.4	PVP	30	1233	27	3725

S.5	SDHW	50	839	8	2864
S.6	GSHP	124	1287	>40	3886

As it is shown in Table 2, investment costs and PBPs of the scenarios based on upgrading window glazing (S.1-a and S.1-b) are low, so do the energy savings associated to these scenarios. Thus, it can be concluded that these scenarios can be suggested for newly constructed and current buildings. Despite the low investment cost of the insulation based scenario, S.2-a, its high PBP makes it not preferable for the retrofit of the current buildings. However, this scenario can be preferred in new buildings. Due to high PBP and very low energy saving of other insulation based scenarios, *i.e.* S.2-b and S.2-c, these scenarios can be concluded to be not applicable both in newly constructed and older buildings. Low investment cost, low PBP, and high energy saving of the last insulation based scenario, S.2-d, resulted in to be applicable in newly constructed and also older buildings. The combination scenario (S.3) which includes wall, window and roof insulation improvements results in low PBP and high energy savings, thus it can be applicable in newly constructed and older buildings.

The electricity generated by the PVP system (Scenario code: S4) is estimated as 7375 kWh/year based on normal climate data, and 8483 kWh/year with 2013 climate data. The monitored electricity consumption of the dwelling during 2013 was 15,702 kWh. The surplus electricity is stored for one day at batteries of the PVP system. As a result of the calculations, electricity required from the grid is determined as 7354 kWh for 2013, which shows that 53% of the total electricity demand of the dwelling can be met by the PVP system. In addition, it was determined that the panels facing south-west has shown to produce 12% more electricity compared to the ones facing south-east. According to the calculations conducted by using various nominal interest rates and electricity price forecasts, PBP of the PVP system is observed to vary from 19 to 40 years. Due to the high capital cost of PVP in Turkey, PBP of the PVP system is estimated relatively high for Central Anatolia climate of Turkey. But it can be beneficial to use a PVP system for homes located at regions where there is higher radiation than Central Anatolia, such as Mediterranean and Aegean regions.

In the next scenario, a SDHW system is applied to the model (Scenario code: S5) and it is estimated to supply 50 GJ/year to the dwelling which currently has a DHW demand of 77 GJ/year (NG equivalent of 2059 m^3/yr). Since the surplus DHW cannot be stored, 27 GJ/year (NG equivalent 720 m^3/year) of the demand cannot be supplied to the home. This scenario results in 64% energy savings and has a short PBP of 7 to 8 years based on various interest rates and natural gas price forecasts. Therefore, it can be concluded that the use of SDHW system is suitable for the climate of Central Anatolia.

The GSHP (Scenario code: S.6) is modeled on ESP-r as heating system. Electricity consumption of GSHP is estimated to be 50 GJ/year, and energy savings is calculated as 124 GJ/year (71%). Since GSHP investment cost is very high and the system consumes high amount of electricity, PBP of the system is calculated to be more than 40 years. Therefore, it is concluded to be not preferable to use GSHP for this dwelling.

CONCLUSIONS

In this study, it is aimed to model the hourly heating demand of a single detached dwelling in Ankara; to calculate the available energy savings and associated reductions in CO_2 emissions; and to apply techno-economic analysis to the scenarios. According to the results of the simulations, high energy savings (12 to 15%) and low PBPs (1 to 5 years) are obtained by applying scenarios based on window glazing; and wall insulation improvements. Due to lack of insulation on the current state of the roof, addition of roof insulation provided high energy savings and also low PBP (4 years). Application of the wall, window and roof insulation improvement scenarios together results in 46% energy saving and a PBP of 4 years; which demonstrates the importance of building envelope improvements. Although high energy saving can be obtained by the use of PVP (53% of electricity demand of the dwelling) due to its high cost, PBP is found to be too high. Because of the high energy saving obtained (64 %) and low cost of SDHW in Turkey, SDHW system scenario is thought to be very reasonable for Ankara. The use of GSHP is not widely in Turkey due to its high capital cost. In this study, high energy saving is obtained by the application of GSHP scenario, however due to the high cost of the system, PBP is found to be more than 40 years. The results presented in this study can be used to estimate the amount of energy, associated emissions and fuel expenditure that can be saved by changing the physical envelope, heating and DHW equipment and electricity supply of the single detached housing stock in Turkey. Consequently, these results can also be used in selecting the optimum insulation strategy, technology, and fuel type for the newly constructed buildings to achieve minimum energy demands.

REFERENCES

Appelfeld D, McNeil A and Svendsen S. 2012. An hourly based performance comparison of an integrated micro-structural perforated shading screen with standard shading systems, Energy and Buildings, 50: 166–176.

Baskent Dogalgaz https://www.baskentdogalgaz.com.tr/DogalgazFiyatYeni.aspx , last accessed on 17 December 2015

Chow T. and Chan A. 2004. Numerical study of desirable solar-collector orientations for the coastal region of South China, Applied Energy. 79: 249-260.

Chow T, Hand J, and Strachan P. 2003. Building-integrated photovoltaic and thermal applications in a subtropical hotel building, Applied Thermal Engineering, 23: 2035–2049.

Dias D, Machado J, Leal V, and Mendes A. 2014. Impact of using cool paints on energy demand and thermal comfort of a residential building, Applied Thermal Engineering, 65: 273-281.

Eke R. and Senturk A. 2013. Monitoring the performance of single and triple junction amorphous silicon modules in two building integrated photovoltaic (BIPV) installations, Applied Energy, 109: 154–162.

ETKB http://www.enerji.gov.tr, last accessed on 10 December 2015.

Florides GA, Kalogirou SA, Tassou SA, and Wrobel LC. 2000. Modeling of the modern houses of Cyprus and energy consumption analysis, Energy, 25: 915–937.

Friess WA, Rakhshan K, Hendawi TA, and Tajerzadeh S. 2012. Wall insulation measures for residential villas in Dubai, Energy and Buildings, 44: 26–32.

Good JT, Ugursal VI, and Fung AS. 2007. Modeling and Technical Feasibility Analysis of a Low-Emission Residential Energy System, International Journal of Green Energy, 4: 27-43.

Høseggena R, Wachenfeldt B, and Hanssen S. 2008. Building simulation as an assisting tool in decision making, Energy and Buildings, 40: 821–827.

Huang Q, Shi Y, Wang Y, Lu L, and Cui Y. 2015. Multi-turbine wind-solar hybrid system, Renewable Energy, 76: 401-407.

Karkare A, Dhariwal A, Puradbhat S, and Jain M. 2014. Evaluating Retrofit Strategies for Greening Existing Buildings by Energy Modelling and Data Analytics, Intelligent Green Building and Smart Grid (IGBSG), Taipei, Taiwan, pp 1-4

Koyunbaba BK, Yilmaz Z, and Ulgen K. 2013. An approach for energy modeling of a building integrated photovoltaic (BIPV) Trombe wall system, Energy and Buildings, 67: 680–688.

Lee JW, Park J, and Jung HJ. 2014. A feasibility study on a building's window system based on dye-sensitized solar cells, Energy and Buildings, 81: 38–47.

Maurer C. and Kuhn T.E. 2012. Variable g value of transparent facade collectors, Energy and Buildings, 51: 177–184.

Nikoofard S, Ugursal VI, and Beausoleil-Morrison I. 2014. An investigation of the technoeconomic feasibility of solar domestic hot water heating for the Canadian housing stock, Solar Energy, 101: 308-320.

Parker D. H. 1998. Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings, Florida, ASHRAE Transactions, 104: 963-975.

Sailor D. 2008. A green roof model for building energy simulation programs, Energy and Buildings, 40: 1466–1478.

Sozer H. 2010. Improving energy efficiency through the design of the building envelope, Building and Environment, 45: 2581–2593.

Syed AM, Fung AS, Ugursal VI, and Taherian H. 2009. Analysis of PV/wind potential in the Canadian residential sector through high-resolution building energy simulation, International Journal of Energy Research, 33: 342–357.

Tavares P, Gaspar A, Martins A, and Frontini F. 2014. Evaluation of electrochromic windows impact in the energy performance of buildings in Mediterranean climates, Energy Policy, 67: 68–81.

Thevenard D. 2005. Review and Recommendatıons for Improving the Modelling of Building Integrated Photovoltaıc Systems, Ninth International IBPSA Conference, Montreal, pp 1221-1228.

TUIK http://tuikapp.tuik.gov.tr/Bolgesel/menuAction.do, last accessed on 6 July 2015

US DOE http://buildingsdatabook.eren.doe.gov, last accessed on November 2015.

USDOE http://apps1.eere.energy.gov/buildings/energyplus, last accessed on 4 December 2015.

Yildiz Y. and Arsan Z D. 2011. Identification of the building parameters that influence heating and cooling energy loads for apartment buildings in hot-humid climates, Energy, 36: 4287-4296.