Re-thinking of energy consumption classification by the patterns of occupant behaviour in dwellings: a conceptual framework

Gülsu Ulukavak Harputlugil – Çankaya University Architecture – gharputlugil@cankaya.edu.tr
Timuçin Harputlugil – Çankaya University Architecture – tharputlugil@cankaya.edu.tr

Abstract

The aim of this paper is to present the conceptual framework of a TUBİTAK funded project titled "*Developing a New Methodology to Improve Housing Quality in Turkey Based on Effects of Occupant Behavior on Energy and Comfort of the Dwellings*". Although the objective of the project is the development of new methodologies and tools to be used for the definition of effects of behavior profiles of housing occupants on the energy consumption and usage of this knowledge for building new houses and renovation of existing buildings, here the first step of research has been executed. By defining sensitivity of occupant behavior on energy consumption, it is planned to classify different models of occupant behavior. With data provided, the aim is to develop an "occupant behavior labeling" which rates occupants instead of buildings. To provide the mentioned data, sensitivity analysis of existing occupant behavior will be analysed based on the Monte Carlo Methodology. This methodology is one of the most used methodologies to analyse accurate distribution of possible outputs relied on inputs based on probability. Inputs for this research are (1) number of occupants for each space (for weekdays and weekend) (2) behaviour for ventilation (Window open/closed and mechanical ventilation on/off) (3) control of heating systems (radiator on/off and/or thermostat degree). These data will be provided with survey and data logging of chosen a house occupant group.

As a consequence of the research, the aim is not only to rate the behavior of housing occupants but also determine occupancy groups/labels. With this approach, based on occupant's behavior labeling, the aim is to realize fast and affective applications for renovation of existing buildings. Moreover, by evaluation/assessment of houses which will be designed in the future based on determined occupant profiles allow to produce high performance dwellings.

1. Introduction

Basically, there are two main issues associated with the world's energy consumption and related political decisions. Firstly, there is a significant decrease in energy sources due to common consumption manners. The second issue is the interaction of fossil-based energy sources with the natural environment. The greenhouse gas emissions caused by the consumption of fossil-based energy sources have a high rate of negative effect on human and nature. Nowadays, it is accepted that economic development would not be possible without accomplishing environmental measures. Regarding the various sectors that consume energy in the developed countries, the building sector is the third highest one following industry and transportation. The indicators showed and the related research revealed that it is essential to make all the stakeholders of the building sector aware of the situation. Reducing environmental impact at the maximum level shall only be possible by fulfilment of their responsibilities within the whole building process beginning from planning and design to construction, usage and renovation. This is not only a requirement for the new constructions but also more essential for renovation of current building stock. As common sense, the sustainable measures are the subject of the design process of new buildings; however, it is obvious that the total environmental impact of the current building stock is huge enough to be considered primarily.

Within the continuous global effort to make the built environment more energy efficient, there is an increasing interest in the role of occupants on building energy use. For instance, the International Energy Agency has recently (late 2013) launched Annex 66 on Definition and Simulation of Occupant

Behavior in Buildings (www.annex66.org). Occupants make a passive contribution to the building energy balance by their very presence; they also can have an active role through activities like opening windows, changing thermostat set points etc. Furthermore, in existing buildings, occupants also play a role in decisions regarding any interventions in the fabric and systems, especially where occupants own the building.

TÜBİTAK funded research started in August 2014, and it will take about 2 years. The main focus of this research is proposing a new perspective to current understanding of occupant effectiveness on energy consumption of the dwellings.

In this paper, only the conceptual frame of the research is introduced, the methodology is discussed and expected outcomes are listed.

2. Literature Review

The literature review on sustainable renovation process has been done based on two main issues. One is the clear understanding of the renovation process of the dwellings. It is not possible to suggest new approaches without a deep understanding of the current situation. Second is the effect of occupant behaviour on renovation process. The main difference between the design process and renovation process of a dwelling is the "real" occupants. During design process, designers usually make assumptions about the behaviours of the occupant. This is acceptable since most of the designs are finalised without any information about the exact users. Nevertheless the renovation process is realised having the whole information about the occupants. By understanding occupant behaviour, it is possible to generate a methodology considering occupants' perspective.

2.1 Renovation process of the dwellings

In the report of IEA (2008), there are six priorities for the renovation of housing; listed as: i) increasing the comfort of life, ii) limiting energy consumption, iii) limiting drinking water consumption, iv) increasing the water resources, v) limiting the production of waste, vi) limiting consumption territory and resources.

Renovation is usually a way of redesigning the building, even though structural characteristics are the same and most of the components are only renewed instead of redesigned. However the process shall be defined as a redesigning process. From this point of view it is necessarily to be aware of the energy and sustainable objectives.

Hazucha (2009) stated in the report of the IEE project "PASSNET" that the building renovation should include; a) the design of appropriate insulation with the thermal characteristics of construction according to passive house recommendations, b) the thermal bridge free solution of construction details (e.g. windows, attics, roof, etc.), c) the airtight layer design with the used sealing materials, d) windows optimised (type of glazing, frame, summer shading, etc.), e) the mechanical ventilation design (appropriate ventilation system, noise and fire, protection, regulation and controlling), f) the heating system regulation and appropriate piping insulation (eventually the heat source replacing), g) energy demand calculation according to national standards and economical calculation of cost-benefits.

Thomsen and Flier (2009) searched for the answer to the question "What is better; replacement or renovation of dwellings?" from the sustainability perspective. The motivation to demolish is related to (a) physical quality of the dwellings (technical, functional) and (b) micro economic quality (market potency, return potency).They stated that the main part of the demolition in the Netherlands occurs in social housing. The literature survey done by Thomsen and van der Flier reveals that the environmental impact of life cycle extension in most cases is less than demolition and new construction, although in practice the better energy performance of new construction reduces the differences.

Kara (2010) worked on three case studies from the Dutch housing stock to reveal the life cycle assessment perspective of selection: renovate or rebuild? He emphasised in his study that in the results of two of the three cases, the new building alternative has a better environmental performance among all alternatives 50 years after the intervention. The life span of the building and related technological developments is highly relevant to the results. Besides he stated that among the environmental categories he considered, operational energy use revealed higher contribution, compared to the contribution due to materials.

2.2 Occupant Behaviour

Energy consumption rate of any space is directly related to the presence of the occupant in that area. Assumptions that are made without the presence of an occupant would give weak results. Being present within the space is a necessary condition for being able to interact with it.

Page (2007) emphasised in his thesis that impacts of occupants' presence and behaviour on a building are; i) control of HVAC set-points, ii) production of internal metabolic heat gains and pollutants, iii) position of blinds (solar gains), iv) use of artificial lighting (associated electricity consumption and internal heat gains), v) use of windows and doors (ventilation rate and associated heat gains and looses), vi) use of appliances (associated with electricity and hot and cold water consumption, internal heat gains and production of grey and waste water).

One of the latest works on the relationship between occupant behaviour and energy consumption was done by Santin (2010). The results of the statistical analysis that she executed showed that the determinants of occupant behaviour that have an effect on energy consumption are i) type of temperature control, ii) type of mechanical ventilation, iii) household characteristics (presence of elderly, children, etc.). Based on the analysis, she figured out five behavioural factors in occupant behaviour: i) 'appliances and space' that related to more use of space and heavy appliances; ii) 'energy intensive' that related to behaviour leading to more use of energy; iii) 'ventilation' that referred to more hours of ventilation; iv) 'media' that related to behaviour seen as more use of computers and electronics, less use of space and more ventilation, v) 'temperature comfort' that related to preferences for a warmer indoor environment and less ventilation.

Occupant behaviour that affects the renovation process is also a subject of the discussion within the literature. In the guidebook of the IEE project PASS-NET (2010), the main problems of occupant behaviours which decrease the expected energy efficiency after the first year of renovation are listed as; i) use of the natural ventilation via windows especially during the winter instead of mechanical ventilation with heat recovery, ii) too high air change rate (ventilation intensity) can cause too dry indoor air, iii) too high indoor temperature – after renovation interior surfaces of walls, windows, etc. are warmer so the room temperature can be lowered while the same thermal comfort is kept, iv) not using the radiator's valves to control the temperature – thermostatic valves can keep the set-up room temperature, v) during the summer time the shading elements are not used properly and the windows are opened during the daytime – this can lead to interior overheating and users discomfort.

In the report of ERABUILD, Itard (et al. 2008) listed key barriers of existing residential buildings. The highlighted barriers of the owner-occupied dwellings are seen as i) lack of professional advice and support, limited offers, complicated procedures; ii) lack of specific knowledge/ knowledge of alternatives; iii) lack of complex decision making process.

Mlecnik (2010) stated in the report of LEHR project that i) increased space, ii) structural improvement and iii) improved comfort are more important drivers than energy saving for owner-occupants during renovation.

In the literature there are various models discussed on occupant behaviour. The most common approach is to develop stochastic models while considering occupant behaviour aspects. Page (2007) summarised the various approaches of occupant behaviour models based on presence and different usages of the components. For instance, i) occupant presence models as Lightswitch model (Newsham et al, 1995; Reinhart 2004) and statistical properties of occupancy by Wang (et al 2005); ii) occupant behaviour model of appliance use by Mc Queen (2004); iii) occupant behaviour model of window opening as either a model to simulate the changes of state during winter by Fritsch (et al., 1990) or the variable modelled the state of the window at each time step rather than the change of the state of the window by Nicol (2001).

Besides, most of these models were attempts to integrate simulation programs to gather more realistic results regarding possible calculations simultaneously the behaviour within a reasonable short time.

3. Proposed Methodology

The aim of the research is to determine occupant behaviour patterns quantitatively and to reveal robustness of occupant behaviour against energy consumption of dwellings. The results will guide the renovation process of the dwellings that considers occupants' 'real' behaviour and related effective intervention level on the building. Based on this perspective the proposed methodology includes the following steps.

3.1 Collecting information of occupants (survey)

The first step of the work includes collecting relevant information about the occupants. A survey is going to be held at the locations that TOKI (Toplu Konut İdaresi Başkanlığı – Housing Development Administration of Turkey) pointed at four different climatic regions in Turkey. The survey questions involved the basic issues listed below:

- *General information of the occupants:* the number of the people living in the dwelling, the ages and gender of each, educational levels, the hours that each of them stays at home during both weekdays and weekends.
- *Exploring physical comfort conditions (feelings) of occupants:* They are queried to rate comfort conditions at the dwelling. Based on thermal, visual and aural comfort, they are expecting to define the levels of comfort in each room at the dwelling.
- *Exploring occupant behaviour based on comfort:* Besides comfort feelings of the occupants, it is necessary to find out how they behave to change the conditions in support of improving the comfort like opening/closing the window, increasing/decreasing thermostat degree, on/off radiator tunes, etc. This information will help to classify user behaviour patterns.

3.2 Collecting physical properties of dwellings (monitoring)

Physical properties of the dwellings are necessary for modelling and simulation.

- *Materials, plans and typologies of the dwellings:* The site plans, floor plans and construction details are collected from TOKİ. This information is required for simulation of base dwelling models.
- *Actual energy consumption of each dwelling:* Based on the bills that the occupants paid for both electricity and fuel (usually natural gas) the energy consumption levels of each dwelling will be revealed. This information will be used both for statistical analysis outcomes gathered from survey results and for calibration of simulation models.
- *Monitoring of each dwelling by means of data loggers:* The information gathered from occupants by the means of survey questions usually assessed subjectively. Thus monitoring is necessary to support these subjective feelings of the occupants with actual conditions in numerically. Thermal comfort conditions (by means of dry-bulb temperature, mean radiant temperature, humidity and air flow measurements); visual comfort conditions (by means of luminance level measurements of both natural and artificial lighting); and aural comfort conditions (by means of noise level measurements of both among rooms inside the dwelling and caused by outside of the dwelling) are monitored.

3.3 Determining energy performance levels of dwellings in current state (energy simulation)

All information gathered from both the survey and measurements are going to be used in simulation models. Firstly a base model is defined with the help of physical properties and actual energy bills of the dwellings. Determining the current state of the dwellings by simulation is important since this is going to be a base model for further evaluations of derived sample models. Moreover, the revealed energy performances of each dwelling type will help to develop renovation levels and a classification based on renovation necessities. This information is also useful for improvement models based on occupant behaviour of the dwellings.

3.4 Determining sensitivity of occupant behaviour on energy consumption

Since the objective of the research considers robustness of the behaviour, the research methodology is based on sensitivity analysis. As a general definition, sensitivity analysis is the study of how the variation in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation. In sensitivity analysis, a mathematical model is defined by a series of equations, input factors, parameters, and variables aimed to characterize the process being investigated. Input is subject to many sources of uncertainty including errors of measurement, absence of information and poor or partial understanding of the driving forces and mechanisms. This uncertainty imposes a limit on the confidence in the response or output of the model (Hamby, 1994; Helton et al. 2006; Saltelli et al. 2006). There are several examples of the application of sensitivity analysis in building thermal modelling (Spitler et al. 1989; Corson, 1992; Lam and Hui, 1996; Fülbringer and Roulet, 1999; McDonald, 2004; Westphal and Lamberts, 2005; Harputlugil et al. 2009). For sensitivity of energy simulation models, a set of input parameters and their values are defined and applied to a building model. The simulated energy consumption of the model is used as a base for comparison to determine how much the output (here measured in terms of energy use per year) changes due to particular increments of input values (Corson, 1992). Consequently the results show which parameters can be classified as “sensitive” or “robust”. Sensitive parameters are the parameters that by a change in their value cause effective changes on outputs (in this case energy consumption). Contrarily, change of robust parameters causes negligible changes on outputs.

The sensitivity of occupant behaviour; which is considered here as factors influencing energy use by behaviour; will be analysed by the Monte Carlo method. The Monte Carlo method is one of the most commonly used methods to analyse the approximate distribution of possible results on the basis of probabilistic inputs (Lomas and Eppel, 1992; Hopfe et al. 2007). Here the inputs (parameters) are several usages that affect energy consumption of the dwelling; listed as, i) presence of occupant (hours that they stay at home during weekdays and weekends); ii) use of heating system (by means of changing thermostat settings and/or radiator tunes), iii) use of ventilation system (by means of operating windows and/or mechanical ventilation system); iv) use of lighting system (by means of operating lightings). The data used for analysis is gathered from both the survey among households and monitoring dwellings in Ankara/Turkey. The steps of the analysis are as follows (Figure-1):

i) Reprocessing survey data within statistical analysis program (the mean and standard deviations (SD) of the input parameters are determined)

ii) Gathering Latin-Hypercube samples from Sim-Lab (2007) pre-processor

iii) Simulating each sample by a dynamic simulation program to collect output data,

iv) Combination of inputs and outputs in post-processor of Sim-Lab to get Monte-Carlo Analysis results

v) Interpretation of the results by classifying the behaviours as “sensitive” and “robust”.

The sensitive and robust behavioural patterns will be used on the background of a decision tool that aims to help owner-occupants on their decisions for renovating their dwellings.

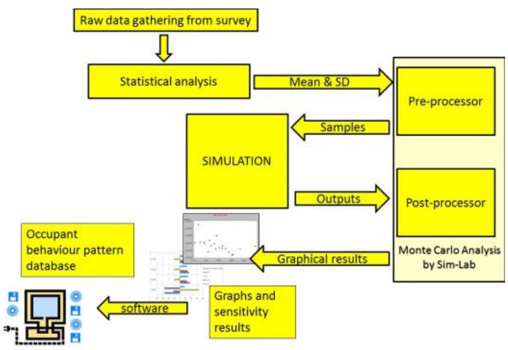

Fig. 1 – Flow chart of sensitivity analysis

3.5 Developing a decision tool based on behavioural patterns of occupants

Revealing the sensitive (or robust) behaviour that is effective on energy consumption of the dwellings leads to the generation of a database. The database consists of occupant behaviour, actual energy consumptions and necessary renovation levels are aimed to use developing a new approach to labelling system of EPC (Energy Performance Certificate). This new classification will group occupants as A, B, C class. The sensitive and robust behaviours will guide the development of behavioural patterns which will be a base for occupant group classes. Although it may not be possible to assign a specific metric for occupants, the numeric response of occupant behaviour will be gathered from the correlation between energy consumptions and behavioural patterns. The more sensitive behaviour will be an indicator of a high level of class. In other words, occupants controlling any of their sensitive behaviour, which means that energy consumption is under control as well, will achieve a high class label. This labelling will assist current occupants during renovation of the dwellings. Besides, designers of future dwellings will use this database while defining occupant related design parameters during design process. Matching the energy class of the dwellings with the energy class of the occupants is expected to be another challenge during design. The web-based decision tool aims to propose a media for all the stakeholders of the design process in order to provide insights into occupant behaviour from an energy consciousness perspective.

4. Discussion and Future Work

Here in this research, the main frame of the hypothesis is: "The patterns of occupant behaviour which directly or indirectly affects energy consumption and indoor air quality can be determined by quantitative methods. Revealing the robustness of the occupant behaviour will be utilized particularly during renovation of the dwellings. Re-thinking of energy consumption classification will bring about a new approach while defining influence rate of occupant behaviour quantitatively".

In this paper, only the conceptual framework of the research is introduced. The work was started in August 2014 and the first results of the survey will be obtained at the end of December 2014.

The expected outcomes of the research can be group into three;

i) The proposed methodology of the research includes sensitivity analysis. The results of sensitivity analysis will assist to suggest a way to define occupant profiles in simulation. If occupant behaviour patterns are clearly defined at the end of the sensitivity analysis, this information will be used for ready-to-use occupant packages to simulation tools.

ii) The data gathered at the end of the research will lead to develop a web-based decision tool which will provide feedback for not only the designers of the future dwellings but also decision-makers of renovation process.

iii) Recently a big revision has been achieved in Turkish energy politics. Considering local and global perspectives on energy efficiency, developing and newly established Turkish laws and regulations are essential. Particularly improvement strategies in current building stock will give an opportunity to saveg more energy than expected. The aim of this research is to create a base for new and developing energy efficiency regulations and provide a different frame from occupant potential perspective.

5. Acknowledgement

The authors would like to thank Scientific and Technical Research Council of Turkey (TÜBİTAK) where the project titled "*Developing a New Methodology to Improve Housing Quality in Turkey Based on Effects of Occupant Behavior on Energy and Comfort of the Dwellings*" is funded under SOBAG No: 113K799 (2014-2016).

References

Hazucha, J., 2009, *Renovation of social buildings, Guidelines for complex renovations*, IEE Project

PASS-NET, Czech Republic.

Thomsen, A., Flier, K., 2009, Replacement or renovation of dwellings: the relevance of a more sustainable approach, *Building Research* and Information, 37 (5-6), 649-659.

Kara, E., 2010, *Renovate or rebuild? A life cycle assessment based case study: 3 examples from the Dutch housing stock*, Master of Science Thesis, Delft University of Technology.

Page, J., 2007, *Simulating occupant presence and behaviour in buildings*, PhD thesis dissertation, École Polytechnique Fédérale De Lausanne, Switzerland.

Santin, O. G., 2010, *Actual Energy Consumption in Dwellings, The effect of Energy Performance Regulations and Occupant Behaviour*, PhD Thesis, OTB Research Institute, Delft University of Technology, The Netherlands.

Itard, L., Meijer, F., Vrins, E., Hoiting, H., 2008, Building Renovation and modernisation in Europe: State of the art review, *Final report of ERABUILD,* OTB Research Institute, Delft, NL.

Mlecnik, E. 2010, Adoption of Highly energy efficient renovation, open house international, Vol. 35, No:2, pp.39-49.

G. Newsham, A. Mahdavi, and I. Beausoleil-Morrison, 1995, Lightswitch: a stochastic model for predicting office lighting energy consumption. *In Right Light Three, the Third European Conference on Energy Efficient Lighting*, Newcastle-upon-Tyne, UK, pp 60–66.

C. Reinhart, 2004, Lightswitch-2002: a model for manual and automated control of electric lighting and blinds. *Solar Energy* 77, 15–28.

D. Wang, C. Federspiel, and F. Rubinstein, 2005, Modeling occupancy in single person offices. *Energy and Buildings* 37, 121–126.

D. McQueen, P. Hyland, and S. Watson, 2004, Monte Carlo simulation of residential electricity demand for forecasting maximum demand on distribution networks, *IEEE Transactions on Power Systems* 19, pp 1685–1689.

R. Fritsch, A. Kohler, M. Nygard-Ferguson, and J.-L. Scartezzini, 1990, A stochastic model of user behaviour regarding ventilation, *Building and Environment* 25, pp 173–181.

J. F. Nicol, 2001, Characterising occupant behaviour in buildings: towards a stochastic model of occupant use of windows, lights, blinds, heater and fans. *In Seventh International IBPSA Conference*, Rio de Janeiro, Brazil.

Hamby, D. M., 1994, "A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models", *Enviromental Monitoring and Assessment*, v.32, pp.135-154.

Helton, J. C., Johnson, J. D., Sallaberry, C. J., Storlie, C. B., 2006, Survey of Sampling Based Methods for Uncertainity and Sensitivity Analysis, *Reliability Engineering and System Safety*, Volume 91, pp. 1175-1209.

Saltelli, A., Ratto, M., Tarantola, S., Campolongo, F., 2006, Sensitivity Analysis Practices: Strategies for Model Based Inference, *Reliability Engineering and System Safety*, Volume 91, pp. 1109-1125.

Spitler, J. D., Fisher, D. E., Zietlow, D. C., A Primer on the Use of Influence Coefficients in Building Simulation, *Proceedings of Building Simulation'89 Conference*, IBPSA, Vancouver, Belgium, (1989) 299-304.

Corson G. C., Input-Output Sensitivity of Building Energy Simulations, *ASHRAE transactions*, 98 (Part I), (1992), 618-626.

Lam J. C. and Hui S. C., Sensitivity Analysis of Energy Performance of Office Buildings, *Building and Environment*, Vol.31 No.1, (1996) 27-39.

Fülbringer and Roulet, Confidence of Simulation Results: Put a Sensitivity Analysis Module in Your Model, *Energy and Buildings*, Volume 30, (1999), 61-71.

Mc Donald, 2004, Assessing the Significance of Design Changes when Simulating Building Performance Including the Effects of Uncertain Input Data, *Proceedings of e-Sim'04*, Vancouver.

Westphal and Lamberts, 2005, Building Simulation Calibration Using Sensitiviy Analysis, *Proceedings of Building Simulation'05 Conference, IBPSA*, Montreal, Canada, 1331-1338.

Harputlugil, G.U., de Wilde, P.J.C.J, Hensen, J.L.M., Çelebi, G., 2009, Development of a thermally robust school outline design for the different climate regions of Turkiye, *Proceedings of Building Simulation '09, 11th International IBPSA Conference*, Glasgow, United Kingdom, July 27-30, 1292-1298.

Lomas K.J., Eppel H., 1992, Sensitivity analysis techniques for building thermal simulation programs, *Energy and Buildings*. Vol. 19, no. 1, 21-44.

Hopfe, C., Hensen, J., Plokker, W., 2007, Uncertainity and Sensitivity Analysis for Detailed Design Support", *Proceedings of the 10th IBPSA Building Simulation Conference*, 3-5 September, Tsinghua University, Beijing, 1799-1804.

SIMLAB, 2007, Simlab version 2.2 manual, http://simlab.jrc.ec.europa.eu/