Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 645 – 650

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Consistent modeling of occupant behavior in detailed and simplified calculation methods for heating energy need

Naomi Morishita[a], Kerstin Seif[a], Thomas Bednar[a]*

[a]*Research Center for Building Physics and Sound Protection, Institute for Building Construction and Technology, Vienna University of Technology, Karlsplatz 13, 1040 Vienna, Austria*

Abstract

In Austria, user behavior is considered as a set of static values in the energy certificate calculations. As part of the research of Annex 53, "Total Energy Use in Buildings", the static user profile is challenged as an accurate representation of user behavior. A consistent approach has been formulated to derive average values for the energy performance calculations for residential buildings along with probability distributions for energy demand for different qualities of building envelopes.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: heating energy need; enerty-related user behavior; stochastic model; energy certificate

1. Background

In March 2007, the European Council set a goal to reduce primary energy consumption by 20% by the year 2020, referencing 1990 levels as part of the action plan to reach the goals set in the Kyoto Protocol [1]. Other associated directives such as the Energy Performance of Buildings Directive (EPBD) [2] and the Energy Efficiency Directive (EED) have the same goals of energy efficiency improvements in buildings and in other sectors such as transport, products and services [3].

Modeling user behavior as a part of whole building simulations is gaining importance as research indicates the large impact of occupants' actions on total energy use in buildings [4, 5]. The availability of whole building simulation tools on the market is increasing with the importance of minimizing energy use in buildings [6]. Until the

* Corresponding Author. Tel.: +43 (1) 58801-20602; fax: +43 (1) 58801-20698.
E-mail address: thomas.bednar@tuwien.ac.at (T. Bednar)

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.048

current trend to reduce overall energy consumption in buildings, simulation programs to predict energy use in buildings primarily focused on various design and performance qualities of the exterior envelope with building systems dimensioned to provide a given set-point temperature [7]. Building performance simulation involves the interaction of four main aspects: the quality of the building envelope, building services, climate, and occupants [8].

Several researchers are incorporating more input parameters related to user behavior in whole building simulations and introducing detailed user modeling tools such as probabilistic modeling using Markov chains and Monte Carlo methods [9], agent-based modeling [10], and artificial intelligence models such as artificial neural networks and support vector machines [8].

For individual buildings, deterministic behavior models in whole building simulations have been criticized for inaccuracies due to generalized assumptions made for all users causing underestimations of actual energy consumption [5, 11]. Especially when comparing the energy use pattern of a single household to the fixed values representing energy-related behavior, large discrepancies have been observed. As energy certificate calculations are required during various phases of design development, design consultants have stated that the detailed simulation tools produce redundant results and are therefore not used [12]. In Austria, user behavior is considered as a set of static values in the energy certificate calculations [13].

The question arises whether the static user profile is sufficient and accurate enough in its representation of user behavior in the energy certificate calculations, or if simulations with detailed representations of occupant behavior are necessary to calculate heating energy load. As part of the research of Annex 53, “Total Energy Use in Buildings”, the appropriateness of a static user profile in energy certificate calculations is questioned.

In this paper, a new occupant behavior model by Seif using stochastic methods is introduced [14]. This two-step model incorporates the outputs of a user action model as the input to a building simulation program to estimate the impact of user actions on heating energy demand for the earliest stages of design development and for estimations of large populations at a regional or national level.

2. A new tool to predict the impact of energy-related occupant behavior

The first model stochastically generates a set of energy-related user actions for a whole family within a single-family home (detached house). The outputs are used as inputs for whole building simulations and calculations of heating energy demand. The user action model is designed as an add-on to the whole building simulation program, BuildOptVIE [14]. Both programs are being developed at the Research Center for Building Physics and Sound Protection at the Vienna University of Technology. The accuracy of the BuildOptVIE building simulation has been validated against measurement results [15, 16]. Within the whole building simulation, the sets of user profiles interacts with three single-family house profiles representing different building standards: existing (E) representing the Austrian building code in the 1970’s, Low Energy (L), and Lowest Energy (LE). The energy demand for space heating from the simulations are averaged and compared to the monthly balance method calculations from the energy certificates using the average values of the occupant behavior sets.

2.1. Input parameters

The user of the occupant behavior tool provides four input parameters [14]:

1. The number of people in the household,
2. The desired set-point temperatures in °C,
3. Internal gains from appliances in W/hour·Person, and
4. Room use type for each room in the house.

The input parameters are based upon the number of people and lifestyle-based energy-related behavior decisions. As the age, gender, or relationship of the inhabitants are not important for the simulation, but rather the occupancy schedule and number of people in the house, people are represented as adults and pre-school children since preschool children are dependent upon a full-time caregiver at home. Personal characteristics are not influential factors and are disregarded in the simulation. The identity of the primary caregiver may also change without affecting either the presence schedule or number of people in the home. Once children begin school, their home occupancy schedule resembles the schedule by working adults. The household sizes vary from one to five people.

The user also provides room use types in the program, as the uses of some rooms in an architectural plan may be ambiguous. For example a secondary "bedroom" may be used as a children's bedroom, home office, guest bedroom, or hobby room. Thus, four use profiles can potentially be applied to the same space with different heating profiles [14].

2.2. How user actions are considered in the tool

The energy-related decision tool analyses the house on a room-by-room basis relating heating type to room function and adjacencies. Primary rooms such as kitchens, bedrooms, living and dining rooms are divided into two categories: always heated and partially heated according to use. Secondary areas, such as circulation spaces and storage rooms, are also broken down into two categories: unheated and heated [14]. The correlation follows that if an occupant is conscious about the impacts of their actions on energy use, they will take measures to minimize their heating energy use by only heating the rooms as they are used, leaving all other rooms unheated. Thus, if an "energy conscious" inhabitant heats their primary rooms according to a schedule, they will also leave their secondary rooms unheated. Dörn illustrated the importance of considering the effect of partial heating. In his study, the homeowners' room heating consumption was significantly lower than estimated due to partial heating patterns [17].

2.3. Outputs from the energy-related occupant model as inputs for building energy calculations

An occupant behavior profile set with 1,000 individual stochastically generated user profiles results from the user actions model. The profiles form one of two input sets for the building performance simulation. Three profiles of a detached house with building characteristics meeting the three different building standards (E, L, and LE) form the second set of inputs. It is assumed that the heating system controls remain the same for all three building standards, and thus the individual households interact within the home in the same manner for all three standards. The simulation results in three sets of heating energy demands which are then averaged for comparison to the monthly balance method calculation results.

The simulation also produces three averaged values as inputs for the monthly balance method calculations [14]:

- average indoor temperature,
- average internal heat gains, and
- average ventilation rate.

The simulation results are calculated together with the averaged values of the occupant behavior sets to determine the monthly balance method annual heating energy demand [14]. Empirical studies have shown that averaged values show greater concurrence with larger sample sizes. A comparison of the energy use in three lowest energy apartment buildings in Vienna using post-occupancy monitoring of heating energy use of DHW and room heating has been published by Bednar et al. [18]. Yao and Steemers also used average values for matching the energy demand to load for planning renewable energy systems in individual buildings at an early design stage [19]. However, Yao and Steemers' electrical load profile model makes assumptions about occupancy schedules, takes the highest possible daily energy load (worst case scenario) for each appliance before using random numbers to generate specific profiles for each scenario. As they determined that the seasonal influence is minimal, the daily use profile was applied for the entire year.

Average value models define key representative parameters for occupant behavior which influences the total energy use of a building for a selected period (e.g. daily, weekly, or monthly basis). Estimating energy use on a larger scale, such as on a regional or national level, does not require the minute detail required for individual buildings. Rather the key characteristics of the representative household for the sample size are required [19].

3. Results and discussion

The set of 1,000 randomly generated occupant behavior household profiles resulted in showing the hourly energy-related behavior for 1,000 different households over a year. Interacting with the whole building simulation, a set of 1,000 heating energy demand outputs for each building standard is generated [14]. Fig. 1 shows the frequency distribution of the occupant behavior family profiles for each building standard. It is seen that the distributions exhibit more positive skewness as the quality of the building envelope improves. The heating energy need of the existing building standard has a normal distribution (blue), the low energy standard shows slight positive skewness (red), and the lowest energy standard exhibits the strongest positive skewness (green) of the three.

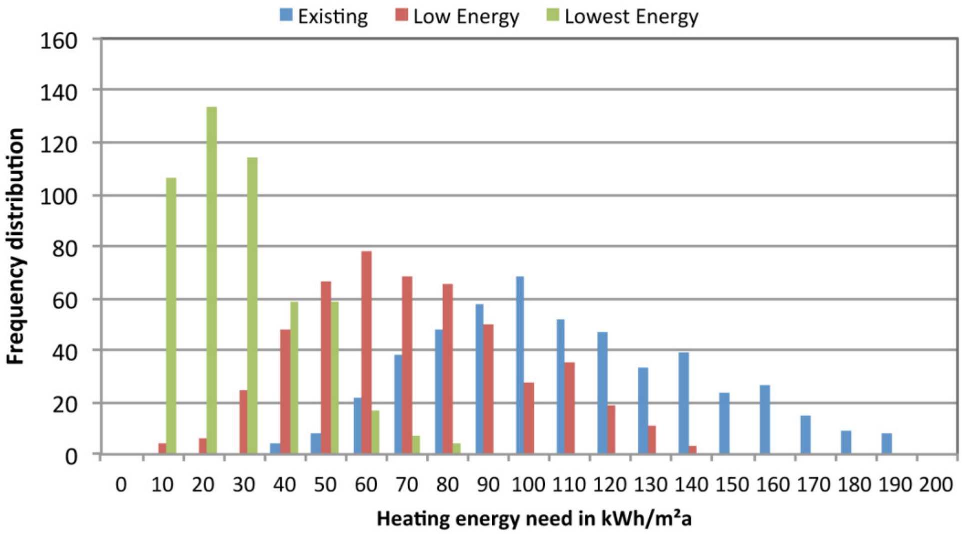

Fig. 1: Frequency distributions for the impact of user behavior on heating energy need for a house built to three building standards: Existing (E), Low Energy (L), and Lowest Energy (LE) [14].

Fig. 2 shows the average heating energy demand for each building standard interacting with the 1,000-profile set calculated using the dynamic building simulation and the monthly balanced method. Similar to Fig. 1, the difference between maximum and minimum values decreases along with annual heating energy demand in relation to increasing building envelope quality.

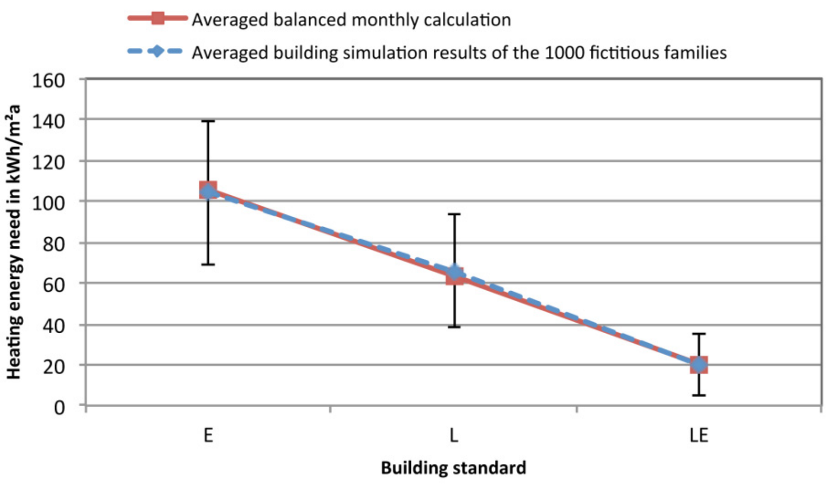

Fig. 2: A comparison of averaged heating energy demand for a house built to three building standards using simulation and monthly balanced calculations [14].

Proportional to the heating energy need, the standard deviation from the dynamic simulation increases with a higher quality building standard indicating that the influence of occupants' energy-related actions increases in sensitivity with a better quality building. The standard deviations are ± 34 %, ± 42%, and ± 75% respectively. Bednar et al. compared the results of the monthly balanced method, simulation results and the actual heating consumption of three different apartment buildings. He also found that the calculated value was representative of heating energy use if the calculation is performed correctly, and if the building envelope and building systems are built meeting the standard's requirements [18]. The frequency distribution of the heating use by individual apartments in the monitored apartment buildings also showed a similar pattern where the average of all household-heating consumptions resembled the calculated energy certificate value. The close correlation between both calculation methods indicates that the average value is representative of a typical household, but the widespread standard deviation shows that differences in energy-related household behavior can significantly impact heating energy need for individual households. Driving forces behind the different heating decisions made are published in Volume 2 of the Annex 53 final report [20].

4. Conclusions

The occupant behavior model considered complex factors such as the relationship of occupancy to the level of independence of family members. Different heating behaviors have been considered in the model, including decisions to partially heat different rooms in the house at different times by different users. Considering partial heating behavior is very important as it has a significant impact on total heating energy need.

The model verifies the accuracy of the monthly balanced method as representative of the average heating energy demand for single-family homes. The average value becomes more representative of heating energy need in all building categories with larger sample sizes. The frequency distribution of heating energy need becomes smaller with better building quality; however, the proportional impact of occupant behavior also increases with building quality.

The models discussed in this paper studied the impact of energy-related occupant behavior in households on heating energy need. The interaction of the two models combines the results of two different simulations to determine the impact of energy-related residential occupant behavior on heating energy need. In the two models, four different sets of factors have been considered: energy-related occupant behavior in the first model, and the interaction of climate, building envelope quality and building technical systems within the second. The energy-related occupant behaviors and building quality were varied to determine how different behaviors influence the heating energy need, and the average of 1,000 household profiles was determined and compared to the output of the quasi-stationary monthly balanced method. A strong correlation was shown between both models indicating that the monthly balanced method is representative of an average Austrian household.

Acknowledgements

Financial support for this research was provided by the Austrian Research Promotion Agency (FFG). This study was carried out as part of an international collaboration project, IEA EBC Annex 53.

References

1. Commission of the European Communities, *Limiting Global Climate Change to 2 degrees Celsius, The way ahead for 2020 and beyond*, in *COM(2007) 2 final*, Commission of the European Communities, Editor. 2007, Commission of the European Communities: Brussels.
2. Commission, E., *DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings*, in *2002/91/EC*, European Commission, Editor. 2002, European Commission,: Brussels.
3. European Commission, *DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC*, in *2012/27/EU*, E. Commission, Editor. 2012, European Commission,: Brussels.
4. Schweiker, M., *Occupant behaviour and the related reference levels for heating and cooling – Analysis of the*

factors causing individual differences together with the evaluation of their effect on the exergy consumption within the residential built environment. 2010, Tokyo City University: Yokohama. p. 231.

5. Fabi, V., et al., *Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models.* Building and Environment, 2012. **58**(0): p. 188-198.
6. Crawley, D.B., et al., *Contrasting the capabilities of building energy performance simulation programs.* Building and Environment, 2008. **43**(4): p. 661-673.
7. Sofic, M., *Erhöhung der Anwendbarkeit vereinfachter Berechnungsverfahren zur Bestimmung des Heizwärme- und Kühlbedarfs von Gebäuden : als Basis für ein Sicherheitskonzept*, in *Research Centre for Building Physics and Sound Protection*. 2009, Vienna University of Technology: Vienna. p. 318.
8. Zhao, H.-x. and F. Magoulès, *A review on the prediction of building energy consumption.* Renewable and Sustainable Energy Reviews, 2012. **16**(6): p. 3586-3592.
9. Yun, G.Y., P. Tuohy, and K. Steemers, *Thermal performance of a naturally ventilated building using a combined algorithm of probabilistic occupant behaviour and deterministic heat and mass balance models.* Energy and Buildings, 2009. **41**(5): p. 489-499.
10. Klein, L., et al., *Coordinating occupant behavior for building energy and comfort management using multi-agent systems.* Automation in Construction, 2012. **22**: p. 525-536.
11. Branco, G., et al., *Predicted versus observed heat consumption of a low energy multifamily complex in Switzerland based on long-term experimental data.* Energy and Buildings, 2004. **36**(6): p. 543-555.
12. Massetti, M., N. Morishita, and T. Bednar, *Influence of Selected Calculation Tool on a Design Process: A Case Study*, in *CESBP 2013 - 2nd Central European Symposium on Building Physics: Contributions to Building Physics*, A. Mahdavi and B. Martens, Editors. 2013, Vienna University of Technology, Department of Building Physics and Building Ecology, Vienna, Austria: Vienna, Austria. p. 269 - 276.
13. Austrian Standards Institute, *Thermal insulation in building construction — Part 5: Model of climate and user profiles*. 2011, Austrian Standards Institute: Vienna, Austria. p. 44.
14. Seif, K., *Einfluss der Anzahl der Bewohner und deren Lebensstil auf dem Heizwärmebedarf in Einfamilienhäusern*. 2015, Technische Universität Wien: Wien. p. 1-113.
15. Korjenic, A. and T. Bednar, *Impact of lifestyle on the energy demand of a single family house.* Building Simulation, 2011. **4**(2): p. 89-95.
16. Korjenic, A. and T. Bednar, *Validation and evaluation of total energy use in office buildings: A case study.* Automation in Construction, 2012. **23**(0): p. 64-70.
17. Dörn, M., *Vergleich von Verbrauchsdaten mit Bedarfsberechnungen für den Energieeinsatz bei Einfamilienhäusern*, in *Research Center for Building Physics and Sound Protection*. 2011, Vienna University of Technology: Vienna, Austria. p. 98.
18. Bednar, T., et al., *Performance and Experiences with Austrian demonstration projects for lowest energy houses (passive houses) in social housing*, in *ASHRAE Buildings XI: Thermal Performance of Exterior Envelopes of Whole Buildings*. 2010, ASHRAE: Clearwater Beach, USA. p. 7.
19. Yao, R. and K. Steemers, *A method of formulating energy load profile for domestic buildings in the UK.* Energy and Buildings, 2005. **37**(6): p. 663-671.
20. Polinder, H., et al., *Occupant behavior and modeling*, in *Total energy use in buildings: Analysis and evaluation methods,* H. Yoshino, Editor. 2013, Tohoku University: Tohoku. p. 1-153.