Investigation on the impact of occupant-centric design method applications on building energy efficiency and comfort – a case study

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Abstract

Designed and actual energy use in buildings depend on various factors. Due to many decades of scientific research and innovation on building technology, construction quality, climate representation, advanced design tools and other non-human-related aspects, energy consumption in buildings started to decrease. However, the desired net zero energy consumption levels many times are far from reality. It was found that an essential component of buildings, humans, needs to be accounted for in a more thorough way during the design process of a building. Without understanding and appropriately representing building occupants and their needs in the design process, it seems impossible to estimate real, in-use energy consumption levels. In a recent research project, building design studios were surveyed in Hungary about the methods used to consider occupants during their design projects. It was found that only 83% of designers know the expected number of occupants in the buildings designed, occupancy schedules are given only to 36% of them. Thermal, acoustic, visual comfort and IAQ expectations of spaces are given to 53%, 33%, 36% and 42% of building projects respectively. According to the survey results, only 39% of designers use some kind of dynamic building simulations to support their energy efficiency calculations in Hungary. Recent research suggests that with a more occupant-centric design approach, with more information on future occupants of the building, not only energy efficiency but comfort levels and space use efficiency can be increased as well. This paper shows to what extent these parameters could be improved in case of a case study office building from Hungary. Our investigations compare the results of the locally widely used, traditional design methods to the case where occupant-centric design methods are used.

Key Innovations

- Occupant-related information availability for designers
- Impact of more detailed occupant representation in building energy performance modelling is shown on consumption results.
- Impact of more detailed occupant representation is shown in case of an early design decision

Practical Implications

- Occupant-related information availability was quantified in case of Hungarian practitioners.
- Occupant representation level of detail alone can account for 8.4-9.5% of yearly energy consumption change.

Introduction

Many studies over the past decades showed important advances in building energy efficiency by focusing on technical and technological factors (Csoknyai *et al.*, 2016), (Røstvik, 2013), (D'Oca, Corgnati and Buso, 2014).

Also, a many times investigated by researchers lately is to address the issue of a performance gap which is a mismatch between the predicted energy performance of buildings and actual measured performance. Increased pressure on the industry to address the challenges of environmental issues and rising energy prices makes it important to address this performance gap, with the general expectation of new high performance buildings to meet increasingly stringent energy efficiency targets. (De Wilde, 2014)

Research studies highlighted that social sciences may be included in this research area to provide answers for both research questions with adequately consider occupants' responses (Sovacool et. al., 2018) and also to enhance building representation in design energy calculations.

Hence there is value in understanding potential occupant influences early in the design process, before occupancy actually occurs. Building performance modelers by necessity often ignore aspects of occupant behaviour by assuming fixed comfort temperatures for example. This is the standard practice even though researchers have shown that occupants influence building performance by their choice of setpoints and behaviour. (Andrews et al., 2016)

There has been significant effort in the research community (Souza and Tucker, 2014) to support designers and their early design decisions with energy calculations of appropriate level of detail and accuracy.

Design choices directly determine many aspects of building performance, but occupant responses to comfort conditions, their experience can also influence energy performance (Bordass et al., 2001). It was also found earlier that building design choices can have positive impact on decreasing the effect of occupant behaviour on energy performance. (Buso et al. 2015)

Occupancy and occupant behaviour in buildings is a significant area of interest within the field of building performance simulation. A recent study investigated the impact of the availability of different spatial resolution of occupancy data on the gap between predicted and measured energy use in buildings. (Chong et al., 2021) However, it is suggested that more studies would be needed to investigate the relationship between occupant data available for practitioners and design level energy calculations supporting design decision making processes.

Introduction to the practitioner survey

To assess current practices in user-centred design and operation, a research group organised in the framework of international project, IEA EBC ANNEX79 (*ANNEX 79 Project*, no date) has created a questionnaire for designers and professionals from different disciplines working in the construction industry.

This survey dealt with building user behaviour. It also looked at how users were taken into account by different design professionals during the design phase and during operation. Participation in the survey was voluntary and anonymous.

The survey consisted of 3 parts:

1. overview: respondent's current position, expertise, company size, project types

2. consideration of building users

3. simulation software, building user models

In Hungary, the survey was conducted in the Autumn of 2021. The total number of Hungarian responses was 36. These were fully completed questionnaires.

Results showed that people working in planning or operation received a surprisingly high percentage of data on future users. However, the information available was typically the number of building users (83%), the preferred temperatures (64%), room functions (89%) while information on sociological factors that influence user behaviour (20%), and the temporal variation of building use (36%) were poorly available.

In a sectoral comparison, workers in the architectural sector were slightly more likely to have information about users than HVAC consultants and designers. However, the essential difference was not the role in design and operation, but the size of the firm. The larger the firm the respondent worked for, the less user-related information was available from the client or project manager (Figure 1).

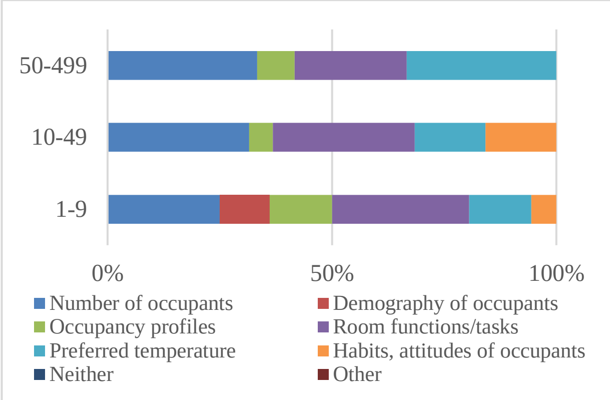

Figure 1 - Occupant information types available according to size of the design company (nr. of employees) of respondent

It was also found that only 39% of designers used some kind of dynamic building simulations to support their energy efficiency calculations in Hungary.

Architects were slightly more likely to use simulation software and more likely to use it for thermal modelling than HVAC consultants and designers, but deeper knowledge did not go hand in hand with more varied simulation and more sophisticated software use.

Aim of research

The goal of this research introduced in this paper is to show to what extent the actual knowledge of occupant-related parameters could affect the design calculations in case of a case study office building from Hungary.

Methodology

In this section, the methods are introduced that were applied to use survey results as a starting point, to carry out simulations on the selected case study building and analyse heating energy consumption of different scenarios investigated.

Survey result implementation

The survey results introduced earlier clearly showed in which areas professionals lacked information i.e., the temporal variation of building use and factors that influence user behaviour.

Only 50% of the survey respondents received data on the habits of future users, attendance profiles and schedules were available to 36% and only 20% know the personal preferences, attitudes, and motivation of building users.

For this reason, in the current research the differences between simpler and more complex building occupant schedules and behavioural details were investigated via building simulation.

In addition, structural comparisons were also made in the simulation to model a realistic decision-making situation in order to see what differences the occupant behaviour and structural related changes make in energy consumption.

Case study building - Simulations

The office building used as a case study is located on the Eastern part of Hungary, in Nyíregyháza. The facility was built in 2012. It consists of a ground floor and an upper floor, as well as an unheated workshop and two warehouses and in total has a heated floor area of 387.2 m^2.

This is the central building and premises of a building engineering design company, 10 people work in the office part and the same number in the workshop and warehouse part.

The office building has a 15-space uncovered parking lot and a 200 m^2 grassy garden.

It is bounded by a busy road to the northwest, a small forest and a stream to the southeast, and an electrical shop to the southwest. The plot is lower than the neighbouring plots.

Figure 2 - Front view of the case study building

DesignBuilder Software (*Design Builder*, 2022) was used for the dynamic simulation examinations.

We got access to the energy certificate of the building, so we were able to set the exact floor plans and window sizes with the help of the document in DesignBuilder.

First, we set the appropriate weather file stored in the program, which was the closest to Nyíregyháza, Hungary, and the orientation, then we determined the geometry of the building, added the windows and doors of the right size, and set the construction layers.

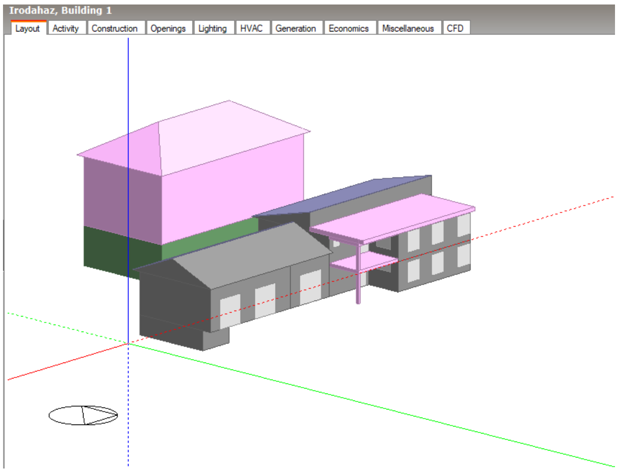

Figure 3 - Building model - Eastern side

The building was divided into different zones. We set different use profiles for each zone based on the above-mentioned questionnaire's different points. We complied with the thermal and visual comfort requirements for indoor environmental quality. These parameters are the number of the occupants, the room functions, i.e. set expected room temperatures, heating and occupancy schedules, ventilation habits, domestic hot water needs, additional heat sources in each room and lighting needs. We also included the individual shading structures.

The modelled HVAC system can be seen on Figure 4.

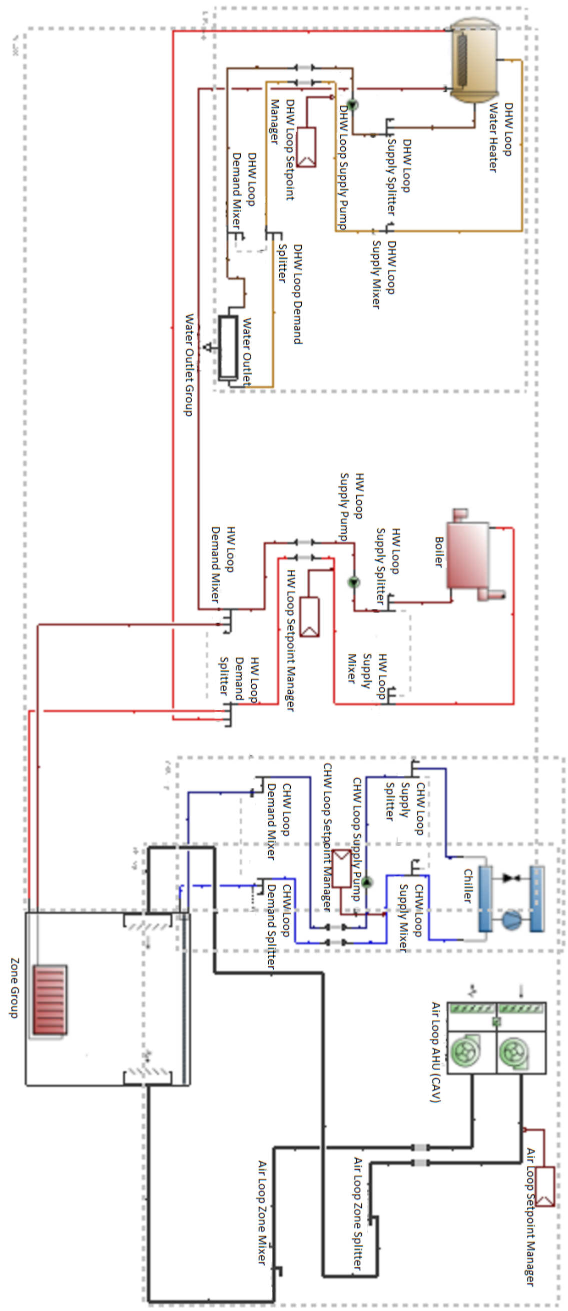

Figure 4 - HVAC system representation in DesignBuilder software

The primary side of the building engineering system consists of a gas boiler, which also produces hot water, as well as a chiller plant and an air handling unit. Radiators were placed in the heated zones and rooms, air supply and exhaust grilles, and radiant ceiling cooling were used. Mechanical ventilation and mechanical cooling were installed in the office building.

The water consumption was also integrated into the model, as well as hot water consumption. However, their value was not changed during the different versions. For hot water consumption, a pre-determined value was set for each wet room (washrooms, kitchen, etc.).

We ran a yearly simulation, which meant 8760 hours.

Due to the nearly passive house-level of insulation of the exterior building structures and good-quality construction, the infiltration was set to a very low value, n50=0.2 [1/h].

Realistic internal striped roller blinds were set as shades. Outdoor lighting was modelled as well.

For internal heat load, the devices that were locally found on the spot were included: printers, computers, laptops, projectors, small and large lamps. For the workshop part, we also included other equipment necessary for physical work.

Solar panels were installed on the semi-gable roof structure of the office building and on the shared gable roof of the workshop and warehouse. The solar panels (12 kWp) were intended to reduce the building's electricity consumption and, if necessary, to supply it.

The heating season was assumed to be from October 1st to April 30th, and accordingly the summer period lasted from May 1st to September 30th.

To investigate the effect of occupant behaviour representation in the model and its effect of yearly energy consumption estimations, 4 model versions were established.

Version 1A– Detailed occupant representation

At first, a thorough model was created, highlighting most occupant-related parameters, where different presence, lighting, ventilation, heating, cooling schedules and Templates were set for each room. The power consumption was also adapted of office equipment to the occupant presence. We have also placed a lighting control / sensor in each room, which meant that the program only calculated with the lights on if indoor natural lighting level was low (300 lux) on the given space’s work pane.

Version 2A – Simplified occupant representation

In the second case, our goal was to investigate the effect of considering building users on the annual simulated energy consumption. Here we assumed that the designers do not know generally in detail how occupants are to be expected to behave and occupy spaces based on results from our survey. In this version, in contrast to the first one, we did not take into account either the shades nor the users in the building, i.e., we assumed, following design traditions, that everyone was always inside, the shades did not move. In this case, we did not first deal with the setting of the various Templates and schedules, but set the values and various characteristics for the entire building in general for the office building.

Versions 1B and 2B – Effect of a design decision (glazing properties of windows)

In the third and fourth cases, the goal was to examine the effect of changing an important design parameter (transparent structures) under the assumption of detailed or simplified building user behaviour. In these cases, we were able to model a decision-making situation of the real planning process. The third case differs from the first only in that, instead of a three-layer window with solar protection glazing (SHGC = 0.33), a two-layer product (SHGC = 0.62) was set for the entire building.

The fourth case (2B) differs from the second (1B) only in that, instead of three-layer windows and doors, two-layer ones were installed for the entire building.

The differences between the individual versions can be seen here, in Table 1:

Table 1 - Parameters of the 4 simulation cases described above

	Version 1A	Version 2A	Version 1B	Version 2B
PV-panels	✓	✓	✓	✓
Order of layers	✓	✓	✓	✓
Detailed occupant representation	✓	✕	✓	✕
Detailed lighting schedules	✓	✕	✓	✕
Shading on	✓	✕	✓	✕
Lighting control	✓	✕	✓	✕
Heating schedules	✓	✕	✓	✕
Ventilation schedules	✓	✕	✓	✕
Operational schedule for the office/kitchen/other equipment	✓	✕	✓	✕
3-layer windows	✓	✓	✕	✕
2-layer windows	✕	✕	✓	✓

The characteristics of the windows in versions A and B are shown in Table 2.

Table 2 - Glazing parameters of versions A and B

	Version A	Version B
Total solar transmission (SHGC)	0.331	0.623
Direct solar transmission	0.192	0.542
Light transmission	0.553	0.618
U – value (ISO 10292/EN 673) (W/m^2*K)	0.806	2.673
U-value (W/m^2*K)	0.925	2.556

Results

The building's annual final energy consumption levels are shown on Figure 5 in case of versions 1A, 1B, 2A and 2B:

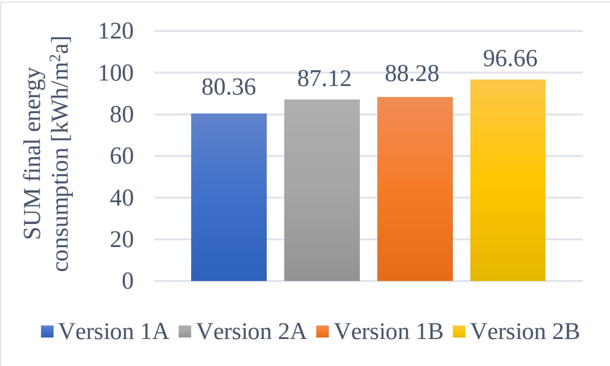

Figure 5 - Energy consumption results of the 4 cases

Annual final energy consumption levels show an 8.4% increase in energy consumption between versions 1A and 2A due to less realistic and simplified occupant presence and behaviour patterns. Similarly, model version 2B with simplified occupant representation produced a 9.5% increase in predicted yearly final energy consumption level compared to version 1B.

When the effect of a design decision is simulated (window type A or B), the change caused a 9.9% increase between versions 1A and 1B.

The same structural change applied to the simplified occupant representation model (versions 2A to 2B) resulted in an 11% increase.

Heating and cooling energy consumption was analysed on a monthly basis. Monthly heating energy consumption of versions 1A to 2B can be seen on Figure 6.

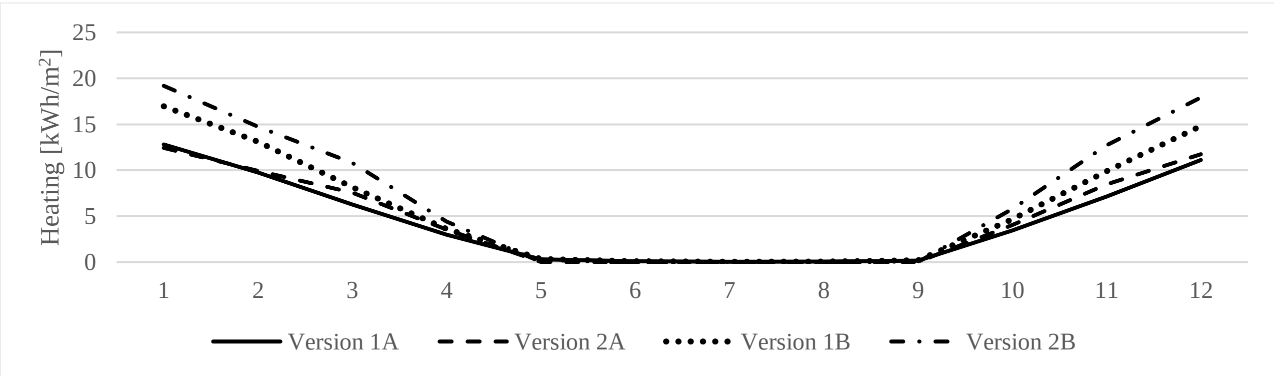

Figure 6 - Monthly heating energy consumption levels

When comparing heating energy consumption in case of versions 1A and 2A, it can be seen that majority of the difference appears during spring and autumn months.

In case of 2B and 1B, the tendency is similar as above but the difference in consumption is larger as the total consumption is larger as well.

Versions B, with lower window insulation levels, compared to versions A consumed more heating energy, in every month investigated.

Discussion

Increased simulated energy consumption levels in case of version 2B compared to 1A indicates that non-realistic occupant representation in building simulation models can lead to overestimated energy use levels and thus might influence the proportion of different types of consumptions in our calculations such as heating levels compared to cooling levels or hot water use.

At the same time, it proves the findings of recent studies showing that the energy performance gap can be addressed by incorporating more occupant-related aspects into design energy calculations.

When comparing B models to versions A, it can be seen that both in case of versions 1 and 2, the window change decision resulted in a 9.9-11% increase due to lower insulation levels. This shows that the occupant representation's effect on design decision calculations are more marginal (1.1%) than in case of yearly energy consumption predictions.

Monthly analyses in case of versions 1A and 2A, it can be seen that majority of the difference appears during spring and autumn months which indicates that more detailed occupant representation affects intermittent seasons more than winter months.

Results show the need for deeper knowledge and understanding of future occupant behaviour for building designers. The fact that according to our survey results only 36% of designers have information on future occupancy of the building is alarming.

At the same time, majority of survey responding designers generally know the number of building users (83%) which enhances the potential quality of building energy-related calculations. Also in many cases preferred heating and cooling temperatures are known during the design process (64%) as well as room functions (89%). However, these values could be increased to 100% in the future as a building design process where neither desired room temperatures nor exact room functions are known for designers, can be very misleading from the energy point of view especially in case of net zero energy consumption buildings. As today information on sociological factors that influence user behaviour is available for only a fragment of designers (20%) as well as the temporal variation and schedules of building use (36%) on the Hungarian building design market, it is desirable in the future to advocate and promote the importance of occupant behaviour representation for building design professionals to in case sustainable and highly energy-efficient building design projects.

Conclusion

The topic of this paper is the investigation of the impact of occupant representation in design-level building energy calculations.

The goal of this research introduced in this paper is to show to what extent the actual knowledge of occupant-related parameters could affect the design calculations in case of a case study office building from Hungary.

Traditional, currently used design practices were surveyed in the country to find out what aspects of a building's future occupant behaviour is available in the design phase for practitioners.

Survey results showed that number of occupants and setpoints are known to designers most of the time whereas occupancy, exact room functions, temporal schedule variations, actual demographical, cultural and behavioural knowledge on occupants is often missing.

Based on these results, a case study building was analysed using dynamic building energy modelling to determine the exact effect of the lack of knowledge on occupants during the design process.

It was found that occupant representation level of detail alone can account for 8.4-9.5% of yearly energy consumption change.

Secondly, it was investigated whether occupant representation in the model has an impact on a design decision, namely the selection of window type. In this case, it was found that occupant representation's effect on design decision calculations are marginal (1.1%).

This work is planned to be expanded in the future to investigate more occupant representation scenarios in case of more building types as well.

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References

Andrews, C. J. *et al.* (2016) 'Using synthetic population data for prospective modeling of occupant behavior during design', *Energy & Buildings*. Elsevier B.V., 126, pp. 415–423. doi: 10.1016/j.enbuild.2016.05.049.

ANNEX 79 Project (no date). Available at: https://annex79.iea-ebc.org/.

Csoknyai, T. *et al.* (2016) 'Building stock characteristics and energy performance of residential buildings in Eastern-European countries', *Energy and Buildings*, 132, pp. 39–52. doi: 10.1016/j.enbuild.2016.06.062.

D'Oca, S., Corgnati, S. P. and Buso, T. (2014) 'Smart meters and energy savings in Italy: Determining the effectiveness of persuasive communication in dwellings', *Energy Research & Social Science*. Elsevier Ltd, 3, pp. 131–142. doi: 10.1016/j.erss.2014.07.015.

Design Builder (2022). Available at: https://designbuilder.co.uk/software/for-education.

Røstvik, H. N. (2013) 'Does research results have an impact? Climate change and building insulation', *Advances in Building Energy Research*, 7(1), pp. 1–19. doi: 10.1080/17512549.2012.736880.

Souza, C. B. De and Tucker, S. (2014) 'Thermal simulation software outputs : a framework to produce meaningful information for design decision- making', *Journal of Building Performance Simulation*, (May), pp. 37–41. doi: 10.1080/19401493.2013.872191.

De Wilde, P. (2014) 'The gap between predicted and measured energy performance of buildings: A framework for investigation', *Automation in Construction*. Elsevier B.V., 41, pp. 40–49. doi: 10.1016/j.autcon.2014.02.009.