Energy and Buildings 148 (2017) 182–198

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A study of the impact of occupant behaviors on energy performance of building envelopes using occupants' data

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ARTICLE INFO

Article history:
Received 8 December 2016
Accepted 28 April 2017
Available online 8 May 2017

Keywords:
Occupant behavior
Residential building
Energy performance
Building envelope
Climate

ABSTRACT

This paper investigates the influence of occupant lifestyle patterns on the energy performance of the residential buildings with various building envelopes in different climate zones.

For this purpose, an existing multi-family apartment building in Iran was selected as the experimental residential building and the validity of energy simulation was examined based on the real data of the building energy consumption.

The energy demand of the building before and after renovation was simulated via EnergyPlus for different climate zones. The sensitivity analyses confirmed that the occupants' behavior has a significant impact on the building's thermal energy usage especially in hot climate areas and can change the heating and cooling loads up to about 90%. Using the validated model, a parametric study was performed to investigate the influences of the occupant's behavior on the efficiency of the building envelope including window and cladding materials in different climate zones. The results show that the interaction between the occupants' behaviors and envelope materials is significant in that the occupant behaviors can change the strategy of choosing the envelop material types. Fluctuation of thermal energy consumption caused by changing of window types can rise to 20% for this case study. Also, it is shown that underestimating the level of occupancy loads can exaggerate the effects of the envelope on the thermal energy consumption rate. Overall, this study emphasizes the importance of applying near actual user behavior data on energy simulation analyses performed for the studies of building sustainability and lifecycle assessment.

1. Introduction and literature review

Residential buildings are one of the most important energy consumer in the world. During the last years in Iran, the building sector consumed about 35% of the total energy of the country [1]. Much of this energy is used by heating and cooling systems to provide a comfort environment for the building occupants. Reduction of the thermal energy consumption is a significant matter that the building industry is facing. One of the solutions for this problem is to consider the efficient materials for the building envelope.

Several parameters affect the envelope energy efficiency. Base on the literature of envelope performance, these parameters can be categorized in four groups including: design, materials and construction, site parameters [2], and occupant behavior. As the design parameters, shape and orientation of a building, window-to-wall ratio, and shading can be mentioned. As materials and construction parameters, types of materials and glazing as well as their thermal properties, layers, thickness, and infiltration can be named. Site factors that are not related to the building but influence the energy demand can be assigned to various parameters such as climate features, position and shape of the detached adjacent building. The last group and occupant behavior parameters are conceptually different parameters which mainly depend on the behavior of users of the building. Occupants' behavior can be defined as "the presence of people in the building and the actions occupants take (or not) to influence the indoor environment" [3]. These behaviors include interactions with operable windows, lights, blinds, thermostats, plug-in appliances, and user presence [4,5].

Research studies have been done through the last decade to achieve the optimal building envelope including materials. Despite that those studies focused on assessment of the materials in the laboratory conditions, many researchers have preferred to employ a simulation software for estimating a building's energy consumption. Energy simulation is an economically more efficient and

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http://dx.doi.org/10.1016/j.enbuild.2017.04.085
0378-7788/

technically more flexible tool for parametric study of real scale buildings. A group of these researchers investigated the effects of some envelope material features on building energy usage during the building operating phase [2,6–9]. Some of them extended the results of their research for various climate zones [10,11]. Another group of researchers considered both embodied energy (or cost) and operational energy to evaluate the energy performance during the building life cycle [12–14]. In addition, other studies showed the benefit of optimization tools for efficiency assessment of a large group of envelope features including materials [15–21].

All of these researchers considered four different approaches for developing their simulation including: (a) using their assumption for developing the computational model, (b) utilizing codes and protocols for model establishment such as Building America's House Simulation Protocols [22] and Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1 Standard with all the appendixes) [23], (c) using a typical building's real data for simulation, and (d) combining all of these approaches. Most of the recent research projects take the first approach and consider their own simple assumption for occupant behavior in energy simulation. Some of these studies are briefly described as follows.

Raji et al. [2] assessed the effects of four envelope parameters on building energy consumption in the temperate climate. In this study, a base case tall office building in Netherlands was selected, and Design Builder software as a graphical user interface for EnergyPlus was utilized to estimate the annual energy demand. The authors used real building physical properties for simulation and applied the measured data for validation of the results. A sensitivity analysis was carried out and the results showed that the building energy usage is highly sensitive to infiltration and glazing types but less sensitive to heating/cooling setpoint temperature and occupancy schedules. In this study, several retrofitting strategies under various categories including glazing type, window-to-wall ratio, shading, and roof strategies were simulated and the result of the analyses were discussed. For the parametric analysis, the heating and cooling setpoints were respectively fixed to 21 °C and 24 °C for the entire year and the building was assumed to be occupied by a fixed number of people per cubic meters even during weekends. They also used a fixed rate (0.5 W/m^2) for miscellaneous equipment during the whole study.

Zolfaghari et al. [11] investigated the effect of using different home exteriors materials on the energy consumption. They simulated a test room using EnergyPlus under three different climatic conditions. The results of their analysis indicated that the brick finishing covering has the best performance in common cladding used in moderate climate by 6.9% energy saving. For hot and cold zones, the study suggests that the firebrick covering material with 23% energy saving and the painted concrete covering with 7.1% energy saving are respectively the best cladding material.

In work by Shabunko et al. [7], effects of the building orientation, shading devise and glazing types were studied. Many residential buildings in Brunei Darussalam were considered and three types of building design were selected among them. Three simulation models were developed for the representative buildings and average hourly schedules were applied to occupancy, lighting and electrical loads for all analyses.

Alaidroos and Krarti [12] also investigated the single family house (villa) envelopes in five different climate zones of Kingdom of Saudi Arabia (KSA). They developed a base case of two stories villa in EnergyPlus and used an optimization process based on life cycle cost and energy saving to determine the optimal building envelope system. Five energy efficiency indicators included in this study were exterior wall insulation, roof insulation, window shading, glazing type, and exterior wall thermal mass. For all simulations, the heating and cooling systems were available throughout the year with no ventilation for the building. The results show that selecting proper facade can result in 40% energy saving.

In another multidisciplinary study [24] of energy demand, comfort level and environmental sustainability, three envelope materials including masonry, wood-cement and wood were compared in hot and dry climate zones of the Mediterranean area. The case study was an unconstructed low-energy multi-family residential building in Italy with internal gains and HVAC winter and summer setpoints equal to 4 W/m^2, 20 °C and 26 °C, respectively.

Karatas and El-Rayes [25] presented an optimization model for enhancing single-family housing design and construction parameters. The model was developed based on the genetic algorithms in MATLAB coupled with EnergyPlus to generate optimal tradeoffs between initial costs and environmental performance during the operational phase of the building. The implemented model was capable of generating 103 Pareto optimal solutions for design and construction variables including heating/cooling system, building envelope (window glazing type, roof and ceiling insulation), water heater, number of lighting bulbs, electrical appliances and water fixtures. This study used the United States' codes and standards for building and internal load simulation. B10 benchmark house was used as a reference single-family house in the Unites State built based on the 2009 IECC code, 2010 federal appliance standards, and lighting characteristics and miscellaneous electric loads [26] most common in 2010.

In addition to above mentioned studies, Table 1 briefly describes the main features of some other recent studies in the field of energy simulation for building envelopes.

Shi et al. [32] and De Boeck et al. [33] briefly reviewed many other previous studies and provided an overview on building design optimization from an architect's perspective.

Among the numerous research projects that investigated the thermal performance of different materials under various climate conditions, some studies discussed about the importance of occupant behaviors. Lin and Hong [34] conducted a simulation-based study and examined the dependency of building energy consumption on design and user behavior parameters in three climate zones. Two office buildings were chosen for simulation from the U.S. Department of Energy commercial reference buildings (CRBs) [35], and effects of several levels of internal loads, infiltration (rate and schedule), thermostat setpoints, in addition to some design parameters on heating energy use were analyzed separately. The paper emphasizes on the importance of operation parameters for energy consumption analysis. Wang and Greenberg [36] also highlighted this issue. They developed an office building simulation model based on their assumptions and investigated the impact of window operation control strategies on heating and cooling energy demand for three types of ventilation systems in three climate zones.

Based on the simulation results presented by Sun and Hong [37], the occupant behavior measures can decrease the building site energy up to 41% for integrated measures. In their study, a real two story office building was considered and energy performance of five behavior measures including lighting, plug load, comfort criteria, HVAC control, and window control was evaluated through the presented simulation approach across four U.S. climates. The authors applied the Occupancy Simulator developed by Lawrence Berkeley National Laboratory to simulate the office user movement with inputs from the site survey. In addition, Gaetani et al. [5] evaluated the effects of three different levels of lighting, occupancy and equipment schedules on a medium-size office building model developed by the U.S. Department of Energy (DOE) [35]. The survey also discussed about how various user behaviors influence a building's energy performance. This paper also presented an overview of the various occupant behavior modeling approaches.

Tahmasebi et al. [38] investigated two of these approaches and studied their effects on the heating and cooling energy through