The relation between indoor environnemental quality (IEQ) and energy consumption in building based on occupant behavior - A review

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Abstract. Indoor Environmental Quality (IEQ) is an important topic which impacts on occupant health, productivity and also energy consumption in buildings. The four main parameters for IEQ evaluation are: Thermal comfort, indoor air quality, visual comfort and aural comfort. The occupant behavior in buildings defines as any direct or indirect act which an occupant selects to change the displeasure environmental condition into the comfort conditions. The selected behavior by human has a significant impact on the energy consumption in buildings. This paper reviews the methods which used to simulate IEQ parameters, energy consumption and human behavior in buildings. It aims to promote the idea of more consideration about the relation between occupant behavior and energy usage in buildings. This summary of existing studies about the importance of human behavior factor in energy simulation software helps to identify new methods and strategies for simulating IEQ, Energy and behavior.

Keywords: indoor environmental quality (IEQ), energy consumption, human behavior

1 Introduction

These Most people spend more than 90% of their time indoors [1]. The importance of Indoor environmental quality (IEQ) is it impacts on energy efficiency and also productivity and health of occupants. Thermal comfort, indoor air quality, visual comfort and aural comfort are four main physical parameters which are normally used to determine IEQ. There will be a rising focus on energy consumption and indoor environmental quality in existing buildings and the future buildings. There is a significant relation between energy consumption and the features which are considered in the indoor environment (temperature, ventilation and lighting) and building design and operation. According to the recent studies the cost of poor indoor environment for the employer, the owner and also for the society, as a whole are frequently considerably higher than the cost of the energy which are used in the same building [2] .

The "behavior" refers to any direct or indirect action that a building occupant selects to manage their surrounding environment. Human behavior is maybe the most important IEQ study topic because human activities and decisions deeply influence every IEQ determinant at every stage of building's lifecycle. Through understanding human behavior the energy prediction models will be improved .The problem is measurement and quantification the human behavior and translation that into the energy algorithm. The technology of simulation is based on several disciplines like as computer and numerical science, physics, mathematic and so on. For simulating human behavior in building, social science modeling can be a useful method.

The aim of this paper is to review the relation between IEQ and energy consumption in building based on Occupant behavior. Also, the human and energy simulation methods are considered.To achieve the objective of this paper, the related studies to the IEQ and building energy usage based on human behaviour are identified through internet searches, review of published papers and conversation with other researcher.The results and methods of these researches areconsidered and the simualated software and methods are analysed.

2 Indoor environmental quality (IEQ)

Based on United States Green Building Council (USGBC), Water efficiency, materials and resources, energy and atmosphere, sustainable sites and indoor environmental quality should be consider for a green building. Measuring of IEQ is commonly validate by four aspects: i.e. Thermal comfort (TC), Indoor air quality (IAQ), Aural comfort (AC) and Visual comfort (VC) [3, 4].

2.1 Thermal comfort

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Thermal comfort is defined "that condition of mind which expresses satisfaction with the thermal environment" according ISO 7730 standard definition and also ASHRAE Standard 55,states that, success means that a building meets the needs of 80% of the occupants [5, 6] . Air temperature (°C), mean radiant temperature (°C), air velocity (m/s) and relative humidity (%) are the four environmental parameters which influence thermal perception of occupants while, metabolic rate (Met) and clothing value (Clo) are considered as personal parameters [7] .Air temperature, air velocity and relative humidity are measured directly. Equation for calculating mean radiant temperature is:

$$T_{mrt} = (\Sigma F_{si} T_i^4)^{1/4} \quad (1)$$

Where T_i=Temperature of black surface, F_{si}=fraction of radiation of the black sphere which reaches the i^{th}

Each person has a special metabolism rate. These rates are able to change according to the activities done, or under special environmental situations. The movement of air and relative humidity can reduce the insulating ability of the cloth depending on the sort of cloth [8]. Based on mentioned parameters the Predicted mean vote (PMV) and predicted percent of dissatisfied (PPD) indexes are defined.

2.2 Indoor air quality

The Indoor air quality (IAQ) is related to the health and comfort of occupants and poor IAQ is related to the Sick Building Syndrome (SBS). The change amount of pollutant per volume of air over time is expressed by:

$$VdC_i/dt = P_i - (ventilation) - (exfiltration) - (sorption, decay, cleaning)\ [\mu g/s] \quad (2)$$

Where: V = volume of space (m^3), C_i = concentration of pollutant in indoor air ($\mu g/m^3$)

There are different group of chemical and biological pollutants in indoor air .There are different research which considered CO_2 concentration as an IAQ Index [9-11]. The equation to calculate ventilation rate for considering IAQ based on CO_2 concentration is:

$$V_{rate} = \frac{EX\ rate}{CO2in - CO2out}, \quad (3)$$

Where V rate = effective ventilation rate in cfm of Outdoor Air (OA) per person ,EX rate = average exhalation rate of CO2 per person in the measured area,CO2in = measured inside concentration level of carbon dioxide, CO2out = outside carbon dioxide concentration, measured or estimated.

2.3 Aural comfort

The direct and diffuse indoor sound pressure which is perceived depends on characteristics of the space like as volume of space. In the field of diffuse the sound pressure level perceived is:

$$L_p \cong L_w + 10log\ (4/A)\ [dB] \quad (4)$$

Where L_p= sound pressure level, L_w = sound pressure level in point, A = surface area of the enclosed space .

The sources of noise (when sound disturb the occupant) are indoor sources like as HVAC systems, sanitary, drinking water, flank transmission through the pipe systems into the building structure installations and outdoor sources like as traffic jam.

2.4 Visual comfort

Lighting (counting as luminance, difference between clarify surfaces, and the spectrum of light) can influence residents' health and efficiency both in a straight line, since work efficiency depends on vision, and not directly, because lighting can straight attention, or affect motivation[12]. The daylight and artificial light are two main sources of light. Based on following equation the amount of direct lighting level is [13]:

$$E = n\ \Phi\ \eta/(l \times b) \quad (5)$$

Where: n = number of light sources; Φ= light flux of all light sources (lumen); η= output (efficiency) of light source; l = length of space (m); b = width of space (m).

2.5 Overall IEQ acceptance

However, each IEQ parameter has an important effect on occupant comfort and productivity, perceive of overall IEQ acceptance is more complicated. There are several studies which assess the IEQ acceptance among occupant by using a multivariate logistic regression [4, 9, 10].The demonstrated model is:

$$\acute{o}_0 = 1 - \frac{1}{1 + \exp(C_{0,0} + \sum_{i=1}^{4} C_{i,0} \acute{o}_i(\zeta_i))} \quad (6)$$

Where: $\acute{o}_0$ = the overall IEQ acceptance, $C_{0,0}$ and $C_{i,0}$ are the regression constants, $\acute{o}_i$ is the occupant acceptance related to the thermal sensation vote ζ_1, the CO_2 concentration ζ_2(ppm), the illumination level ζ_3(lx) and the sound pressure level ζ_4(dBA).

The thermal environment acceptance $\acute{o}_1(\zeta_1)$, is :

$$\acute{o}_1 = 0.95\ exp\ [-(C_{0,a}\zeta_1^{\ 2} + C_{1,1}\zeta_1^{\ 4})] \quad (7)$$

And the acceptance of $\acute{o}_2(\zeta_2)$, $\acute{o}_3(\zeta_3)$ and $\acute{o}_4(\zeta_4)$ are demonstrated by below regression when $C_{0,j}$ and$C_{1,j}$ are regression coefficient :

$$\acute{o}_j = 1 - \frac{1}{1+\exp(C_{0,j} + C_{1,j}\zeta_j)}, j = 2,\ldots,4 \quad (8)$$

3 Human behavior & building energy consumption

The amount of energy consumption in residential and commercial buildings was about 41 % of total energy usage in U.S in 2014. As illustrated in Figure 1, according to Hoes et al.[14], Energy use in buildings is closely linked to the behavior of occupants in building. The researches on thermal comfort and adaptive control [15] , lighting control [16] , possible window control [17] , and shading control [16] are some of the research subjects which began to assess the occupant behavior that influences in building operation and energy efficiency.

Behavioral in buildings are intricately linked with multiple factors that stem from the physical, cultural, psychological, social, and so on [18]. Some studies have also suggested that the perceived ability or inability to behave adaptively in the field has a psychological effect that must be considered by thermal comfort calculations [15, 19, 20]

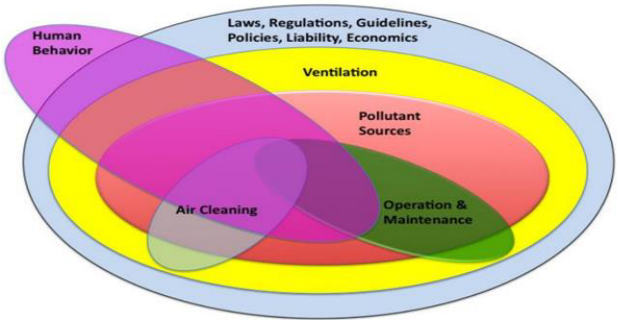

Figure 1. Inter relationships of IEQ determinants. Human Behavior factors affect all other determinants (Source:T.J. Phillips).

3.1 IEQ simulation tools

The aim of this part is to consider simulation tools and software which are using to predict occupant satisfaction, energy efficiency and occupant comfort in buildings. The simulation of building is a good strategy for testing building efficiency in different conditions[21] .

Estimating the amount of energy consumption and designing the HVAC system is the most common usage of simulations. In some studies IEQ aspects are considered based on temperature set points and ventilation rate[22] .There are different developed computational models for simulating each IEQ aspect [21, 23, 24]. Most of these simulating models consider each IEQ aspect separately and the inability to consider the interaction of a specific IEQ parameter with other IEQ Parameter is the drawback of these methods[25].Based on U.S Department of Energy (DOE2015) , just 2 of the 417 simulation software in the Building Energy, are capable to simulate all four IEQ aspects. Loonen et al. reviewed different building performance simulation (BPS) programs and their capability to calculate the various IEQ parameters. This overview is shown in Fig 2.

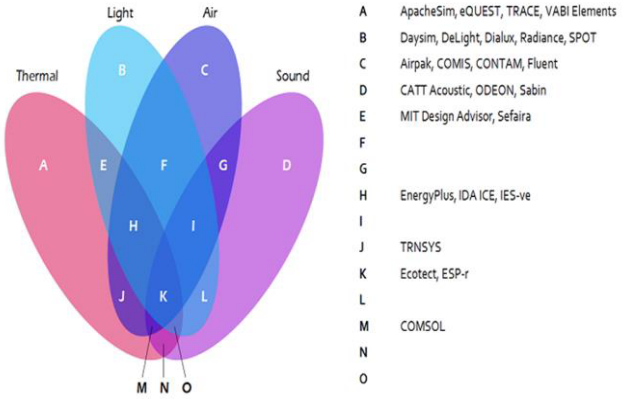

Figure2. overview of different BPS programs [22]**.**

3.2 Human behavior

The "behavior" is the actions or reactions of an object, usually in relation to its environment. In the most research, the presence of occupant and heat generation and energy consumption by occupant are considered without taking account the way which they behave to use energy [26]. Considering the actual behavior of occupant in simulation methods leads to more realistic simulation. Recognition information within humans are captured by many behavior illustration models[27] .

The human behavior representation model based on earlier studies are summarized in Table 1.Based on Langevin suggestion [28] , there are different steps to acheive better understand about the concept of human behavior simulation. These suggested steps are:

a) Additional longitudinal field study
b) Individually behavior modeling
c) Assessment of behaviors and their sequencing
d) Behavior modeling in multiple building types
e) An accessible behavior/energy co-simulation structure

Table 1.Summary of human behavior representation model

Study	Proposed model	Description
[27]	ACT (atomic components of thoughts)	focuses on the way which humans organize their knowledge in order to behave intelligently
[29]	CAPS (concurrent activation based production system)	Considering each specifying the conditions and consequent actions

[30]	COGNET (cognition as a network of tasks)	Consider cognitive behavior by assumption of human capability to perform multi tasks
[31]	CCT (cognitive complexity theory)	models human performance as Goals, Operators, Methods and Selection rules
[32]	DCOG (Distributed cognition)	explain that cognition is distributed through the environment
[33]	EPIC (executive process/interactive control)	Focus on the perceptual and intellectual.
[34]	APEX (architecture for procedure execution)	Consider human behavior in dynamic environment
[35]	Brahms (Business redesign agent-based holistic modeling system)	Considering human social behavior over times
[36]	HOS (human operator simulator)	a model of human abilities and restrictions to support the design of human-machine systems

4 Discussions

Thermal comfort, Indoor air quality, aural comfort and visual comfort are the four main parameter to evaluate the IEQ in buildings. The poor IEQ is caused sick building syndrome, less human productivity and also more energy consumption.One the most important reason for considering IEQ in buildings is reducing the amount of energy usage.However, the heating, cooling, ventilation, water heating, lighting and electronics equipment are the main reasons for increasing building energy consumption , but the occupant activities affect on all of them.Occupant behavior is a physical and also psychological response to the environmental conditions to manage the dissatisfied conditions .This is why , the human behaviour is closely related to the energy usage in residential and commercial buildings and should be consider as an important factor in the field of built environment.

5 Conclusions

Based on review different paper in the field of IEQ it is concluded that, most researches were considered the relation between just one or two IEQ parameters and occupant satisfaction. Some researcher promoted a multivariate logistic regression to predict the overall IEQ acceptance based on subjective and objective measurement.These studies focused on occupant satisfaction and the lack of a relationship between overall IEQ parameter and energy consumption is obvious.Other studies used different type of simulation methods and softwares to predict the amount of energy consumption by considering one or two IEQ parameters. The disability of simulating all IEQ factors at the same time and considering the affect of human behavior is the drawback of these methods.Also, some study promoted different models to simulate the human behavior. In a simulation process, considering physical, psychological and social behavior of occupant is required. Since the human behavior changes the energy usage in building, the aim of this consideration is to measure and predict the occupant behavior while facing with uncomfortable conditions. The complexity and uncertainties of occupant behavior leads to lack of behavior prediction and feedback in simulating software. The current simulation programs have a limitation to predict dynamic behavior of occupant and just supported implausible forms of human behavior.

Therefore, the development of existing knowledge to be used in considering and simulating human behavior in various methods and different kind of buildings with different IEQ conditions provide a valuable contribution in the energy simulation programs.Also, it is suggested to use an algorithm to consider building energy consumption based on human behavior by considering all IEQ factors

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