A technical framework to describe occupant behavior for building energy simulations

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June 2013

ABSTRACT

Green buildings that fail to meet expected design performance criteria indicate that technology alone does not guarantee high performance. Human influences are quite often simplified and ignored in the design, construction, and operation of buildings. Energy-conscious human behavior has been demonstrated to be a significant positive factor for improving the indoor environment while reducing the energy use of buildings. In our study we developed a new technical framework to describe energy-related human behavior in buildings. The energy-related behavior includes accounting for individuals and groups of occupants and their interactions with building energy services systems, appliances and facilities. The technical framework consists of four key components:

i. the *drivers* behind energy-related occupant behavior, which are biological, societal, environmental, physical, and economical in nature
ii. the *needs* of the occupants are based on satisfying criteria that are either physical (e.g. thermal, visual and acoustic comfort) or non-physical (e.g. entertainment, privacy, and social reward)
iii. the *actions* that building occupants perform when their needs are not fulfilled
iv. the *systems* with which an occupant can interact to satisfy their needs

The technical framework aims to provide a standardized description of a complete set of human energy-related behaviors in the form of an XML schema. For each type of behavior (e.g., occupants opening/closing windows, switching on/off lights etc.) we identify a set of common behaviors based on a literature review, survey data, and our own field study and analysis. Stochastic models are adopted or developed for each type of behavior to enable the evaluation of the impact of human behavior on energy use in buildings, during either the design or operation phase. We will also demonstrate the use of the technical framework in assessing the impact of occupancy behavior on energy saving technologies. The technical framework presented is part of our human behavior research, a 5-year program under the U.S. - China Clean Energy Research Center for Building Energy Efficiency.

Keywords: Occupant behavior, building simulation, energy efficiency, framework, XML schema

Introduction

Green buildings often fail to meet design expectations for energy performance. Building simulation tools are used to predict the energy use of these buildings during the design phase. It is this predicted energy use to which the real, operating energy use of the buildings is compared. While the building physics models and algorithms used by the simulation tools are now fairly mature, there is a distinct shortcoming in quantifying the energy use attributable to the building occupants. Interactions between occupants and building systems such as thermostats, windows, lights and blinds can have a dramatic impact on the total energy use of a building. Such occupant behavior has been shown to affect the energy performance of a building by up to a factor of 300% [1]. An accurate description of occupant behavior is key to improving the accuracy and reliability of building simulation tools.

Numerous models to predict the energy impact of building occupants have been developed e.g. [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12]. The models are generally based on experimental measurements and survey data. However, the models are developed by different researchers and groups from all around the world. Each researcher conducts different measurement campaigns and/or surveys that focus on different physical variables and different human factors/responses in different buildings. Consequently, there is very little structure in the field, behavior models are difficult to compare to one another and can be difficult to incorporate into building simulation tools. To address this problem we propose a technical framework to standardize the description of energy-related occupant behavior in buildings. The framework aims to allow the capture of the vast majority of occupant behaviors that impact the building energy use. Adopting a common technical framework will allow the building simulation community to incorporate more quickly accurate occupant behavior models into building simulation tools and reduce the gap between the predicted and measured energy performance of buildings.

This paper outlines the occupant behavior framework and efforts to deploy it in the form of an XML (eXtensible Markup Language) schema known as obXML (occupant behavior XML), so that it may be adopted in an interoperable form convenient for existing building simulation tools.

The occupant behavior framework

The impact of the behavior of occupant or groups of occupants on building energy use can be described using four main components – drivers, needs, actions and systems:

- ***Drivers*** represent the stimulating factors that provoke an occupant into performing an energy-related behavior or an interaction with a system
- ***Needs*** represent the physical and non-physical requirements of an occupant that must be met in order to ensure the satisfaction of the occupant with their environment
- ***Actions*** are interactions with systems or activities that an occupant can conduct in order to achieve environmental comfort
- ***Systems*** refer to the equipment or mechanisms within a building with which an occupant may interact to restore or maintain the environmental comfort of the occupant(s)

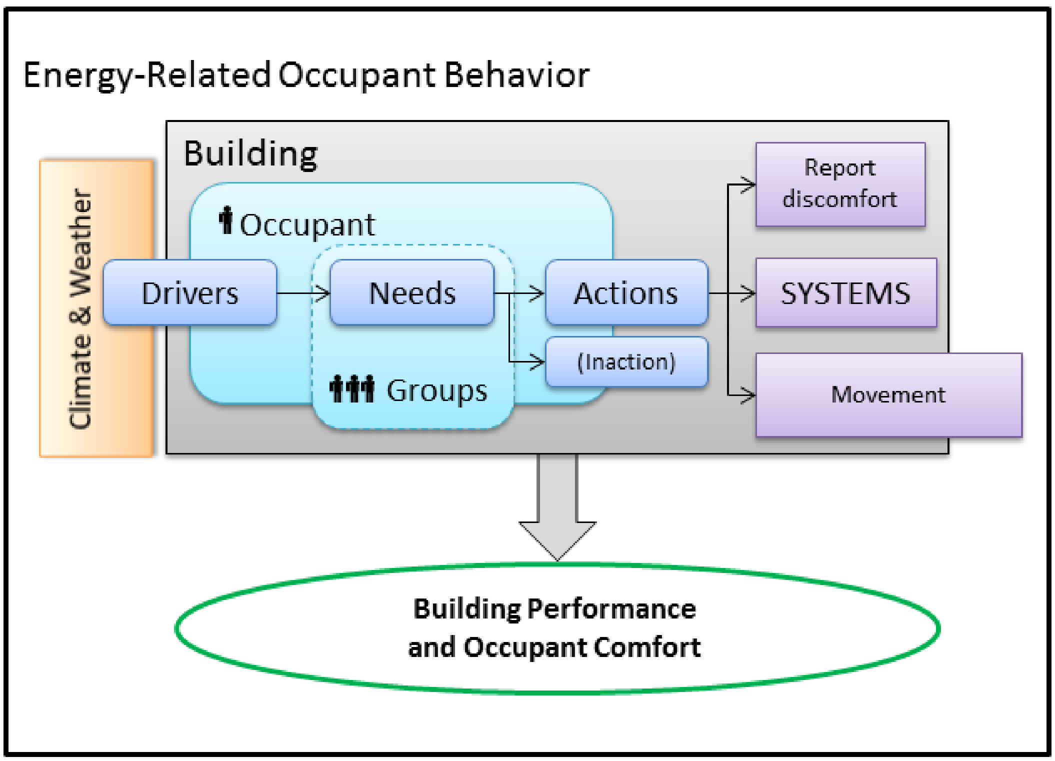

Figure 1: The occupant behavior framework

As an example of the drivers, needs, actions and systems concept, consider the following simple scenario. An occupant is working inside a naturally ventilated office with operable windows during the summer. The indoor room temperature increases throughout the morning until the occupant becomes uncomfortably hot. The occupant then opens the window in order to admit cooler outside air into the building. As a result the room temperature decreases and the occupant becomes satisfied with the indoor conditions. In the above example the 'driver' is the indoor air temperature. The 'need' is the requirement for thermal comfort of the occupant. The 'action' is the opening of the window by the occupant. The 'system' is the window. The nature of the drivers, needs, actions and systems will be discussed below.

Drivers

A driver can be anything that prompts a building occupant to perform either an action or an interaction with a building system that impacts on the energy use of a building (Figure 2). The drivers can include environmental factors, such as indoor air temperature and solar radiation, as well as non-physical factors such the time of day or the season of the year.

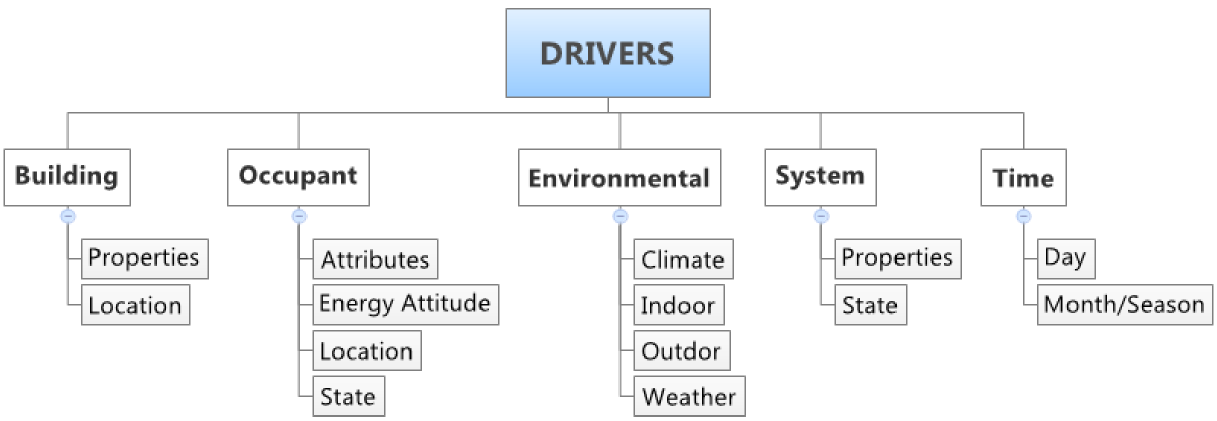

Figure 2: Drivers behind energy-related occupant behavior

- *Building* – physical properties of the building itself can act as drivers, such as the building's orientation (façade exposure to solar radiation) [13], construction material [14], floor layout etc. The location of the building in relation to other buildings, busy roads, fields etc. can also affect the behavior of the occupants [14].
- *Occupant* – the attributes of an occupant relate to the occupant's age [15], gender [16], physical mobility [17] etc. which can dictate how an occupant behaves and their response to environmental drivers and hence, how they interact with building systems. Specifically, the 'energy attitude' of the occupant is important [18]. The framework will provide a platform to allow a range of occupant energy attitudes from 'energy frugal' to 'energy profligate' via 'energy indifferent'. The energy attitude of the occupant will govern how the occupant interacts with energy-related building systems. The location of the occupant determines to which environmental drivers they are exposed. The state of the occupant describes their metabolic rate, and whether they are arriving into a space, remaining in the space, or departing. Metabolic rate is a widely accepted input to thermal comfort models [19], [20] and so has a profound

impact on occupant behavior. Window opening, blind use and lighting use have been found to be more sensitive to when occupants first arrive in a space and when they leave, compare to when they remain in a space [5], [9], [21].

- *Environmental* – climate, weather and indoor and outdoor environmental conditions such as air temperature, humidity, solar radiation and air quality are all fundamental drivers behind the response of occupants to the environment.
- *System* – studies have shown that the existing state of a building system acts as a statistically significant predictor to the probability of an occupant interacting with the system. An example of this effect is the state of a window. Once a window has been opened or closed by an occupant in the morning, the window is likely to remain in that state independent of other driving forces [8].
- *Time* – the time of day is fundamental to the presence and location of occupants in a building, and to the daily change in outdoor weather. The change in season also affects the outdoor weather and resulting conditions inside a building. All of which effect the interactions between occupants and building systems.

In behavior modeling there is some debate as to what are the correct drivers to use to model certain actions. In the above example, the driver behind the window-opening action is given as the indoor air temperature [8]. However, it has been argued that the indoor air temperature is actually driven by the outdoor air temperature, and so the outdoor air temperature is the real driver behind the window-opening action [3]. To address this conflict we introduce the concept of direct and indirect drivers. The direct drivers are the ones that immediately impinge on the comfort of the building occupant. The indirect drivers are the ones that impinge upon the direct drivers. Again, using the above example of window opening, the direct driver is the indoor air temperature and the indirect driver is the outdoor air temperature. As the outdoor air temperature is also a function of the time of day and the time of year, these two may also be considered indirect drivers when consider window-opening behavior.

Secondary drivers can include physical properties of the buildings themselves. For example, the geographical location in which a building resides can have a very profound effect on how occupants interact with the building systems, but is not directly responsible for those interactions. Similarly the orientation of a building will affect the solar thermal gains of a particular façade, and hence the behavior of the occupants located along that façade.

Needs

An occupant will have certain criteria for or expectations of their environment which relate to the overall comfort of the occupant. When these criteria and expectations are met, the occupant can be described as comfortable (Figure 4). Once they are violated, the occupant can be described to be uncomfortable or experiencing discomfort. Needs can be either physical or non-physical. The two broad overarching categories were chosen so that all needs could be encompassed and easily classified, while leaving scope for additional needs to be added in the future. Physical needs of the occupant include the need for:

- *Thermal comfort* - satisfaction with the temperature of the indoor environment [19], [20]
- *Visual comfort* - not subjected to glare, excessive contrast or unacceptable levels of brightness [22], [23]
- *Acoustic comfort* - levels of background noise within an acceptable range [24]
- *Indoor environmental health* - good indoor air quality or humidity [25]

Non-physical needs can include factors such as the need for privacy [26] or the need to maintain views to outside (environmental satisfaction) [27] for example. Both of these contribute to the overall satisfaction of the occupant, but can also impact upon the building energy performance by influencing the manner in which an occupant may interact with systems such as blinds.

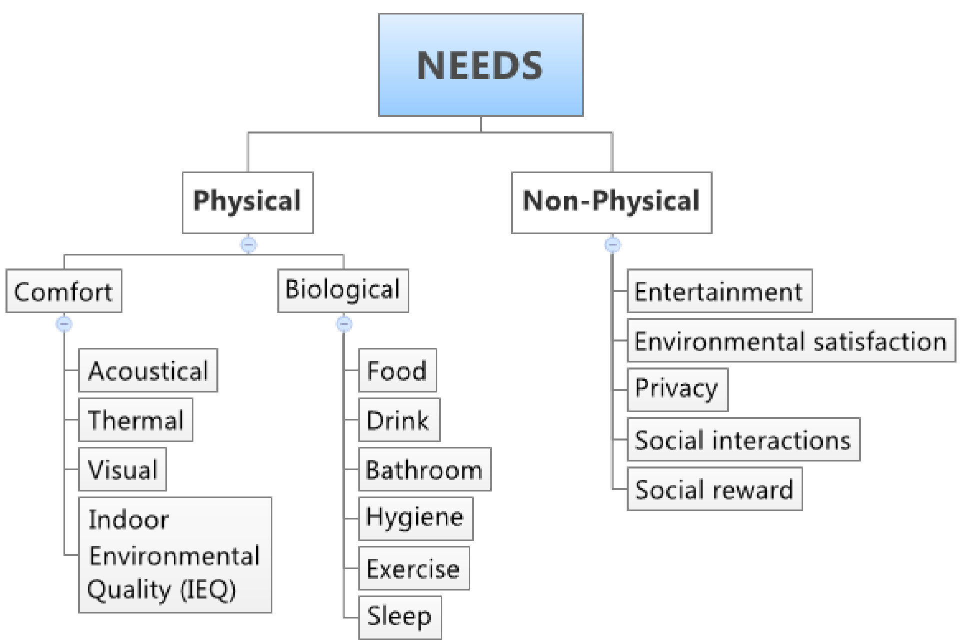

Figure 3: Needs of building occupants that may result in an action that changes the building energy use when they are not met

Actions

Violation of one or more of an occupant's needs leads to a 'crisis of comfort' [28]. The uncomfortable state of the occupant will provoke an action (Figure 5). The action can be an interaction with a system that the occupant anticipates will restore their personal comfort. An example of an action would be to adjust levels of clothing, open a window, or turn down the thermostat when too hot. Actions can also include other measures such as reporting discomfort to a building manager, moving to a different location within a building, or leaving the building entirely.

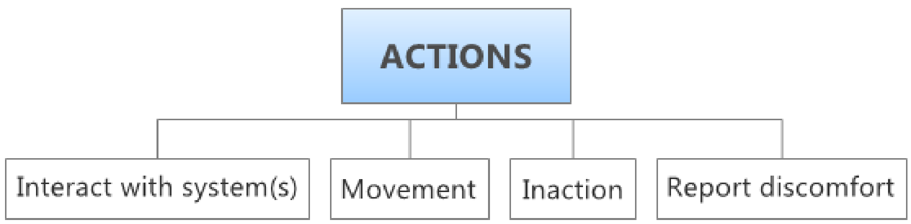

Figure 4: Actions undertaken by building occupants when their needs are not met

There is also the possibility for inaction where the occupant decides to suffer the discomfort. This could be caused by the occupant deeming the effort required to mediate the discomfort too high or not having access to suitable systems [29]. Social pressure may also cause inaction, whereby an occupant modifies their willingness to perform a discomfort alleviating action due to the presence of other occupants who would be affected by the action [21].

Systems

Systems, or building systems, describe any piece of equipment or mechanism inside a building that can affect the energy performance of a building when it has been subjected to an interaction with an occupant of the building (Figure 3). In order for a system to affect the occupant-related energy performance of a building, it needs to be acted upon or controlled by an occupant. Common systems that are subject to occupant control and actions include windows, window blinds/shades, lights and thermostats.

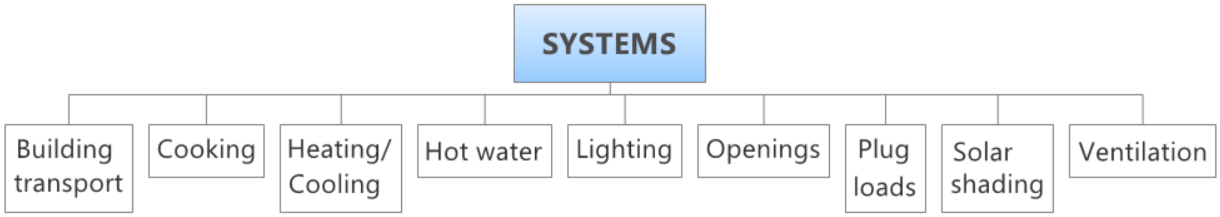

Figure 5: Building systems with which an occupant may interact causing a change in building energy use

The control method of the systems is important when considering the energy performance of the building. Manual systems such as non-programmable thermostats (or programmable thermostats which simply have not been programmed) and operable windows can be directly controlled by occupants. Automated systems such as programmable thermostats and automatic blind systems can be acted upon by occupants provided that they have an override function.

obXML – An XML schema to describe occupant behavior for Occupant Information Modeling (OIM) and building energy simulations

An XML (eXtensible Markup Language) schema called obXML is under development to facilitate the integration and adoption of the occupant behavior framework with building simulation tools. An XML schema is used to describe the data content and format of an XML document – a format that can be used to describe data structures. XML documents are both machine- and human-readable and provide a convenient and simple way of storing and transferring data.

Figure 6 shows the upper tiers of the obXML schema. Note that the practical implementation of the framework does not identically mirror the conceptual level of the framework, for reasons of space-efficient data storage. The schema is being developed to capture occupant behavior that, to date, has been studied and may be studied in the future. A description of the building(s), the occupant(s) and the drivers are included, along with any energy-impacting actions that may be simulated. Presently, the needs are represented as a subcategory of the occupant.

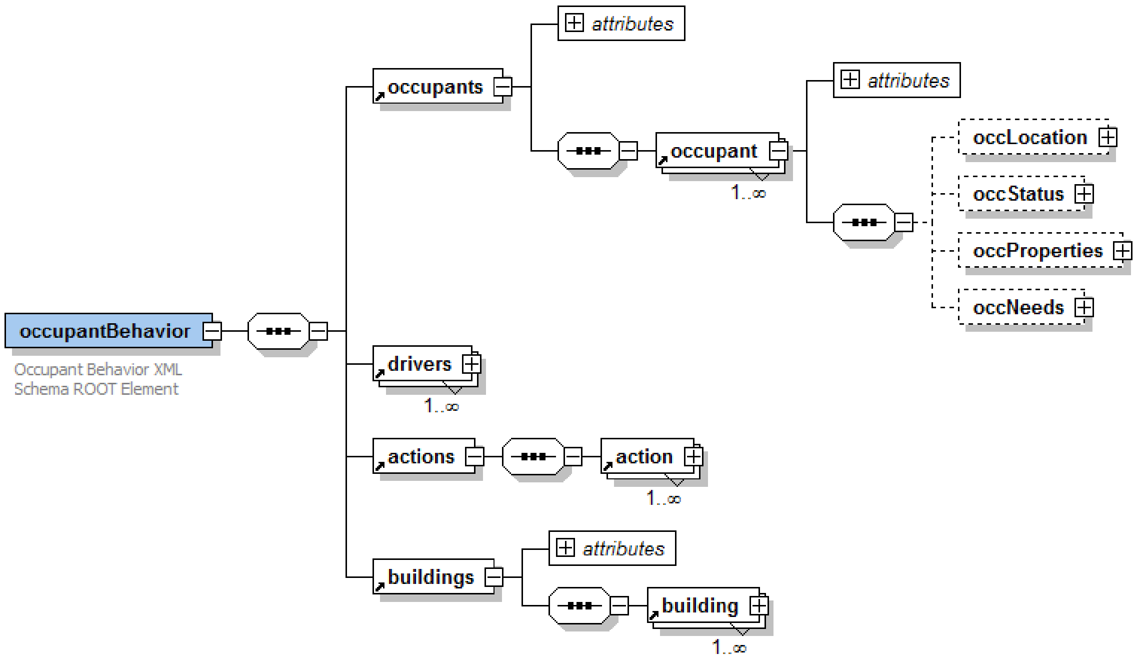

Figure 6: A high-level screenshot of the obXML schema

Summary

A framework to standardize the description of the energy impact of occupant behavior in buildings has been outlined. The framework includes four main components: the drivers behind the occupant behavior that impacts on the energy performance of the building; the needs of the occupants which must be met in order for the occupant to be comfortable and satisfied with their environment; the actions which occupants can perform in order to satisfy their needs; and the building systems with which occupants can interact to affect the building energy performance. An XML schema called obXML is under development. Adoption of the framework and the obXML schema will allow promote comparison and validation of occupant behavior models, while also facilitating their integration with building simulation tools.

Endnotes

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