Occupant Behavior: Impact on Energy Use of Private Offices

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ABSTRACT

Measured energy use of buildings demonstrated large discrepancies even between buildings with same function and located in similar climates. Among various factors contributing to the discrepancies, occupant behavior is a driving factor. Occupant behavior is also one of the most significant sources of uncertainty in the prediction of building energy use by simulation programs. How occupants set the comfort criteria (including thermal, visual, and acoustic), interact with building energy and services systems, and response to environmental discomfort directly affect the operation of buildings and thus their energy use. This study employs building simulations to evaluate the impact of occupant behavior on energy use of private offices with single occupancy. Typical occupant behavior we studied includes how an occupant sets comfort criteria, operates lights, office equipment, space thermostat, and HVAC systems. The behaviour is categorized into three workstyles: 1) austerity – occupants are proactive in saving energy, 2) standard – average occupants, and 3) wasteful – occupants do not care about energy use. The simulation results demonstrate the impact of occupant behavior on building energy use is significant, and even so at the energy end use levels such as lighting, space cooling and heating. For a typical single-occupancy office room, compared to the standard or reference workstyle, the austerity workstyle consumes up to 50% less energy, while the wasteful workstyle consumes up to 90% more energy.

Three methods are proposed to model occupant behavior depending upon the complexity: 1) use EnergyPlus directly, 2) use the advanced feature of EnergyPlus - Energy Management System, and 3) use modified code of EnergyPlus. Our study provides a method to evaluate energy impact of occupant behavior, which can be a good tool for decision makers of behavioral programs that target energy savings in buildings.

KEYWORDS

Building simulation, Energy use, EnergyPlus, Occupant behavior, Office buildings

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INTRODUCTION

Occupant behavior affects the building energy use directly and indirectly by opening/closing windows, turning on/off or dimming lights, turning on/off office equipment, turning on/off heating, ventilation, and air-conditioning (HVAC) systems, and setting indoor thermal, acoustic, and visual comfort criteria. Measured energy use of buildings demonstrated large discrepancies even between buildings with same function and located in similar climates. Among various factors contributing to the discrepancies, occupant behavior is a driving factor. Occupant behavior is also one of the most significant sources of uncertainty in the prediction of building energy use by simulation programs due to the complexity and inherent uncertainty of occupant behavior. With the trend towards low energy buildings that reduce fossil fuel use and carbon emissions, getting occupants actively involved during the design and operation of buildings is a key to achieving high energy performance without scarifying occupant comfort or productivity. Pilot projects demonstrated that low energy systems, such as natural ventilation, shading to control solar heat gains and glare, daylighting to dim lights, and demand controlled ventilation, especially need the interactions and collaborations of occupants. Energy savings from 5 to 30% were achieved by behavioral studies that motivate changes to occupant behavior.

In the last decade, new designs target net-zero energy buildings which emphasize the importance of energy efficiency technologies, integrated design, building operation and maintenance, and occupant behavior. Good operation practice and high design efficiency in buildings could lower the energy use (Mahdavi et al. 2008, Linden et al. 2006). Santin (2011) looked at the relationship between user behavior and space heating energy use, and concluded that behavior patterns could be used in building energy calculations and usage profiles with different behavior could be discerned.

Mahdavi (2008) described an effort to observe control-oriented occupant behavior in a few office buildings in Austria. His results imply the possibility of identifying certain patterns of user control behavior as a function of indoor and outdoor environmental parameters such as illuminance and irradiance. However, his observations also underscore the need for typologically differentiated occupancy and control action models for different buildings. Parys (2009) evaluated various lighting and blind control systems in combined with four types of user behavior in office buildings in Belgium. His simulation results demonstrated that the energy savings of a daylight dimming system in an individual office decrease by about 10% when the occupant behavior is accounted for.

On windows operating, Haldi (2008) and Rijal (2008)'s study are based on the presumption that the main driver of occupant window intervention is occupant discomfort. The adaptive thermal comfort model by Humphrey and Nicol (1998), proposed that the occupants' comfort temperature changes with the monthly outdoor air mean temperature from a number of surveys conducted world-wide for natural ventilated buildings. Although the adaptive comfort model was original obtained for naturally ventilated buildings, it can be adapted for mechanically cooled spaces. Rijal (2008) proposed a method of implementing Humphrey's observations of occupant window opening behaviour in a building simulation model, assuming that occupants only interact with windows when they are thermally uncomfortable, defined as 2 ℃ above the upper bound or below the lower bound of the adaptive comfort temperature.

Peng et al (2012) presents a quantitative description method of human behavior in residential buildings. The method can be used to predict the impact of the human behavior on the indoor environment and energy use. It was applied to a household in Beijing with comparisons to on-site observations of the occupants' behavior and measurements of energy use for validation.

The objective of this study is to identify, understand, and categorize occupant behavior that can have significant impact on energy use of private offices, and evaluate how different types of occupant behavior affect the energy use by building simulations. The study applies to private offices with single occupancy, assuming the occupant has freedom to interact and change his indoor environment. Open offices or private offices with multiple occupants involve the complexity of group behavior, which is not covered in the study.

RESEARCH METHODS

First, occupant behavior in private offices is categorized into three different workstyles according to the level of energy is used to provide comfort for the occupants: 1) the Austerity workstyle with occupants being proactive in saving energy; 2) the Standard workstyle representing most occupants in terms of average energy use behavior; and 3) the Wasteful workstyle with occupants consuming energy at will, lacking motivation to reduce energy use. The three types of occupant behavior is based on literature review and occupants surveys like the post occupancy survey done by Center of the Built Environment, University of California at Berkeley; they aim to represent general situation. Then building simulations using EnergyPlus (USDOE 2012) version 7.0 are employed to quantify and evaluate the impact of the three workstyles on energy use of private offices. To look at the influence of climate, three U.S. typical climates are studied.
The energy metric used in the study is the source or primary energy use by the individual office, which includes the source energy of the natural gas for heating, and the source energy of electricity for cooling, ventilating, lighting, and office equipment (plug-load).

Characteristics of the private offices

Three adjacent and equal size private offices, located on the south facade of a middle story of a medium size office building, are selected for the study. Each office has only one exterior wall (with a window) facing south, and has a rectangular shape with a floor area of 15 m^2. The private office is occupied by only one person, and is served by a constant air volume HVAC system with heating from a gas furnace and cooling from a direct-expansion unitary system. The efficiency levels of the building envelope, lighting, and HVAC are set to meet the minimum requirements of ASHRAE Standard 90.1 (2004). The internal loads, including the interior lighting power and plug loads (both at 10.76 W/m^2), and operation schedules (Figure 1) stay the same across climates. The building operates 6am to 10pm, while the typical private office is occupied 8am to 5pm. Cooling and heating thermostat of the private offices are set to 24°C and 21°C respectively. The occupant is assumed to take three breaks: half hour in the morning, one hour lunch, and half hour in the afternoon. The middle office is occupied by one person with standard workstyle, while the adjacent two offices are each occupied by one person with austerity and wasteful workstyle respectively. The interior walls of the three offices are insulated well to ignore heat transfer from adjacent offices.

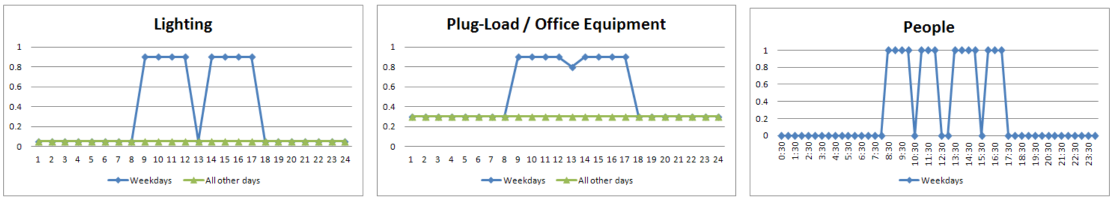

***Figure 1**. Schedules of lighting, plug-load, and people*

Climate zones

Three climates, Miami (Hot and Humid), San Francisco (Coastal, Mild), and Chicago (Cool Summer, Cold Winter), are selected in this study to represent typical climates in the U.S. Table 1 lists the climate zone information for the three representing cities based on ASHRAE Standard 90.1-2010. In the table, HDD18 is the Heating Degree Days with a base temperature of 18 ℃, and CDD10 is the Cooling Degree Days with a base temperature of 10 ℃.

Table 1. *Characteristics of selected cities and climate zones*

Cities	ASHRAE Climate Zones	HDD18	CDD10
Miami	Hot –Humid, 1A	200	9474
San Francisco	Warm-Marine, 3C	3016	2883
Chicago	Cool-Humid, 5A	6176	3251

The TMY3 weather data was used in the EnergyPlus simulations. The TMY3 weather data represented typical weather conditions during 1991 to 2005 and was available for download at EnergyPlus web site (USDOE 2012).

Occupant behavior

Typical occupant behavior related to energy use is studied and summarized in Table 2, including:

- Cooling setpoint

  The Standard occupant prefers a room air temperature of 24 ℃ during cooling. The Austerity occupant prefers a warmer temperature of 26 ℃, while the Wasteful occupant likes a cooler temperature of 22 ℃. The lower the cooling setpoint, the higher the cooling energy use.
- Heating setpoint

  The Standard occupant prefers a room air temperature of 21 ℃ during heating. The Austerity occupant prefers a lower temperature of 18 ℃, while the Wasteful occupant likes a warmer temperature of 23 ℃. The higher the heating setpoint, the higher the heating energy use. Note that the heating setpoint of the Wasteful occupant is actually higher than the cooling setpoint, which is not unusual for people with such workstyle.
- Adaptive comfort

  Adaptive comfort theory allows the indoor cooling comfort temperature to be adjusted upward based on the monthly average outdoor air temperature. Hot climates with higher monthly average outdoor air temperatures would have higher indoor comfort temperatures. The Austerity occupant adjusts the cooling setpoint based on the adaptive comfort model, while the Standard or Wasteful occupant does not. As shown in Figure 2, for Miami climate, the cooling setpoint in July and August can be adjusted as high as 26.5°C, which is 2.5°C higher than the constant setpoint 24°C. This reduces the cooling energy use.

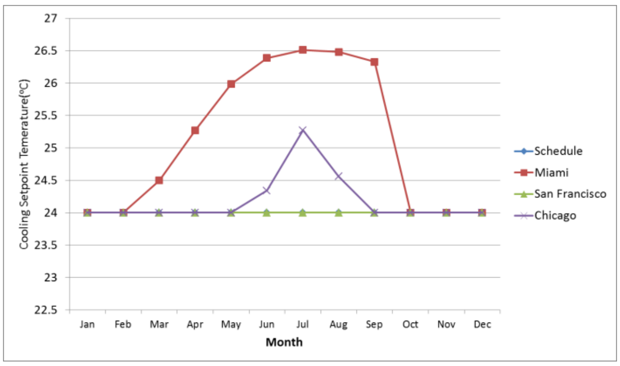

Figure 2*. Adjusted cooling setpoints based on the ASHRAE adaptive comfort model*

- Occupancy controls
  For the Austerity occupant, he turns off lights and HVAC, and turns down plug-load 30% when he leaves office for break. The Standard occupant operates lights, HVAC, and office equipment according to schedules (Figure 1). The Wasteful occupant leaves everything 100% on during breaks.
- Daylighting controls
  The Austerity occupant dims lights to 50% or completely turns them off if adequate daylight meets the visual comfort. The other two occupants do not response to daylight.
- HVAC operation time
  Compared to the standard HVAC operation schedule, the Austerity occupant turns on HVAC one hour late at 9am and turns off one hour early at 4pm. The Wasteful occupant sets the HVAC operation the same as the whole building - from 6am to 10pm.
- Cooling startup control
  The Austerity occupant turns on cooling only when he feels warm, which usually occurs when the space air temperature reaches 28°C. When the cooling is turned on, cooling setpoint temperature of 24°C is maintained. This is demonstrated in Figure 3 for a hot summer day. The other two occupants set the startup temperature the same as the cooling setpoint.

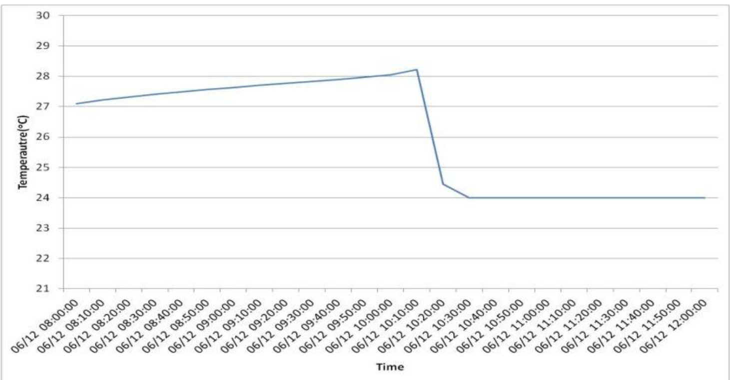

Figure 3. Cooling startup control

Table 2. *Occupant behavior categorized into three workstyles*

Occupant behavior	Austerity workstyle	Standard workstyle	Wasteful workstyle
Cooling setpoint (°C)	26	24	22
Heating setpoint (°C)	18	21	23
Adaptive comfort	Yes	None	None
Occupancy controls	If unoccupied, turn off lights and HVAC, turn down plug-load 30%	Scheduled	Leave everything on: lights, HVAC, and plug-load
Daylighting Control	3 Steps Dimming	None	None
HVAC operation time	Turn on 1 hour late and turn off 1 hour early: 9am to 4pm	Scheduled on: 8am to 5pm	Same as the whole building schedule: 6am to 10pm

Cooling startup control	Cooling turns on when space air temperature reaches 28°C, then maintains at 24°C. Cooling turns off when unoccupied.	Follow HVAC operation schedule (8am to 5pm) to maintain 24°C. Same as above.	Follow HVAC operation schedule (6am to 10pm) to maintain 24°C. Same as above.
Combined	All above behavior	All above behavior	All above behavior

Modeling approaches

Three different approaches using EnergyPlus, in order of difficulty, are used in the study to model the occupant behavior discussed before:

1) Direct modeling with EnergyPlus

Occupant behavior, including cooling setpoint, heating setpoint, daylighting control, and HVAC operation time, is modelled directly with EnergyPlus by changing corresponding inputs from the base cases for the Standard occupant. The advantage of this approach is easy implementation.

2) Using the energy management system (EMS) in EnergyPlus

EMS is an advanced feature of EnergyPlus and designed for users to develop customized high-level, supervisory control routines to override specified aspects of EnergyPlus modeling in the EMS program. EMS has certain limitations and its use requires advanced knowledge of EnergyPlus and computer programming. EMS is used to model occupant behavior of adaptive comfort and Occupancy control. The Occupancy control can also be modelled directly by pre-calculating the new schedules for lights, HVAC, and office equipment, but the Direct Modeling approach would not work if the occupant schedule is stochastic.

3) Modifying EnergyPlus source code

Modifying the existing EnergyPlus source code, the third modeling approach, is used when both the Direct Modeling and EMS approaches cannot be applied. This approach requires users to have a thorough understanding of the EnergyPlus data structure and existing source code before being able to modify code. This is the most difficult approach but offers the most flexibility to model complex occupant behavior. This approach is used to model the Cooling start up control.

RESULTS AND DISCUSSIONS

The simulation results are presented as percentage changes of source energy of the Austerity workstyle and Wasteful workstyle compared to the Standard workstyle for individual occupant behavior as well as the combined behavior. Figures 4 to 6 show the results for the three climates.

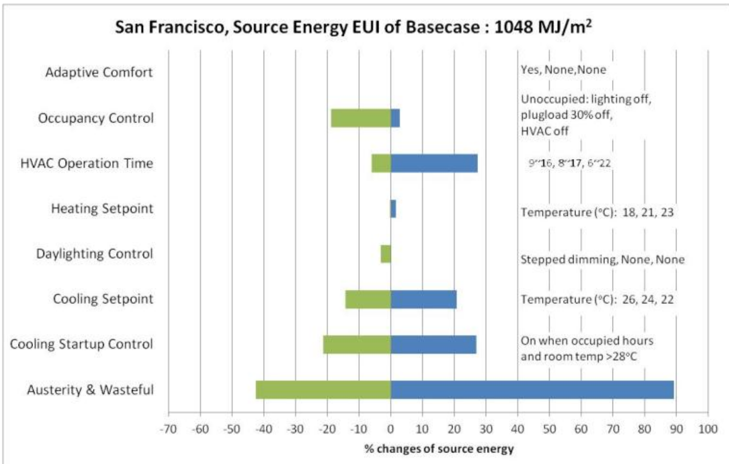

Figure 4. *Changes of source energy in San Francisco climate*

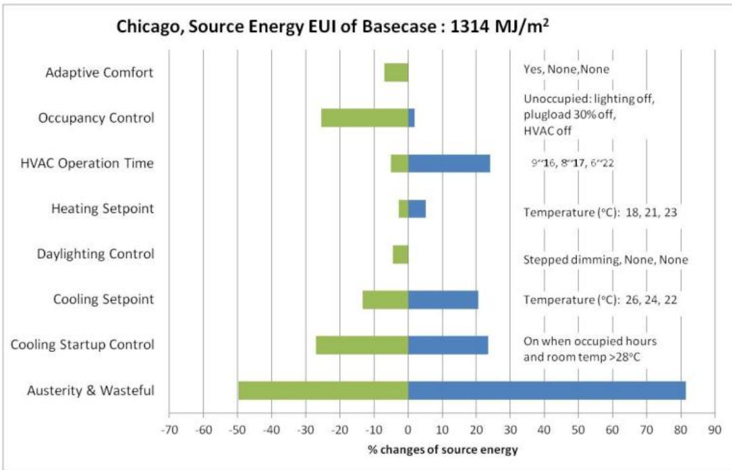

Figure 5. *Changes of source energy in Chicago climate*

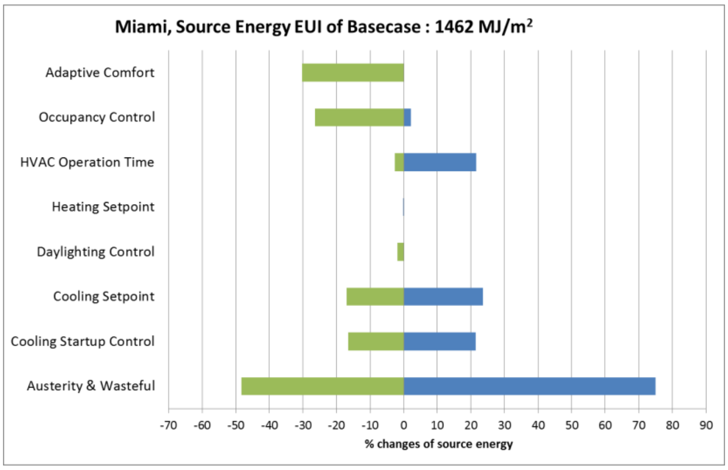

Figure 6. *Changes of source energy in Miami climate*

From these results, it can be seen that:

- The combined Austerity workstyle and Wasteful workstyle have significant impact on energy use of the private office. Compared to the Standard workstyle, the Austerity workstyle can save 42%, 50%, and 48% of source energy in San Francisco, Chicago, and Miami respectively; while the Wasteful workstyle consumes 89%, 81%, and 74% more energy for the three climates respectively.
- For the Austerity workstyle, the Cooling startup control, the Occupancy control, and the Cooling setpoint have the most energy savings. While for the Wasteful workstyle, the Cooling startup control is the same as the HVAC operation time, and the Cooling setpoint cause the most increase of energy use.
- The impact of Heating setpoint is relatively small because the heating source is natural gas which is valued much less in source energy compared to other end uses in electricity.
- The adaptive comfort model based Austerity occupant behavior can save 30% of source energy for the hot climate of Miami.
- Occupant behavior that leads to longer HVAC operation time and lower cooling setpoint increase of energy use significantly.
- Occupant behavior that leads to delay the cooling (Startup control), higher cooling setpoint (including Adaptive comfort), and turning off or down equipment when unoccupied reduce energy use significantly.

CONCLUSION

This study identified and evaluated a few typical occupant behavior related to operation and control of energy service systems of private offices. The behavior is categorized into three workstyles – Austerity, Standard, and Wasteful – according to the potential impact on energy use. The simulation results demonstrate that occupant behavior has significant impact on energy use of private offices – the combined Austerity workstyle can save up to 50% of source energy, while the combined Wasteful workstyle can increase energy use by 89% compared to the Standard workstyle.

Three approaches to modelling occupant behavior using EnergyPlus are discussed. Our on-going research focuses on occupant behavior in operating windows and shading devices, and implementing our behavior models in EnergyPlus for public use.

It is a different topic, well worth exploring but outside our expertise, on how to motivate occupants to change from Standard workstyle to Austerity workstyle to save energy. There have been many pilot behavioral programs presented in the Behavior, Energy, and Climate Change conference (Anon.).

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