kepSmart – Energy Savings Potential

ABSTRACT:

Occupant behavior is a leading factor influencing energy use in buildings. kepSmart's common sense solution has demonstrated significant potential energy savings. Estimating the behavioral savings potential is essential for an effective design of behavior change interventions, supporting more effective energy-efficiency policies. This study introduces a simulation approach to assess the energy savings potential of occupant behavior measures. The behavior measures energy performance using EnergyPlus (https://energyplus.net/) simulation for a simulated office building. Based on the simulation results, the occupant behavior measures can achieve overall site energy savings from 30.2% and up to but not limited to 41.0%. Although energy savings of behavior measures would vary depending upon many factors, the simulation approach is robust and quantify occupant behavior impact on building performance.

INTRODUCTION:

Occupant behavior in buildings refers to occupants' comfort preference, presence, and movement, and interactions with building systems that have an impact on building performance (thermal, visual, acoustic, and indoor air quality {IAQ}) [11]. The interactions include adjusting thermostat settings, opening or closing windows, dimming or turning on/off lights, pulling up or down window blinds, switching on or off plug loads, and consuming domestic hot water [1]. People spend most of their time in buildings; energy-related occupant behavior in buildings is one of the six influencing factors of building performance [2][3], including climate, building envelope, building equipment, operation and maintenance, occupant behavior, and indoor environmental conditions. Daily interactions between building systems and occupants drive total energy use. Occupants' expectations of desired comfort and satisfaction within their indoor environment incentivize the occupant to perform various actions to satisfy their physical and non-physical needs. These actions not only affect the built environment (e.g., indoor temperature, humidity level, lighting, CO2, etc.) and the energy use [4][5] but also affect the energy-saving potentials of energy conservation measures (ECMs) [6]. Indirectly, this has economic, physiological, and psychological impacts on the occupant. Clearly understanding and accurately modeling occupant behavior in buildings is crucial to reducing the gap between design and actual building energy performance. When dealing with low-energy buildings relying more on passive design features, occupancy-controlled technologies, and occupant engagement [7][8], the kepSmart system considers using artificial intelligence and controls. kepSmart takes into account behavioral patterns, comfort, and occupancy to remove the dependency of training individuals to lower energy use to automatically perform energy savings tasks. It also benefits the building by providing virtual zones where previously there were no zones.

RESULTS:

1.0 **OVERVIEW**

Whole building simulation, using EnergyPlus, was used to evaluate the energy performance of the occupant behavior measures. EnergyPlus is an open-source program that models heating, ventilation, cooling, lighting, water use, renewable energy generation, and other building energy flows [9] and is the flagship building simulation engine supported by the United States Department of Energy (DOE). It includes many innovative simulation capabilities, including sub-hourly time-steps, natural ventilation, thermal comfort, co-simulation with external interfaces, renewable energy systems, and user-customizable energy management systems (EMS). Some innovative capabilities such as natural ventilation, thermal comfort, and EMS were used in this case study. The following were used as the standard efficiency numbers:

	ASHRAE 90.1-1989	ASHRAE 90.1-2010
Water-cooled chiller COP	3.8	5.5
Gas boiler thermal efficiency (Et)	0.7	0.75

	ASHRAE 90.1 version 1989	ASHRAE 90.1 version 2010
Wall U-factor W/(m2.K)	0.72	0.511
Roof U-factor W/(m2.K)	0.3	0.27
Window U-factor W/(m2.K)	3.35	3.12
Window SHGC	0.435	0.4

Calculations take into account VRF, variable refrigerant flow, and VFD, variable frequency drive fans to already improve static efficiency. The kepSmart system adds to the benefit of using energy-efficient cooling and heating systems by automating the behavioral aspect of energy use.

1.1 THERMAL COMFORT

Thermal comfort we can focus on cooling and can determine probability from the following [10]:

Turn on AC when feeling hot:

$$P = \begin{cases} 1 - e^{-\left(\frac{T-u}{L}\right)^{k} \Delta\tau}, T \geq u \\ 0, T < u \end{cases}, when\ occupied$$

Turn off AC when feeling cold:

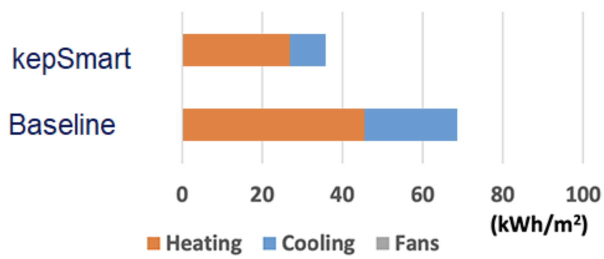
$$P = \begin{cases} 1 - e^{-\left(\frac{u-T}{L}\right)^{k} \Delta\tau}, T \leq u \\ 0, T > u \end{cases}, when\ occupied$$

The parameter u stands for the threshold of independent variable T, beyond which the probability of an occupant taking action would become 0. For air conditioning, when the indoor temperature T is lower than u, the probability of turning on the AC is 0. The parameter L describes the scale of the function, which is used to nondimensional (T-u). The parameter k represents the slope of the function. The greater the k value is, the more sensitive the occupant is to indoor temperature. In each scenario, the three parameters are predetermined to meet specific criteria. For example, for the probability function of turning on HVAC when the occupants feel hot: (1) the heating setpoint 70°F was set as the u value. In other words, it is considered impossible for the occupants to turn on the HVAC because of feeling hot when the indoor temperature T is lower than the heating setpoint. (2) The L and k values were obtained assuming that the probability of turning on HVAC is about 20% at the cooling setpoint 76°F (cooling setpoint satisfies thermal comfort in 80% of the population) and about 50% at the upper limit of ASHRAE comfort zone 83°F.

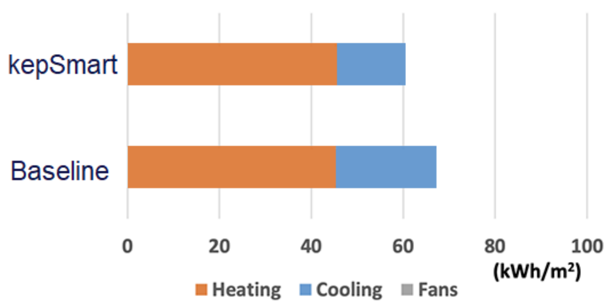
The kepSmart system

- Applies the above probability curve of AC or Heat use on system startup and learns the behavioral pattern.
- Takes into account Window open/close patterns for ventilation. An individual zone is turned off if a window is opened to redirect needed BTUs to rooms with closed windows. An individual zone can be a single office room or a bedroom.
- Takes into account the Solar Heat Gain Coefficient (SHGC) to cool rooms that need cooling or heat rooms that need heating.
- Looks at occupancy history to turn on heat only in virtual zones that are occupied. The occupancy is learned and used to turn off heat or AC using artificial intelligence.
- Takes into account a building envelope to predict when heating or cooling needs to be turned on despite a static calendar setting.

The following are results from the simulation:



kepSmart electrical savings from baseline



kepSmart added savings from just Window Sensors

During simulation, changing environmental parameters changed the kepSmart system efficiency from 30.2% to 41.0%. As many factors as possible were considered, and the results are for an already efficient building per ASHRAE 90.1 version 2010. As a building is more inefficient, the solution would exceed 41.0%, especially in combination with VFD, VRF, and other static technology additions.

REFERENCES:

1. T. Hong, S. C. Taylor-Lange, S. D'Oca, D. Yan, S.P. Corgnati, Advances in research and applications of energy-related occupant behavior in buildings, Energy Build. 116 (2015) 694–702. doi:10.1016/j.enbuild.2015.11.052.
2. International Energy Agency, Total energy use in buildings: Analysis and evaluation methods, 2013. http://www.iea-ebc.org/fileadmin/user_upload/images/Pictures/EBC_Annex_53_Main_Report.pdf.
3. D. Yan, T. Hong, IEA EBC Annex 66 : Definition and Simulation of Occupant Behavior in Buildings, 2014.
4. T. Hong, S. D'Oca, S.C. Taylor-Lange, W.J.N. Turner, Y. Chen, S.P. Corgnati, An ontology to represent energy-related occupant behavior in buildings. Part II: Implementation of the DNAS framework using an XML schema, Build. Environ. 94 (2015) 196–205. doi:10.1016/j.buildenv.2015.08.006.
5. K. Sun, D. Yan, T. Hong, S. Guo, Stochastic modeling of overtime occupancy and its application in building energy simulation and calibration, Build. Environ. 79 (2014) 1–12. doi:10.1016/j.buildenv.2014.04.030.
6. S. Wei, S.K. Firth, T.M. Hassan, F. Fouchal, Impact of occupant behavior on the energy saving potential of retrofit measures for a public building in the UK, 8975 (2015) 0–11. doi:10.1080/17508975.2016.1139538.
7. C.J. Andrews, D. Yi, U. Krogmann, J.A. Senick, R.E. Wener, Designing buildings for real occupants: An agent-based approach, IEEE Trans. Syst. Man, Cybern. Part ASystems Humans. 41 (2011) 1077–1091. doi:10.1109/TSMCA.2011.2116116.
8. R.J. Meyers, E.D. Williams, H.S. Matthews, Scoping the potential of monitoring and control technologies to reduce energy use in homes, Energy Build. 42 (2010) 563–569. doi:10.1016/j.enbuild.2009.10.026.
9. D.B. Crawley, L.K. Lawrie, F.C. Winkelmann, W.F. Buhl, Y.J. Huang, C.O. Pedersen, et al., EnergyPlus: Creating a new-generation building energy simulation program, Energy Build. 33 (2001) 319–331. doi:10.1016/S0378-7788(00)00114-6.
10. X. Ren, D. Yan, C. Wang, Air-conditioning usage conditional probability model for residential buildings, Build. Environ. 81 (2014) 172–182. doi:10.1016/j.buildenv.2014.06.022.
11. Lawrence Berkley National Lavratory, A Simulation Approach to Estimate Energy Savings Potential of Occupant Behavior Measures, 2016. https://simulationresearch.lbl.gov/sites/all/files/t_hong_-_report_-_a_simulation_approach_to_estimate_energy_savings_of_ob_measures.pdf