ABSTRACT

Sadeghi Seyed Amir. Ph.D., Purdue University, January 2018. Visual Preferences and Human Interactions with Shading and Electric Lighting Systems. Major Professor: Panagiota Karava.

Buildings in the United States are responsible for 40% of the primary energy use and 30% of carbon dioxide emissions. As awareness is being raised for the energy consumption and environmental impacts of buildings, it is not surprising that improving building performance has gained significant attention over the past years. Increasing the energy efficiency and reducing the emissions associated with buildings is possible through the use of high-performance building design and implementation of advanced building controls. Moreover, as part of the modern life style, people in developed countries spend most of their time inside the buildings. This fact necessitates consideration of two important requirements. First that energy saving achieved by efficiency methods in practice should not compromise occupants' comfort. Second, energy impacts of building users and their indoor environment preferences should be taken into account at both design and operation phases.

Therefore, understanding and modeling human-building interactions and their links to energy consumption and occupant satisfaction with the indoor environment is the main goal of this research. To this end and with a focus on the visual environment, systematic data collection from a large number of participants is undertaken and novel probabilistic modeling approaches are explored to provide new insights towards human-centered sustainable buildings. The specific research objectives of this thesis are:

1. Study human interactions with motorized roller shades and dimmable electric lights as well as human perception and satisfaction with the luminous environment in private offices with variable daylight and electric light conditions.
2. Develop a novel Bayesian approach to model the interrelated human interactions with window shades and electric lights.
3. Develop a Bayesian classification and inference modeling framework for occupants' visual preferences in daylit perimeter offices.

To this end, four identical private offices in a high performance building located in West Lafayette, IN were equipped with sensing network and online survey questionnaires to study almost 300 occupants during the two sets of field studies conducted for this thesis. The first field study extends the knowledge of human-building interactions to advanced building systems such as motorized roller shades and dimmable electric lights and reveals behavioral patterns enabled through side-by-side comparisons of different environmental controls and user interfaces ranging from fully automated to fully manual and from low to high levels of

accessibility (wall switch, remote controller and graphical web interface). Results of the field study reveal: (a) occupational dynamics and human variables as two key features, in addition to environmental variables, in describing human-shading and -electric lighting interactions; (b) higher daylight utilization in offices with easy-to-access controls; (c) strong preference for customized indoor climate, along with a relationship between occupant perception of control and acceptability of a wider range of visual conditions.

With the insights gained from the first field study, the research extends to exploit the resulted dataset as a basis for the development of a hierarchical Bayesian approach which is used, for the first time, to model human interactions with motorized roller shades and dimmable electric lights. Bayesian multivariate binary-choice logit models have been constructed to predict shade raising/lowering and electric light increasing actions while Bayesian regression models with built-in physical constraints to estimate the magnitude of shading and electric lighting actions. The proposed models, in their structure, account for (a) intermediate operating states of the systems; (b) interrelated operation of shades and lights; (c) personal characteristics and human attributes. Moreover, the developed human-building interaction modeling framework benefits from the advantages of the Bayesian formalism as it (a) provides a systematic approach to identify significant features in describing the human-building interactions; (b) incorporates prior beliefs about the systems; (c) captures the epistemic uncertainty, which is important when dealing with small-sized datasets, a ubiquitous issue in human data collection in actual buildings.

The second field study was designed and conducted to collect data for occupants' satisfaction with the visual environment when exposed to different combinations of daylight and electric light conditions, along with data from room sensors, shading and light dimming states. The resulted dataset is then used as a basis to model occupants' visual preferences such as prefer darker, prefer brighter, or satisfied with current conditions. Bayesian multinomial logistic regression is augmented with Dirichlet process prior to encode within the model structure that occupants' visual preferences are influenced by a combination of environmental and control state variables as well as individual visual characteristics. The latter is treated as a hidden random variable which is used to cluster occupants with similar visual preference characteristics and to determine the optimal number of clusters among the observed population. Modeling results based on observations from 75 occupants in glare-free conditions suggest work plane illuminance, window unshaded area, and electric light ratio as significant features of the general visual preference model and reveal the existence of three distinct clusters with physical interpretation; preference for bright, moderate, and dark conditions. In the final step, a method for learning the visual preferences of new occupants is deployed which uses a mixture of the general probabilistic sub-models to infer new occupants' cluster values and personalized preference profiles. The proposed approach proves to be efficient as it is shown to predict personalized profiles with 81% prediction accuracy with very few observations (less than 16) from each new occupant.

In summary, the systematic data collection methods and prototype interfaces used in this dissertation establish a consistent and reliable approach for studying human interactions with building systems and satisfaction with the indoor environment. Unique datasets for human attributes towards the visual environment in perimeter building zones have been generated especially for the occupants' direct preference votes with different visual conditions which is currently lacked in the literature. The probabilistic models for human interactions with shading and lighting systems and occupants' visual preferences incorporate individual characteristics and account for uncertainties associated with limited data, thus, are to increase prediction accuracy when implemented in Building Performance Simulation tools. The research presented herein facilitates an effective pathway towards implementation of adaptive personalized environments and is a necessary precursor for future investigation and expansion to human-centered building controls.