ABSTRACT

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Title: An Adaptive Personalized Daylighting Control Approach For Optimal Visual Satisfaction and Lighting Energy Use in Offices.

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In perimeter building zones with glass façades, controllable fenestration (daylighting/shading) and electric lighting systems are used as comfort delivery systems under dynamic weather conditions, and their operation affects daylight provision, outside view, lighting energy use, as well as overall occupant satisfaction with the visual environment. A well-designed daylighting and lighting control should be able to achieve high level of satisfaction while minimizing lighting energy consumption. Existing daylighting control studies focus on minimizing energy use with general visual comfort constraints, when adaptive and personalized controls are needed in high performance office buildings. Therefore, reliable and efficient models and methods for learning occupants' personalized visual preference or satisfaction are required, and the development of optimal daylighting controls requires integrated considerations of visual preference/satisfaction and energy use.

In this Thesis, a novel method is presented first for developing personalized visual satisfaction profiles in daylit offices using Bayesian inference. Unlike previous studies based on action data, a set of experiments with human subjects was designed and conducted to collect comparative visual preference data (by changing visual conditions) in private offices. A probit model structure was adopted to connect the comparative preference with a latent satisfaction utility model, assumed in the form of a parametrized Gaussian bell function. The distinct visual satisfaction models were then inferred using Bayesian approach with preference data. The posterior estimations of model parameters, and inferred satisfaction utility functions were investigated and compared, with results reflecting the different overall visual preference characteristics discovered for each person.

Second, we present an online visual preference elicitation learning framework for efficiently learning and eliciting occupants' visual preference profiles and hidden satisfaction utilities. Another set of experiments with human subjects was conducted to implement the

proposed learning algorithm in order to validate the feasibility of the method. A combination of Thompson sampling and pure exploration (uncertainty learning) methods was used to balance exploration and exploitation when targeting the near-maximum area of utility during the learning process. Distinctive visual preference profiles of 13 subjects were learned under different weather conditions, demonstrating the feasibility of the learning framework. Entropy of the distribution of the most preferred visual condition is computed for each learned preference profile to quantify the certainty. Learning speed varies with subjects, but using a single variable model (vertical illuminance on the eye), most subjects could be learned to an acceptable certainty level within one day of stable weather, which shows the efficiency of the method (learning outcomes).

Finally, a personalized shading control framework is developed to maximize occupant satisfaction while minimizing lighting energy use in daylit offices with roller shades. An integrated lighting-daylighting simulation model is used to predict lighting energy use while it also provides inputs for computing personalized visual preference profiles, previously developed using Bayesian inference from comparative preference data. The satisfaction utility and the predicted lighting energy use are then used to form an optimization framework. We demonstrate the results of: (i) a single objective formulation, where the satisfaction utility is simply used as a constraint to when minimizing lighting energy use and (ii) a multi-objective optimization scheme, where the satisfaction utility and predicted lighting energy use are formulated as parallel objectives. Unlike previous studies, we present a novel way to apply the MOO without assigning arbitrary weights to objectives: allowing occupants to be the final decision makers in real-time balancing between their personalized visual satisfaction and energy use considerations, within dynamic hidden optimal bounds – through a simple interface.

In summary, we present the first method to incorporate personalized visual preferences in optimal daylighting control, with energy use considerations, without using generic occupant behavior models or discomfort-based assumptions.