Abstract

Compressor-based cooling contributes a large part of energy consumption in buildings, especially in hot and humid climates. In Singapore, electricity comprises the largest percentage of building operating expense, of which about 50% is for air conditioning. Increasing cooling setpoint and utilizing elevated air speed generated by fans is a viable and promising approach of delivering thermal comfort with less energy use.

The work presented in this thesis leverages recent advances on human thermal comfort research and indoor positioning techniques to develop cost-effective, energy-efficient and occupant-satisfied solutions for indoor location-based cooling. Specifically, the occupant-aware operations of both a single fan and a system of fans were introduced; an indoor tracking system with a more generalized noise model for obtaining more accurate occupancy information was developed. The effectiveness of the proposed solutions was demonstrated through simulations and experiments.

For personalized thermal comfort, a smart tracking fan system is developed by using camera-based indoor localization. Personal cooling is provided upon the detection of the occupant in the area bounded by virtual geofences. The dynamic position of the occupant is constantly tracked by a camera-based localization system and subsequently used for determining the occupant-fan distance and direction of air flow. The state-of-art PMV-SET (Predicted Mean Vote-Standard Effective Temperature) thermal comfort model is used to quantify the effect of air speed on thermal comfort and determine the desired air speed under different environmental conditions. The input fan power is then obtained based on the desired air speed and occupant-fan distance according to a calibrated mapping scheme.

For multiple occupants, a patented technology for cooperatively controlling a system of fans to provide optimized air movement is presented. A cost-effective calibration method to obtain the relationship between air speed and fan speed setting is proposed to predict airflow in the actual environment. Fans operation is optimized by minimizing the maximum deviation of the actual air speed generated by fans from the desired air speed inferred from occupant feedback. This minimax-error problem is reformulated as a linear programming problem which can be solved readily using standard methods.

To obtain occupancy information, an indoor tracking system was implemented. A common problem with indoor tracking is the disturbances encountered in dynamic and complex indoor environments and the proposed system uses the generalized t-distribution (GT) to model them. A recursive filter based on the GT noise model is developed. Because of the more accurate noise model, the proposed filter can produce better position estimates than that of the Kalman filter which makes the usual assumption of Gaussian noise. An equation to compute the variance of the estimation error is also derived. The variance equation can be used as an analytic tool for designing and assessing the tracking system. Both theoretical and experimental results showed that the variance of the estimation error from the proposed filter is less than that from the Kalman filter. The experiments also showed that the filter with GT noise model could handle outlier better than the Kalman filter.

The work presented in this thesis aims to create a new paradigm that is promising to improve our buildings through increased convenience, comfort and energy efficiency.