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IMPACT OF INCREASING OUTDOOR VENTILATION RATES ON ENERGY CONSUMPTION FOR OFFICE BUILDINGS IN TROPICAL CLIMATES

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INTRODUCTION

Buildings in tropical climates consume a relatively large amount of energy for conditioning outdoor ventilation air compared to mild climates, mainly due to the warm and humid outdoor air conditions. However, providing sufficient amounts of outdoor air to occupants is a critical component of buildings. Several previous studies have found an association between low ventilation rates (< 10 L/s per person) and building-related adverse symptoms. Recent scientific studies (Sundell et al., 2011; Fisk et al., 2009) indicate benefits for higher ventilation rates, up to 25 L/s per person, for reducing building-related symptoms and promoting occupant health, satisfaction and productivity. Nonetheless, higher ventilation rates may require a significant increase in energy use, especially in tropical climates due to the additional energy required for treating warm and humid outdoor air. The present study estimates the potential energy consumption and cost of increasing ventilation rates for office buildings in tropical climates, considering Singapore as an example locale.

METHODS

Annual hourly weather data were retrieved for Singapore from IWEC (International Weather for Energy Calculations) data. The daily median outdoor temperature ranges from 24.1 °C to 30.0 °C for the whole year. The outdoor *RH* ranges from 68% to 98%, and the corresponding humidity ratio is in the range 0.17-0.21 kg_w/kg_{da}. Building energy consumption due to outdoor air ventilation was calculated as a function of ventilation rate (10-40 L/s per person), indoor dry-bulb set-point temperature (22 °C to 30 °C) and relative humidity (*RH*, 30-90%). The ranges of coefficient of performance (COP, assumed to be in the range 2-6) and electricity cost (Singapore dollar, S$0.20-0.40/kWh) were applied to predict ventilation energy cost based on current and expected future values of these parameters (Energy Market Authority of Singapore, 2013). Using these parameters, energy consumption was estimated by calculating specific enthalpy of moist air, sensible energy, and latent energy (ASHRAE, 2009).

RESULTS AND DISCUSSION

Figures 1a and 1b show monthly and annual sensible and latent energy demands to provide ventilation rate of 10 L/s per person for supply temperature of 23 °C and RH of 60%. The estimated annual sensible and latent demands for providing a ventilation rate of 10 L/s per person are 1660 MJ/person and 8230 MJ/person, respectively, indicating that a significant fraction (83%) of the total ventilation energy requirement is latent. This result demonstrates the critical importance of dehumidification of outdoor moist air for building ventilation systems in tropical climates.

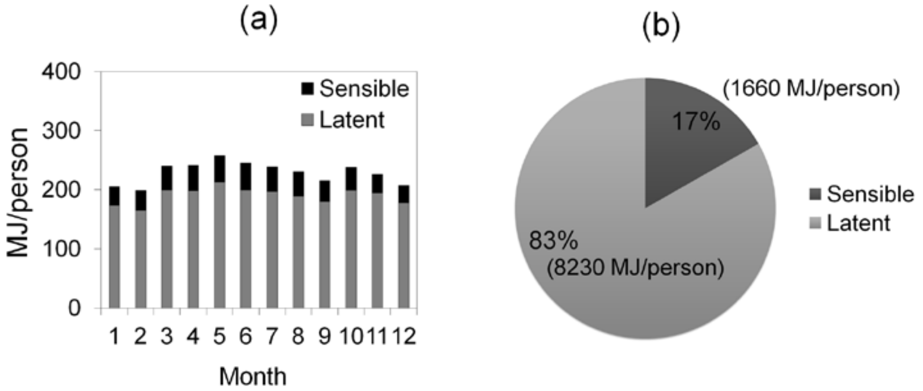

Figure 1. (a) Ventilation energy demand (sensible vs. latent) for providing 10 L/s per person at an indoor condition of *T* = 23 °C and *RH* = 60 %; (b) Comparison between annual sensible and latent energy.

Considering that ventilation energy for treating outdoor air varies with the indoor set-point conditions (temperature and *RH*), Figures 2a and 2b present annual ventilation energy consumption (kWh/y per person) and associated cost for varied conditions of indoor dry-bulb air temperature and *RH*. In both figures, the *x*-axis and the *y*-axis represent the indoor set-point temperature and *RH*, respectively. The numbers at contour lines represent the total annual energy consumption (Figure 2a) and the associated total annual cost (Figure 2b) for providing a ventilation flow rate of 10 L/s per person.

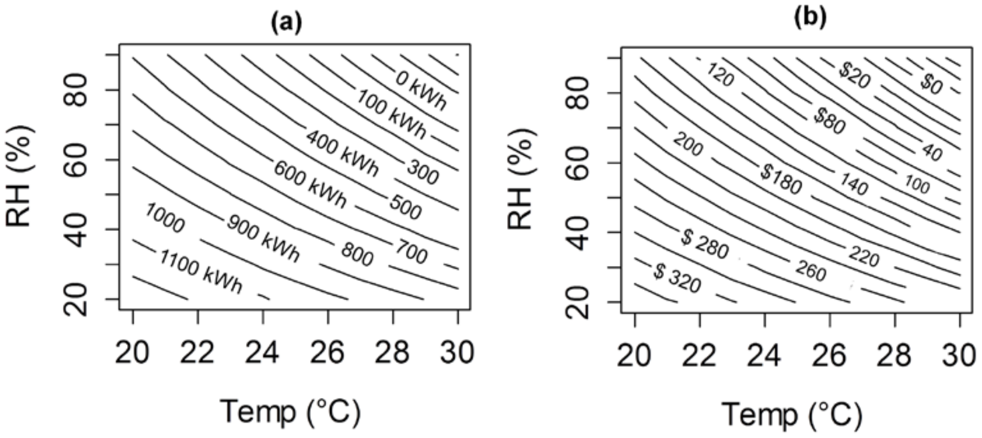

Figure 2. (a) Annual ventilation energy consumption (kWh/y per person) for varying indoor *T*/*RH* conditions to provide 10 L/s per person (assuming COP = 4); (b) Annual cost (Singapore dollar (S$)/y per person) for providing 10 L/s per person (using electricity cost = S$0.27/kWh, Source: Energy Market Authority of Singapore).

As expected, the figures show that under indoor conditions of high temperature and *RH*, an increase in ventilation rate can be achieved at relatively low costs. As an example, the cost of increasing the ventilation rate by 10 L/s per person for an office building that has indoor conditions of temperature 26 °C and *RH* 60% is estimated to be S$130/y per person, while the cost is S$280/y per person for lower temperature (22°C) and *RH* (40%) conditions.

Figures 3a and 3b display the incremental energy costs for increasing ventilation rates from 10 to 40 L/s per person. Improved system performance can allow for cost-effective increases of ventilation rate. A system with high COP (>4) can achieve a ventilation rate of 25 L/s per person at relatively small annual ventilation energy costs (< S$400/y). This cost is significantly lower than the annual wage (S$42,400/y per person) of Singapore office workers (Ministry of Manpower, Republic of Singapore 2013). Considering the potential productivity loss, sick leave, and healthcare costs associated with poor ventilation, health and productivity benefits of increasing the building ventilation rate are expected to exceed the associated energy costs. Furthermore, as shown in Figure 3b, a ventilation rate increase from 10 to 25 L/s per person could be attained without additional energy use if the indoor set-point were to be increased from 22 °C to 28 °C. In this case, thermal comfort could be restored, in principle, by using personal comfort systems as cooling fans (Schiavon and Melikov, 2008).

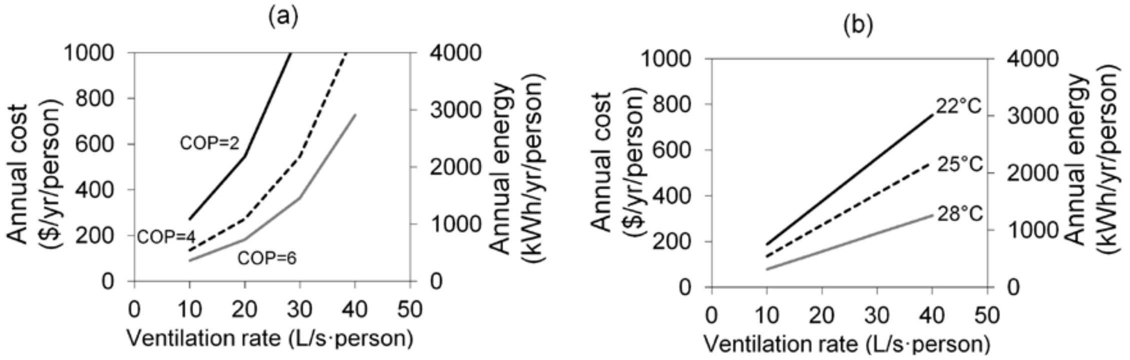

Figure 3. Annual cost and energy use due to increased ventilation rate for (a) varied COP (*T* = 25 °C, *RH* = 60%, S$0.27 for 1 kWh) and (b) for indoor temperature (COP = 4, *RH* = 60%).

CONCLUSIONS

The present study estimates the potential cost of increasing ventilation rates for office buildings in tropical climates. Although there has been an emphasis on reducing building energy consumption, the energy cost due to increased ventilation in tropical climates appears moderate compared to the annual wage of office workers. Increasing indoor temperature and RH set points and using more efficient cooling system (COP > 4) may fully compensate for the increase in energy use caused by the higher outdoor ventilation rates.

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