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ScienceDirect
Solar Energy 83 (2009) 1902–1913
SOLAR ENERGY
www.elsevier.com/locate/solener

Night ventilation control strategies in office buildings

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Received 30 September 2008; received in revised form 14 May 2009; accepted 13 July 2009
Available online 14 August 2009

Communicated by: Associate Editor Matheos Santamouris

Abstract

In moderate climates night ventilation is an effective and energy-efficient approach to improve the indoor thermal environment for office buildings during the summer months, especially for heavyweight construction. However, is night ventilation a suitable strategy for office buildings with lightweight construction located in cold climates? In order to answer this question, the whole energy-consumption analysis software EnergyPlus was used to simulate the indoor thermal environment and energy consumption in typical office buildings with night mechanical ventilation in three cities in northern China. The summer outdoor climate data was analyzed, and three typical design days were chosen. The most important factors influencing night ventilation performance such as ventilation rates, ventilation duration, building mass and climatic conditions were evaluated. When night ventilation operation time is closer to active cooling time, the efficiency of night ventilation is higher. With night ventilation rate of 10 ach, the mean radiant temperature of the indoor surface decreased by up to 3.9 °C. The longer the duration of operation, the more efficient the night ventilation strategy becomes. The control strategies for three locations are given in the paper. Based on the optimized strategies, the operation consumption and fees are calculated. The results show that more energy is saved in office buildings cooled by a night ventilation system in northern China than ones that do not employ this strategy.

Keywords: Control strategy; Mechanical night ventilation; Parameter analyses; Energy efficiency; Cold climate

1. Introduction

In the cold region of northern China the demand for building cooling is increasing with the development of architecture industry and global warming. In order to save energy in HVAC systems, lightweight construction and insulating materials are widely used. It is noted that night ventilation (NV) may save cooling energy and improve indoor thermal comfort in moderate climates (Fletcher and Martin, 1996; Kolokotroni et al., 1998; Kolokotroni and Aronis, 1999; Gratia et al., 2004; Breesch et al., 2005; Finn et al., 2007) and Continental and Mediterranean type climates (Blondeau et al., 1997; Givoni, 1998; Geros et al., 1999; Shaviv et al., 2001; Pfafferott et al., 2003, 2004). The efficiency of night ventilation is high especially for heavyweight construction (Kolokotroni et al., 1998; Kolokotroni and Aronis, 1999; Geros et al., 1999; Shaviv et al., 2001; Finn et al., 2007; Artmann et al., 2008). Whenever the nighttime outdoor air temperature is low enough, natural or mechanical ventilation can be used to cool the exposed thermal mass of a building in order to provide a heat sink during the following day (Artmann et al., 2008). Natural night ventilation may further increase energy savings, however, it is not easier to control compared to mechanical night ventilation. Is mechanical night ventilation suitable for lightweight construction in the cold climate of northern China? How can the operational parameters be optimized so that mechanical night

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doi:10.1016/j.solener.2009.07.003

ventilation would be beneficial if it is applied in lightweight construction in northern China?

Many studies have been carried out to evaluate the effect of different parameters on indoor thermal environment and the efficiency of night ventilation. The parameters generally assessed are as follows: climate, air change rates, thermal mass and internal heat gains. Based on the parameters analyzed, the ideal control strategies of night ventilation cooling were given. Fewer researchers considered heat transfer coefficient (Artmann et al., 2008). However, night ventilation duration was not considered in these studies except Kolokotroni and Aronis (1999) and Finn et al. (2007). The results show that daily peak temperatures in office buildings decrease by up to 2–4 °C (Fletcher and Martin, 1996; Kolokotroni et al., 1998; Geros et al., 1999; Blondeau et al., 1997; Pfafferott et al., 2003).

Blondeau et al. (1997) indicated that for a cooling load of approximately 20 W/m^2, a potential energy reduction on the order of 25% was achievable by using night ventilation in France. These savings were obtained at ventilation rates of 8–10 ach (air change rate). It is found that night ventilation succeeded in decreasing the diurnal indoor air temperatures from 1.5 to 2 °C, with a resultant improvement in comfort conditions.

Kolokotroni et al. (1998) pointed out that the cooling provided by night ventilation is up to 20 kW h/m^2 cooling per annum, whereas the typical air-conditioning load for a standard UK office building is approximately 30 kW h/m^2 per annum (CIBSE, 2000). For internal gains of 20 and 40 W/m^2, with an external temperature of 28.5 °C and day and night ventilation rate 1–4 ach, the internal temperatures are reduced by about 1–1.5 °C compared to the cases with no night ventilation. For heavyweight buildings with a given internal load of 25 W/m^2, and external temperatures of 29 °C maximum and 18 °C minimum, the peak indoor temperature is reduced approximately 2.5 °C when the night ventilation rate is changed from 0 to 10 ach (day vent was set to 3 ach). When the building weight is varied from light to heavy, the peak indoor temperature is decreased by approximately up to 4 °C (day vent was set to 3 and night vent to 10 ach).

Kolokotroni and Aronis (1999) considered some building parameters such as internal gains, building mass, glazing ratio, solar gains, building orientation, as well as climatic variables and operational parameters. They found that by optimizing building design (heavyweight, high airtightness) for night ventilation, air conditioning energy consumption could be reduced by approximately 20–25%, at internal gains of 20 W/m^2.

The cooling potential of night ventilation techniques has been experimentally and theoretically studied under different conditions and variable airflow rates for three full-scale buildings in Greece. Geros et al. (1999) found that the efficiency of night ventilation is strongly related to the difference between indoor and outdoor temperature during the night period, the airflow rate and the thermal capacity of the building.

Shaviv et al. (2001) simulated the maximum summer indoor temperature in a residential building in the hot humid climate of Israel. They took into account air change rate, thermal mass and daily temperature difference. In a heavy mass building, the maximum indoor temperature was found to be reduced by 3–6 °C compared to the outdoor maximum.

Pfafferott et al. (2003) simulated and monitored the energy consumption of two offices in a continental German building in order to evaluate the efficiency of night ventilation dependent on air change rate, solar and internal heat gains. The results from a long-term monitoring show that room temperatures are comfortable even at high ambient air temperatures (Pfafferott et al., 2004).

Gratia et al. (2004) observed that for moderate climates peak internal loads for commercial buildings typically vary from 30 W/m^2 (low cooling load) to 100 W/m^2 (very high cooling load) in Belgium. Night ventilation can offset cooling loads of the order of 10–40 W/m^2. Gratia thought that beneficial savings would be achieved by night ventilation cooling particularly in moderate climates.

In Belgium, a yearly average ambient temperature of 9.7 °C and an average daily maximum and minimum temperature in July of, respectively, 21.8 and 12.7 °C exist, which is suitable for the applicability of night ventilation (Breesch et al., 2005).

Finn et al. (2007) investigated the effect of design and operational parameters on the performance of a night-ventilated library building in the moderate maritime climate of Ireland. Increasing building mass from 800 to 1600 kg/m^2, the peak daily temperature was reduced by up to 3 °C. Reducing internal gains from 40 to 20 W/m^2, and ventilation rates up to 10 ach were also found to have a significant effect on internal comfort, with a reduction in peak internal temperature of up to 1.0 °C. However, no further improvement was observed increasing ventilation rates beyond 10 ach.

Artmann et al. (2008) evaluated the effect of climate, thermal mass, heat gains, air change rates and heat transfer coefficient on the effectiveness of nighttime ventilation. They found that climatic conditions and airflow rate during nighttime ventilation are the most important factors. But thermal mass and internal heat gains also have a significant effect on cooling performance and thermal comfort.

Many studies on night ventilation cooling and improving indoor environment have been undertaken in China (Chen and Chen, 1993; Fu et al., 1996; Cao and Li, 1999; Li et al., 2001; Wu et al., 2006; Wang and Sun, 2006; Zhou et al., 2008). Some studies focused on hot and humid climates, such as Shanghai, which is close to the Changjiang River. However, energy savings can not be obtained by mechanical night ventilation cooling in the areas with small diurnal temperature variation such as in Shanghai. Wu et al. (2006) studied the coupled operation strategy of night ventilation and active cooling for a large supermarket in the cold climate of China. The results described that the operation times, duration and air flow rate of night venti-