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Passive ventilative cooling in residential buildings: a review

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Abstract. The energy-saving potential of passive ventilative cooling has been underestimated, and the abuse of mechanical ventilation has resulted in significant energy waste in air quality. The use of large temperature difference between day and night; large temperature difference between indoor and outdoor during the transitional season; surface cold storage can greatly enhance the cooling effect of passive ventilation, reduce energy consumption and improve indoor air quality (IAQ). This paper analyzes and summarizes the research process of techniques and methods for realizing passive ventilation and cooling in residential buildings by using large temperature difference and accumulation of cold. The research results of the literature are mainly divided into two categories. On the one hand, the research methods and application characteristics of natural ventilation passive cooling technology formed by large temperature difference, which is dependent on climatic factors and residential conditions are described. On the other hand, the application environment and research technology of energy storage such as tunnel wind, which is based on the ventilation strategy and installation were described. Most of the research results show that the tunnel wind is relatively stable and comfortable, but the construction cost is too high, and the temperature difference is used to depend on the building category and climate environment. Passive ventilative cooling studies with focus on residential buildings are presented including both challenges and potential for improving building energy performance.

1. Introduction
The proportion of building energy consumption in global energy use is growing with people's living standards improvement. At present, the energy consumption of the construction industry has exceeded the transportation industry, accounting for 20%-40% of global energy consumption[1]. Among which, the rising rate of energy consumption in residential buildings has already shown the obvious trend extremely, accounting for 35-40% of global energy consumption[2]. Figure 1 shows the changes in energy consumption of various components of the building from 1930 to 2003.

It is obvious that as time goes by, the energy consumption of exterior walls, windows and roofs has been significantly reduced, but for the component of ventilation has not changed significantly, but even increased lately.

Because of the incomplete consideration of energy saving, air conditioning is usually used directly to cool down the overheating problem in the indoor environment of buildings, which can lead to huge building energy consumption. In this process, if the cooling potential of building ventilation is considered in the design stage, the energy consumption of building will undoubtedly decrease significantly. Therefore, it is necessary to improve the ventilation research system. This paper aims to
summarize the research status of global ventilation and cooling technology, and lay a foundation for the research system and design method of ventilation and cooling in residential building.

![Energy consumption ratio of each part of the building.](image)

**Figure 1.** Energy consumption ratio of each part of the building.

2. Ventilative cooling of residential buildings

Overheating is an important reason for residential buildings to require ventilative cooling. In the design and construction stage, there are mainly several factors that caused building to be overheated, such as the airtightness of the building is gradually increasing, the thermal insulation performance of the envelope structure is gradually improved, the greenhouse effect is gradually intensified, and the internal heat source is increased with the internal functions of the building. However, throughout the architectural design phase, these effects are often ignored. In most cases, good ventilation design is enough to solve the problem of overheating in the indoor environment, but in China, the important role of ventilation and cooling has been ignored, which is why ventilative cooling needs to be taken seriously. According to different building models, geographical environment, climatic conditions, the use of outdoor environment to provide cooling capacity to the room, so that the indoor environment is cooled to the temperature of the appropriate comfortable area of the human body is defined as ventilative cooling. The degree time of ventilative cooling estimated based on the building type, cooling time, natural driving forces, urban environment is called ventilative cooling potential\[^3\].

The ventilative cooling capacity of buildings are great affected by indoor and outdoor temperatures. Different climates in different regions is also very significant on it. For example, it is generally believed that in hot summer and cold winter areas, the daily temperature difference is small, and the average temperature at night in the hottest month is high, so the ventilation potential is at a low level. In the cold period, the ventilation and cooling capacity of the building is very significant. During the mild period, the ventilation and cooling capacity is small, while during the hot period, it is necessary to determine the application ventilative cooling time according to the daily hourly temperature. Night ventilation is usually used to store cold in this period.

Among them, climate factors are reflected in the following aspects: outdoor average temperature, temperature amplitude, relative humidity, wind speed and direction, and solar radiation level. Document\[^4\] creatively puts forward the concept of Climate Cooling Potential (CCP), and lately according to the European indoor environment standard, the applicability of the model in different typical areas was revised\[^5\].

3. Ventilative passive cooling technology formed by large temperature difference

3.1. Transitional ventilation potential

The typical clothing level in summer and winter comfort in ASHRAE Standard 55 is 0.5 and 0.9 clo, respectively. ASHRAE comfort range is 3°C with a seasonal shift of 3°C\[^6\]. Experimental studies have shown that the comfort environment under the air conditioning system is smaller than the comfortable environment.
under natural conditions. The average temperature required for comfort is 23℃, the standard deviation is 1-1.5℃, and the temperature changes with the season is 0.5-1℃[7]. However, for natural ventilation, the thermal comfort of a naturally ventilated building is greater than the seasonal range assumed by the ISO 7730 and ASHRAE 55 standards [8-11]. From this, the upper and lower limits of the comfort zone temperature can be obtained. Fig. 2 shows the evaluation method for the ventilative cooling potential of residential buildings. As is shown above, $T_{cu}$ and $T_{cl}$, $T_{fr}$, free-running temperature, is an important parameter used to evaluate the free cooling potential[12]. $T_o$ is outdoor temperature.

![Figure 2](image)

**Figure 2.** Comfort range for air conditioning and for natural ventilation:

The results show that when the ventilation and cooling conditions are consistent with the indoor and outdoor temperature curve and comfort zone, the ventilative cooling effect is more prominent.

3.2. Day and night temperature difference ventilation operation strategy

Since residential buildings are the most frequently used in all kind of buildings at night, it is more difficult to use night-time ventilation and cooling technology to solve the overheating problem of residential buildings than other types of buildings. Frequency distribution and Cumulative frequency distribution of the calculated cooling load without night ventilation are shown in Fig 3. Many important experiments have investigated the energy-saving effects of using nighttime ventilation[13-17]. These experiments show that the nighttime ventilation strategy is used in buildings that rely on the natural flow of air. The peak temperature of the room will be reduced by about 3K on the second day. In the air-conditioned room, the night ventilation strategy will be used, and the peak energy consumption of the room will drop more on the second day. In order to verify this conclusion, the relevant scholars also made a theoretical analysis of the sensitivity of each building to climate[18]. The research shows that the use of free-running temperature has this advantage, that is, when the indoor temperature changes, the free-running temperature can be used in summer air-conditioned buildings. But there are also the following problems which needs to be considered, regions with strong cooling capacity also have less cooling demand. Otherwise, most of the research is mainly for commercial buildings[19], there is still a lot of research spaces in the sensitivity upon climate.
Figure 3. Frequency distribution and Cumulative frequency distribution of the calculated cooling load without night ventilation.

Figure 4. Calculated decrease of the cooling load because of the use of night ventilative techniques in all the considered buildings.

Under the same climatic conditions, the effect of nighttime ventilation is mainly related to the driving force of the airflow and the building characteristics. The figure 6 shows the indoor cooling load demand reduced during the building design process using nighttime ventilation and cooling technology (refer to this article). It can be seen that the night ventilative cooling technology can reduce the cooling load to 40 kWh/m²/y. The results in the figure can be approximated into a linear trend. It can also be seen that, in general, the building with higher cooling load demand, the ability to cool the load at night by ventilation is also greater. Although buildings with demand of larger cold load eliminating have less cooling load reduced by nighttime ventilative cooling, their reduced cooling load accounts for the percentage of total cooling load, as shown in Figure 5, the percentages are between 10% and 40%. The average is close to 26%.

At the same airflow speed, the cooling load after nighttime ventilative cooling is linearly related to the original cooling load. The greater the wind speed, the better the cooling effect. Figure 6 shows the nighttime ventilation energy contribution as a function of initial cooling load for 2, 5, 10, 20 and 30 air changes per hour, respectively.
**Figure 5.** Percentage of cooling load reduction in all buildings because of the use of night ventilative techniques.

**Figure 6.** The calculated energy contribution of night ventilation as a function of the initial cooling load for various levels of air flow rate and in particular for 2, 5, 10, 20 and 30 air changes per hour.

**4. Conclusions**

In past construction and HVAC design, building overheating and ventilative cooling potential have been ignored. In the past ventilation design of buildings, ventilative cooling only exists in a few cases, such as the combination of stratified air conditioning design of high and large space, and needs to be popularized urgently. In this paper, the definition of ventilative cooling potential, the evaluation method is based on the existing research, and on the basis of this, the method and strategy of transitional season and night ventilative cooling are summarized. Whether in the transitional season or at night, the conditions for ventilation and cooling must be consistent with the indoor and outdoor temperature curves and comfort zones. In the process of adopting ventilative cooling, different driving forces, different climatic conditions, and different building shapes produce different cooling effects. It provides a theoretical basis for the establishment of building ventilation design guidelines and the development of ventilation and cooling technology. It is precisely because of the influence of different climate conditions, building shape, driving force and so on that this paper and related research can not give a universal control strategy, but there is still great research space in this part, such as through mathematical models, considering the correlation and weight of each influence. This requires detailed study of different regional climates and different architectural forms. Research can continue to explore in depth.
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