Stack Effect Ventilation in Different Climates

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Abstract

The effect of stack ventilation is dependent on the height of the air column and the temperature difference across the column's enclosure. So climate is one of the most important factors to induce the stack effect. Outdoor air temperatures vary for each season and each day in different climates. By this fact, the characteristics and force of the stack effect varies in different climates. The fundamental equation from ASHRAE (2017) is used for the calculations for the airflow rates caused by stack effect. For this study, comparisons are made among different climates in USA to analyze the impact of different times of day within each climate determined the effect of time and season, proposes to compare the different results for the whole year, which gave a basic understanding of the stack effect of those climates in different seasons. The results show that the airflow rate caused by stack effect is high in winter and low in summer. Also, it is high in the nighttime and low during the daytime in all climates. This study introduces basic understanding of the stack effect ventilation which is useful for designer before applying to buildings, practically.

Keywords: Stack Effect, Ventilation, Air Flow, Climate

1. Introduction

Passive ventilation within an enclosed space is created by pressure differences between inside and outside of the building induced by wind and air temperature differences. These provide the two main mechanisms of wind induced ventilation and stack, or thermal buoyancy, ventilation (Figure 1).

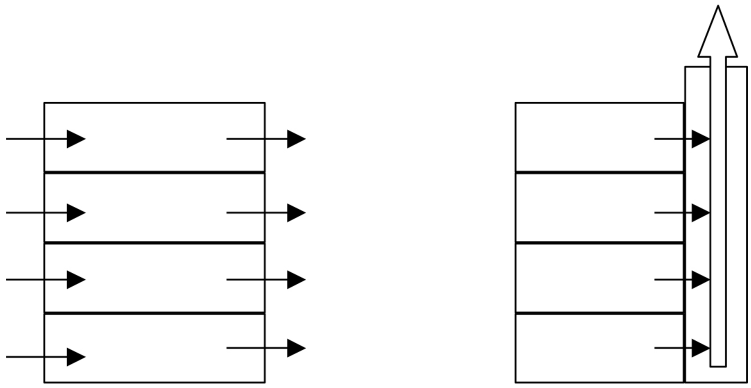

Figure 1: Wind Induced Ventilation (left) and Stack Ventilation (right)

For the wind-induced ventilation, the immediate environmental forces can be the main factors that dominant the behaviors of ventilation. These environmental forces vary significantly and building designers are required to develop designs, which counteract these forces for every case. On the other hand, the stack effect ventilation occurs, typically within the building and is subject to internal, as well as external forces. Furthermore, Awbi (1998) stated that building which require ventilation rates greater than those achievable using either single-sided or cross ventilation may be ventilated using stack. The stack phenomenon can be designed to provide the suitable ventilation for the building in purpose of saving energy.[1]

The stack effect is the flow of air mass resulting from hydrostatic pressure differences caused by density differences in two fluid columns [2]. For building, the fluid is air and the density difference is caused by large temperature differences. Although humidity and other variations in the air mass can cause density differences, Sherman (1998) stated they are usually minor compared with normal temperature differences and can be ignored.[3]

ASHRAE stated the stack pressure as influenced by temperature differences between indoors and outdoors cause density differences (and therefore pressure differences) in an air mass, which drives infiltration. The magnitude of the stack effect is dependent on both the temperature differences and the height of the air column. [2}

Stein suggested that the effective use of stack effect in buildings needs several conditions: warmer air indoors that can enter the bottom of the stack, cooler air outdoors, and low inlets to admit that cooler outdoor air to the building.[4] According to Stein, the cooler outdoor air picks up heat radiated or convection from the building and enters the bottom of the stack space or atrium. Within the stack space, this now- warm air rises, because it is less dense and therefore lighter than the cooler outdoor air that surrounds the top of the stack.

The airflow rate caused by stack effect depends on several factors: the inside and outside air temperatures, the area of the openings, and the height difference between the top and bottom openings. However, increasing the outlet area over inlet area (or vice versa) increases airflow but not in proportion to the added area. When openings are unequal, use the smaller area in equation (1) and add the increase as determined from Figure 2. [1]

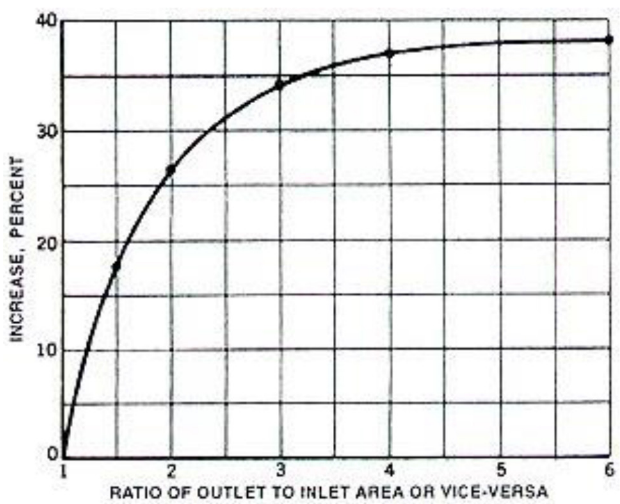

Figure 2: Increase in flow caused by excess area of one opening over the other. (ASHRAE, 2017)

2. Methodology

The calculation of this section is based on the airflow rate caused by stack effect from the ASHRAE (2017).

$$Q = 60C_D A\sqrt{2g\Delta H_{NPL}(T_i - T_o)/T_i} \quad \text{--} \quad (1)$$

Where

Q = airflow rate caused by stack effect, cfm

CD = discharge coefficient for opening, assume = 0.65

A = in square feet, the smaller of either total free area of inlet or outlet openings or horizontal cross sectional area (throat area) of the stack

g = gravitational constant, 32.2 ft/s2

HNPL = height from midpoint of lower opening to NPL, ft

Ti = temperature indoors, oF

To = temperature outdoors, oF

The stack cavity for the calculation is eight story or 110 ft. height. So, the HNPL of this stack cavity is 55 ft. The opening area of inlet and outlet is assumed to be equal as 10 sq.ft. The monthly and hourly air temperature of each climate is applied as outdoor temperature (To) for the calculation, while the indoor temperature (Ti) is assumed to be 5 oF higher than outdoor temperature. Air Temperature Data for four cities in the United States are used as outdoor temperatures for the calculations. Each city represents four main climates as Minneapolis represents the Cold Climate, Chicago represents Temperate Climate, Miami represents Hot-humid Climate, and Phoenix represents Hot-arid Climate. The results are divided into two sets of data based on air temperature including monthly and hourly data.

3. Results

3.1 Monthly Results

The average air temperature of each month in different climates was applied to equation (1) for the calculation. This provides the first rough look of the airflow rate caused by stack effect in different seasons through the year.

The result from Figure 3 shows that the value of airflow rate caused by stack effect in January of each climate has the greatest cubic feet per minute (cfm) rate. The lowest point of each month is in July. This result shows that the airflow rate caused by stack effect in winter is higher than in summer. However, the difference between summer value and winter of hot-humid climate is the lowest, while in cold climate is the highest. Furthermore, the average airflow rate caused by stack effect in the cold climate is also the highest and the hot-humid climate is the lowest. Among all of them, the highest point of the value is in January, cold climate, and the lowest point of the value is in July, the hot-arid climate. Although in average, the airflow rate caused by stack effect in the hot-humid climate is the lowest, but the lowest point of this climate is higher than the lowest point of the hot-arid climate. Moreover, in the hot-humid area, the values in winter and summer are not much different like other climates.

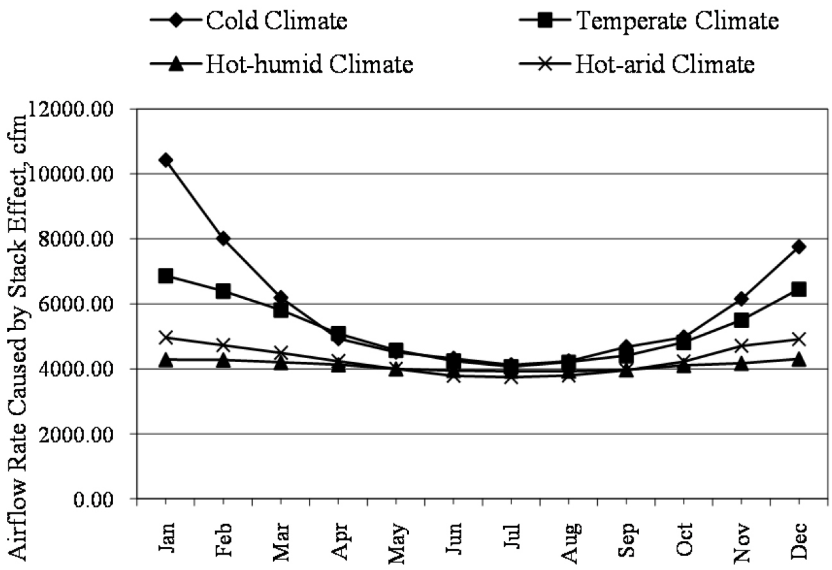

Figure 3: Monthly Airflow Rates in Different Climates

This result provides the first glance of the stack effect behaviors in different climate. It can be concluded here that the airflow rate caused by stack effect in every climate will have a high value when the air temperature is low.

3.2 Hourly Results

In this section, the hourly air temperatures are based on the 21st of each month from representation climate files. This study purposes to find out the behaviors of the airflow rate caused by stack effect in different time of the day. Also, the comparison of the results of each month will be a good guideline of understanding the behavior of stack effect before applying this natural ventilation in different time of the day in different season.

In winter, Figure 4 shows that the airflow rate caused by stack effect in the cold climate is always the highest among the four climates at all times, while the hot-humid climate is the lowest. The difference of the values between nighttime and daytime in the cold climate is the greatest, while the temperate and hot-arid climate are in the middle. The hot-humid climate has the lowest difference of the values of nighttime and daytime. The lowest points of the values of all climates occurred at 1:00 pm. The highest point of the values occurred at 6:00 am for the cold and temperate climate, and occurred at 5:00 am for hot-humid and hot-arid climate.

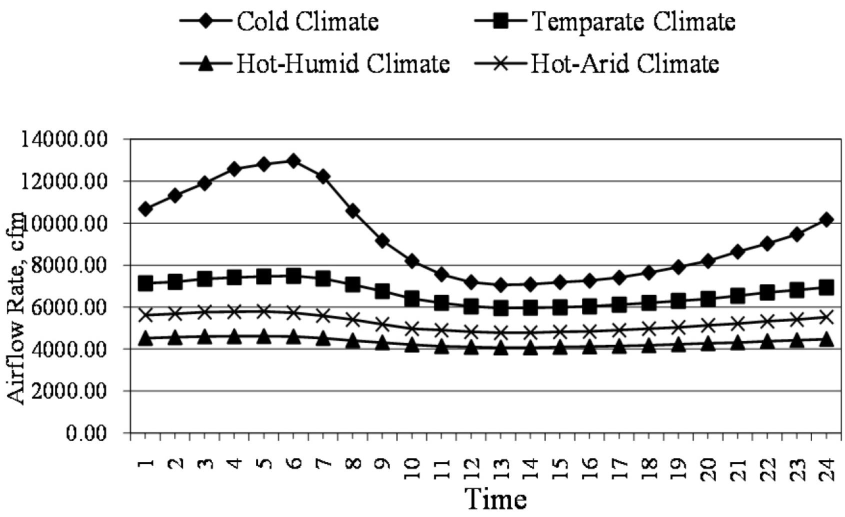

Figure 4: Hourly Airflow Rate on January 21st

In summer, the result in Figure 5, shows that the hot-arid climate has the highest value and the lowest airflow rate. That means the difference between the nighttime and daytime in the hot-arid climate is the highest. Compare among the high point of each climate, the hot-humid climate has the lowest rate of stack effect derived airflow. On the other hand, if comparing among the lowest point of each climate, the result shows that the temperate climate has the highest rate. The lowest point of all climates occurred at 3:00 pm. The highest points of the cold and temperate climate occurred at 5:00 am, while the hot humid climate and hot arid climate occurred at 4:00am.

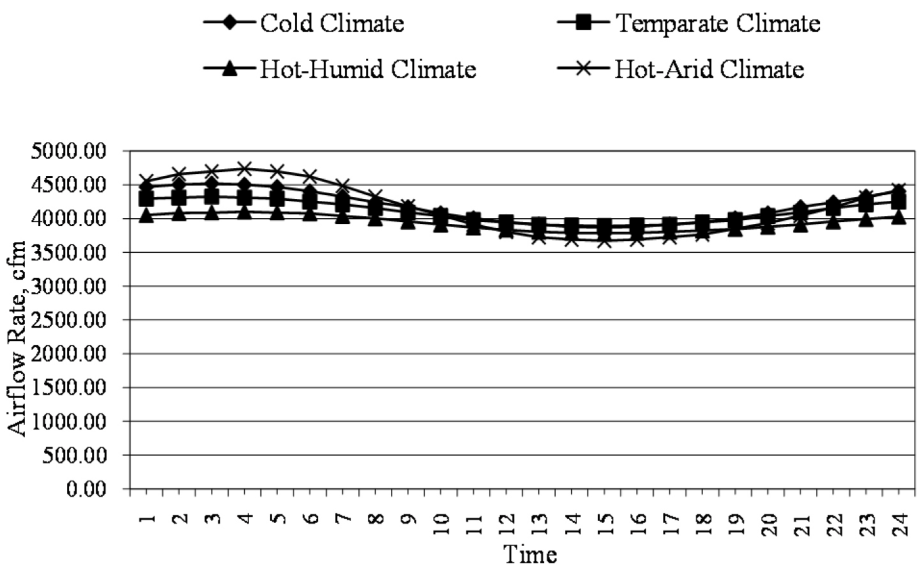

Figure 5: Hourly Airflow Rate on July 21st

4. Summary and Discussion

The results show that the airflow rate caused by stack effect is high in winter and low in summer. Also, it is high in the nighttime and low during the daytime in all climates. The main factor influencing this behavior is outdoor temperature. In winter, the outdoor temperature on average in all climates is lower than summer. At nighttime, the outdoor temperature is normally lower than the daytime. These are the key reason for the value of the airflow rate caused by stack effect. However, the mean average outdoor temperature for each climate is different. So, the behaviors of the airflow rate caused by stack effect in similar air space in each climate are also expected to be different.

Before applying the stack effect ventilation to buildings in each climate this fundamental concept has to be understood. For example, a building in a hot-humid climate must be fully studied to apply the idea of a ventilated air space because the airflow rate caused by stack effect in both winter and summer is not high. However, in the hot-humid climate the demand for heating is small, therefore, the application of the stack effect ventilation will be primarily on summer time use. During summer, the airflow rate caused by stack effect in the hot-arid climate is the highest. It is because in the summer the outdoor temperature at night of this climate is still low. This advantage is ideal for use in a night ventilation strategy. For winter, the stack effect ventilation should focus on daytime because the results of these calculations indicate the use of a passive solar strategy will probably only reduce heating demand. It is found that the cold climate has the highest airflow rate caused by stack effect and the hot-humid climate has the lowest airflow rate. Practically, when the solar space indirectly exposed to solar radiation, the temperature within the facade cavity should be much higher than the assumed values in this calculation because there are also heated store in building structures and others. So, the temperature difference between indoor and outdoor of the system on a sunny day must be higher. This will provide higher airflow rate during the daytime.

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