ANALYSIS OF RESIDENTIAL HYBRID VENTILATION PERFORMANCE IN U.S. CLIMATES

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ABSTRACT

This study examines the potential for using passive ventilation systems to meet ASHRAE 62.2 requirements as a step in the process for optimizing hybrid ventilation systems. A brief review of the literature with reference to the passive and hybrid ventilation systems in residential building is presented. The review focuses on key aspects of ventilation system performance, including indoor air quality, air distribution and ventilation rates. For the evaluation of capability of the natural ventilation system to meet the requirements yearly simulations are performed and a multi-zone airflow simulation tool (CONTAM) is used. The case studies are developed for three residential buildings located in several U.S. Climate zone, each with the same occupancy. The first and the second houses are detached houses of one and two stories, the third is a three story attached house. The floor areas of the three houses are respectively 86 m^2, 276 m^2 and 145 m^2. The simulation results are compared with that one's obtained by simulating a mechanical ventilation system.

KEYWORDS

Residential ventilation; indoor air quality; air distribution; ventilation rate.

INTRODUCTION

The primary purpose of ventilation is to provide acceptable indoor air quality and thermal comfort. Fresh air can be introduced indoors by natural ventilation, mechanical ventilation or by an hybrid combination of them. Hybrid ventilation systems are systems that provide a comfortable internal environment using both natural ventilation and mechanical systems. The main difference between a natural ventilation system and a hybrid system is the fact that the latter has an intelligent control system that can switch automatically between natural and mechanical modes in order to minimize energy consumption (Heiselberg). Currently there is great interest in the investigation of the differences between the natural and the mechanical ventilation systems in terms of air quality of indoor.

Hybrid ventilation system analysis methods incorporate three aspects: natural ventilation mode, mechanical ventilation mode and control strategy. When the system is designed for dwellings, we must identify issues such the point at which natural driving forces fail to fulfill ventilation demand becomes the first aspect to analyze.

Recently several studies were carried out aiming at analyzing hybrid ventilation features and relative operating parameters in relation to commercial buildings (Heiselberg, Emmerich et al.). For the residential buildings published information on analysis methods for hybrid ventilation system is limited.

The purpose of building simulation tools is the evaluation of the building response to the outdoor climate. Multi-zone air flow models are the most suitable to evaluate performance of natural and hybrid ventilation system. For the study CONTAM multi-zone airflow and contaminant transport analysis software is used. Because of the performance of the natural and hybrid ventilation systems depend on the climate, the objective of this study is to perform simulations for four US climate zones. The results are given in terms of concentration and air flow rate ventilation.

BRIEF LITERATURE REVIEW

The starting point for this study was a review article. A literature search was conducted on the hybrid ventilation topic of residential buildings. More of this work was developed by the EU RESHYVENT project. Only a small number of real buildings with ventilations system was found in the literature, and the real buildings analyzed for the experimental study are for the most part educational buildings or office buildings. The main results for these studies show a very high cooling potential for the stack effect with fan assistance technology with temperature control strategy (Jacobs et al., Li et al.). An experimental campaign is performed in two urban canyons in Athens in order to investigate the impact of the urban environment on natural and hybrid ventilation (Jreijiry). Theoretical studies of the hybrid ventilation system are basically based on parametric models, and the design methods. For the first case the scope of the studies is the evaluation of the demand control strategies developed for the hybrid ventilation system, which is in general based on the occupant detection or on the indoor CO_2 levels. For the second case the studies have put the attention on the design parameters, sensitivity analysis and design constrains on essential element like wind effects in the build environment and modeling air flows in spaces (Niachou et al., Charvat et al.).

MODELLING

For the present study different model houses are considered. The houses represent a reasonable cross-section of a database of most common US dwellings (Persily et al.). The case studies are developed for three residential buildings located in several U.S. Climate zone, each with the same occupancy. The first and the second houses are detached houses of one and two stories, the third is a three story attached house. The floor areas of the three houses are respectively 86 m^2, 276 m^2 and 145 m^2. The envelope leakage was modeled considering an average overall leakages n50 [ach/h] equals to 3.5. All the leakage elements to suit the requirements of the simulations (indoor to outdoor openings) are calculated. All doors between habitable rooms are opened. The indoor temperature is constant and fixed to 23°C. No windows airing is considered. Steady state conditions are assumed on each systems running hour. To characterize the airflow between zones and the outdoors, different types of flow elements that combine leakage area and orifice area data from the literature are considered.

The scope of the study is limited to the comparison of the contaminant exposure between the natural case and the mechanical case, considered as reference case. For the natural case and the reference case the same contaminant and occupant profiles, weather, leakages are used. The reference case is a mechanical ventilation

system that presents continuous exhaust at the state of the art. The state-of-the-art in IAQ regulations are building codes based on prescribed ventilation rates such as in American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 62.2.
The natural ventilation system is constituted by ducts that are disposed on vertical position for the air exhaust. The duct is integrated in the building as a fitting structure, the air is rejected by one common duct. Duct parameters considered for the simulations: vertical length on the building 5 m, two different diameters, 0.1m and 0.2m.
Two different diameters are chosen to collect information about the duct performance to achieve the ventilation requirements. Naturally, the stack effect is not the same in the selected house because the total lengths of the air outlet vertical ducts are not the same, being the house of different levels.
A simple recirculation air handling system (AHS) was added to each model, with a supply in each room and a central return on each floor. There is no contaminant removal in the AHS, as well as no sinks in the home. The system ductwork has no leakage and that the supply and return systems are fully balanced.
A generic contaminant generated is used. Generation of household contaminants is a combinations of the occupant-generated contaminant, volume weighted sources and kitchen and bathroom sources.
Weather conditions greatly affect natural ventilation, and for this reason simulations in several climates on year-round periods are considered.

RESULTS

The required air-exchange rates for the three houses are respectively 23.4, 58.8 and 39.2 l/s. The ventilation rates according to the outdoor temperature for the whole year change for different climates. In quite all the climates considered, the larger the diameter the higher the ventilation rates are. In the Figure 1 the ventilation rates for the diameter duct 0.1 and 0.2 m for the mild climate zone is reported.

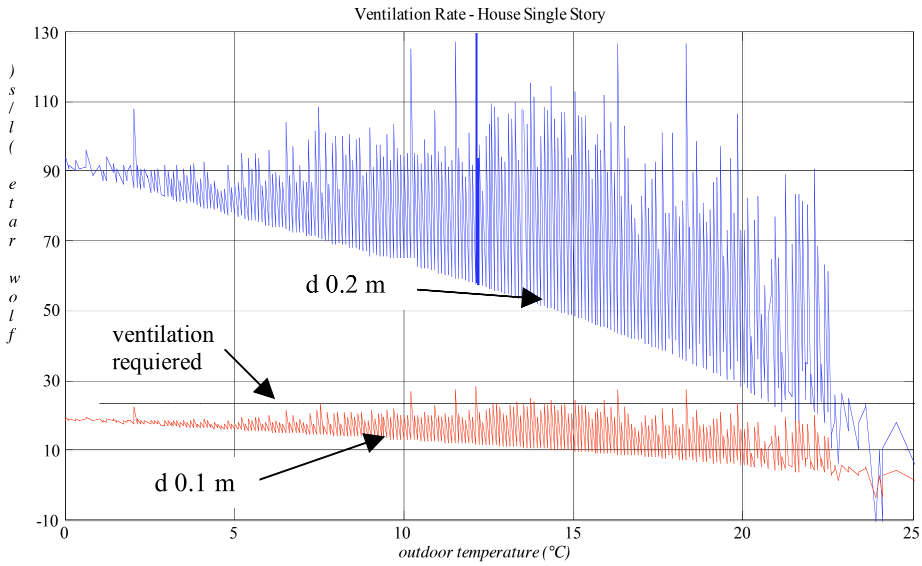

Figure 1: The ventilation rates according to the outdoor temperature for the whole year.

In the figure the airflow rate depending on the outdoor-indoor difference temperature is shown. The black line plotted in the graph represents the ventilation air required by the ASHRAE Standard 62.2. The indoor temperature is constant at 23°C. Flow rate raises in a range between -10 to 30 l/s for a diameter of duct, d, of 0.1 m, while for a duct of 0.2 m the increase is more significant, from -10 to 130 l/s. In the first case the flow rate never fulfills the requirement, opposite result happens for the second case. For all the simulations the percentage of times that the requirements are fulfilled is reported in the Table 1.

TABLE 1: Simulations results in terms of percentage of times that requirements are fulfilled

Percentage	d 0.1 m			d 0.2 m		
Climate Zones	1fl	2fl	3fl	1fl	2fl	3fl
COLD	0.37	0.00	0.00	89.61	79.00	88.78
MILD	0.54	0.00	0.00	98.47	94.47	98.82
WARM	0.11	0.00	0.02	96.30	80.95	95.96
DESERT	1.13	0.01	0.16	54.61	42.08	54.73

With a duct diameter of 0.1m for all the climates taken into account the air flow requirements are never fulfilled, in the second case, all the climate zones, except the last one, present a percentage up 79%, for all the houses. For the hottest climate zone this value is around 50%.
In the Figure 1 it's possible to see that the requirement for the ventilation is reached for 99% of the time. What makes it possible is in part the temperature difference outdoor-indoor; when the outdoor temperature is lower than 20°C the passive ventilation guaranties the minimum airflow rate for the whole building, and just for 1% of the time a mechanical ventilation is needed.
In the Figure 2 the outdoor temperature cumulative distribution for the whole year is shown. More than 99% of the time the outdoor temperature is lower than 20°C.

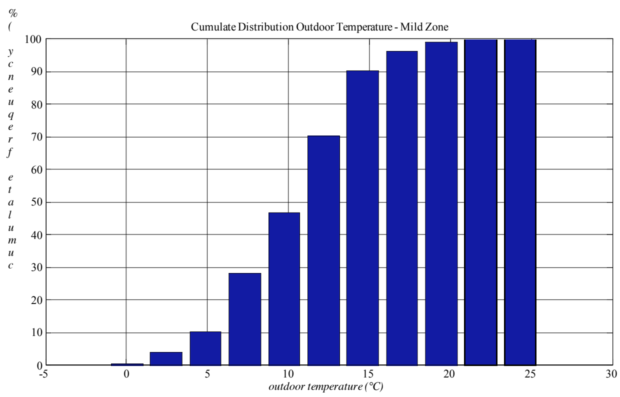

Figure 2: Cumulative distribution outdoor temperature.

As expected, the ventilation rates reaches the whole building air flow ventilation rates according to the outdoor temperature, as reported for the desert climate zone, reported in Figure 3 (a and b).

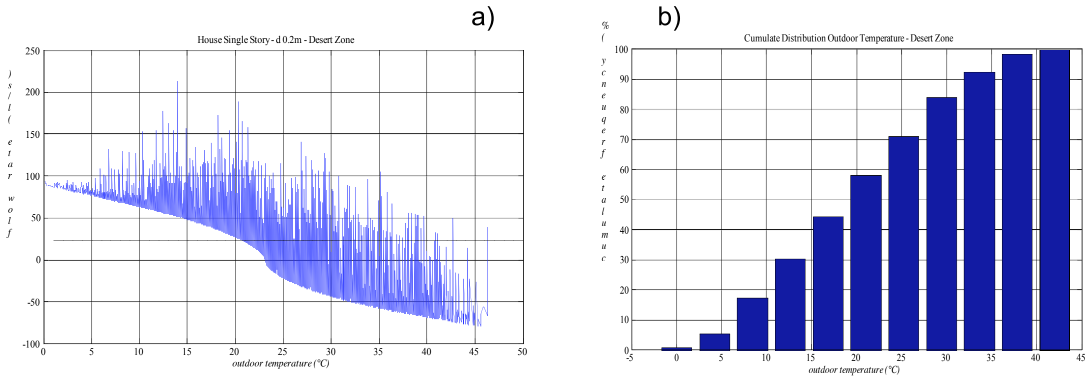

Figure 3: Ventilation rate and cumulative distribution outdoor temperature.

The results show that for the 55% of the time the passive ventilation is higher than the minimum (horizontal line) required (Figure 3, a), according with the percentage of occurrences that the outdoor temperature is under 20°C (Figure 3, b).
The same result occurs in every house case and for all the climate zones, for different temperatures depending on the house characteristics.

With our step-by-step discrete values, the relative concentration for the passive ventilation system (compared to the reference one) is calculated. We need to look at how the concentration changes over time. The Table 2 shows the ratio of the annual average concentration for the test case to the reference case for all the climate zones.

TABLE 2: Simulations results in terms of ratio of annual average concentration

Concentration	d 0.1 m			d 0.2		
Climate Zones	1fl	2fl	3fl	1fl	2fl	3fl
COLD	1.08	1.08	1.12	0.65	0.95	0.72
MILD	1.06	1.08	1.08	0.62	0.93	0.66
WARM	1.11	1.10	1.14	0.65	0.93	0.70
DESERT	1.16	1.11	1.16	0.71	0.96	0.80

As expected, the larger the diameter the lower the average concentration. The comparison between the percentage of occurrences of the air flow ventilation on the required value and the relative concentration is interesting. The values in the Table 1 and 2 are not proportional as expected. In the desert climate zone for 50% of the time the air flow ventilation doesn't fulfill the requirement, but the average concentration has the same value as others climate zones where the air flow ventilation fulfills the requirements.

We found no trend in the results relative to the yearly ratio average concentration for all the climate zones and for all the houses taken into account.
For a duct diameter of 0.2 m the yearly concentration is always under unity; the minimum value is 0.62, which means that the stack effect helps the concentration to goes down with the mechanical ventilation for 40% of the time. The results show that the climate doesn't influence the value of the concentration, even if the air flow ventilation rates can be very different in the analyzed cases. For example, for the desert zone, due to the particular outdoor temperature, the stack effect doesn't help

the natural ventilation to reach the requirements, but the average concentration is not so different from the values found for the others climate zones.

For a duct of 0.1 m the average yearly concentration is always higher than the same ones of the mechanical ventilation system. In this case it's possible to image a combination of a mechanical ventilation system to improve the ventilation performances. The hybrid ventilation system should work just in the summer periods, and for a very few hours, except for the desert zone, where the yearly and daily difference temperature is particularly high. It's possible to imagine a hybrid ventilation system based on the flow rate measurement; when the value goes down the set point, a mechanical ventilation fan turns on to improve the stack effect, enhancing envelope pressure difference during the periods of weak natural driving forces. Such hybrid systems will be a topic for future research.

CONCLUSION

We carried out a study on passive stack operation considering different duct diameter to evaluate ventilation rates evolution for different US climates. Passive ventilation systems using stack effect are able to help to meet the ventilation requirements. In a few cases the use of hybrid ventilation system is required. The complexity of the components and the important number of variable characteristics suggests further research to increase the number of computed analysis to define design guidelines.

REFERENCES

Blomsterberg A., Johansson T.. 2005. "Use of Multi-Zone air Flow Simulations to Evaluate a Hybrid Ventilation System". *Building Simulation*.

Charvat P., Jicha M., Niachaou A., Santamouris M.. 2005. " Simulation of the Performance of a Hybrid Ventilation System in Different Climates". *Building Simulation*.

Emmerich, SJ. 2006. " Simulated Performance of Natural and Hybrid Ventilation Systems in an Office Building". *HVAC&R*, **Vol 12**.

Heiselberg P, 2002. "Principles of Hybrid Ventilation", *IEA ECBCS Annex 35 "Hybrid Ventilation in New and Retrofitted Office Buildings",* ISSN 1395-7953 R0207.

Jacobs P., Gids W.F.. "Reshyvent Demand Controlled Residential Hybrid Ventilation". *RESHYVENT REPORT*.

Jreijiry D., Husaunndee A., Villenave JG.. 2005. "Evaluation of Hybrid Ventilation Control Strategies in Residential Building". *International Conference "Passive and Low Energy Cooling for the Built Environment"*.

Li Y., Heiselberg P.. 2003. "Analysis Methods for Natural and Hybrid Ventilation – a Critical Literature Review and Recent Developments", *International Journal of Ventilation*.

Mansour Y., Allard F., Musy M., 2003. "Conceptual Implementation of Natural Ventilation Strategy". *Building Simulation*.

Niachou K., Livada I., Santamouris M.. 2005. "A study of temperature and wind inside two urban street canyon in Athens". *International Conference "Passive and Low Energy Cooling for Built Environment"*, Santorini, Greece.

Niachou K., Santamouris M., Georgakis C.. May 2007. "Natural and Hybrid Ventilation in the Urban Environment. *Technical Note AIVC 61*.

Niachou K., Santamouris M., Hassid S.. 2005. "Performance of natural, hybrid and mechanical ventilation system in urban canyons". *International Conference "Passive and Low Energy Cooling for Built Environment"*, Santorini, Greece.

Persily A.K., Musser A., Leber D. 2006. "A Collection of Homes Representing U.S. Housing Stock". NISTIR 7330.

Sherman M.H., and Walker I.S.. 2006. "Energy Impact of Residential Ventilation Standards in California". *LBNL-61282*.

Weber A., Dorer V.. 2004. "Description of reference buildings and ventilation systems". *RESHYVENT REPORT*.