CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 7

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 7*. Department of Civil Engineering, Aalborg University.

A study on the influence of dwellers' ignorance of ventilation upon indoor air quality

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Abstract

The state of ventilation in houses was investigated using a national survey on mold and mite. The influences of building factors or living styles upon the rate of using ventilation systems were analyzed using a statistical method. The ratio of houses continuously ventilated was 20% in the case of exhaust ventilation systems and 60% in the case of exhaust and supply ventilation systems in winter. Each ratio in summer was 25% and 75%. These results show that ventilation systems are used temporally to control indoor environment. Sometimes dwellers use their ventilation systems to exhaust pollutants from their kerosene stoves in winter and sometimes to make rooms dry in summer. Dwellers use both ventilation systems and windows in winter, especially in the case of exhaust ventilation systems.

Indoor air quality was calculated in some typical models of houses with dwellers' ignorance using a simulation program "Fresh". The temperatures, humidity, concentrations of carbon dioxide, carbon monoxide and chemical compounds, and energy consumptions were calculated considering the building performances and dwellers' behaviors in houses. These simulation results showed that indoor air quality depends on the operation of ventilation systems especially in airtight houses. The use of kerosene stoves even if the ventilation systems are operated, makes indoor air quality harmful for dwellers. The simulation results show that giving information about indoor air quality is very important for dwellers as well as home builders.

Keywords - ventilation system; dwellers' ignorance; questionnaire survey; simulation

1. Introduction

Ventilation systems have been installed in all newly-built houses in Japan since the amendment of building standard toward a sick house problem in 2003. However ventilation systems are not used continuously by most dwellers. The reasons are thought to be energy saving, the noise of ventilation systems, the lack of understanding of indoor air quality, and etc. After the Great East Japan Earthquake, saving electric energy is required and portable stoves using kerosene are used in many houses. Therefore it is also required to give correct information about indoor air quality to every dweller.

In this study, the way of using a ventilation system is investigated using the survey results on mold, mite, living styles and other environmental factors in houses in 2006.

And the concentrations of pollutants which may lower indoor air quality are calculated using a simulation program “Fresh”. The annual changes of indoor air quality in the houses of dwellers who are ignorant of their housing environment are compared with those in the houses of dwellers who are concerned about their housing environment: the intermittent usage of ventilation systems, the usage of kerosene stoves and the emission of chemical compound from building materials, etc.

2. Methods

2.1 Analysis of the operation of ventilation systems

In order to clarify the indoor environment and its factors in Japanese houses, the living style, the characteristics of houses and other environmental factors were investigated using questionnaires in 2006. Table 1 shows the questions to the dwellers. In this study, the state of operation of ventilation systems in houses is analyzed using the results. The factors which influence upon the operating time of ventilation systems is selected and their modeling capabilities are predicted using a statistical analysis program J.M.P.

Table 1. Questions on houses and living style to dwellers

Question	Choice etc.
Ownership	Privately-owned house, Rented house
Total number of rooms	1LDK,2K,2DK,2LDK,3K,3DK,3LDK,4K,4DK,4LDK,5K,5DK, 6 rooms or more
Years of residence	≦2y, ≦5y, ≦10y, ≦20y, 20y<
Region	1($D_{18\text{-}18}$≧3500), 2(3500＞ $D_{18\text{-}18}$≧3000), 3(3000＞ $D_{18\text{-}18}$≧2500), 4(2500＞ $D_{18\text{-}18}$≧2000)
Insulation of walls	Energy-saving standard in 1999, 1993, 1980, Without thermal insulation, Unknown
Insulation of windows	Single glass, Pair glass, Double window
Vapor condensation on walls	Yes (m^3) , No.
Vapor condensation on glass of windows	Yes , No.
Ventilation system	No ventilation system, Exhaust ventilation system, Exhaust and supply ventilation system
Operation of ventilation system Opening windows Ventilators	No, ≦1h, ≦3h, ≦5h, 5h<, 24h (in winter /in summer)
Other questions Prevention of moisture under floor, Sun shine in rooms, Pets of indoor breeding, Number of stories, Use of mats on the floor, Use of furniture made of cloth, Temperature of Heating or Cooling preset by dwellers, Land use of surrounding, Infants, Floor area of rooms, Interior finishing, Size of windows, Repair condition, Ventilators on walls, The time length of opening windows, Main heating method, Time length of heating, Heating equipment, Frequency of cleaning, Cleaning method in rooms, Method of insect control, Washing hung in rooms, Time length of staying in the room.	

2.2 Simulation of I.A.Q. considering dwellers' ignorance

Air leakage network models were used in the simulations. The network models were made using building cut models in the former investigations. Fig.1 shows the cut model of an improved post-and-beam wooden structure and Fig.2, Fig.3 and Fig.4 show the equivalent leakage areas in three structures: a common post-and-beam wooden structure, an improved post-and-beam wooden structure and an improved wooden 2 inch x 4 inch stud structure. These improved structures were built according to the latest building insulation code which was established in 1999. Leakage areas in concealed spaces and leakage areas between concealed spaces and indoor spaces were measured using mass-flow controllers and pressure analyzers.

Next, the movements of pollutants were calculated using the simulation program. The program simulates temperatures, air flow rates, concentrations of pollutants using the NHK standard living schedule model and the HASP weather data on Tokyo.

Fig.1 A cut model of post-and-beam structure

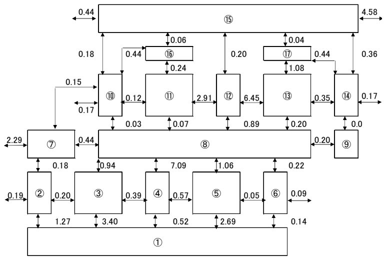

Fig.2 The leakage network of an improved wooden 2x4 stud structure (cm^2/m)

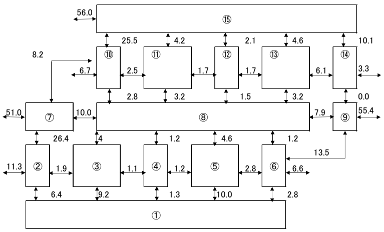

Fig.3 The leakage network of an improved post-and-beam structure (cm^2/m)

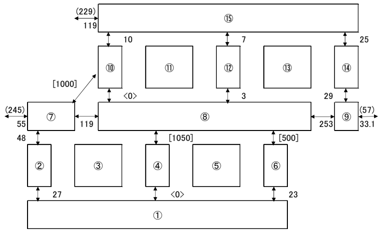

Fig.4 The leakage network of a post-and-beam structure (cm^2/m)

The thermal loads by human behaviors such as cooking, watching television and cleaning rooms, are calculated from the daily schedule model of a family. The air-conditioner and the windows are operated to make indoor climate comfortable considering the daily schedule of a family. The air-conditioning systems and the windows are controlled as follows: the room temperatures are controlled to be 22 deg.C using heaters. If the room temperature becomes higher than 26 deg.C, the dwellers try to make the room temperature 26 deg.C with opening and closing sliding windows. If the room temperature becomes higher than 28 deg.C, the dwellers try to make the room temperature 28 deg.C by cooling. These operations are done by dwellers in a room where they are, and when they are not sleeping.

Fig.5 shows the model of a house for simulation. The house is a two-story house and the same type of houses are connected on the east and west side. The depth of the house is 8m. Fig.6 shows air flow vectors in a simulation model.

The equivalent leakage areas of the three structures were estimated using this simulation program. A large fan was set and the inside air was exhausted. The airflow rates were controlled to meet five ranks of the pressure differences from 10 to 50 (Pa). The equivalent leakage areas were calculated using these results. The equivalent leakage area of the model of a wooden 2x4 stud structure was 0.3 (cm^2/m^2) and that of an improved post-and-beam structure was 2.8 (cm^2/m^2). That of a common post-and-beam structure was 5.0 (cm^2/m^2). The standard of equivalent leakage area was established in the energy saving law in 1999. The standard value is 2.0 (cm^2/m^2) in region 1 and 2. That is 5.0 (cm^2/m^2) in the region 3 and in the milder region.

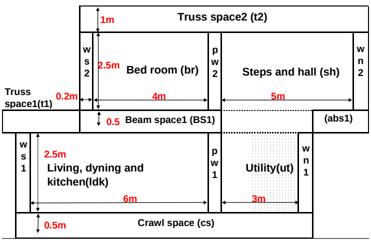

Fig.5 Building model for simulations

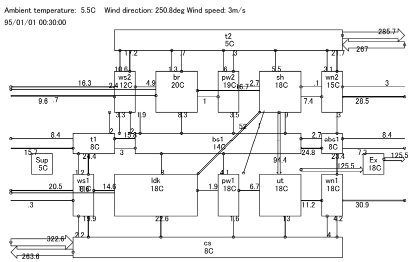

Fig.6 Airflow rates in a post-and-beam structure with an exhaust ventilation system

The emission rates of CO_2 and CO are calculated using the average Japanese daily schedule and the data on the emission rates caused by dweller's behavior in houses. The family's daily schedule of each family in a house is calculated considering the plan of the house using the results of the survey on the Japanese daily schedule by NHK.

Fig.7 shows the calculated emission rates of CO_2 and CO on a weekday and a holiday in the house model. The emission rates of CO_2 change with the behavior of the family and the emission rates are high in the bedrooms on the second floor at night and are also high in the living room on the first floor at daytime. This is pattern of emission rates of CO_2 is a typical of a Japanese detached house where a couple and two children live. The emission rate of CO depends on the use of a cooking gas. The emission rates of CO and CO_2 in the combustion gas are calculated considering the gas collected by range hood (80%).

The formaldehyde (HCHO) generates not only from interior surface, but also from building materials in concealed spaces like crawl spaces, beam spaces and wall cavities. The emission rates of HCHO were calculated using an equation considering the surface area of building materials including interior. The influences of temperature and surface absorption were considered in the equation.

$$E = E25 \cdot a^{(T-25)} - \beta \cdot C(t) \quad (1)$$

where E: emission rate (μg/h.m^2), E25 (=100 μg/h.m^2): emission rates measured in small chamber when temperature is 25 deg.C, T: temperature, a=1.11: measured in small chambers, β (= 0.06): ratio of surface absorption measured in small chambers, C(t): concentration (μg/m^3)

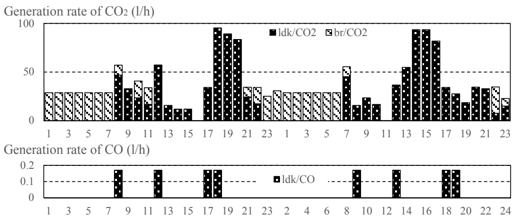

Fig.7 Generation rates of CO_2 and CO in the simulation

Table.2 shows the condition of twelve models. The forced air flow rates are set to be 0.5(1/h). In model “A E&S off” means that the airtight level is the highest and an exhaust and supply ventilation system is installed but it isn’t operated. The concentrations of CO_2, CO and HCHO were calculated through a year, and the risks of indoor pollution was estimated using the calculated concentrations in winter.

Table.2 Structures and ventilations of simulation models

	Structure	Equivalent leakage area	Ventilation systems and the operation			
			E	E off	E&S	E&S off
A	Improved 2x4 stud	0.3 (cm^2/m^2)	A E	A E off	A E&S	A E&S off
B	Improved post-and-beam	2.8 (cm^2/m^2)	B E	B E off	B E&S	B E&S off
C	post-and beam	5.0 (cm^2/m^2)	C E	C E off	C E&S	C E&S off

E: exhaust ventilation system, E&S: exhaust and supply ventilation system

3. Results and discussion

3.1 Analysis on the operation of ventilation systems

The answers of 184 families were analyzed on the operation of ventilation systems. The years of their residence are from a year to over twenty years as shown in Fig.8. The most of the houses are in region 4, where the heating degree-day is from 2000 to 2500. The insulation levels of walls and windows depend on the years of residence. The ratio of houses without ventilation systems also depends on the years and is about 45%. The ratio of exhaust ventilation systems “E” is higher than that of exhaust and supply ventilation systems “E&S”.

Fig.9 shows the operating time length of ventilation systems and the time length of opening windows in winter and summer. The ratio of houses continuously ventilated is 20% in the case of exhaust ventilation systems and 60% in the case of exhaust and supply ventilation systems in winter. Each ratio is 25% and 75%. The ventilation systems are not used continuously in many houses. The windows are open in almost half of the houses, even in winter. The windows are open in most houses in summer. The time length of opening window is various in summer.

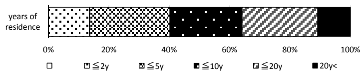

Fig.7 Component ratios of years of residence

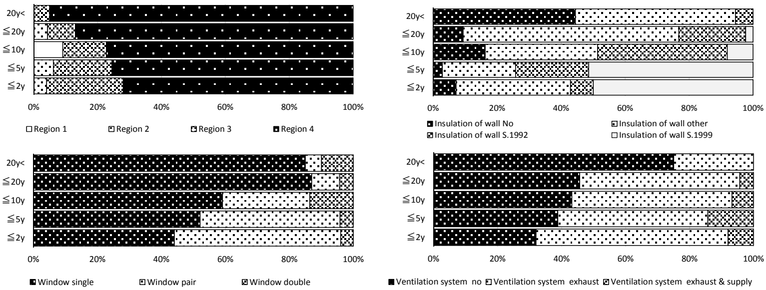

Fig.8 Relationship between the years of residence and regions, the insulation of walls, windows, ventilation systems and vapor condensation on walls/windows

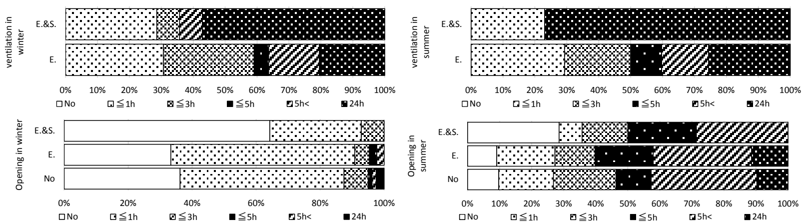

Fig.9 Relationship between operation of ventilation system and opening windows

Fig.10 shows the predicted modeling capabilities toward the operating time of ventilation systems in winter and summer. These results show that the operating time of ventilation systems depends on the kinds of ventilation systems, the time length of opening ventilators on walls, the heating equipment (unvented open-type stoves), and the time length of opening windows in winter. The operation time of ventilation systems is longer in houses with “E&S” than in “E”. This operation time depends on the time of opening ventilators. The operation time of ventilation systems is short in houses where the time of opening windows is long. If an open-type stove is used, the operation time of ventilation is long, but its capability is questionable. The dwellers are required to open windows once or twice per hour, in order to prevent indoor air pollution and the toxic symptoms caused by carbon monoxide. But it is difficult for dwellers to open windows infallibly in winter, even if these cautions are given in the manuals of open-type stoves.

The operating time of ventilation systems in summer depends on the kinds of ventilation systems, the time length of opening ventilators, the regions, the drying equipment and the years of residence. The influences of the kinds of ventilation systems and the time length of opening ventilators are similar to the results in winter. The operation time of ventilation systems is longer in mild regions than in cold regions. This time is longer, if dwellers use dehumidifiers in summer.

These results show that ventilation systems are used temporally to control the indoor environment. Sometimes dwellers use their ventilation system to exhaust pollutants from their kerosene stove in winter and sometimes to make rooms dry in summer. Dwellers use both ventilation systems and windows in winter, especially in the case of exhaust ventilation systems.

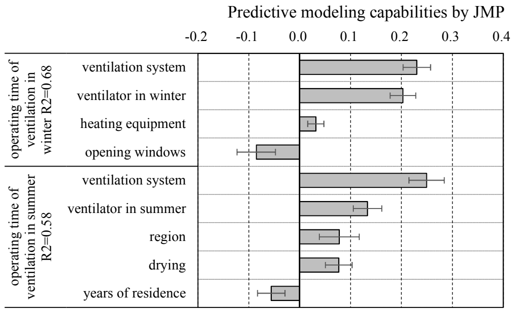

Fig.10 Predicted modeling capabilities toward operating time of ventilation systems in winter and summer

3-2 Simulation of I.A.Q. considering dwellers' ignorance

Fig.11 shows the changes of CO_2 concentrations when the ventilation systems are operated continuously. The concentrations are almost lower than 1000 ppm. Relatively, the concentrations in the models with exhaust ventilation systems are higher than those with exhaust and supply ventilation systems. The difference is large in bedrooms in winter. It is caused by the lack of air supply to the bedrooms on the second floor through ventilators in winter.

Fig.12 shows the changes of CO_2 concentrations when the ventilation systems are not operated. The CO_2 concentrations increase in October and April, because of the decrease of ventilation force by temperature difference between the indoors and the outdoors. The concentrations are higher than 1000 ppm with an exception of Model "C": low airtight post-and-beam structure. The concentrations are very high in the high airtight models ("A E&S off" and "A E off").

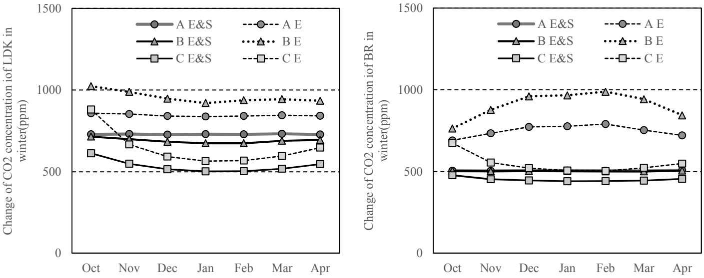

Fig.11 Predicted CO_2 concentrations when ventilation systems are operated

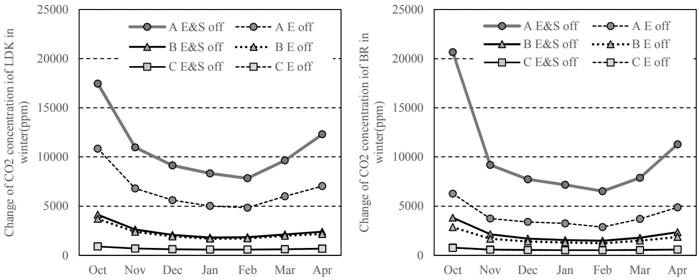

Fig.12 Predicted CO_2 concentrations when ventilation systems are not operated

The comparison of the CO_2 concentrations shows that the main factor of CO_2 concentration when the ventilation system is not operated, is the airtight level of a house as shown in Fig.13.

If the ventilation systems are operated continuously, the HCHO concentrations are almost lower than the Japanese guide line: 100 (μg/m^3). But the concentrations are higher than the guideline in the case that the ventilation systems are not operated (“A E&S off”, “A E off”, ”B E&A off” and “B E off”). In the case of the lowest airtight model “C”, the concentrations are not high, even if the ventilation systems are not operated as shown in Fig.14.

The CO concentrations are higher in LDK than in bedrooms. If the ventilation systems are operated, the CO concentration is lower than 0.1 ppm in the bedrooms. In the case of “C”, the concentrations are lower than 0.1 ppm in bedrooms even if the ventilation systems are not operated as shown in Fig.15.

Fig.16 shows the means of CO concentrations in LDK and the bedrooms. ”No O.S.” is the result without open-type stoves. “O.K.S. 0.3(l/kg)” and “O.K.S. 1.0 (l/kg)” are the results with open-type kerosene stoves from which generation rate of CO is set to 0.3 (l/kg) and 1.0 (l/kg). The annual average heat consumption is 1.19 (kW) and the annual average supply rate of kerosene is 0.136 (kg/h). If the ventilation systems are operated, the CO concentrations are lower than 10 ppm. But, in the case of “A E&S off” and “A E off”, the concentrations are higher than 10 ppm even if the generation rates are 0.3 (l/kg). The CO generation rates depend on the heat loads of the houses. In these simulations, the rooms are heated only when the rooms are used.

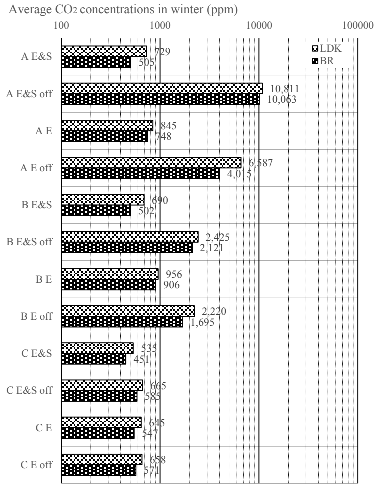

Fig.13 Average CO_2 concentrations

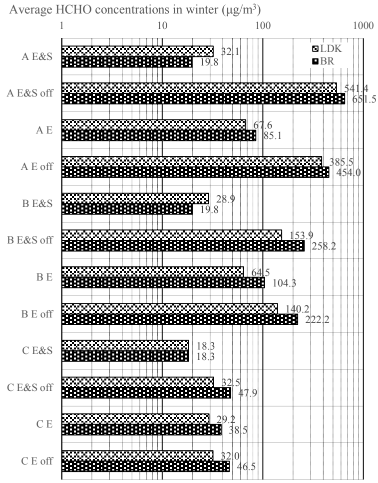

Fig.14 Average HCHO concentrations

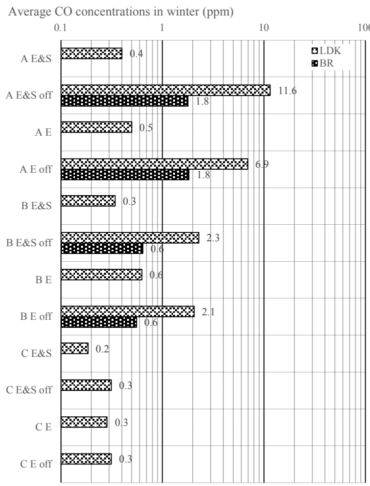

Fig.15 Average CO concentrations in houses without open-type stoves

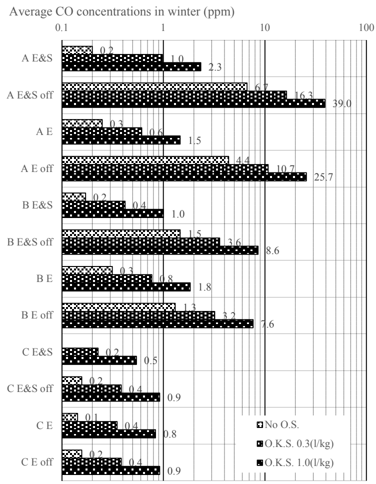

Fig.16 Average CO concentrations in houses with/without open-type stoves

The CO generation rates also depend on the CO generation characteristics of kerosene stoves. The CO generation rate increases when the concentration of O_2 is low. The influence of the lack of O_2 is not considered in these simulations. Therefore these results did not show the highest risk of CO pollution.

These simulation results showed that indoor air quality depends on the operation of ventilation systems especially in airtight houses. If the ventilation systems are not operated, the use of open-type kerosene stoves make indoor air harmful for the dwellers. The simulation results showed that giving information about indoor air quality is very important for dwellers as well as home builders.

Acknowledgments

This study is carried out using the results by a committee on the status of the pollution by allergen of mold and mite in houses. This committee is held by Center for Housing Renovation and Dispute Settlement Support under the commission of Ministry of Land, Infrastructure, Transport and Tourism. The authors express their graduate to many dwellers who joined this survey. And the authors express their gratitude to Dr. Kousuke Takatori, Dr. Tomoyuki Hashimoto, the other members of the committees, the secretariats and Miyuki Matsui and Aya Kusaka, former graduate students of Miyagigakuin Women's University.

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