Energy and Buildings 41 (2009) 337–353

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Comparison of physical performances of the ventilation systems in low-energy residential houses

T. Maier [a], M. Krzaczek [b], J. Tejchman [b,*]

[a] Büro V. Maier, Höchstadt, Erlangen, Germany
[b] Gdańsk University of Technology, Faculty of Civil and Environmental Engineering, 80-952 Gdańsk-Wrzeszcz, Narutowicza 11/12, Poland

ARTICLE INFO

Article history:
Received 18 September 2008
Accepted 18 October 2008

Keywords:
Adaptive comfort
Heat consumption
Humidity
Measurements
Questionnaire
Temperature
Ventilation system

ABSTRACT

The paper presents experimental results of the effect of ventilation systems in modern residential low-energy houses on thermal and humid conditions, heat consumption and perception of thermal comfort and air quality by their residents. Practical projects of modern residential houses with various ventilation systems which realize thermal, humid and psycho-physical comfort were worked out. To analyze the influence of ventilation systems on human comfort, results of questionnaires and comprehensive experimental measurements were taken into account. For measurements, 22 identical residential houses in Germany were chosen where 4 various ventilation systems were installed: gravitational (natural) ventilation, air heating system, mechanical ventilation with in- and out-leading air elements and a function of heat recovery and mechanical ventilation with single ventilators. The following parameters were measured in test units: relative air humidity, concentration of CO_2 in the air, air temperature, consumption of electricity, gas and heat, working time of the window opening, working time of the mechanical ventilation and number of residents. Advantages and disadvantages of ventilation systems were outlined. Experimental results were evaluated. Relationships between ventilation systems and thermal comfort were discussed by taking into account opinions of house residents.

1. Introduction

Environmental, epidemiological and economical reasons increase the pressure to design, construct and maintain friendly residential buildings with respect to the energy efficiency and the individual indoor thermal comfort. However, the full knowledge about the interaction between indoor air quality, ventilation energy consumption and comfort is still lacking with respect to experiments and theory. Experimental investigations are important but extremely expensive and are related to specific conditions. Advanced theoretical models of the buildings behavior can predict the indoor air quality, comfort parameters and heat consumption in the design stage and define requirements for heating and ventilation systems [1–3]. However, they are mainly deterministic and do not take into account habits of residents. Thus, the expected comfort and reduction of the heat consumption are not guaranteed due to an incorrect estimation of the indoor air quality and comfort conditions [4–6]. An incorrect use of ventilation systems causes unexpected and random loads disturbing the indoor air flow. The loads of this kind are caused by residents trying to improve the comfort parameters. Due to the lack of knowledge about the acceptance level of ventilation systems by residents [7], it is difficult to implement this kind of loads in the heat and mass balance model of residential buildings used for development of ventilation and heating control systems. The knowledge about the acceptance level of ventilation systems by residents of buildings is limited and there is still a lack of the information on optimal solutions from the point of view of residents [7]. Only, the complete knowledge about opinions of residents on advantages and disadvantages of ventilation systems, their construction method and location and habits of residents is a condition for their effectiveness in reduction of the heat consumption and in improvement of the psycho-physical comfort. Up to now, the models of ventilation systems have been mainly based on technical design rules without taking into account any psycho-physical aspects of their activity.

The objective of this paper is to show full-scale field investigations how the type of the ventilation system in residential low-energy houses influences local thermal conditions and the perception of psycho-physical comfort by residents and how it affects the heat consumption. The paper presents results of experimental investigations performed in identical modern residential houses equipped with various ventilation systems

* Corresponding author.
E-mail addresses: IVM-Erlangen@t-online.de (T. Maier), marek.krzaczek@wilis.pg.gda.pl (M. Krzaczek), tejchmk@pg.gda.pl (J. Tejchman).

0378-7788/$ – see front matter
doi:10.1016/j.enbuild.2008.10.007

which both realize thermal and psycho-physical comfort from the point of view of residents [8–12] and are simple, easy and effective in service. The investigations [13,14] were divided into two stages. In the first stage, a system of initial questionnaires for residents of modern residential low-energy houses was worked out. The questionnaires dealt with problems related to the process of design and construction of houses and ventilation systems, quality and circulation of air in rooms and thermal comfort. The questionnaires were performed in a dozen of newly built residential houses located in different places in Germany. On the basis of questionnaire results, a project of friendly residential low-energy house equipped with a ventilation system was developed which ensured comfort and convenience from the point of view of residents. Such range of the data acquisition containing economical, ecological and psychological elements is novel in the field of the building physics when designing a ventilation system. The test houses were located in the colony of identical residential low-energy houses in Germany. In the second stage, the comprehensive experimental measurements were performed in the test units. The houses were equipped with four different ventilation systems: window ventilation (gravitational ventilation), mechanical ventilation with single ventilators, mechanical ventilation with in- and out-leading air elements and a function of heat recovery and system of air heating. During 2 years, the quality, humidity and temperature of air, consumption of gas, electricity, thermal energy, working time of ventilation and time of opening operable windows were systematically monitored and opinions of residents in 22 houses were gathered. In total, 1022 measuring points were installed (46 in each house). Next, the obtained results were evaluated. Environmental conditions in test houses were represented by values of the CO_2 concentration, temperature and relative humidity. The personal control of environmental conditions was represented by a modification of the internal heat generation, a modification of the air flow rate produced by ventilation systems, time of ventilation and time of opening of operable windows. In order to check the effectiveness of the applied ventilation system, questionnaires were again performed among residents. On the basis of results of measurements and questionnaires, a concept of a friendly ventilation system which ensures the most advantageous level of the psycho-physical comfort and the lowest heat consumption was proposed.

The innovation of the paper is a direct connection of detailed psychological and experimental results of different ventilation systems in 22 identical residential houses. The residential houses and their heating and ventilation systems have been designed according to the results of initial questionnaires. The houses were low-energy consuming and the heating and ventilation systems installed in these houses were effective and user-friendly. The paper compares the physical performances of different ventilation systems and their ability to maintain the residents' satisfaction with respect to comfort.

2. Problem

The simulation methods of the building behavior can predict the heat consumption and thermal and humid changes. However, the residents can often feel dissatisfaction about the comfort on the basis of the heat exchange between people and environment. The response is essentially the same throughout the year – the only difference between summer and winter is that people change their clothing levels, resulting in different preferred temperatures. However, due to preferences and expectations, people in warmer climatic zones prefer warmer conditions and vice versa. The recent research [15] has demonstrated that residents of naturally ventilated (NV) buildings feel more comfortable than residents of air-conditioned (HVAC) buildings. The residents of HVAC buildings are more get used to narrow and constant conditions typically provided by mechanical conditioning while the residents of NV buildings prefer conditions that reflect outdoor climate patterns. Also the predicted mean vote (PMV) seems not to hold in NV buildings. The residents' reaction to the comfort dissatisfaction can be expressed by the adaptive comfort principle which states that if any change occurs in the thermal environment which produces discomfort, people try to restore their comfort. Comfort can be either achieved by residents by adapting themselves to building conditions or by improving their comfort perception. The types of the behavioral action which can be taken by the residents are following: (a) modification of the internal heat generation (e.g. autonomically by shivering), (b) modification of the body heat loss rate (e.g. autonomically by vasoregulation or consciously by changing clothing levels), (c) modification of the thermal environment (e.g. by opening a window), and (d) selecting a different environment (e.g. by moving out of direct sunlight). Discomfort arises where temperatures change too fast during the adaptation time, they are beyond accepted limits or they are unexpected and beyond the individual control. Discomfort leads to the uncontrolled heat consumption in buildings. The problem of how the personal control of environmental conditions in office settings influences local thermal conditions and comfort was investigated by Brager et al. [16]. They stated that the most important issue in naturally ventilated buildings were windows. Windows can be used for ventilative cooling of building structures and for the attainment of the thermal comfort by letting air move through buildings. However, full understanding of the effect of the air movement on comfort in buildings is lacking. The research studies indicate that the personally controlled air movement is an underestimated cooling method in the contemporary design. The authors conclude that occupants experienced surprisingly similar thermal feeling, independently of the proximity and degree of the personal control of windows. Despite the similarity of thermal exposures, their reactions were significantly different. Ideal comfort temperatures (defined by the "neutral" temperature) for occupants with higher degrees of control were much closer to temperatures they actually experienced, supporting the adaptive comfort hypothesis which states that thermal preferences are not based on conventional heat balance factors but rather on expectations resulting from higher degrees of control over their own environment.

To reduce the heat consumption and ensure thermal comfort in buildings, the heat and mass balance model should take the adaptive comfort principle into account [3]. In the case of HVAC control systems, it is difficult. The goal of the radiant system is not to maintain the space conditions but rather to meet thermal comfort of the occupants directly. The authors [3] assumed that the heat loss is mainly a function of the difference between the outdoor and indoor air temperature and the building heat loss factor. The proposed model assumes that there are only three mechanisms that contribute to the total heat consumption: building heat loss factor, air infiltration rate quantifying uncontrolled air flow through all little cracks and openings in buildings and heat loss in the heat supply system. The goal of the proposed control system is to reduce the heat loss in the heat supply system by forecasting the supply water temperature and water flow rate in the radiators to maintain a desired thermal comfort in zones. The advantage of this model is its simplicity and low computing power required for implementation. However, the great disadvantages of this approach are: one cumulative loss factor and the dependence of the heat loss on the outdoor temperature only. This model of heat losses does not take into consideration an influence of unexpected responses to a change of the thermal environment. Kazanavičius et al. [3] proposed a PI (proportional and integral) controller to regulate a heating system. The PI regulating system is very sensitive to rapid and random