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On-site diagnosis of hybrid ventilation system in a renovated single-family house

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ABSTRACT

There are approx. 5.5 million residential buildings in Poland including 5 million single-family houses, 90% of which were built before 2002. Most of the existing single-family houses are not energy-efficient and a large amount of energy is wasted. It is therefore essential to develop, experimentally validate and then disseminate strategies for thermal modernization of the existing single-family houses, including strategies for ventilation systems renovation. In two-storey single-family houses with sloping roofs it is possible to locate a ventilation heat recovery (VHR) unit and ventilation ducts in the unheated roof space. The paper presents the results of tests of combined ventilation systems: mechanical ventilation with heat recovery in rooms on the second floor and stack ventilation in the rooms on the first floor. On-site measurement of the efficiency of ventilation heat recovery was performed, the airtightness of the house was measured twice before and after its improvement. The results of the experimental tests of the hybrid system were used to estimate the ventilation airflow in the house and the energy demand for ventilation. The ventilation airflow was calculated using the software CONTAM. The estimated heat demand for the tested ventilation system was 37.4 kWh/m^2/season; though it seems possible to reduce it below 20 kWh/m^2/season.

1. Introduction

Energy conservation in buildings is a priority in the policy of many countries all over the world. The EU Member States have taken the commitment to achieve a fully decarbonised and highly energy-efficient building stock by 2050. Since approximately 75% of the EU's buildings are not energy-efficient and most of them will be still in use in 2050, the European Union is facing a challenge to intensify the process of the building renovation [1]. The owners of the buildings meet multiple barriers during the renovation process. Difficulties in accessing finance may cause prolongation of these activities for many years. Very often the barrier is a lack of knowledge of the measures to apply and of the order of their application [2,3]. The assessment of the undertaken measures efficiency is another important issue for the building owners.

The main goal of building renovation is to reduce the energy consumption and greenhouse gases emission. There are approx. 5.5 million residential buildings in Poland including 5 million single-family houses, 90% of which were built before 2002 [4]. Most of the existing residential buildings do not meet the current European low energy consumption requirements and they should be renovated. Thermal modernization of Polish single-family houses is rarely based on a detailed energy audit, neither are there strategies developed to carry out a deep renovation of such buildings. Thermal renovation of single-family houses in Poland is mainly financed by the house owners' own funds and therefore is often staggered in time. Usually, thermal retrofitting starts with the improvement in thermal insulation of the partitions and windows and is completed with a heat source replacement. Renovation of the ventilation system is often ignored and one important reason for that may be lack of proven methods of ventilation system modernization. Residential buildings in Central Europe and Scandinavia are very often ventilated using stacks i.e. vertical ventilation ducts. The stack inlets are usually located in 'wet' rooms, such as bathrooms, toilets and kitchens while the stack outlets are located outside the buildings, above the roofs. Stack ventilation is suitable for moderate and medium cold climates [5]. The fresh air enters the building through the air inlets, cracks or window joints. In some countries residential buildings have to be compulsorily equipped with the air inlets for window (trickle ventilators), e.g. it refers to all naturally ventilated buildings in Poland built after 2002 [6]. However, older buildings in Poland usually have not intentionally made inlet openings. In naturally ventilated buildings the airflow is caused by a combination of stack (buoyancy) pressure and wind induced pressure (stack and

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Nomenclature

A	Surface area, m^2
C	coefficient, m^3/(s Pa^n)
c	specific heat at constant pressure, J/kgK
h	specific enthalpy, J/kgSpecific enthalpy, J/kg
φ	Relative humidity
$\dot{m}$	Mass flow rate, kg/s
n	Air change rate, exponent
N	Electric power, W
p	Pressure, Pa
q	Heat demand per unit area, kWh/m^2
$\dot{Q}$	Heat flux, W
r	Heat of water evaporation at temperature of 0 °C, J/kg
ρ	Density, kg/m^3
t	Temperature, °C
U	Absolute uncertainty
v	Measured value
$\hat{v}$	Corrected measured value
$\dot{V}$	Volume air flow rate, m^3/s
V	Volume, m^3
x	Humidity ratio, kg/kg
η	Efficiency

Subscripts

a	Dry air
b	Barometric
e	Exhaust
g	Stack (gravitational) ventilation
h	Heat exchanger
i	Indoor, installation,
m	Mechanical ventilation
o	Outdoor
p	at constant pressure
r	Recovered, recuperator
s	Supply
t	Total
w	Water vapour
v	Ventilation
vg	Stack ventilation
vm	Mechanical ventilation

wind effect). The driving forces and consequently the ventilation airflow vary widely depending on the weather conditions. The stack pressure is proportional to the indoor and outdoor temperature difference and to the height of the stack. In winter cold periods of time the airflow of stack ventilation can be twice higher than average in the heating season and it increases the energy consumption significantly. On the other hand, when old windows are replaced by the air tight new windows significant reduction in the airflow can be observed which is disadvantageous from the viewpoint of the indoor air quality.

Therefore, it is necessary to find out how to carry out renovation of the ventilation in buildings with the stack ventilation. The paper presents the results of modernization of the ventilation system in a semi-detached single-family house. The modernization consisted in the introduction of mechanical ventilation with heat recovery in the rooms located on the second floor, leaving the active stacks providing ventilation of the rooms on the first floor. The use of mechanical ventilation with heat recovery maintains the constant air change rate in the bedrooms located on the second floor, regardless of the outdoor temperature value.

Fig. 1. View of the semi-detached single-family houses.

Ventilation systems with heat recovery (VHR) have been used for more than thirty years. Reviews of such systems are presented in papers [7–10]. Various aspects of the VHR have been analysed so far. The possibility of using air handling units with new type of recuperator in order to recover heat in ventilation systems of buildings have been analysed in [11]. Energy savings and carbon dioxide emission when VHR is used, depending on the heating system, the building type, the energy conversion coefficient and the heat exchanger type are discussed in [12–15]. Annual performance of VHR applied in residential and commercial low energy buildings is studied in [16]. Heat recovery exchangers modelling and its experimental validation are presented in [17,18]. The performance of VHR systems was experimentally tested both in laboratory conditions and on-site, in residential buildings [19–22]. Control strategies of VHR including different climatic conditions and the impact of the defrost cycle are presented in [23,24]. Renovation of a ventilation system is usually considered in an analysis of different scenarios of the building retrofitting [25,26].

A typical ventilation heat recovery (VHR) system consists of the following elements:

- air handling unit, equipped with supply and exhaust fans, a heat exchanger, filters, a speed control unit, DDC with control panel and an air heater for reheating (optionally),
- ventilation ducts,
- supply and exhaust components (valves, diffusers, air transfer units, etc.),
- external intake and exhaust louvers.

Moisture in the exhausted air can condense, which requires condensate discharge. Condensation is associated with the recovery of latent heat, increases the heat flux and heat recovery efficiency. At the negative value of the inlet air temperature icing phenomenon occurs. This negative phenomenon causes an increase in the flow resistance. The experiments have been conducted [27] for typical value of indoor temperature 20 °C and a large range of the values of the exhausted air humidity from 20 to 75% and more. The recuperator worked in the real conditions of the winter climate in Bialystok (Poland). The icing phenomenon can also cause mechanical damage to the regenerator permanent structure.

Most of the existing single-family houses in Poland are two-storey buildings with sloping roofs, Fig. 1. Typically, the living room and the kitchen are located on the first floor while the bedrooms are on the second floor. Under the roof there is a thermally insulated but unheated space, which is often used as a utility room.

In the existing single-family houses it is difficult and expensive to provide mechanical ventilation in all the rooms. Mechanical ventilation of the rooms located on the first floor requires significant intervention in the building structure. In the considered two-storey single-family houses with sloping roofs it is possible to locate a VHR unit and ventilation ducts in the unheated roof space. It is relatively easy to distribute the air from that space to the bedrooms located on the second floor. Owing to the lower buoyancy effect stack ven-