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Research Paper

Energy and defrosting contributions of preheating cold supply air in buildings with balanced ventilation

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HIGHLIGHTS

- A ventilation air preheating system using residential wastewater is presented.
- A temperature dependent profile for heat recovery efficiency is utilized.
- The heat recovery efficiency of MVHR is the dominant factor.
- Preheating inlet air decreases defrosting need during coldest months by 30–50%.

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ABSTRACT

Residential wastewater is a constant and available source for saving energy. This paper mainly investigated the possibility of utilizing wastewater heat to reduce ventilation heat load. Swedish residential buildings are to a significant extent served by mechanical ventilation with heat recovery (MVHR) systems. MVHR in airtight buildings has greatly reduced ventilation heat loads, especially in cold climate countries such as Sweden. However, cold outdoor air might lead to frost formation in heat recovery exchangers which increases the energy use. Therefore, this study focused on reducing the defrosting need by preheating the incoming cold outdoor air to MVHR during the coldest days. The effects of preheating the incoming air to MVHR on ventilation heat load and annual ventilation heating demand were also studied. It was found that the heat recovery efficiency of MVHR is the most decisive factor in rating the performance of the combined system with an air preheater. Contributions of the studied air preheater to annual energy savings were negligible. On the other hand, the reduction of the initial defrosting need was significant. The obtained results showed that the defrosting need in a building located in central Sweden in two cases of an MVHR system equipped with a rotary heat exchanger/plate heat exchanger was eliminated/reduced to one-third. The defrosting need was reduced by 50% in northern Sweden for both cases.

1. Introduction

The Swedish government has mandated a 20% and 50% reduction in total energy use in buildings by 2020 and 2050, respectively, as compared to the usage levels in 1995 [1]. Transmission and ventilation together with wastewater are the major sources of heat loss. In order to further improve the energy performance of buildings, wastewater and ventilation heat losses must be addressed. Wastewater has a growing share in buildings with low heat losses and improved air tightness. Average wastewater flow rate, which corresponds to water consumption, is 120–180 l/(day·person) in Sweden with an average temperature of 20 °C [2]. The domestic hot water fraction of total energy demand has increased from 10–20% to 40–50% in airtight buildings [3]. Ventilation heat losses are the other major source of energy loss in buildings. Many efficiency measures have been taken to reduce the ventilation heat losses. In Sweden, a portfolio of six energy conservation packages was assessed, from which two mainly focus on investments and improvements in ventilation heat recovery system [4].

The improvements of air tightness in buildings have decreased the infiltration (unwanted air leakage) rate. This, in return, has increased the need of controlled ventilation inflow. Mechanical systems are used in buildings to ensure the required ventilation rates. The two most

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Nomenclature

ACH	air change rate
AHU	air handling units
AP	air preheater
DHW	domestic hot water
ECM	energy conservation measure
HVAC	heating, ventilation and air conditioning
HX	heat exchanger
MEV	mechanical exhaust ventilation
MVHR	mechanical ventilation with heat recovery

Symbols

P_{exh}	exhaust air heat rate, W
$P_{V,\ N}$	normalized ventilation heat load, W
P_{ww}	heat supply by wastewater, W
Q_B	building heating demand, W
RH_{ret}	return air relative humidity, %
T_{inlet}	inlet air temperature to MVHR, °C
T_{out}	outdoor temperature, °C
$\Delta T_{preheated,\ W}$	weighted inlet air temperature increase to MVHR, °C
ΔT_{inlet}	increase in inlet air temperature to MVHR, °C
$\Delta\eta_w$	energy wheel efficiency drop, %
η_w	energy wheel efficiency, %

common ventilation systems in Swedish apartment buildings are mechanical exhaust ventilation (MEV) and balanced mechanical ventilation with heat recovery (MVHR) [5]. Since 1970s, MVHR systems were increasingly installed in Swedish multi-family houses, and the more common MEV system has been gradually replaced by MVHR in retrofitted buildings [6].

In cold climates, an influential parameter on the performance of MVHR is frost formation and defrosting need. Freezing of condensation or direct sublimation can occur in heat recovery exchangers (such as, plate heat exchanger, energy wheel) if they are exposed to cold outdoor air and moist warm return air from the rooms. If the surface temperature of a heat exchanger drops below the dew point of return air, the condensation turns into a thin layer of ice (frost). The frost layer has a high thermal resistance because of air pores with low thermal conductivity. This phenomenon negatively affects the performance of heat recovery in ventilation systems [7,8]. Among various available defrosting methods, this paper investigates the potential of using wastewater in order to preheat the inlet air to MVHR and also examines the possibility to decrease the annual ventilation heating demand.

1.1. Previous studies

In cold countries with long heating seasons such as Sweden, energy use in buildings is significantly affected by the heat recovery efficiency of ventilation systems and the used air changes per hour (ACH). Previous investigations have shown that approximately 80–90% of ventilation energy need can be saved by shifting to MVHR systems [5,9,10]. The adequacy of heat recovery systems in buildings with low rates of energy use depends on the building type, heating load, and the ventilation device characteristics. Among all influential factors, the thermal performance of the energy wheel/plate heat exchanger is decisive [9]. In the past, studies have usually been conducted using constant efficiency or a typical range of efficiency for the energy wheel of the air handling unit (AHU) [9,11–14]. A number of previous investigations have also evaluated the efficiency of MVHR with respect to various parameters. They suggested sensible and latent efficiency correlations as functions of revolution speed, relative humidity, and air velocity [15–17]. However, currently there is a lack of a representative function that relates the efficiency of the energy wheel/plate heat exchanger to the inlet air temperature. Such a function would provide a more realistic value for efficiency during the entire year.

In order to further improve the performance of MVHR systems in cold countries, the inlet air to AHU can be preheated. The potential of such a system was recently evaluated in two field measurement studies. Simanic [18] studied the potential of preheating the incoming ventilation air with heat from boreholes without use of heat pumps. The air preheater (AP) was able to increase the inlet air temperature to the AHU from −15 °C to −3°C. Kempe and Jonsson [2] also studied the performance of a similar ventilation system in a multi-family building in Stockholm (central Sweden). The building was equipped with an air preheating system as used by Simanic [18]. The air preheater increased the air inlet temperature to the AHU from −15 °C to −5°C. MVHR systems equipped with the above-mentioned air preheaters have eliminated the defrosting need for most of the studied period except for hours with outdoor temperatures between −15 °C and −21 °C. However, defrosting was required for MVHR systems without the air preheater when the outdoor temperature was below −5 °C. Note that this is the case for plate heat exchangers. Heat recovery efficiency, in this case [18], dropped from an initial value of 80% to between 60% and 30%.

A similar study has recently explored the potential of wastewater to preheat inlet air to AHU [6]. However, the focus in that study was on the evaluation of the possibility to reduce the ventilation heating load and not on reduction of defrosting need. Furthermore, the time period used in the study was limited to the coldest month in one of the coldest regions in Sweden. These limitations may be a limiting factor in getting a realistic insight of the potential of this system. Therefore, the overall aim of the present study was to address these limitations in more detail than before and to further explore the potential of the combined heat recovery system under more realistic conditions.

1.2. Objectives

This research work intends to study the possibility of reducing ventilation heating demand of a multi-family building by preheating the incoming air to AHU. The impacts of preheating the incoming air to AHU on defrosting need in cold periods are also studied. A sensitivity analysis of energy wheel efficiency is given special interest in two cases of constant and temperature variable efficiencies.

2. Methodology

This research work is undertaken for multi-family houses in Sweden, particularly in the Stockholm climatic zone. The performance assessment of the studied ventilation and heat recovery systems is carried out by simulations using TRNSYS. TRNSYS is graphical transient simulation software with an extensive library of components for simulating energy systems. The modular structure of TRNSYS enables the user to utilize or modify the existing components and examine the performance in both component and system levels [19]. Heating and ventilation are major assessment results of these systems. Sensitivity analysis of the energy wheel efficiency is conducted in order to determine the performance of the combined wastewater and exhaust air heat recovery systems. A field measurement study of the MVHR system in a number of multi-family houses has rated the energy wheel efficiency as a function of inlet air temperature [20]. The obtained function