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A new approach to regenerating heat and moisture in ventilation systems

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Abstract

For countries with a cold climate the large difference (30–60 °C) in winter between indoor and outdoor temperatures leads to (a) large heat losses in ventilation systems; (b) moisture freezing at the systems exit; (c) great reduction in the indoor humidity. Here we present a new approach for regenerating heat and moisture in ventilation systems in cold climates which allows resolution of these problems. The method has been tested under climatic conditions of West Siberia (winter 2005–2006). The prototype system requires very little maintenance, has a low capital cost, is compact and energy efficient. Technical, economic and social aspects of this method are discussed.

Keywords: Heat regeneration; Ventilation; Thermal comfort; Cold climate; Moisture exchange; Efficiency; COP

1. Introduction

The current global changes of the climate, due to greenhouse gas emissions [1], have brought about an increased necessity of rational use of energy in dwellings. To reduce consumption of energy there is a trend towards improving heat insulation and air-tightness. For the purpose of tightening a building's thermal envelope, therefore, providing of adequate ventilation is required [2]. The main function of residential ventilation systems is to exchanges stale, contaminated room air with fresh outdoor air. Particular features of residential ventilation systems strongly depend on standards of indoor air quality and outdoor climate conditions [3]. For relatively cold climates a mechanical ventilation with heat recovery plays a vital role in securing optimum air quality, thermal comfort and saving thermal energy [2]. Estimates show that as much as 70% of the energy lost through mechanical ventilation can be recovered by the use of ventilation heat recovery systems [4]. For this purpose heat exchangers (counter-current units or enthalpy wheels) are used to transfer heat from the exhaust air to the supply air [4–8]. In [2] the low grade heat recovered from the exhaust air is upgraded by a heat pump and used for heating the fresh supply air.

For winter season in severe climates (typical for Russia and the North Europe) the difference ΔT between indoor and outdoor temperature can reach 60 °C or even more, that leads to enormous heat losses and freezing of moisture at the system exit. As a result, common heat recovery units integrated in ventilation systems may not be capable to work at these conditions. Moreover, such systems are not able to manage the indoor humidity, which dramatically reduces in winter season that greatly disbalances the indoor heat comfort [9]. Thus, to fill these three main gaps in the current knowledge and technique the following actions should be performed:

- efficient exchange of heat between the exhaust and supply air fluxes to reduce heat losses, reasonable drying of the exhaust air to avoid ice formation at the system exit;
- moisturizing the supplied air to provide indoor conditions of human thermal comfort.

Here we present a new approach (so called VENTIREG) for regenerating heat and moisture in ventilation systems in cold climates, which resolves the obstacles mentioned above.

2. Descriprion of the approach

To exchange the sensible heat between the inlet (fresh) and outlet (exhausted) air fluxes, a granulated layer 1 of heat storing

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Nomenclature

COP	coefficient of performance
d	absolute humidity (g/m^3)
$\Delta\tilde{d}$	dimensionless difference in the absolute humidity
n	water content in crystalline hydrate (mol/mol)
S	area
t	time (min or s)
T	temperature (°C)
ΔT	temperature difference (°C)
$\Delta\tilde{T}$	dimentionless temperature difference

Greek symbols

β	efficiency of moisture regeneration
θ	efficiency of heat regeneration
$\Delta\tau$	half cycle time (min or s)

Subscripts

in	income
out	outcome
0	predetermined
MAX	maximal

material (HSM) is placed closer to the unit exit (Fig. 1). Before this layer (closer to the room side), a layer 2 of water adsorbing material is located. It serves as a water buffer. The unit is intermittent and operates in two modes:

- *Outflow mode*. (Fig. 1a): a warm and humid indoor air is blown by an extract fan through the relatively dry adsorbent, which captures and retains the indoor moisture [10]. Dried and warm air enters the layer 1 and heats it up. After that, the air flux switches.
- *Inflow mode*. (Fig. 1b): a dry and cold outdoor air is blown by a supply fan through the warm layer 1 and is heated up to the temperature close to that in the room T_{in}, thus, recovers the stored heat. Passing through the layer of the humid adsorbent, warm and dry air causes the retained water to be desorbed and come back to the room [10], thus, maintaining the indoor moisture balance. Because of the finite heat capacity of layers 1 and 2, temperature T of incoming air is slowly decreasing, and the air flux switches when $T_{in} - T$ reaches a predetermined value ΔT_0, and so on.

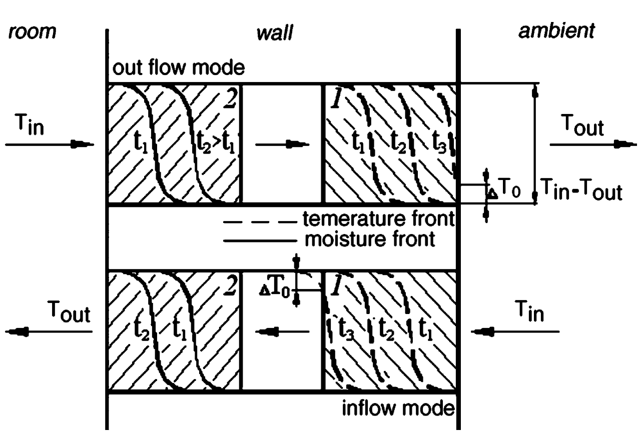

Fig. 1. Scheme of the regeneration process: the temperature and moisture profiles at various times $t_1 < t_2 < t_3$.

After a transient period a steady-state regime is observed with the time interval $\Delta\tau$ (a half cycle time) between the flux switches (Fig. 2). For continuous operation two similar units should work in the opposite modes (Fig. 1).

To study and optimize the heat and moisture recovery three experimental units with the air flux up to 25 m^3/h (I), 40 m^3/h (II) and 135 m^3/h (III) have been built and tested. Fig. 3 presents one of the units. Both common (silica, alumina) and novel (alumina impregnated with $CaCl_2$ [11]) adsorbents were used as buffers of water. In the smaller units the HSM was a layer of balls made of glass or lead with a fixed diameter (2–4.5 mm), while in the large unit—a layer of gravel of irregular shape 4–7 mm in size.

As air fluxes during the inflow and outflow modes were equal, the evolution of air temperature T and absolute humidity d during a cycling operation of the VENTIREG unit allows the

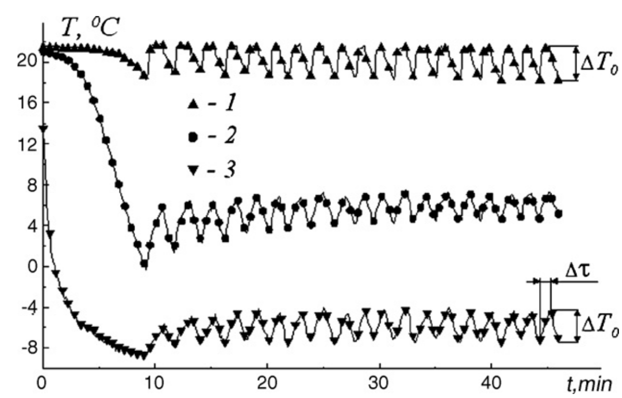

Fig. 2. Typical evolution of air temperature T during cycling operation of the VENTIREG unit I: 1, indoor side, 2, at the middle of the unit, 3, outdoor side. T_{in} = 20.5 °C, T_{out} = −8 °C, ΔT_0 = 3 °C.

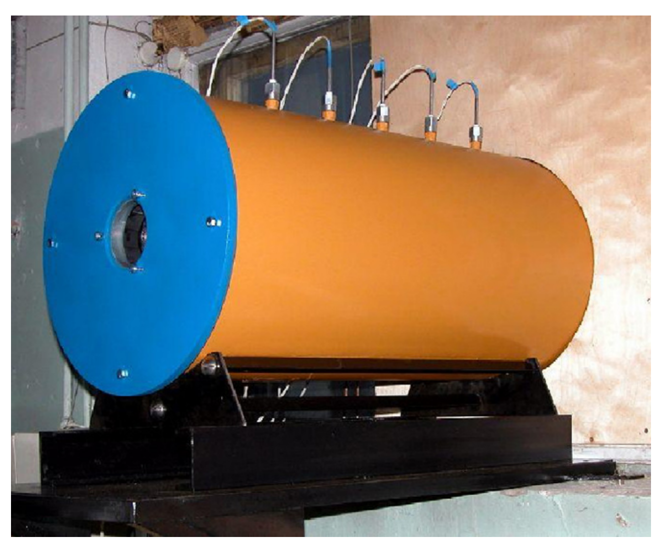

Fig. 3. View of experimental unit III (air flux up to 135 m^3/h).