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Experimental study of energy performance in low-temperature hydronic heating systems

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ABSTRACT

Energy consumption, thermal environment and environmental impacts were analytically and experimentally studied for different types of heat emitters. The heat emitters studied were conventional radiator, ventilation radiator, and floor heating with medium-, low-, and very-low-temperature supply, respectively. The ventilation system in the lab room was a mechanical exhaust ventilation system that provided one air change per hour of fresh air through the opening in the external wall with a constant temperature of 5 °C, which is the mean winter temperature in Copenhagen. The parameters studied in the climate chamber were supply and return water temperature from the heat emitters, indoor temperature, and heat emitter surface temperature. Experiments showed that the mean supply water temperature for floor heating was the lowest, i.e. 30 °C, but it was close to the ventilation radiator, i.e. 33 °C. The supply water temperature in all measurements for conventional radiator was significantly higher than ventilation radiator and floor heating; namely, 45 °C. Experimental results indicated that the mean indoor temperature was close to the acceptable level of 22 °C in all cases. For energy calculations, it was assumed that all heat emitters were connected to a ground-source heat pump. Analytical calculations showed that using ventilation radiator and floor heating instead of conventional radiator resulted in a saving of 17% and 22% in heat pump's electricity consumption, respectively. This would reduce the CO_2 emission from the building's heating system by 21 % for the floor heating and by 18% for the ventilation radiator compared to the conventional radiator.

1. Introduction

The level of water temperature supplied to the heat emitter in buildings plays a major role in primary energy consumption and environmental impacts. As more and more buildings are becoming energy-efficient due to better thermal insulation, less infiltration and more efficient heating and ventilation systems, heat losses from buildings are decreasing. All these changes could be the reasons to reduce the need to supply the heating system with water at temperature as high as previously. As the temperature to the heat emitter decreases, heat losses from the heat production unit and from distribution pipes decrease, and consequently, more renewable and low-quality energy sources can be used [1]. Boerstra et al. [2] defined different supply temperature levels; namely, 55 °C for medium-, 45 °C for low-, and 35 °C for very-low-temperature heat emitters. The main principle of low-temperature heating system is to provide the same thermal comfort as a medium-temperature heating system, while using a lower supply temperature [3]. Supporting a low-temperature heat emitter with a heat pump is thermally efficient. Generally, the thermal efficiency of a heat pump is improved by one to two percent for every degree by which the supply water temperature is reduced [4]. Heat pumps have been recognized for many years as an energy-efficient and sustainable heat source that, by utilizing renewable energy, uses three to four times less electrical energy to deliver the same amount of heat as a direct electrical heater. By 2013, more than half of detached and semi-detached dwellings in Sweden have had heat pumps installed [5]. Therefore, as the number of heat pumps sold in Sweden and Europe increases, there is a growing need to adjust the temperature of heat emitters to this change in order to attain greater efficiency; that is, to use low-temperature heat emitters. In addition, some recent studies have focused on low-temperature district heating, known as the fourth generation of district heating networks [6]. This means that, in the future, the supply water temperature to buildings connected to district heating – that is, more than 90 % of Swedish apartment buildings – will also decrease. Therefore,

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Nomenclature

COP	coefficient of performance
D_h	degree hours per year, °C h year^{-1}
E	energy demand by building, kWh year^{-1}
E_{el}	electrical energy consumption by heat pump, kWh year^{-1}
g_{el}	CO_2 emission factor for electricity, kg_{CO_2} kWh^{-1}
GSHP	ground-source heat pump
$h_{gl,surf}$	total heat transfer coefficient at inner glazing surface of windows, W m^{-2} K^{-1}
n	number of measurements
$P_{passive,indirect}$	passive (indirect) internal and external heat gains, W
Q_{tot}	specific heat loss, W °C^{-1}
SD	standard deviation
U_{wall}	heat transfer coefficient of wall, W m^{-2} K^{-1}
U_{window}	heat transfer coefficient of windows, W m^{-2} K^{-1}
x_i	measured parameter
x_m	mean value of measured data
θ_{base}	base temperature at which the heat loss from building is equal to heat generated by active heating system, °C
$\theta_{gl,surf}$	window's surface temperature, °C
θ_i	indoor temperature, °C
θ_o	outdoor temperature, °C

there is also a need to renovate existing apartment buildings to be adapted for a lower supply water temperature. A reduced return temperature level also favors district heating networks in terms of higher efficiency of heat generation plants, heat pumps, and solar collectors. Furthermore, with a requirement for lower supply temperature level surplus and waste heat could be used as an efficient heat source in a district heating system.

Using a low-temperature heating system is also more sustainable due to a reduction in the generation of carbon dioxide. For every degree reduction of the supply temperature in a heating system, the carbon dioxide emission decreases by 1.6% [4]. Ploskic [4] showed that by using a water supply temperature of 40 °C instead of 55 °C, heat pump efficiency would increase by 25 % and the carbon dioxide emissions would decrease by 24%.

In some investigations [7–9], low-temperature panel heating had better indoor air quality than a high-temperature heating system. This was due to the correlation between the temperature of heating surface and particle deposition and also the mite population. In addition, thermal comfort increases by a greater share of radiant heat transfer and lower vertical temperature gradient in a room with low-temperature panel heating, which makes it possible to reduce the indoor temperature. This would also decrease ventilation heat losses. Experimental investigations by Zhao et al. [10] showed better thermal environment and energy savings with low-temperature heating and high-temperature cooling compared to the jet ventilation system in China's International Airport. Primary annual energy calculation based on Energy Performance of Buildings Directive (EPBD) by Olesen and Carli [11] showed that a low-temperature heating system connected to a ground-source heat pump has better overall energy performance than a conventional radiator connected to a boiler or an air to water heat pump. Hasan et al. [12] studied the performance of low-temperature heating systems in terms of energy consumption and thermal comfort. Their results showed that although the supply temperature decreased to 45 °C in a conventional radiator, the indoor temperature never dropped below 20 °C. This was due to an oversized conventional radiator for a well-insulated building.

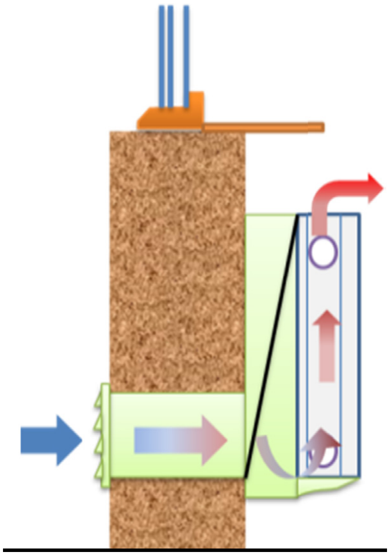

Fig. 1. Schematic of ventilation radiator; that is, the combination of supply ventilation with radiator to preheat the cold supply air and increase the efficiency of the radiator.

Maivel and Kurnitski [13] investigated the distribution and emission losses for a low-temperature heating system compared to a high-temperature heating system installed in different building types located in a cold and Central European climate. Their results showed that depending on the building type, climate condition and heating period, using high-temperature heating with 70 °C water supply temperature has 4–40% higher losses compared to low-temperature heating system with 40 °C water supply temperature. Nagy et al. [14] developed a model to investigate the influence of retrofit measures to the supply water temperature. Their results showed that the supply water temperature to the existing building without any retrofit measures can be decreased by 10 °C; that is, from 55 to 45 °C, without sacrificing thermal comfort. In addition, they showed that improving the building's insulation would allow to decrease the supply temperature to 40 °C and to save energy by 60% compared to the reference case.

There are different types of low-temperature room heaters in which the large surface area or improved forced convection makes it possible to reduce the supply water temperature without sacrificing the heat output. Examples include panel heating such as floor, ceiling or wall heating, or forced-convection radiator such as ventilation radiators [15], or add-on fan radiators [16]. In a ventilation radiator, the ventilation supply is placed behind the radiator; see Fig. 1. This combination increases the forced convection heat transfer and makes it possible to pre-heat the supply air before it enters the room. An experimental investigation [15] showed that an efficient ventilation radiator produced twice as much heat output as a conventional radiator under the same conditions. This was due to the high convective heat transfer by combining it with incoming air, and also the large temperature difference between cold incoming air and the heat emitting surface.

In the add-on fan radiator, fans are placed below the radiator panels to boost the convection heat transfer. A previous study [16] showed that having five fans below the radiator increases the heat output to almost twice that of a conventional radiator. This was due to increasing the convection heat transfer along the radiator surfaces. Added fans below the radiator consumed very small amounts of electricity, that is, the ratio of electricity consumption by the fan to increasing the heat output of the radiator was between one and two percent.