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Performance evaluation of radiant baseboards (skirtings) for room heating – An analytical and experimental approach

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HIGHLIGHTS

- Thermal performance of radiant baseboards (RBs) used for space heating was analyzed.
- The proposed heat output equation can be used with confidence for RBs heaters.
- The heat transfer ability of RBs was 50% higher than that of panel radiators.
- The heat emission from RBs increased by roughly 2.1% per centimeter of height.
- The RBs of maximum height should be used for water supply temperatures below 45 °C.

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ABSTRACT

The aim of this study was to investigate the thermal performance of the hydronic radiant baseboards currently used for space heating in built environments. The presently available equations for determination of heat outputs from these room heaters are valid for a certain height at a specific temperature range. This limitation needed to be addressed as radiant baseboards may be both energy and cost efficient option for space heating in the future. The main goal of this study was therefore to design an equation valid for all baseboard heights (100–200 mm) and excess temperatures (9–60 °C) usually used in built environments.

The proposed equation was created by curve fitting using the standard method of least squares together with data from previous laboratory measurements. It was shown that the predictions by the proposed equation were in close agreement with reported experimental data. Besides, it was also revealed that the mean heat transfer coefficient of the investigated radiant baseboards was about 50% higher than the mean heat transfer coefficient of five conventional panel radiators of different types.

The proposed equation can easily be used or programed in energy simulation codes. Hopefully this will help engineers to quantify more accurately the energy consumption for space heating in buildings served by radiant baseboards.

1. Introduction

Different types of hydronic and electric systems are currently used for space heating in the Swedish residential sector [1]. In hydronic systems, heat is usually distributed by conventional hot-water radiators while in electrical systems various distribution arrangements are used. Between 1960 and 2010 electrical systems were predominantly used for space heating in Swedish single-family dwellings. Accordingly, approximately 70% of the country's single-family houses either used or could use electricity for space heating in 2001. By that time, around 34% of 1.6 million Swedish single-family houses were heated by direct-acting electricity and water-based electric heating [2]. In addition to these 34%, another 36% had electric heating as an alternative heating system [2]. This means that about 1.12 million of country's single-family houses used electricity either as sole or as a supplementary heating system in 2001.

In order to reduce the electrical peak loads and energy consumption during the heating season, the Swedish government has undertaken a number of measures over the last decades. Thus, during the period between 2006 and 2010 the homeowners could have been refunded with up to 30% of their conversion costs, when

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Nomenclature

Latin letters

A	area m^2
a	constant in Eq. (3) -
b, c and d	exponents in Eq. (3) -
c_p	specific heat capacity, J/(kg °C)
d	diameter, m
H	baseboard height, m
h	height of waterway, m
f	flow friction factor between water and waterways
K	heater constant, W/°C^n
k	equation number
L	length, m
$\dot{m}$	mass flow, g/s
n	temperature exponent or number of samples
P	heat output/thermal power, W
q	heat output per m, W/m
Re	Reynolds number
SEE	standard error of estimate, W/m
U	total heat transfer coefficient, W/(m^2 °C)
v	velocity of water, m/s
w	width of waterway, m

Greek letters

ε	absolute inner surface roughness, m
θ	temperature, °C
Δ	percentage difference, %
$\Delta\theta$	excess temperature = mean temperature difference between room heater and room air, °C
Δp	pressure loss, Pa

Subscripts

ave	average
calc	calculation by Eq. (9)
eq	equivalent
max	maximum
ref	reference value
room	room
rtn	Return
supp	supply

conventional radiator types

10	single panel
11	single panel + single convector plate
21	two panels + single convector plate
22	two panels + two convector plates
33	three panels + three convector plates

converting from electric to alternative heating systems [3]. As a result of conversions between 2006 and 2010, the electrical energy consumption for space heating in the residential sector has been decreased by 476 GWh/year. It was estimated that about 34% of this total saving could be directly attributed to the government's financial support [4].

In addition to the above-mentioned, the installation of heat pumps in Sweden increased greatly between 1994 and 2011. As a result of this the one-millionth heat pump was put in operation in single-family houses in 2010 [5]. The Swedish Heat Pump Association has estimated that by that time approximately half of the installed heat pumps were of the air-to-water and closed-loop types [6]. By 2010, these two heat pump types stood for approximately 490 MW of installed nominal power in Sweden [7].

As is generally known, the efficiency of the heat pump in a heating system is strongly dependent on the supply water temperature of the system. The lower the supply water temperature, the higher the efficiency of the heat pump. Up to now, the supply temperature of the heating system in Swedish single-family houses was usually decreased by increasing the number of room heaters. Although various types of the room heaters were available on the market at that time, conventional radiators were mainly used for heat distribution in dwellings heated by heat pumps. Similarly, conventional radiators were also predominantly used when converting from direct-acting electricity to hydronic heating. Despite the fact that perhaps some other types of room heaters could have been more appropriate option, especially for homes served by heat pumps.

It should also be noted that Sweden is not alone in making efforts to improve the efficiency of the heating systems. Different research groups in several European countries are also currently working on finding methods to improve thermal efficiency of the heating systems in residential buildings. Meir et al. [8] presented a new method for temperature control in buildings with floor heating. The presented control method decreased the response time and resulted in closer follow of changes in outdoor temperature. Consequently, this control method was more energy efficient than the traditional one with conventional thermostats. The joint influence of the enhanced emissivity and the surface roughness of a wall behind a hot radiator was studied by Shati et al. [9]. They found that the total heat output from the radiator could be increased by 26% through the use of a high emissivity saw-tooth wall surface. Pinard et al. [10] studied the possibility to enhance the heat output from a room heater using induced stack effect. Reported results suggested that this method could improve the total heat output by approximately 24%, at maximum. Badescu [11] investigated the potential of using active solar heating in a passive house. He found that 62% of the total annual heat demand could be met by this system. Hewitt et al. [12] analyzed performance of an air-source heat pump connected to a radiator system. Not surprisingly, they concluded that low-temperature radiators would increase the heat pump efficiency.

In conclusion, findings from the presented studies clearly suggest that the need for efficient and flexible heating systems is broad.

1.1. Potential of radiant baseboard heaters

A hydronic heating system that is still limitedly used in Swedish residential sector is radiant baseboards (Fig. 1a). The radiant baseboards usually have two waterways. One supply and one return pipe, which are attached to the enclosing metal plate (Fig. 1b). The waterways are also connected by a 180° u-bend at the opposite end of the circuit. The typical height of the radiant baseboards is between 120 and 180 mm, and their length is normally ranging from 8 to 15 m per room. Since enclosing plates have no openings at the front side, the adjacent room air is prevented from passing over the inner part of the unit. Consequently, a large portion of the emitted heat is transferred by thermal radiation [13]. An additional example of radiant baseboards placement in a real-life room is given by Fig. 1c.

Due to their low height, the transferred convective heat flux from radiant baseboards to the room air is high [15]. Also, since radiant baseboards are installed at the base of the walls they are