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Case study

Thermal performance of hydronic radiator with flow pulsation – Numerical investigation

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HIGHLIGHTS

- CFD simulation of type 10 and type 11 panel radiators with constant and pulsed flow conditions.
- Pulsating the flow enhances the heat transfer performance of panel radiators.
- As flow pulsating frequency increases, the specific heat output of panel radiators increases.
- Pulsating the flow resulted in energy saving of up to 17% for type 10 and 20% for type 11 radiators.

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ABSTRACT

Improving the heat output of hydronic central heating system in buildings can play a major role in energy saving. Current panel radiators of central heating systems are operating at constant flow strategy with thermostat control device. Such operating mode is not efficient in terms of energy consumption; therefore an alternative operating scenario is required to enhance the heat output of the panel radiator. The main aim of this research is to investigate the effect of pulsed flow input on the energy consumption of panel radiators while maintaining the target panel surface temperature. CFD modelling of two hydronic panel radiators with constant and pulsating flows were developed using the conjugate heat transfer module in COMSOL Multiphysics software. The radiators used were one with single finned surface (type11) and the second is without fins (type10), both with the dimensions of 500 mm long and 300 mm high. The CFD results of the constant flow conditions were compared to published experimental work showing good agreement with maximum deviation of 2.4% in the heat output. To investigate the effects of pulsating flow on the performance of the two panel radiators, a wide range of input pulsating flows with amplitude ranging from 0.027 m/s to 0.051 m/s and frequency ranging from 0.0523 rad/s to 0.209 rad/s while the flow supply temperature remained constant at 75° were simulated. The simulation results showed that using pulsed flow can reduce the energy consumption of panel radiators by up to 20% compared to constant flow operating condition while maintaining the same radiator surface temperature of 50 °C. Such results highlight the potential of using pulsed flow to reduce the energy consumption of central heating systems in buildings without compromising the user comfort.

1. Introduction

Building energy utilization has important impact on energy consumption and greenhouse gas emission all over the world. The energy statistical data indicates that around 50% of the total energy consumed in the developed countries is for buildings usage [1]. This produces significant amounts of CO_2 emission and other environmental pollutants which contribute to global warming [2]. This has led the European Union to legislate for reducing its energy consumption by 20% before 2020 which was adopted by the member states [3]. Enhancing the efficiency of domestic central heating system is an important factor in achieving this target.

Considerable research has been carried out in order to improve the domestic central heating systems. The studies were carried out based on the heat sources and heating appliances. Heat sources include Heat pump, District heating, Boiler (Combi boiler, Condensing boiler), and CHP (Combined Heat and Power). Heating appliances include panel radiators with convective fins and

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without convective fins, floor heating and air heating, skirting's (baseboard). Hydronic (water based) heating radiators are predominantly used for internal heat emission within the residential sector in Europe [4]. The advantages of the heating panel radiator as a heat emitter are: compact design, less space requirement in the rooms and ease of installation to new buildings or retrofits. Various research works have been carried out to enhance the central heating system performance based on design optimization of the panel radiator. Myhren and Halberg [5] achieved improvement in the heat transfer output from panel radiators by increasing the air flow on its heat transferring surfaces. They concluded that, using ventilation-radiators the desired thermal climate could be achieved with a radiator surface temperature as much as 7.8 K lower than standard values. The possibility of enhancing the heat output from the panel radiator by coating the wall behind the radiator in different colours with different emissivity values was also studied by Bangert [6]. The study concluded that, the wall coated with higher emissivity (smooth black surface) material can improve the heat output of the heating panel radiator by up to 26%. Beck et al. [7] investigated the heat transfer enhancement of panel radiations by placing one or two high emissivity metal sheets between the interior surfaces of double panel radiators. They concluded that placing two high emissivity metals in the interior side of the double panel radiator can produce an improvement of about 88% compared to the double panel radiator. Enhancement of hydronic heating system using baseboard device integrated air supply was reported by Ploskic and Holmberg [4,8]. The aim of their work was to minimize the supply temperature by pre-heating the incoming ventilation air flow and concluded that the heat output of their proposed system can produce about 21% more heat compared to the traditional hydronic baseboard heating system [4,8]. Myhren and Holmberg [9] carried out a study to enhance the energy efficiency in exhaust-ventilated buildings with warm water heating system using ventilation radiator combined with heat emission device. A CFD model of the proposed system was developed and results showed that the heat output can be increased by 20% compared to traditional radiators.

The hydronic baseboard heating system was studied by Ploskic [10]. The aim of the study was to investigate the capability of the baseboard supplied at low temperature ranges 40 °C–45 °C to suppress strong downdraughts. They concluded that the baseboard at these range of temperature is unable to suppress the strong downdraught instead they have used a supply temperature of 55 °C and that was able to overcome the downdraughts to comfort level. Optimization of heat output of the ventilation radiator was studied by varying the distribution of the vertical longitudinal convection fins using computational fluid dynamics (CFD) [11]. They showed that heat transfer can be enhanced by up to 17% by changing the geometrical design of the fins, decreasing the fin to fin distance and cutting the middle section of the fin array. Sanjay and Avanic [12] investigated the use of phase change material to optimize the heat output from the hydronic panel radiator and concluded that 20–25% of energy can be saved compared to the traditional radiators. Kerrigana et al. [13] investigated the use of heat pipes to improve the performance of panel radiators at supply temperature as low as 55 °C.The power density of the tested panel radiator fitted with heat pipes was nearly tripled compared to the traditional panel radiator. Therefore the researchers concluded that the heat pipe based naturally aspirated radiator is a possible alternative to replace traditional panel radiators particularly when low temperature water heating systems such as heat pumps are used.

Extensive study has been carried out by various researchers to enhance the heat transfer of various heat emitting devices. Flow pulsation is a method of heat transfer enhancement applied in various industrial applications including heat exchangers, pulse combustors, electronic cooling devices and cooling of nuclear reactors [14]. A study was carried out by Ref. [15] to enhance the heat transfer of the parallel and counter flow heat exchangers using ball valve as pulsar device. Results showed that using pulsed flow, the heat transfer can be enhanced by 20% for the parallel flow heat exchangers and 90% for the counter flow ones. The effect of flow pulsation in heat transfer enhancement of the double pipe steam water heat exchangers using solenoid valve triggered by pressure switch was studied by Lemlich [16]. The test was performed at Reynolds number ranges from 500 to 5000; and frequency of 1.5 Hz and concluded that the overall heat transfer coefficient was increased by 80% depending on closeness of the solenoid valve to the test section. Effect of pulsed perturbation on convective heat transfer for laminar flow on co-axial cylindrical tube heat exchangers was experimentally investigated by Shuai et al. [17]. The test was performed at lower Reynolds number ranging from 150 to 1000; frequency of 0–2 Hz with reciprocating pump was used as pulsating device. Based on the results they concluded that the heat transfer coefficient can be enhanced by 300% using the strong pulsed perturbations. Experimental study was carried out to explore the convective heat transfer enhancement from heated cylinder in a pulsating flow. A series of experiments was conducted to compare the heat transfer enhancement for pulsed air jet and steady flow air jet and results showed that about 50% heat transfer enhancement was achieved with the pulsed jet compared to the steady flow jet [18]. Sailor et al. [19] investigated the potential of embedding pulsating heat pipes for space or terrestrial applications. The enhancement technique was based on the selection of Biot number that minimizes the conductive resistance of the thermal radiator. They concluded that effective thermal conductivities of 400 W/m K–2300 W/m K can be achieved due to the applied pulsed flow.

Despite the number of studies reported for using pulsating flow to enhance heat transfer of heating or cooling devices, there are limited studies regarding its use to improve panel radiators in hydronic heating systems. Therefore, this work aims to investigate the heat transfer enhancement due to flow pulsation in panel radiator based hydronic central heating system using computational fluid dynamics modelling with COMSOL multi-physics software. The work investigates the energy saving by using flow pulsation in two types of panel radiators namely; type 10 without fins and type 11 single fined panel radiators.

2. CFD simulation

CFD three dimensional simulations of panel radiators type 10 and 11 were carried out using conjugate heat transfer physics within COMSOL multi-physics [20]. The Navier Stokes equations (Eqs. (1)–(3)) of continuity, momentum and energy used to simulate the heat transfer and fluid flow within the panel radiators and the surroundings [21].

$$\rho\frac{\partial u}{\partial t}+\rho(u\cdot\nabla)u=\nabla\cdot\left[-pI+(\mu+\mu_T)\left(\nabla u+(\nabla u)^T\right)-\frac{2}{3}(\mu+u_T)(\nabla\cdot u)I-\frac{2}{3}\rho\kappa I\right]+F \tag{1}$$

where: $\mu_T=\rho C_\mu\kappa^2/\varepsilon$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho V)=0 \tag{2}$$

$$\rho C_p\frac{dT}{dt}+\rho C_p V\cdot\nabla T=\nabla\cdot(k\nabla T)+Q \tag{3}$$