Energy and Buildings 121 (2016) 298–308

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Numerical evaluation of indoor thermal comfort and energy saving by operating the heating panel radiator at different flow strategies

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ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form
21 December 2015
Accepted 23 December 2015
Available online 8 January 2016

Keywords:
Indoor comfort
Specific energy output
CFD
Heat transfer
Pulsed flow

ABSTRACT

Enhancing the performance of central heating systems in buildings can play a major role in energy savings. Pulsed flow to the radiators can lead to enhancing the specific heat output of radiators. The aim of this work is to investigate the effect of radiator flow pulsation on the indoor spatial temperature and velocity distributions to achieve energy saving without compromising the user thermal comfort defined by ASHRAE standard 55 and EN ISO 7730. CFD modelling of panel radiators at constant and pulsed flows were carried out and the results were validated with published data. Such radiators were then incorporated in a room and CFD modelling of the room was carried out using flow pulsation strategies.

The simulation of the radiator at constant flow was validated against published experimental data in terms of heat output showing maximum deviation of 2.44%. Results from CFD simulation of the radiator with pulsed flow using frequency ranging from 0.0083 Hz to 0.033 Hz and amplitude ranges from 0.0168 kg/s to 0.0228 kg/s showed that 25% improvement in the specific heat output can be achieved while maintaining the same radiator target surface temperature of 50 °C. Also using the pulsed flow applied in this work the pump power can be reduced by about 12% compared to the pump operating at constant flow. As for the heated space with the integrated radiator, results of CFD simulation for pulsed flow with frequency of 0.033 Hz and amplitude of 0.0192 kg/s showed that the temperature, velocity and draught rate were maintained within the required comfort levels of 20 ± 1.5 °C; less than 0.15 m/s and less than 15%, respectively.

1. Introduction

Published energy consumption data indicate that around 50% of the total energy consumption is used for buildings in developed countries [1]. For example, in the UK buildings services consume 40% of the overall energy consumption, thus contributing about half of the UK's CO_2 and other environmental pollutants emissions which contribute to global warming [2]. To meet the 20% energy reduction target by 2020, the UK is aiming to reduce residential buildings energy consumption by 52% [3]. Enhancing the efficiency of domestic central heating system without affecting the wellbeing/comfort of the occupants is an important factor in achieving the considered reduction target [4]. Various research works have been published regarding enhancing the performance of such system and the user indoor comfort phenomena. Fig. 1 describes the closed loop panel radiator hydronic heating system showing the heat source, panel radiator and the space to be heated. The parameters used to assess the comfort of occupants in air conditioned space include indoor temperature (T_{ind}), indoor air velocity (V_{ind}), Percentage Dissatisfied (PD), Percentage Experienced Draught (PED) and Draught Risk [DR] [5].

According to ASHRAE standards 55 maintaining indoor comfort phenomena is key objective when one attempt to reduce the heat energy consumption of buildings integrated with central heating system. Various research papers have been reported regarding the indoor comfort parameter including temperature, velocity, PD, DR and PED. The indoor comfort was investigated under ventilated hydronic radiator as a heat source in a room with Swedish standard of ventilating air flow of 0.0086 kg/s per person using CFD. Results showed that ventilated radiators are able to create more stable thermal comfort climate than the traditional radiators [6]. An office room was investigated numerically at high, medium and low temperature radiator surface as well as floor heating to investigate the indoor comfort including air speed, cold draught and temperature. And it was conclude that, room installed with low temperature radiators can offer lower indoor temperature fluctuations which lead to low energy consumption and better occupants comfort [7]. Kana et al. investigated the effect of wall thickness

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http://dx.doi.org/10.1016/j.enbuild.2015.12.042
0378-7788/

Nomenclature

Symbols

A	area [m^2]
F	volume force [N/m^3]
d_h	hydraulic diameter [m]
DR	draught risk [%]
f	frequency [Hz]
g	gravity [m/s^2]
HTER	heat transfer enhancement ration (%)
C_p	specific heat capacity [J/(kg K)]
L	characteristics length [m]
LMTD	log mean temperature difference [K]
$\dot{m}$	mass flow rate [kg/s]
P	pressure [Pa]
PD	percentage of dissatisfied [%]
PED	percentage experience draught [%]
Per	perimeter [m]
Q	heat energy [W]
Sp.Q	specific heat capacity [kW/kg]
Re	Reynolds number [–]
St	Strouhal number [–]
T	temperature [K]
t	time [s]
TI	turbulent intensities [%]
U	average velocity [m/s]
V	velocity [m/s]

Greek symbols

ρ	density [kg/m^3]
α	thermal conductivity [w/(m K)]
ν	kinetic viscosity [m^2/s]
μ	dynamic viscosity [N s/m^2]

Subscripts

out	outlet/output
in	inlet/inflow
PF	pulsed flow
CF	constant flow
rad	radiator
ind	indoor

in thermal energy consumption and indoor comfort of the occupants [8]. They concluded that the thermal loss of thin wall (20 cm) is 53% higher compared to thicker wall (40 cm) while having the same heat transfer coefficient, also indoor comfort temperature of thinner wall is 4.6 °C lower compared to the thicker walls. Therefore it was concluded that indoor comfort and thermal energy loss can be affected by thermal conductivity variation of the walls. Ge et al. study to investigate the cause of cold indoor draught due to extreme cold outdoor temperature combined with poor glazing transmittance [9]. They recommended that the cold draught comfort problem can be improved using well insulated glazing. Arslan and Kose also conducted thermoelectric optimization on the insulation thickness in building [10]. Bhaskoro et al. conducted CFD simulation of heated space with two radiators as a heat sources and virtual sitting of manikin in the room to investigate the occupant comfort parameters [11]. They concluded that properly insulated external walls and windows glazing create stable indoor comfort and low energy consumption in the air conditioned room.

Smart control management of central heating system can also play important role to reduce energy consumption and improve the comfort temperature of the occupants [12]. Artificial neural network (ANN) based predictive and adaptive logic control also has a potential for indoor comfort control by decreasing the standard deviation of indoor temperature range, decreasing percentage of overshoots and undershoots of the desired indoor comfort ranges [13]. Embaye et al. investigated the indoor comfort temperature using PID control system compared to the on/off control system and concluded that using PID control system can create better indoor stability with lower indoor fluctuations of ±1 °C and lower energy consumption of the building to be heated [14].

There are various heat transfer enhancement methods including: rough surfaces; nanofluids; fluid slipping enhancers, surface coating, fin attachments, mechanical mixing device, vibration, magnetic electric fields and flow pulsation [15–18]. Flow pulsation was used to enhance heat transfer in various industrial applications including heat exchangers, pulse combustors, electronic cooling devices, cooling system of nuclear reactors leading to a potential of reducing energy consumption by up to 60% [19–23]. Embaye et al. investigated the effect of flow pulsation on the energy consumption of heating radiators [24] and concluded that up to 20% of energy saving can be achieved by pulsation the flow with 0.033 Hz frequencies and 0.0228 kg/s amplitudes. However they didn't investigate the effect of flow pulsation of heated radiator on the thermal comfort of heated space. Thus the presented work aims to investigate

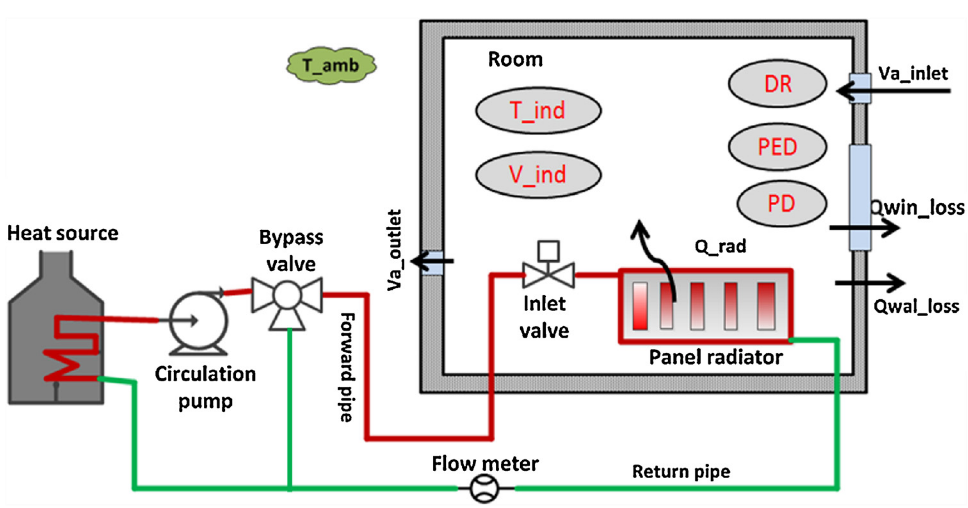

Fig. 1. Closed loop hydronic central heating system layout.