Building and Environment 106 (2016) 378–388

Contents lists available at ScienceDirect

Building and Environment

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

Can radiant floor heating systems be used in removable glazed enclosed patios meeting thermal comfort standards?

Davide Astiaso Garcia

DIAEE—Department of Astronautic, Energetic and Electric Engineering, Sapienza University, Corso Vittorio Emanuele II 244, Rome 00186, Italy

ARTICLE INFO

Article history:
Received 14 May 2016
Received in revised form
24 June 2016
Accepted 14 July 2016
Available online 15 July 2016

Keywords:
Underfloor heating
Glazed enclosed patios
Thermal comfort
Radiant floor heating panels
Floor surface temperature
Heat transfer efficiency

ABSTRACT

Many systems are used for heating glazed enclosed patios of restaurants, pubs or other restaurant businesses. This paper explores the possibilities of use radiant floor heating systems (RFHS) in removable glazed enclosed patios maintaining thermal comfort in terms of predicted percentage of dissatisfied (PPD) and predicted mean vote (PMV) optimal ranges. The effects of different envelope structures of glazed enclosed patios on floor surface temperature using a radiant floor heating system have been analyzed. In addition, considering the use of removable and modular radiant floor heating panels, delivery and return pipes layouts from a heat power generator to each single radiant floor heating panel have been analyzed assessing flow velocity and pressure drops in order to pinpoint the best layout for optimizing heat transfer efficiency and energy saving. The findings showed at assumed outdoor and indoor temperatures what are the considered glazed enclosed patio envelopes that allow the use of a RFHS maintaining the floor surface temperature within thermal comfort ranges and avoiding local thermal discomfort due to floor temperature and vertical radiation asymmetry. Moreover, the flow velocity and concentrated/distributed pressure drops analysis pinpointed optimal pipe layouts for connecting heat power generator to each underfloor heating panel. concluding, the paper highlighted that, up to meet thermal comfort standards, under floor heating systems could be used for heating glazed enclosed patios only for certain envelope structures. Additionally, a delivery and return pipe layout should be properly designed for minimizing pressure drops and optimize heat transfer efficiency.

1. Introduction

Many heat exchangers typologies are used to transfer heat energy into an enclosure: convectors, radiators, fan coils and others. Among them, underfloor heating systems (UFHS) are considered as valid options for producing comfortable environments.

The results firstly obtained by Olesen et al., that investigated about thermal comfort in a room heated by different methods, showed up that an UFHS can give a more satisfactory indoor microclimate than radiator or other heating systems for the homogeneous air temperature field it provides [1]. In particular, Li et al. [2] assessing thermal comfort and IAQ (Indoor Air Quality) of UFHS found that thermal comfort is mainly influenced by the local thermal sensation at the feet due to the floor temperature field.

Low temperature floor panels are widely used in buildings mainly for improving the indoor thermal comfort thanks to a uniform room temperature distribution; anyway floor temperature should be maintained within certain ranges in order to avoid local thermal discomfort due to vertical radiation asymmetry [3]. Additionally, this kind of panels provide opportunities for applying low-grade energy resources such as solar hot water. Indeed, the opportunity to supply renewable energy makes UFHS one of the strategy to support building stock decarbonization [4].

Hajabdollahi et al. analytically presented a thermal modeling of an UFHS verifying the results in energy conservation point of view with acceptable precision [5]. Their aim was to optimize four design parameters (tube length, tube radius, water mass flow rate and number of panels) in order to minimize the total annual cost. Zhou and He investigated the performance of a low-temperature radiant floor heating system with different heat storage materials, sand and phase change material (PCM) [6]. Particularly, they showed that the floor structures using PCM as thermal mass release heat about 2 times longer than the cases using sand. Considering economic aspects, Athienitis and Chen proved that UFHS are an economically efficient alternative to other more common forms of heating [7]. Mustafaraj et al. simulated a building to identify possibilities of

E-mail address: davide.astiasogarcia@uniroma1.it.

http://dx.doi.org/10.1016/j.buildenv.2016.07.013
0360-1323/

List of acronyms

A	area (m^2)
ACH	air change rate (h^{-1})
c	Heat capacity for standard pressure (J Kg^{-1} K^{-1})
D	pipe inner diameter (m)
f	Darcy friction factor (–)
h	adduction coefficient (W m^{-2} K^{-1})
G	volumetric flow rate (m^3 s^{-1}) (l s^{-1})
Gr	Grashof number (–)
H	design ventilation heat loss coefficient (W K^{-1})
HPG	heat power generator (W)
IAQ	indoor air quality
IHG	Internal heat gains (W)
k	loss coefficient of elbows (–)
K	heat transfer coefficient (W m^{-2} K^{-1})
L	pipe length (m)
Nu	Nusselt number
Δp	pressure drop (Pa)
PCM	phase change material
Pr	Prandtl number
Q	Heat transfer rate (W)
R	Thermal resistance (m^2 K W^{-1})
Re	Reynolds number (–)
RFHP	radiant floor heating panel
s	thickness of a material (m)
T	temperature (K)
U	flow velocity (m s^{-1})
UFHS	underfloor heating system
V	air flow rate (m^3 h^{-1})

Greek letters

α	building orientation coefficient
ε	emissivity
λ	thermal conductivity (W m^{-1} K^{-1})
μ	dynamic viscosity (Kg m^{-1} s^{-1}) (Pa s)
ρ	Density (Kg m^{-3})
σ	Stefan-Boltzmann constant, 5.67E-8 (W m^{-2} K^{-4})
Ψ	linear thermal transmittance (W m^{-1} K^{-1})

Subscripts

a	air
as	air space
c	curtain
co	concentrated
d	distributed
f	frame
fix	fixture
fl	floor
g	glass
in	indoor
m	average
nc	natural convection
out	outdoor
r	radiation
v	ventilation

energy savings supplied by a water to water heat pump to underfloor heating system [8]; they found that electricity consumption savings from the heat pump can vary between 20% and 27% on monthly bases.

Furthermore, comparing 5 simulated systems in terms of both indoor thermal comfort and energy consumption [9], the possibility of cooling by means of radiant systems coupled with dehumidification systems has been analyzed in relatively hot and humid climates, when mechanical ventilation is installed.

Starting from these findings the research is focused on an analysis of UFHS performance if installed in removable glazed enclosed patios often used by restaurants, pubs or other restaurant businesses as hosting customers places in private gardens or cities squares, assessing if it is possible to use this system typology meeting thermal comfort ranges in terms of indoor air temperature and floor temperature. These ranges have been considered evaluating predicted percentage of dissatisfied (PPD) and predicted mean vote (PMV).

Additionally, using radiant floor heating panels (RFHPs), flow velocity and pressure drops have been compared using different delivery and return pipes layouts from the heat power generator (HPG) to each RFHP, in order to pinpoint the best layout for optimizing heat transfer efficiency and energy saving.

Indeed, an UFHS with RFHPs has been considered since the use of RFHPs allows a modular user friendly and removable heating system for enclosed patios; moreover their use permits a parametric analysis for a particular model whose results could be easily applied to enclosed patios of different dimensions.

Enclosed patios have been analyzed by previous papers mainly for assessing their use as energetic strategies for influencing indoor environment [10,11]. Considering heater systems for enclosed patios in winter, limits and wasteful of mushroom-shaped technologies has been highlighted by Hitchings [12], while to the author's knowledge there is no scientific literature on the use of UFHS in enclosed patios.

In particular, the paper deals with studying of some specific design parameters that modify the value of transferred heat in an UFHS, considering: i) the effects of different removable and glazed patio envelopes (frames, glasses and curtains) on heat losses and consequentially on the floor temperature needed to maintain the established indoor temperature with an UFHS; ii) the effects of different delivery and return pipes layouts and HPG localization on pressure drops and flow velocity, trying to optimize heat transfer efficiency and energy saving.

Four different envelopes structures for glazed enclosed patios have been considered in a parametric study in order to identify the ones whose heat losses implicate a floor surface temperature within thermal comfort ranges if used an UFHS.

Thermal comfort is one of the focal aspects to consider when a heating and ventilation system is designed and it is usually measured by PPD and PMV [13,14]. The use of UFHS optimizes vertical gradients of air temperature and radiant temperature asymmetry. Anyway, according to Fanger [15,16], for thermal comfort principles, floor temperature should not exceed 30 °C in order to avoid thermal discomfort associated with an excessive vertical radiation asymmetry. In particular PPD is close to 5% with floor temperature of 25 °C, and rises to 20% with a floor temperature of 33 °C, to 30% with 35 °C and until 50% of dissatisfied with a floor temperature of about 40° C [16]. These thermal discomfort values, evaluated for floor temperatures higher than 33 °C, are mainly caused by a vertical radiation asymmetry.

In addition, confirming the above-mentioned thermal comfort ranges, Song analyzed the effect of the heated floor on blood flow, and the skin temperature of the feet attesting that a partial heating