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A comparison of heating terminal units: Fan-coil versus radiant floor, and the combination of both

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ABSTRACT

Several control strategies are compared for a hydronic heating system that combines two different terminal units, radiant floor and fan-coil, in the same thermal zone. The performance of the combined system is evaluated in terms of energy consumption and comfort level. The production unit is an air-water heat pump. Four control strategies are defined and compared using a TRNSYS model: one strategy is applied when only the radiant floor operates, two strategies (simply and improved) are applied when only the fan-coil operates, and one strategy is applied when both terminal units operate simultaneously. Simulations are undertaken for three major cities with different heating requirements. In terms of comfort, the combined system achieves the higher scores, ensuring comfort conditions during most of the heating season. In terms of energy consumption, the worst option is the one that uses a fan-coil with fixed air velocity and fixed inlet water temperature. Nonetheless, there are not important differences between the analysed control options. The energy consumption of the system is mainly influenced by the part load performance of the heat pump, although the differences are small.

1. Introduction

The use of radiant floors for heating is widespread. The main advantages are improved comfort and a lower energy consumption [1,2]. An important drawback is the higher thermal mass of the floor, which complicates the control of the system. The large thermal inertia can cause delays and overheating, leading to higher energy consumption and dissatisfied occupants. Compared to radiant floors, fan-coils work with higher water temperatures and shorter response times.

This paper examines the integration of radiant floors and fan-coils in the same thermal zone. Despite a higher investment cost, the combination of both terminal units can offer interesting benefits. A good example of this is found in zones with highly variable occupation. During the heating-up phase from the initial state, the use of fan-coils fed with water at 45 °C helps the system to reach the zone set-point temperature quickly. At the same time, the floor will be gradually increasing its temperature until it is able to deal by itself with the total thermal load. The efficiency of the thermal production unit increases when the floor works alone because of the lower production temperature required (around 35 °C). In this way, the combined system should improve comfort levels during the first hours of occupancy and reduce the energy consumption during the rest of the time.

Another important benefit of combining both terminal units is to increase the total capacity of the HVAC system. A classic example of this is the operation in cooling mode, where the maximum capacity of the radiant floor is 40–50 W m^{-2} [3,4] because the risk of condensation limits the floor surface temperature. The concurrent operation of fan-coils makes it possible to satisfy the latent load and the fraction of sensible load that the floor cannot satisfy [5,6]. Nevertheless, the operation in heating mode has not been studied in depth.

Concerning the control strategies, a good classification can be found in Afram and Janabi-Sharifi [7]. There are many options, ranging from classical controls like on/off or PID, to advanced control methods like model-based predictive (MPC), fuzzy logic or neural networks. However, in our case, the complexity of the control system is not economically justified. The number and type of sensors and actuators are restricted in residential applications, and the "intelligence" of the system is limited. See for instance Marušić and Lončar [8] and Brooks et al. [9], who prove that the energy savings achieved by complex control strategies are not high enough to justify the increased cost.

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Nomenclature

C	Capacitance (kJ h^{-1} K^{-1})
Cap	Thermal power at nominal conditions (kW)
COP	Coefficient of performance
Cp	Specific heat (kJ kg^{-1} K^{-1})
$\dot{m}$	Mass flow rate (kg h^{-1}) or volumetric flow rate: air (m^3 h^{-1}), water (l h^{-1})
PLR	Partial load ratio
$\dot{Q}$	Heat flux (W)
t	Temperature (°C)
$\dot{W}$	Electric consumption

Greek letters

Δ	Temperature difference
δ	Change of the room dry-bulb temperature during six minutes (°C)
ε	Effectiveness

Subscripts

a	Air
ct	Catalogue
fan	Fan
max	Maximum
min	Minimum
MR	Mean radiant
O	Outdoor
P	Production
PL	Partial load
R	Air zone
s	Supply air
SP	Set-point
surf	Radiant floor surface
v	Fan speed
w	Water
1	Input
2	Output

The control strategies for combined systems use to be quite simple. For example, Backman et al. [10] studied a combined system during a whole year in two different locations in the USA. The fan-coil removed the latent load and complemented the floor when necessary. There was not a “smart” control to optimize the energy consumption. On the other hand, Beghi et al. [11] presented a more complex optimal strategy based on load prediction.

This paper analyses the best operation strategy for a hydronic heating system in which the production system is an air-water heat pump and the terminal units are a radiant floor and a fan-coil. The simplicity of the control system is an important practical restriction. We compare four different control strategies using TRNSYS 17 [12]. All of them must fulfil the following constraints:

- Same production temperature of hot water for both terminal units.
- Constant water flow.
- Control decisions are only based on the zone dry-bulb temperature.

The optimal control strategy must answer the following questions: a) which is the operation priority for each terminal unit, b) what is the set-point temperature for hot water production if each terminal unit needs a different temperature, and c) how to avoid zone overheating when the radiant floor is operating.

2. Description of the system

Fig. 1 shows the scheme of the system proposed in this work. Notice that the hydraulic circuit was simplified by replacing the traditional three-way mixing valve, designed to reduce the water temperature entering the floor, by an on-off two-way valve. The controller outputs are: the hot water set-point for the air-water heat pump, the operation signal (on-off) of the circulating pump, the operation signal for the heating floor (on-off of the two-way valve) and, finally, the velocity and operation (on-off of the two-way valve) of the fan-coil.

2.1. Heat pump model

We have developed an air-water heat pump model in TRNSYS that is based on two set of curves. With the first set, the COP at full load is calculated from the outdoor and water production temperatures. Fig. 2 (a) represents the data for a Daikin Altherma air-water heat pump [13]. These curves include the effect of defrosting cycles. With the second set of curves, we modify the full load COP as function of the part load ratio (PLR). This correction is very important because residential heat pumps predominately operate at part load.

The part load performance of a heat pump depends on numerous factors related to its constructive details (type of compressor, size of the heat exchangers, circuiting, etc.) and the control strategies used to match load and capacity (compressor/s, pump/s and fan/s regulation). Some authors have reported on the effect of some of these factors. According to Safa et al. [14], the use of variable speed compressors improves the efficiency at part load operation in comparison with other technologies. The work of Edwards and Finn [15] proves that using a control strategy that optimizes the water flow improves the system efficiency at partial load. The reference In et al. [16] shows that the type of refrigerant also affects the part load performance.

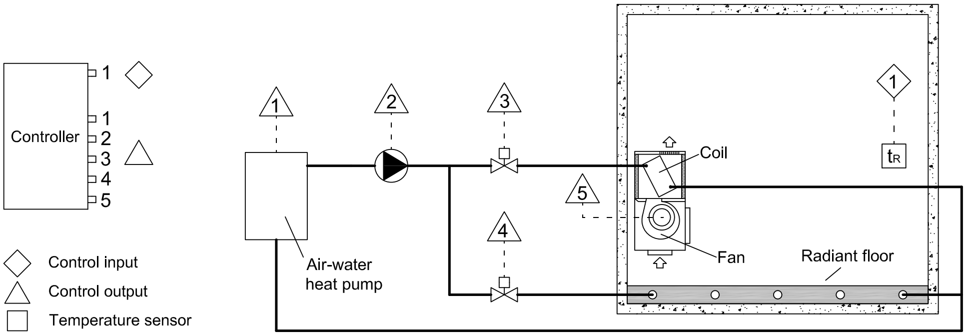

Fig. 1. Scheme of the proposed hydronic heating system: radiant floor coupled with a fan-coil.