Study of control for **heating hydronic systems**

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Contents

1. INTRODUCTION

There is an increasing demand within the residential sector of integrated solutions that respond to any thermal demand (cooling, heating and DHW) with a single generation unit (see diagram in Figure 1).

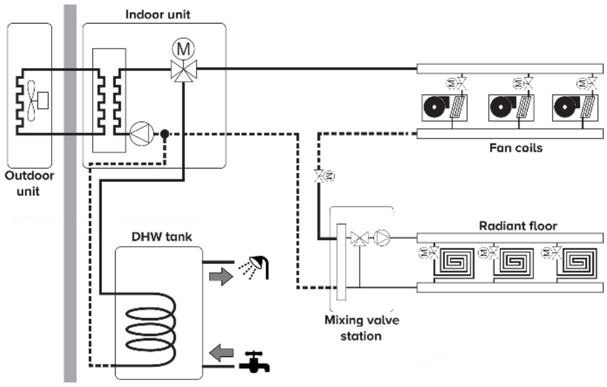

Figure 1. Air-to-water heat pump (connection diagram of mixed installations: underfloor heating + fan coils).

In its effort to improve its products, Airzone has developed a control system for heat pump hydronic units that efficiently manages the production based on the thermal demand and the number of thermal emitters. In this context, the control strategies are defined:

- Underfloor heating and cooling control.
- Fan coil control.
- Combined control (underfloor heating/cooling + fan coils)

Each strategy is detailed in the following sections. Additionally, a summary of the results obtained in a study carried out by the Group of energy from Grupo de Energética de la Escuela Técnica Superior de Ingeniería Industrial de Málaga (GEUMA) is presented. The present study, carried out together with TRNSYS [1], compares Airzone control strategies to traditional control solutions for underfloor heating/cooling and fan coil.

2. MAIN FEATURES OF AIRZONE CONTROL ALGORITHMS

①*Active management of leaving water temperature*. In air-to-water heat pumps the HTF is water. Therefore, it becomes essential to the manage the production temperature of this fluid. As observed in Figure 2, as the temperature of production is decreased, the performance of the unit is increased. In addition, the drop-in water temperature reduces thermal loss during the distribution of energy from the production system to the terminal units.

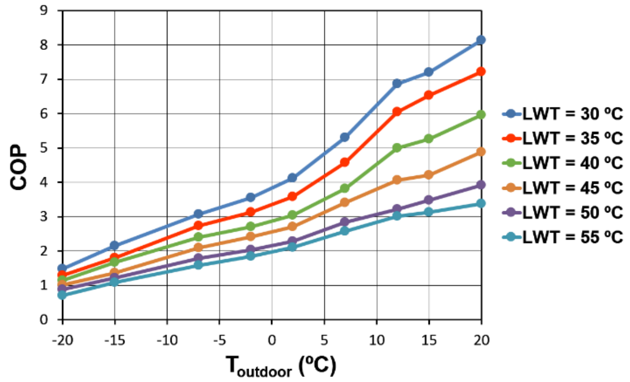

Figure 2. COP based on outdoor temperature and the water production temperature [2].

Airzone communication gateways allow a dynamic selection of the production temperature of water. This way, it is possible to maximize the potential of the emitters available by selecting the most efficient and comfortable combination in every scenario.

- Underfloor heating/cooling: It can achieve a more efficient water temperature production and higher level of comfort.

  When the heat exchange (mainly by radiation) is produced, the comfort temperature can be approximately 2 ºC less demanding when compared to convective emitters.

  UNE-EN ISO 7730 standard [3] limits the surface temperatures that can be reached by underfloor heating. This temperature is restricted to 29 ºC in heating in areas of permanence, to 33 ºC in bathrooms and 35 ºC in peripheral areas. When cooling, the temperature is restricted to 19 ºC.

  UNE-EN 1264 standard [3] sets the maximum theoretical thermal emission for underfloor heating and cooling systems, according to (1) and (2), respectively.

$$q\left({}^{W}/_{m^2}\right) = 8{,}92(T_{\text{floor surface}} - T_{\text{room}})^{1{,}1} \tag{1}$$

$$q\left({}^{W}/_{m^2}\right) = 7(T_{\text{floor surface}} - T_{\text{room}}) \tag{2}$$

  Therefore, considering a scenario where the surface temperature of the floor is 29 ºC for heating and the room temperature is 21 ºC, the theoretical limit of the underfloor system is 87,86 W/m^2. Likewise, considering a second scenario where the surface temperature of the floor is 19 ºC for heating and the room temperature 26 ºC, the theoretical limit of the underfloor system is 49 W/m^2. Hereafter, it is exposed how the systems operate when a zone is configured with the radiant stage.

  The control proposed by Airzone bases its operation on the room temperature (see Figure 3). While the ambient temperature is far from the defined set point ($T_{room} < T_{hysteresis}$), the solenoid valve is open ($T_{hysteresis} = T_{set\text{-}point}$ – Hysteresis with Hyteresis ∈ [1, 2, …, 5]). However, in order to be consistent with the set-point temperature set in the zone, when the room temperature is close to the desired set-point ($T_{room} \geq T_{hysteresis}$) a PWM control is performed on the solenoid valve so that the thermal inertia of the type of emitter is considered.

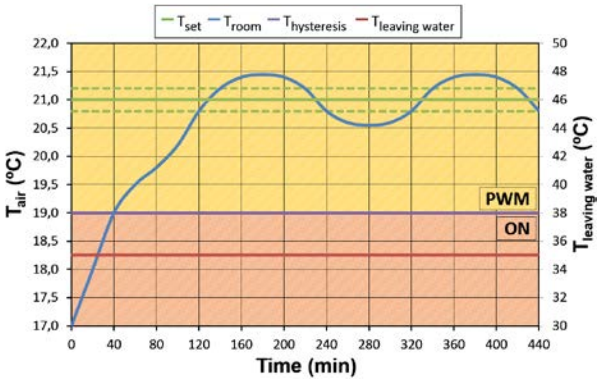

Figure 3. Airzone control for underfloor heating/cooling.

- Fan coil: it offers a quick thermal response.

  Airzone communication gateways allow the imposition of different temperatures of production based on the level of demand (see Figure 4).

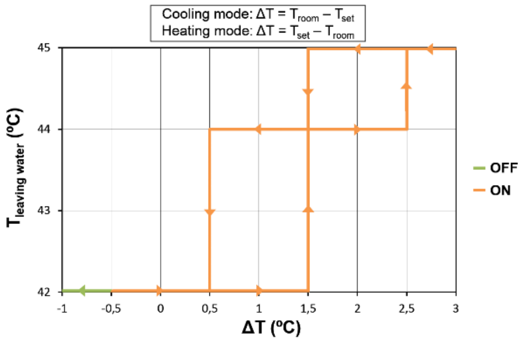

Figure 4. Airzone control for fan coil.

- Fan coil + Underfloor heating/cooling: it combines the advantages of both emitters. In this type of control, three ranges of operation are defined (see Figure 5).

  When the room temperature is very far from the set point, only the fan coils are activated. The objective is to rapidly increase the room temperature to reach the set point.

  Once the room temperature is close to the temperature of comfort, the underfloor unit is also activated. This way, both the underfloor unit and the fan coil operate together to reach the temperature of comfort. As the room temperature is closer to the room temperature, water production temperature is decreased and the speed of the fan coils is reduced.

  Finally, when the underfloor unit can keep the comfort temperature by itself, the fan coils are deactivated. The water production temperature is adapted to the operation with underfloor heating, which maximizes efficiency and comfort.

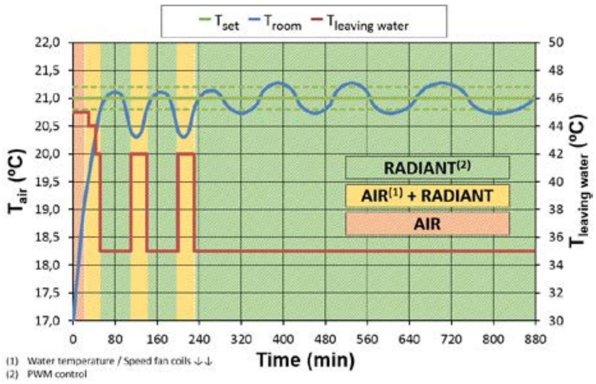

Figure 5. Airzone combined control (underfloor heating/cooling + fan coil).

②*Automatic control of the speed of the fan coils*. This feature avoids annoying draughts.

③*Regulation of the solenoid valves of underfloor heating/cooling*. This feature prevents room temperature from exceeding the set point.

④*Supervision of the relative humidity*. This feature prevents from condensation when using underfloor cooling.

3. STUDY CONDUCTED BY GEUMA

3.1. Controls analyzed

This study has considered a total of 6 control algorithms (see Table I) for heating mode. The first two are traditional controls for underfloor and fan coil units respectively, while others are Airzone control strategies.

No. of control	Terminal unit		Description
	Underfloor heating/cooling	Fan coil	
1	×		Non-zoned control for underfloor heating/cooling (from a single control point). Production temperature is constant.
2		×	Non-zoned control for fan coil (from a single control point). Production temperature and fan coil speed are constant.
3	×		Airzone control for underfloor unit.
4		×	Airzone control for individual fan coil (one in each zone).
5		×	Airzone control for ducted fan coil.
6	×	×	Airzone combined control (underfloor heating/cooling + fan coil).

Table I. Overview of the control strategies analyzed by GEUMA.

3.2. Case study

The case study is based on a single-family apartment situated on a block of apartments. It is composed of 5 individual zones (living room, kitchen, office, bedroom 1 and main bedroom). The corridor and the bathroom are considered as a single room that is not air-conditioned.

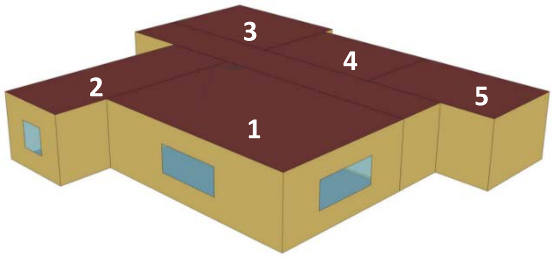

Figure 6. Three-dimensional view of the apartment.
(1-Living room, 2-Kitchen, 3-Office, 4-Bedroom and 5-Main bedroom).

A sensitivity analysis simulating several locations (Barcelona, Madrid, Malaga and Valladolid) is carried out to assess the influence of climate on energy savings and comfort that is achieved with each control. The climate files for every location under study are obtained from the EnergyPlus database [5]. It also examines the performance at partial load of the unit of thermal production, analyzing the influence of different curves of modification on the performance of the unit (COP) based on the partial load ratio (PLR). The different correction curves are displayed in Figure 7.

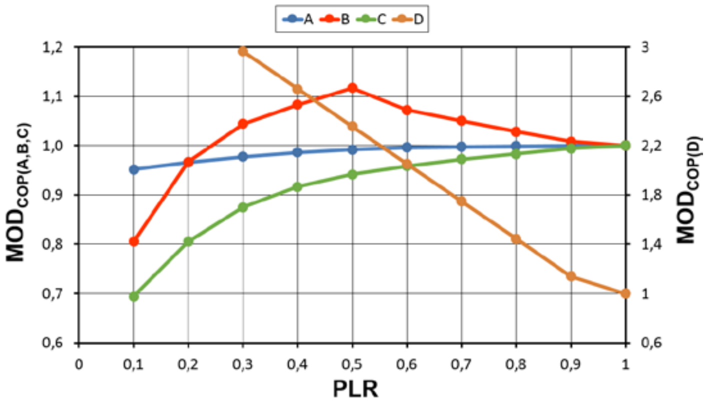

Figure 7. Performance modifiers (COP) based on the partial load ratio (PLR).

A, B and C curves have been obtained from [6], while D has been taken from the study entitled "*Report on Airzone zoning system and the comparison to non-zoned systems* ". In this collaborative study, between Airzone and GEUMA, experimental tests were performed in a double climatic chamber with a RZQ-B equipment from Daikin.

3.3. TRNSYS model

The heat pump model developed is based on the typical performance curves obtained from the catalogs of several manufacturers. In addition, the model can incorporate the modification of the performance of the unit (COP), caused by the fraction of load, using the equation (3):

$$\mathrm{COP} = MOD_{COP}(PLR) \cdot COP_{PLR=1} \tag{3}$$

Where $MOD_{COP}(PLR)$ is obtained from the curves collected in Figure 7.

On the other hand, the fan coil model consists of a battery water with consistent efficiency for each fan speed, which is derived from the values reflected in the catalogs of each manufacturer.

Finally, during the simulation performed on the underfloor unit, type705 component (based on the finite-volume method) is used. In the model, the insulation of the floor and the perimeter strip are assumed as ideal; therefore, the sides and the bottom of the floor will be adiabatic surfaces.

3.4. Results

During the simulations for the control algorithms that use underfloor heating/cooling as emitter (controls 1, 3 and 6), the set-point temperature has been set to 21 ºC while during the simulations for control algorithms that use fan coil as emitter (controls 2, 4 and 5), there are two different set points: 21 ºC and 23 ºC. The reason behind this is that, when controlling convective emitters with a set point of 21 ºC, the comfort criteria is not achieved (Percentage of People in Discomfort (PPD) is lower than 10%). This index is calculated using the following equation (4):

$$\mathrm{PPD}\ (\%) = 100 - 95 \cdot e^{-0.3353 \cdot PMV^4 - 0.2179 \cdot PMV^2} \tag{4}$$

Where PMV is the estimated mean vote that presents values between -3 (very cold) and 3 (very hot) and is result of several factors such as metabolic activity, type of clothes, dry temperature of the air, average radiant temperature, air speed and degree of humidity.

Table II displays the energy savings achieved with each control strategy, taking as a reference strategy no. 2 (non-zoned ducted control).

		Locality															
		Barcelona				Madrid				Malaga				Valladolid			
	Curve PLR	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Nº of control	1	37.3	35.7	38.2	15.7	35.5	33.4	36.6	9.6	45.6	44.5	46.1	34.3	36.0	34.6	36.8	18.1
	3	39.8	40.9	38.7	36.9	39.4	40.1	38.0	44.7	47.3	48.1	46.4	51.4	40.1	41.2	37.9	51.5
	4	20.9	23.8	15.7	37.6	24.8	27.6	20.8	50.3	21.5	21.7	14.4	44.9	24.3	27.7	19.6	54.4
	5	27.2	29.3	21.2	51.5	28.0	29.9	23.9	50.3	25.6	26.2	19.8	45.6	28.9	27.0	25.3	51.9
	6	31.2	30.8	29.7	28.9	28.9	28.9	28.3	25.2	40.5	40.8	40.1	36.9	27.3	27.9	26.1	29.6

Table II. Energy savings (%) of the different types of control analyzed compared to control no.2.

4. CONCLUSIONS

Airzone control strategies have been tested through simulation using TRNSYS software.

It has been demonstrated that the highest energy-saving strategy is control strategy number 3. However, during the first hours of operation, a discomfort situation arises due to the low temperature of the surface of the floor.

Control strategy 6 (combined option: underfloor heating/cooling and fan coil) is a remarkable option as it guarantees a perfect thermal comfort in all types of climate. Additionally, it ensures energy savings of between 25 % and 41 % according to several factors such as type of climate and performance at partial load of the unit of thermal production.

5. REFERENCES

[1] TRNSYS 17. http://www.trnsys.com.

[2] Daikin Altherma LT. http://www.daikin.es/products/index.jsp?id=ERLQ-CV3.

[3] UNE-EN ISO 7730:2006. Ergonomía del ambiente térmico. Determinación analítica e interpretación del bienestar térmico mediante el cálculo de los índices PMV y PPD y los criterios de bienestar térmico local.

[4] UNE-EN 1264:2012. Sistemas de calefacción y refrigeración de circulación de agua integrados en superficies.

[5] Ficheros climáticos EnergyPlus: http://apps1.eere.energy.gov/buildings/energyplus/

[6] K. C. Edwards and A. C. Finn. Generalized water flow rate control strategy for optimal part load operation of ground source heat pump system. *Applied Energy*, vol. 150, pp. 50 - 60, 2015.

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