CLIMAMED 2021 - 10th Mediterranean Congress of Climatization
Towards Climate Neutral Mediterranean Buildings and Cities
Lisbon, 11-12 May 2021

IMPACT OF ZONING HVAC CONTROL SYSTEMS IN USERS COMFORT AND ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS

Francisco Fernández Hernández[1]*, José Miguel Peña Suárez[2], Juan Bandera Cantalejo[2] and Mari Carmen González Muriano[2]

1: Energy Research Group of University of Málaga
Escuela de Ingenierías
University of Málaga
C/ Dr. Ortiz Ramos s/n. Campus de Teatinos. 29071 Málaga
e-mail: ffernandez@altracorporacion.es

2: Altra Corporation S.L.
Calle de Marie Curie, 21, 29590 Málaga
e-mail: jmpena@altracorporacion.es web: http://www.airzone.es

Keywords: Zoning HVAC control system, Energy Efficiency in Buildings, Sustainability certification methods

Abstract *Recent developments in sensors, electronics and communications have motivated a lot of research into designing and optimizing HVAC control systems for buildings, often referred to as smart buildings. In particular, the standard EN 15232 regulates the use of HVAC control systems in buildings including thermal zoning as a fundamental condition in the energy efficiency in buildings. It means an HVAC zoning system can adapt the HVAC system working regime to meet the thermal demand in each zone monitoring the air temperature according to users' preferences, in order to ensure thermal comfort in each zone and optimizing the HVAC system energy consumption. This is possible with a smart control system that can communicate with the HVAC system and control fan speed and set point temperature of the equipment's indoor unit. However, sometimes it is difficult to evaluate new technological solutions employing conventional software because they are still not modeled and included in their libraries.*

In addition to this energy policy legislation, several voluntary standards and sustainability assessment methods for buildings have been developed by independent bodies, as BREEAM and LEED methodologies which have emerged as the most widely used around the world.

This paper presents an analysis of a zoned control system compared to the case with no zoning control. A residential building is studied in terms of the BREEAM certification scheme, in different European cities. A model of the zoning system together with implemented HVAC control algorithms, developed in TRNSYS17, is presented and used for evaluating how the zoned control system guarantees a category B of thermal comfort and generates energy savings from 21-42%.

1. INTRODUCTION

A widely used HVAC system in Spain is the air-to-air heat pump. This system, whose indoor unit has a constant volume fan, can be configured to serve multiple zones. In these situations, the heat pump is controlled by a single thermostat located in one of the zones. However, in many buildings there is a variety of zones with different users and varying thermal loads can result in thermal discomfort. As an alternative, in some European countries, the standard EN 15232 [1] regulates the use of HVAC control systems in buildings including thermal zoning as a fundamental condition to ensure energy efficiency and thermal comfort. In other words, a zoned control system provides the ability to control each zone temperature independently, with a thermostat installed in each room, allowing the thermal demand in each of the zones to be determined, and the selection of an independent set-point temperature depending on the preferences of the user. When the set-point temperature in a zone is reached, a control signal is sent to the zone's motorised damper which interrupts the air supply to that room. So, in this situation, a zoned control system provides the ability to control each zone temperature independently, keeping the dampers of the zones which are in demand open, and closing the zones which are not in demand or not occupied.

However, although the zoned control system may be a good alternative to the traditional on/off non-zoned system, could be inefficient if it is not complemented with a control system that can act over the performance of the DX unit. In this sense, a new simple and robust control system is presented, based on the concept of thermal zoning, and the use of a communication gateway that allows the interoperability of different technologies. The communication gateway is a device that enables a two-way communication between the control board and the DX unit. This is only possible if the control system is able to read and set the operational parameters such as the operating mode, the fan speed or the set-point temperature. From the information of the DX unit and the thermal situation of each zone, an algorithm could be designed in order to optimize the performance of the installation, ensuring thermal comfort and achieving energy savings, by increasing the number of hours in which the DX unit works under part-load conditions.

Likewise, the use of zoned control system is very important in the voluntary standards and building assessment rating systems, such as the UK-developed Building Research Establishment–Environmental Assessment Method (BREEAM) and the US-developed Leadership in Energy and Environmental Design (LEED) [2]. However, in order to assess the credits awarded in energy-related categories, which have the most significant impact on the overall rating, these systems utilize computer-based Building Performance Simulation tools (BPS) [3] where, although the zoning control systems are an advanced solution, the simulation libraries of this conventional software do not provide for the division into zones and the singular control solutions of each company. Therefore, it becomes essential to have a mathematical model that describes its behaviour and quantify its potential impact.

The main objective of this communication is to show how including a zoning and control system in the building impacts voluntary sustainability certifications of buildings, in terms of energy and comfort, which are setting the tendency to follow in terms of energy sustainability. To this aim, the paper is structured as follows. Firstly, the comparison between zoning and non-zoning systems is described. Then, the modelling and the integration in Trnsys17 [4] is explained in detail. Finally, the case of study for a residential dwelling, in the BREEAM certification scheme, for different European cities, is presented and the results in terms of thermal comfort and energy consumption of the HVAC system are compared and evaluated.

2. HVAC ZONING CONTROL SYSTEM

2.1. Description of HVAC zoning control system.

Figure 1 shows the scheme of the system. The installation is composed of a ducted direct expansion inverter system, a control board, a communication gateway, motorised dampers, and thermostats. The control board receives the information from the rooms: the air temperature (Tz_1, Tz_2,…, Tz_n) and the set-point temperature ($Tset_{z1}$, $Tset_{z2}$,…, $Tset_{zn}$) imposed by users, from the thermostat placed in each zone (orange dashed lines). With this information, the algorithm imposes, thanks to the communication gateway, the control strategy with the configuration of the next elements (black lines):

- The operation mode according to the user's preferences (stop, ventilation, cooling, or heating).
- The internal unit's fan speed (F) that is dynamically selected according to the airflow rate demanded by each zone, the number of zones in demand, and the temperature difference between the zone and the air set-point temperature.
- The set-point temperature of the DX unit based on the set-point temperatures in each zone, the air temperature, and the return air temperature to the DX unit, considering the effect of thermal inertia in each zone.
- The position of the dampers (D) of each room which control the amount of air supplied to the zones (Dz_1, Dz_2,..., Dz_n),
- The limitation of the set-point temperatures of the rooms.

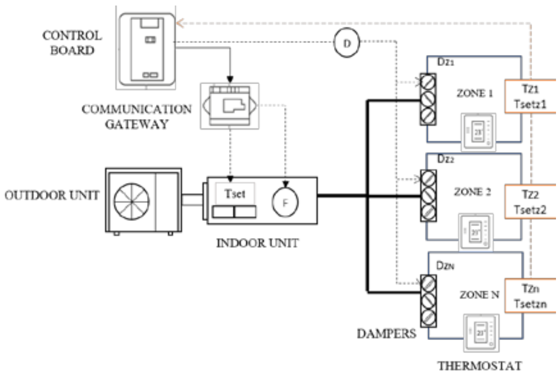


Figure 1. Control zoned system scheme.

2.2. Modelling the HVAC zoning control system in Trnsys.

Mathematical models of all HVAC systems defined in the previous section have been run using TRNSYS 17. As described in Figure 1, the control system acts at two levels: zones and system. At zone level, the system has been modelled as an off/on control which is continuously turning on and off the HVAC unit depending on if the temperature of the zone is inside or outside the dead-band temperature range (typically 0.5ºC) with respect to the air set-point temperature. As each zone has its own thermostat and motorized damper, when the zone air temperature is in the comfort dead-band, a control signal is sent to the zone's motorized damper which interrupts the air supply to the zone. Also, the dampers are closed in the zones that are not occupied. Dampers will be opened when the HVAC unit is on and closed when it is off.

Concerning the system level, the control algorithm sets the indoor unit fan speed and set point temperature as a function of the thermal behaviour and needs of each zone. The algorithm selects the indoor unit fan speed according to the total weight of zones in thermal demand, which depends on the number of zones in demand and, considering a type of discrete control, the number of speeds available in the fan. Each zone has an assigned weight that depends on its thermal importance in the building. Then, the total weight of zones in thermal demand is the ratio between the sum of the weight of the zones which are in demand with respect to the total sum of the weight of the zones. From this value, the speed of the fan is selected as shown in Table 1.

Table 1 Selection of the fan unit's speed

Fan selected	Speed stages available			
	V2	V3	V4	V5
1	[1-50]	[1-34]	[1-25]	[1-20]
2	[51-100]	[35-67]	[26-50]	[21-40]
3	-	[68-100]	[51-75]	[41-60]
4	-	-	[76-100]	[61-80]
5	-	-	-	[81-100]

On the other hand, the algorithm controls the DX unit set-point temperature and, also, allows attenuating the effects of the air temperature stratification. The system checks the difference between the zone temperature and the established setpoints in each zone and takes the maximum of these values (ΔT_{max}). A new DX unit setpoint temperature is calculated as follows, considering the ΔT_{max} value and the thermal inertia of each zone, together with the return air temperature measured by the indoor unit.

3. CASE OF STUDY. RESULTS

3.1. Description of the dwelling

The present study has been modeled using TRNSYS, one of the most advanced simulation programs on the market. Mathematical models of all HVAC systems defined in the previous section have been run using this calculation platform. The results for a home simulated in the regions of Milano, Paris, München and London are shown in Figure 3.

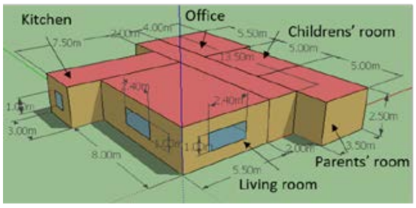


Figure 3. Floor plan of the home. 3D representation with measurements

The enclosures are representative of the different regulations prevailing in each country.

3.2. Results. Energy.

In the Energy category, the "Reduction of energy use and carbon emissions" requirement offers up to 15 points in recognition of those buildings which are designed to minimize operational energy consumption. Moreover, with the "Energy monitoring" requirement up to 2 points are available. Thanks to the system's strategies designed to control and manage the HVAC installation, energy savings are achieved and therefore also a reduction in carbon emissions. Figure 4 shows the results obtained for the comparison of these systems for the different cities under study.

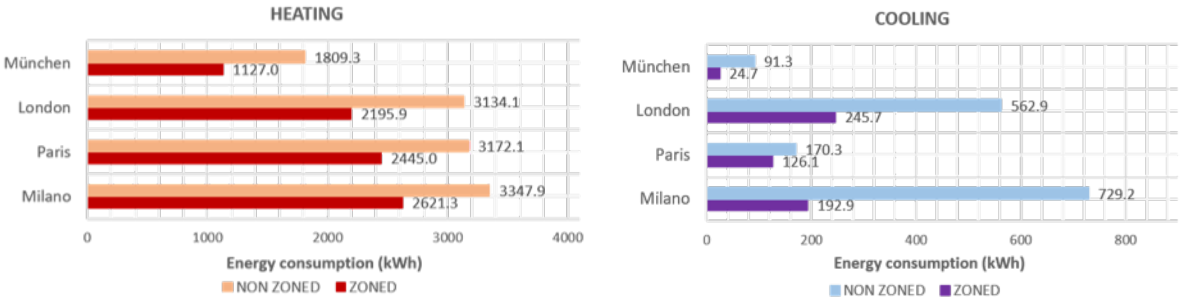


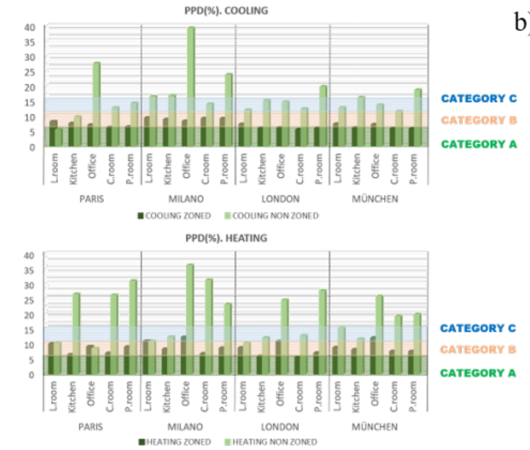
Figure 4. Comparative energy consumption and energy savings.

By way of example, in the case study, the potential for energy savings zoned control system was assessed for the four cities modelled. The savings are 21-37% in heating mode, and 25-73% in cooling mode, improving the BREEAM certification in the Energy category.

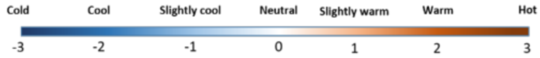
3.3. Results. Health and Wellbeing. Thermal comfort.

In the Health and Wellbeing category, up to 3 points are available in the "Thermal zoning" and "Thermal comfort" requirements. This is based on the calculation of the PPD and PMV comfort parameters, and on compliance with category B of comfort, according to the EN ISO 7730 [5]. In standard conditions of comfort associated with levels of clothing, metabolic rate and relative air speed, a comparison was made of the PPD and PMV parameters in a zoned and non-zoned system. Figures 5a and 5b show the comparison of the average PPD and PMV parameters, both evaluated in each city for heating and cooling periods.

a)



b)



CITY	ZONE	PMV			
		COOLING		HEATING	
		ZONED	NON ZONED	ZONED	NON ZONED
MILANO	Living room	-0.3	-0.5	0.5	0.5
	Kitchen	-0.2	-0.7	0.4	1.0
	Office	-0.2	-0.8	0.6	0.4
	Childrens' room	-0.2	-0.5	0.3	1.6
	Parents' room	-0.2	-0.8	0.4	1.1
PARIS	Living room	-0.2	-0.1	0.4	0.5
	Kitchen	-0.2	0.3	0.2	1.0
	Office	-0.3	-1.0	0.5	0.4
	Childrens' room	-0.1	-0.3	0.3	1.6
	Parents' room	-0.1	-0.5	0.4	1.1
LONDON	Living room	-0.3	-0.5	0.4	0.4
	Kitchen	-0.2	-0.6	0.3	0.3
	Office	-0.2	-0.6	0.4	0.7
	Childrens' room	-0.2	-0.5	0.2	0.5
	Parents' room	-0.2	-0.6	0.3	1.0
MÜNCHEN	Living room	-0.2	-0.4	0.4	0.7
	Kitchen	-0.1	-0.7	0.3	0.1
	Office	-0.3	-0.6	0.4	1.1
	Childrens' room	-0.1	-0.4	0.2	0.7
	Parents' room	-0.1	-0.4	0.2	0.8

Figure 6. Comparative energy consumption and energy savings.

In a zoned system, the minimum comfort requirements demanded of category B with a PPD lower than 10% and a PMV below 0.5 are met in each of the areas of the home for the four cities modeled, while the non-zoned system obtains good results in the living room zone, but the rest of the zones experience significant undercooling in zones in cooling mode and overheating in heating mode.

4. CONCLUSIONS

The present study demonstrates the advantages of a zoned climate control system in terms of energy consumption and thermal comfort when compared to a non-zoned system, in a residential building and subjected to different climatic conditions. These benefits contribute positively to the possibility of obtaining BREEAM certification for the building, obtaining fundamental points in key areas such as Energy and Health when compared to a non-zoned HVAC system.

REFERENCES

[1] European standard EN 15232-1:2017 on "Energy efficiency in buildings – Influence of BuildingAutomation and Control and Building Management".

[2] Suzer O. Analyzing the compliance and correlation of LEED and BREEAM by conducting a criteria-based comparative analysis and evaluating dual-certified projects. Building and Environment 147 (2019): 158-170.

[3] Schwartz Y., Raslan R. Variations in results of building energy simulation tools, and their impact on BREEAM and LEED ratings. A case of study. Energy and Buildings 62 (2013) 350-359.

[4] ISO 7730:2005. Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.