Innovative and energy efficient algorithm for HVAC-R systems control based in the ISO 7730 thermal comfort standard

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Keywords: Control algorithm, HVAC-R, thermal comfort, ISO 7730.

Abstract. This paper presents the development of an innovative and energy efficient algorithm for Heating, Ventilating, Air Conditioning and Refrigeration (HVAC-R) systems control based in thermal comfort standards. Most of the actual control of these systems is done by thermostats that measure only the air temperature but don't take into account the air humidity neither the occupant's individual parameters like their activity and clothing. Thus, these systems require frequent adjustment of thermostats set-point in order to promote thermal comfort to the occupants. This paper presents a control algorithm that uses as set-point, not the air temperature, but the Predicted Mean Vote (PMV) index, which is defined by the thermal comfort ISO 7730:2005 standard and depends on more parameters than just the air temperature. Thus, it provides a more efficient control and greater comfort to the occupants. Besides this innovative aspect concerning the control algorithm, another one is related to the wireless and energy harvesting sensors and actuators that can be used to provide much more flexibility and energy autonomy.

Introduction

Presently, the analysis of the final end use of energy in the EU-27 [1] shows three dominant sectors, namely transport, industry and households. The shares of these last two sectors was around one quarter each of the EU-27's final energy consumption in 2009.

Energy efficiency in buildings is mandatory but the occupants' thermal comfort must be preserved. In general, thermal comfort improves morale and productivity as well as health and safety. In uncomfortable hot and cold working environments, its significance is related to unsafe working behaviors due to deterioration of people's ability to make decisions and/or perform manual tasks [2, 3]. Thermal comfort is can be defined as the 'state of mind that expresses satisfaction with the existing environment' [4]. Currently, on thermal comfort research there are two common approaches: static heat balance models of human body based on laboratory studies and adaptive models based on field studies. The most known static heat balance model, is the lab-based Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied people (PPD) method developed by Fanger [5]. This model is described as a function of four environmental variables (air temperature, mean radiant temperature, air relative humidity and air velocity) and two personal variables (activity and clothing level of the occupants).

The sole purpose of a Heating, Ventilating, Air Conditioning and Refrigeration (HVAC-R) system is to maintain desired environmental conditions in an indoor space [6]. HVAC-R systems are generally necessary in buildings to provide or remove heat, mainly through convection or radiation. Air filtering, dehumidification, and humidification systems can be added. Typically, in most systems the distribution medium is air or water/steam depending if it is a central forced air system (convective heat transfer) or a central hydronic system (radiative heat transfer and convection), respectively. The former uses as terminal devices: diffusers, registers and grilles to provide heated or cooled air. The latter uses radiators, radiant panels or fan-coil units to transfer heat. Both systems affect directly the PMV index. The former mostly through the air temperature parameter and the latter mostly by the mean radiant temperature parameter. Depending on the relative humidity and personal variables, in heating and cooling modes both parameters have respectively a minimum and maximum values to ensure thermal comfort. Energy efficiency and thermal comfort are improved if the control system takes into account the parameters involved in the PMV index.

Heating and cooling equipment are typically controlled by a wall thermostat. Currently, microelectronic models are replacing the conventional wall thermostats, allowing to set the heating and cooling equipment at different temperature levels depending on day-time. This kind of modes perform numerical calculations and act accordingly to a control algorithm which uses sensors information to command the actuators.

HVAC-R systems control algorithm based in the PMV index

This paper presents a control solution using a microelectronic model for a typical HVAC-R system in order to provide the desired environmental conditions to occupants based on several variables rather than just the air temperature. This condition is accomplished using the PMV index defined on the thermal comfort ISO 7730 (2005) standard [7]. The individual parameters are fixed in the microcontroller (MCU) memory with the more usual values according to the building/room location and activity level since it can't be measured on real time. Apart the air velocity, the environmental parameters are estimated on real time enabling the MCU to set the HVAC-R system actuators behavior in order to maximize the occupants comfort. If there is little variation from the individual parameters fixed priorly, the MCU can indirectly predict the necessary heat to add or remove from the room based on these environmental parameters measured locally by the sensors. Usually, sensors are located in each room, requiring a signal transmission method and a communication protocol with the controller unit. ASHRAE [8] review the various methods for signal transmission used in HVAC-R systems. Typically, in most of HVAC-R systems, the signal transmission is made by wire, but it is known that installation costs are between 20% to 80% of the total cost of sensors and control points. Therefore, reducing or eliminating installation costs have a dramatic effect on the overall system cost. Depending on the communication protocol used, the signal transmission can be made by wire or wireless. Currently, wireless sensors and actuators are developed to improve the ability to acquire information from the physical world. With technology development, some of these devices are energy harvesters [9-10].

The main advantage of this algorithm is based on the MCU ability to adjust the operation of the actuators integrated in the HVAC-R system according not only to the air temperature but also to the estimation of the mean radiant temperature, air humidity and mean air velocity on the room. Thus, the occupants don't have to be constantly adjusting the thermostat set-point trying to find the most comfortable temperature that suits them every time. This algorithm can be applied in any HVAC-R system which uses solenoid or motorized control valves/dampers (open/close). Other advantage, not concerning the control algorithm but the communication between the control system components rely on the use of wireless and energy harvesting sensors and actuators, enabling an easier and faster installation without wires and maintenance free. Some minor disadvantages are the use of more sensors and the fact of being an on/off control strategy. Nevertheless, the cost of proportional valves/dampers required by a Proportional-Integral (PI) control system is greater.

Proposal for control system configuration

The control system is designed to regulate the air temperature, t_{air}, or the mean radiant temperature, *MRT*, of the room in order to provide thermal comfort to the occupants. Thus, the device is regularly calculating an approximation of the PMV index using data from the temperature and humidity sensors installed in each room. Based on this index, the MCU controls the actuators aperture time and consequently providing more or less heat to the room in order to achieve a thermal comfort near class A category ($-0.2 < PMV < 0.2$).

For this control algorithm operation is needed a set of three general sensors (indoor air temperature, wall temperature and air relative humidity) in each room to estimate the PMV index. The PMV calculation is dependent of the HVAC-R system and requires: (1) in panel heating systems, the surface temperature to estimate the *MRT* and (2) in forced air systems, the discharged air temperature. In hydronic systems the actuators that typically regulate the water flow are: pumps (single or variable speed) and solenoid/motorized valves (open/close or proportional). To control forced air systems are used usually fans with variable-speed motors and automatic dampers (open/close or proportional). This control algorithm is suited to heating and cooling systems, with open/close actuators, which can be controlled using wire or wireless relays.

The flowchart shown in Fig. 1 illustrates the proposed control algorithm. The controller begins by reading the telegrams sent by the sensors in each room. Following, it calculates the PMV index in each room. Depending on the PMV value, the controller sets a target temperature for the panel surface or discharged air accordingly to Table 1.

In the first loop, a routine starts the HVAC-R system operation. Another routine runs to determine if the PMV range is the same of the last loop in order to adjust correctly the *OC* (open/close) virtual variable. This algorithm is for heating and cooling systems. So, if the PMV index is less than 0.5 the heating equipment is activated and the cooling one is deactivated and vice-versa if that index is superior. The 0.5 value was chosen instead of 0 to prevent the cooling equipment to start due to some inertial increase of the PMV value. The remainder of the flowchart shown in Fig. 1 details the control algorithm procedure.

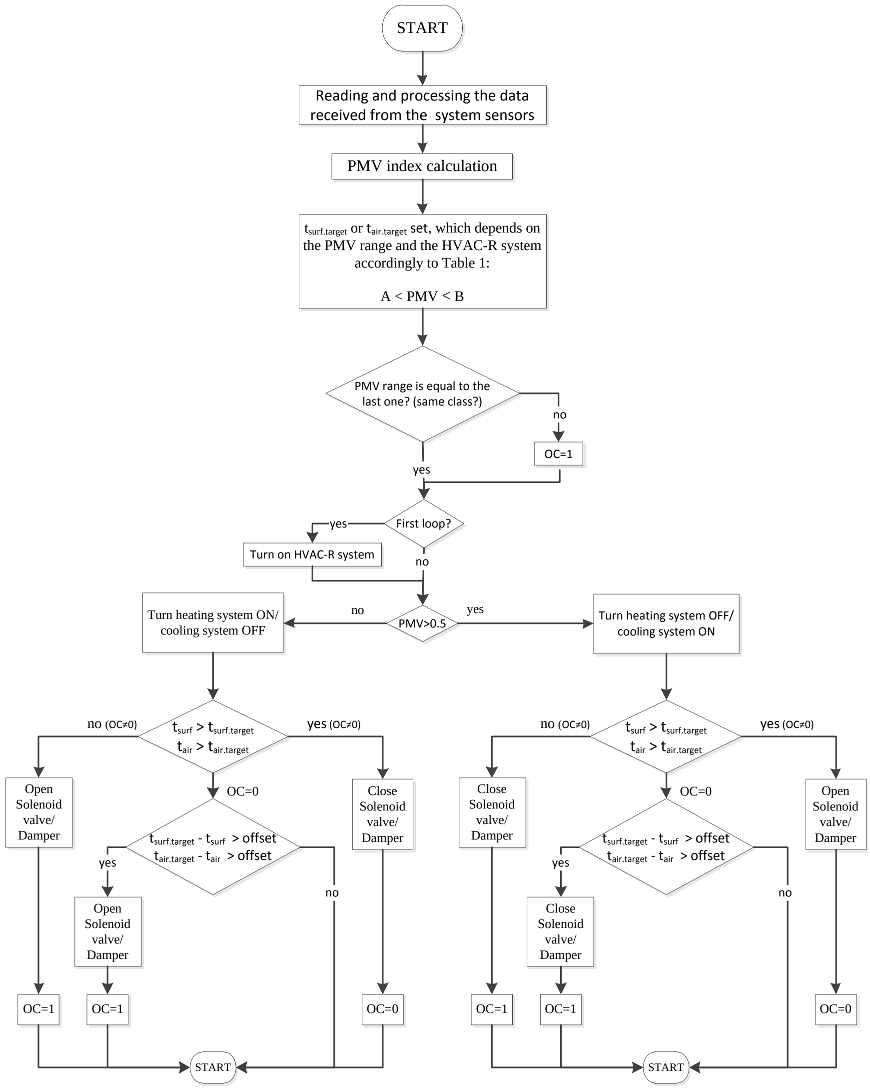

Fig. 1 - Flowchart of the controller program based on the PMV index.

Table 1 – Possible temperature target values and offsets at different PMV index ranges that can be implemented in the controller program.

PMV		*Class*	$t_{surf.target}$ (ºC) *Radiant floor heating*	*Offset example*	$t_{surf.target}$ (ºC) *Radiator*	*Offset example*	$t_{air.target}$ (ºC) *Forced air system*	*Offset example*
A	*B*							
-	-0.7	Cold	29.0	0.5	100.0	2.0	30.0	1.0
-0.7	-0.5	C	27.0	1.0	80.0	5.0	27.0	2.0
-0.5	-0.2	B	25.0	2.0	60.0	10.0	23.0	3.0
-0.2	0.2	A	23.0	3.0	40.0	15.0	20.0	4.0
0.2	0.5	B	21.0	2.0	20.0	10.0	17.0	3.0
0.5	0.7	C	20.0	1.0	15.0	5.0	13.0	2.0
0.7	-	Hot	19.0	0.0	10.0	2.0	10.0	0.0

Conclusions

In this work was developed a control algorithm which offers an alternative strategy to control HVAC-R systems, more flexible and efficient that ensures a better thermal comfort with little or no intervention by the user. It is an alternative to the actual thermostat control-based systems which neither create nor maintain a functional and comfortable indoor environment unless with user intervention, causing the system to operate inefficiently if the occupant don’t intervene. Once the major type of automatic control valves/dampers in HVAC-R systems are open/close it’s easier to upgrade the older systems to this new one. This strategy shows some advantages comparing to other systems as the occupants achieve thermal comfort without being constantly changing the thermostat temperature set point (useful for example, in hospitals or nursing homes). It also can be used in office and domestic buildings offering with minimum energy costs, a better comfort, improving occupants’ morale and productivity as well as health and safety. A minor disadvantage is the need of more sensors. Although, it is an on/off control strategy using open/close valves/dampers instead of proportional control making use of more expensive proportional valves/dampers. A set of control buttons for user interface can be added to the control system allowing the occupant to adjust to its desire the comfort level.

Acknowledgments

This study is framed in the anchor-project "InovEnergy - Energy Efficiency in Agro-Industrial Sector" activities encompassed within Action Programme of InovCluster: Association of Agro-Industrial Cluster of Center region. The study was funded by the National Strategic Reference Framework (QREN 2007-2013) - COMPETE/POFC (Operational Programme for Competitiveness Factors), SIAC - Support System for Collective Actions: 01/SIAC/2011, Ref: 18642).

References

[1] Eurostat, Consumption of Energy - European energy statistics. Eurostat, European Commision. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy

[2] J. Singh, Impact of indoor air pollution on health, comfort and productivity of the occupants. Aerobiologia 12(1) (1996), p. 121.

[3] Information on http://www.hse.gov.uk/temperature/thermal/explained.htm

[4] ANSI/ASHRAE Standard 55. Thermal Environmental Conditions for Human Occupancy. ASHRAE, Inc. (2004).

[5] P.O. Fanger, Thermal comfort: analysis and applications in environmental engineering. USA: McGraw-Hill (1970).

[6] ASHRAE: 2008 ASHRAE Handbook – HVAC Systems and Equipment (SI Edition). ASHRAE, Inc. (2008).

[7] ISO: ISO 7730, 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. International Organization for Standardization (2005).

[8] ASHRAE: 2009 ASHRAE Handbook – Fundamentals (SI Edition). ASHRAE, Inc. (2009).

[9] EnOcean: Energy harvesting wireless technology (http://www.enocean.com) (accessed 2012, April, 11).

[10] G. Batista, P.D. Gaspar and P.D. Silva, Control, regulation and command system of hydronic radiant floors heating by wireless and energy harvesting sensors and actuators, in: International Conference on Materials and Applications for Sensors and Transducers (IC-MAST 2012), May 24-28, Budapest, Hungary (2012).