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Implementation of Pmv Based Thermal Comfort Sensing for Energy Efficient Air Conditioning

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Abstract: For energy efficient control of HVAC systems this paper presents an invasive control of air conditioners by implementing a thermal comfort index proposed by Fanger. This improves the indoor comfort level by considering six comfort related variables and a genetic algorithm optimization is used to solve the PMV model which is more accurate than particle swarm optimization. This evaluates the thermal sensation in range numbered from -3 to +3 and based on the sensation level the controller operates in energy efficient way to reduces the cost. The wireless sensor network measures the value of temperature, relative humidity, air velocity, mean radiant temperature, metabolic rate. Clothing is considered as constant. The simulation of feedback controllers such as fuzzy, fuzzy PID and on/off is used and their cost response for time is plotted. Compared with the conventional fixed temperature settings, the proposed methods efficiently save energy 17%. The control methods and efficiency of controller characteristics are validated by results.

Key words: Non Linear dynamics · Genetic Algorithm · Predicted Mean vote (PMV) · PID controller · Fuzzy PID controller

INTRODUCTION

Thermal comfort and indoor air quality are important factors for energy efficient buildings design [1]. Indoor environment quality has become an important area of research because of its influence on human health and energy consumption profile [2-4]. The indoor environment affects indoor physical environment, subsequently health and quality of life of its occupants. The energy scarcity problem has become acute in recent past because of the rapid un-sustainable growth in building sector. This is primarily due to changes in lifestyles, increased dependence on artificial energy and also health related issues [5-7]. A recent study has put forth that 30 to 40% of total natural resources are oppressed by the buildings for producing energy and moreover, air-conditioning systems consume about 40%-50% of the total electricity use in buildings [2]. Therefore, energy control of air conditioning systems in buildings deserves research. Due to the increasing use of unitary air-conditioners, there has been an increase in electricity consumption during summer substantially. Therefore, the use of better control techniques for steady temperature control and energy saving has become a major topic in the study of air-conditioning systems. Unitary systems mainly use the ON/OFF method as temperature control, which causes unstable room temperatures. The changes in room temperatures, from various unitary systems working at the same time, create large surges in energy consumption; therefore, this paper proposes various control schemes to achieve both energy savings and steadiness in the temperature of air-conditioning systems. Thermal comfort and indoor air quality are important factors for energy efficient buildings design. It has become an important area of research due to its influence on human health and energy consumption profile, it uses a wireless sensor network using predicted mean vote (PMV) proposed by fanger, as a thermal [3] comfort index around occupants in buildings. The network automatically maintains thermal comfort by means of changing compressor's speeds and control the opening of expansion valves and control fan speeds in air conditioners based on computed thermal comfort levels. Compared with conventional fixed temperature settings, the present control methods effectively maintain the PMV[4] value within the range of and energy is saved more than 30% in this study.

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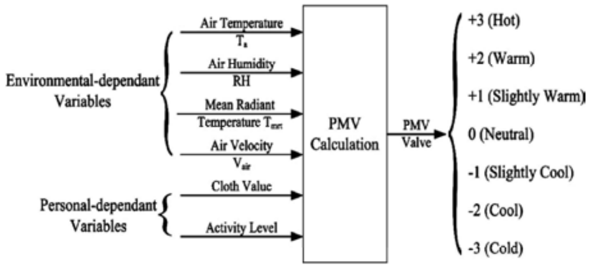

Fig. 1: Thermal Sensation Scale of PMV

Thermal Comfort Index and Pmv Model: The PMV model includes four environmental variables such as air temperature, relative humidity, air velocity and average radiation temperature and two human factors such as thermal load on the body. It can quantitatively evaluate the thermal sensation and adopt a range of sensation levels, numbered from -3 to 3 for quantization. The thermal load on the body varies with personal factors and environment factors. The personal factors consist of activity and clothing insulation. The PMV model is a nonlinear and multivariable model and it is not easy to find the analytical solution of the PMV model. There are many optimization techniques available both traditional and non-traditional. The traditional optimization techniques fail to converge on a feasible solution in many cases. The Non-traditional optimization techniques differ from the conventional traditional optimization techniques in that it produces optimal results in a short period of time. Most of the traditional optimization techniques based on gradient methods have the possibility of getting trapped at local optimum depending upon the degree of non-linearity. Hence, these traditional optimization techniques do not ensure global optimum and also have limited applications. The problems considered are Non Linear optimization which is single objective where the constraints are only bounds for environmental variables. Artificial intelligence strategies such as ant colony optimization, genetic algorithms, particle swarm algorithms, neural networks or the combination of the above strategies are useful for modeling nonlinear characteristic and solving complicated problems. PMV can be computed using the following equation.

$$PMV= [(0.028 + 0.3033e\text{-}0.036m)*(M\text{-}W)\ 0.000699(M\text{-}W) - Pa - 0.4(M\text{-}W) - 58.15 - 0.0173M\ (5.867 - PA) - 0.0014M*(34 - Ta) - 3.96.10\text{-}8\ fcl\ (Tcl + 273)4 - (Tmrt + 273)4 - fcl.\ hc\ (Tcl - Ta)]$$

$$Tcl = [35.7 - 0.28(M - W)\text{-}0.155Icl\ 3.9610\text{-}3\ fcl\ (Tcl + 2273)4 - (Tmrt + 273)4 - fcl.hc\ (Tcl - Ta)]$$

$$hc=[2.38(Tcl\text{-}Ta)0.25]\ \text{for}\ [2.38(Tcl - Ta)0.25 = 12.1vvair\ ]$$
$$[12.1\ vvair\ ]\ \text{for}\ [2.38(Tcl - Ta)\ 0.25 = 12.1\ vvair\ ]$$

The parameters are defined as follows:

PMV : Predicted mean vote.
M : Metabolism (W/m^2).
W : External work, equal to zero for most activity
I_{cl} : Thermal resistance of clothing (Clo).
Fcl : Ratio of body's surface area.
T_a : Air temperature.
T_a : Air temperature.
T_{mrt} : Mean radiant temperature.
V_{air} : Relative air velocity (m/s).
P_a : Partial water vapour pressure (Pa).
H_c : Convection heat transfer coefficient (W/m^2).
T_{cl} : Surface temperature of clothing.

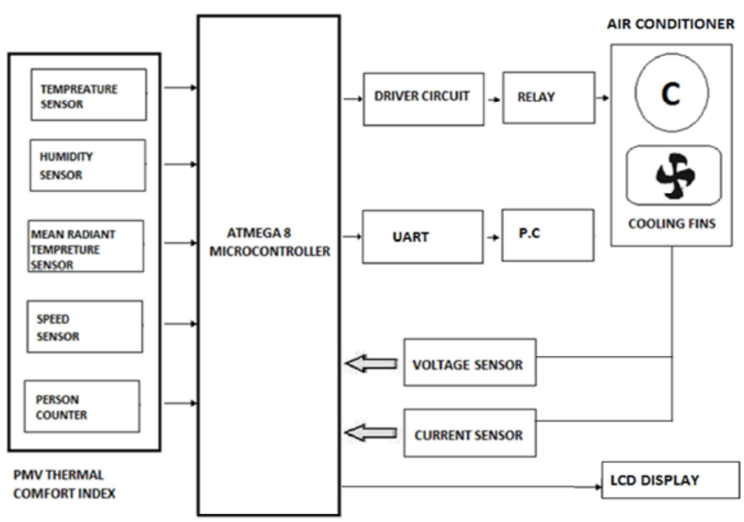

Fig. 2: SYSTEM FRAMEWORK

System Design: Fig. 2 shows the whole system, which consists of the PMV portable mobile measurement, controller unit and power measurement system of air conditioner. First, the measurements of air temperature, RH, air velocity, metabolic rate and mean radiant temperature are converted into a standard voltage or current signal through signal conditioning and then sent into the integrated acquisition instrument. The integrated acquisition instrument wirelessly transmits the analogy signal to the computer-aided PMV measurement system for data acquisition, PMV calculation and further analysis. Based on the calculated PMV value the controller controls the compressor speed and cooling fin speed of the air conditioner. Thus the energy efficiency of air conditioner can be obtained as the watts consumed by it. The watts can be measured as the product of current and voltage. The entire PMV value, energy efficiency, time used can be displayed in P.C through the USB coordinator.

Hardware Configuration: The thermal comfort measurement system hardware mainly consists of an acquisition instrument and a computer. The acquisition instrument is divided into sensor module, control module and power supply. The computer functions as the monitoring terminal. This configuration can reduce the temperature change caused by the heating of electronics and the data acquisition module. Fig. 2 shows the physical hardware configuration of our system. To measure the indoor air temperature and RH, the temperature and humidity sensor is deployed; whose sensitivity is 12 °C/V and 20%/V, respectively. Its power supply is 24 V dc and its output signal is in the range of 0-5 V. Similarly, an air velocity sensor module is used to measure the indoor air velocity, which has a 24 V dc voltage supply, an output voltage signal of 0-10 V and the sensitivity of 0.5 (m/s)/V. Radiant temperature is related to the amount of radiant heat transferred from a surface. It depends on the material's ability to absorb or emit heat, namely emissivity. The mean radiant temperature experienced by a person in a room with sunlight streaming in is based on how much of his or her body is under the sunlight.

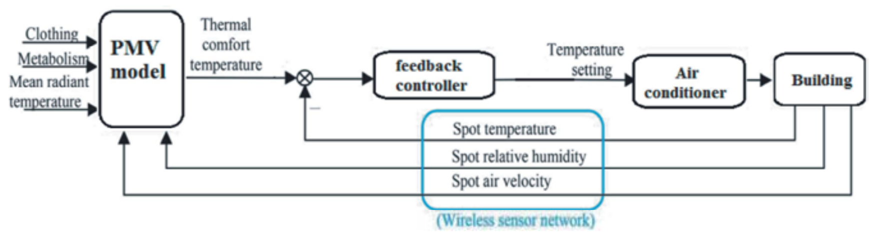

Fig. 3: Control Block Diagram of Air Conditioner.

The sensitivity of the sensor is 15 °C/V with a 24 V dc voltage supplies and a module output voltage signal of 1-5 V. The whole system shares a common-mode voltage and a common-mode noise rejection capability so that the quality of the measurement can be effectively improved.

Control Methods: The feedback controller is responsible for automatically adjusting the indoor temperature, compensating the difference between the temperature measured by wireless sensor network. Here, fuzzy control and self tuning fuzzy PID control are adopted as the feedback controller.The genetic algorithm is adopted for optimization of PMV model so as to determine optimized thermal comfort temperatures. In optimizing PMV models, the genetic algorithm is more accurate than particle swarm optimization. Their performance for saving energy cost is evaluated. The network automatically controls air conditioning by means of changing compressor's speeds and control the opening of expansion valves and control on solved PMV model. The feedback controller is responsible for automatically adjusting the indoor temperature, compensating the difference between the temperatures measured by wireless sensor network. The wireless sensor network module measures the existing thermal comfort from the building through temperature sensor, relative humidity sensor, man radiant sensor and air velocity sensor.

Fuzzy Controller: Fuzzy control based on the fuzzy set theory was developed initially by Mamdani. Fuzzy control was also adopted to improve the performance of air conditioning systems. In this study, input variables are the temperature error (E) and the temperature error change (CE). The difference between the desired and the indoor measured temperatures is E, where e(n) is the current temperature error, is the previous temperature error and T is the sampling time. The output variable is the Pulse width to the compressor of air conditioner

Self tuning Fuzzy PID Controller: This control scheme is built on the basis of a PID controller. With the aim of both taking into account-energy buildings, a hybrid PID-fuzzy controller is proposed, as the combination of the two just-mentioned control structures based on PID and fuzzy controllers: the"parallel" structure. With this combination one can take advantage of the properties of the two structures, filling in their respective gaps. The Fuzzy controller

Experimental Setup and Simulation: First a thermal model of house is constructed. This model calculates heating costs for a generic house. It loads the information about the house such as

- Defines the house geometry
- Specifies the thermal properties of house materials.
- Calculates the thermal resistance of the house.
- Provides the thermal characteristics.
- Defines the cost of electricity.
- Specifies the initial room temperature.

The heat cost and indoor versus outdoor temperatures is plotted on the scope. Heat gain is defined as energy transferred from conditioner to room and heat loss is defined as energy transferred from to room external environment. Room temperature is also taken in consideration. The model defines geometry of room which takes length, breath and width of room. No of windows and area of wall is used to model equivalent resistance. Cost is defined as the ratio of unit energy consumed. Fuzzy logic system and fuzzy PID system is constructed and simulated to run for 48 hours using previous stated rules and member ship function stated before and cost is determined as rupees. Error and change in error is given as input to the fuzzy inference system and pulse width is obtained as output to control the operation of conditioner. Error and change in error uses Gaussian membership function and pulse width uses triangular membership function. Defuzzification method used is here is centroid method. It takes centre value of input functions. The ranges are in values of 0 to 1 for elimination complexity in computation. The performances of different controllers and their corresponding energy efficiency is being tabulated above. It is infered that the cost saving of self tuning fuzzy PID controller is maximum about 21% and fuzzy logic controller cost efficiency is about 17 % while comparing to closed loop system. Also mathematical model for the system is not obtained. The entire approach is not about obtaining a transfer funtion for the system. This makes tuning of the feedback controller easy.

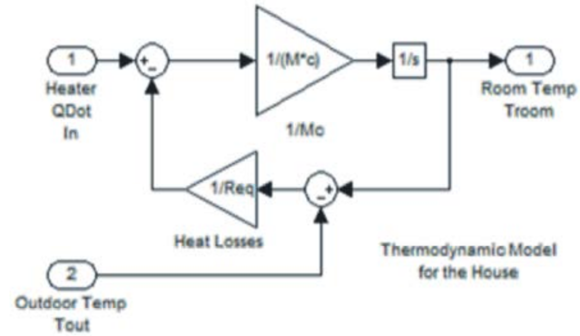

Fig. 4: Simulink block diagram for house sub system.

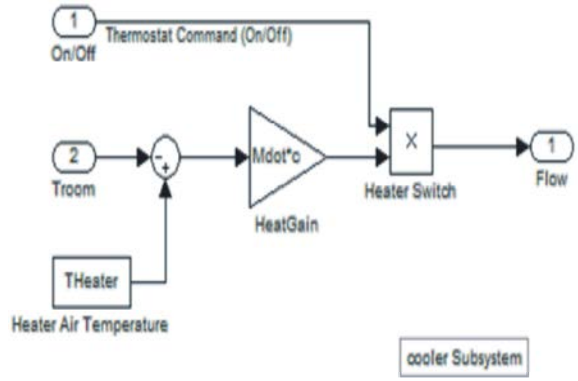

Fig. 5: Simulink block diagram for cooler sub system.

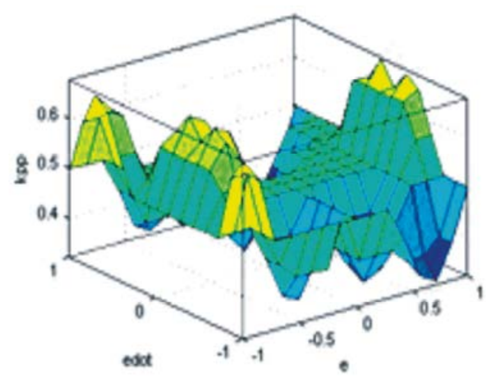

Fig. 6: Fuzzy PID surface for error and change in error

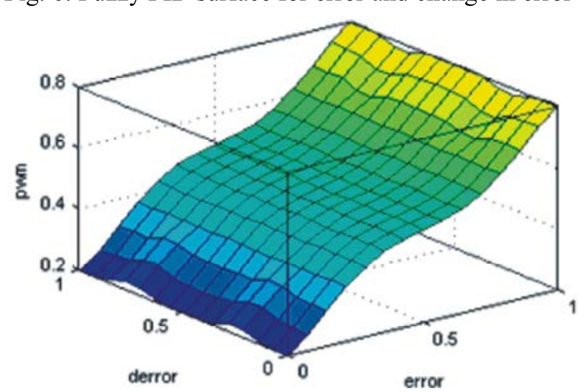

Fig. 7: Fuzzy surface for error and change in error

Experimental Results: Experiments were performed for three control methods. The first control method is the conventional method, i.e., fixed temperature setting. The other two control methods belong to the PMV model with the fuzzy feedback control and with digital self-tuning control. The air conditioner is operated to track the thermal comfort temperature by the last three controllers. The PMV model computes thermal comfort temperature in real time based on the desired PMV, measured air velocity and humidity. Performances of the three methods are compared based on PMV response curves. The cost of the conventional method changes more severely than the other two controllers. The PMV values of the three nonconventional controllers maintain between 0 and 0.5. The three perform better than the conventional method because the inverse PMV model can real time generate proper comfort temperatures, which are in turn continuously tracked by each of three controllers. Furthermore, according to the measured indoor temperature around occupants and the thermal comfort temperature, the three nonconventional controllers appropriately change the temperature setting in the air conditioner, which is equivalent to adjusting cooling capacities at any time.

CONCLUSION

Thermal comfort or sensation (PMV) is considered to be acceptable if the value lies between -0.5 to + 0.5. In the experiment conducted using fuzzy logic and non-traditional optimization techniques the thermal sensation takes the value 0.129 and -0.5 respectively. Hence the thermal comfort of the office and residential buildings is found to be optimum. From the above we can conclude that the thermal sensation and indoor environmental quality is within the acceptable range. Experiments have been carried out by using three control methods. PMV response curves of every controller fluctuate due to 1 C increment of air-conditioner temperature commands. Therefore, it remains to develop methods and devices to maintain PMV near 0 and smooth responses while saving energy. Thus by implementing the present control method can maintain thermal comfort and saves 30% more energy than the conventional method. For accurate estimation, the clothing insulation can be determined by measurement on heated mannequins and the metabolic rates can be estimated from measuring CO and O2 in a person's Exhaled air. Therefore, it is desired in future work to devise wearable or non-contact sensors to measure the values of metabolic rates and clothing insulation and improve the human factor measurement process. Also advanced controllers such as model predictive controller can be implemented for further optimization and to reduce power consumption. Also performance evaluation of model can be computed using artificial neural network or adaptive neuro fuzzy inference system for solving PMV models.experiment conducted using fuzzy logic and non-traditional optimization techniques the thermal sensation takes the value 0.129 and -0.5 respectively. Hence the thermal comfort of the office and residential buildings is found to be optimum. From the above we can conclude that the thermal sensation and indoor environmental quality is within the acceptable range. Experiments have been carried out by using three control methods. PMV response curves of every controller fluctuate due to 1 C increment of air-conditioner temperature commands. Therefore, it remains to develop methods and devices to maintain PMV near 0 and smooth responses while saving energy. Thus by implementing the present control method can maintain thermal comfort and saves 30% more energy than the conventional method. For accurate estimation, the clothing insulation can be determined by measurement on heated mannequins and the metabolic rates can be estimated from measuring CO and O2 in a person’s Exhaled air. Therefore, it is desired in future work to devise wearable or non-contact sensors to measure the values of metabolic rates and clothing insulation and improve the human factor measurement process. Also advanced controllers such as model predictive controller can be implemented for further optimization and to reduce power consumption. Also performance evaluation of model can be computed using artificial neural network or adaptive neuro fuzzy inference system for solving PMV models.

Table I: Comparison of Measured Energy Consumption

Methods	Energy Consumption (kWh)	Energy Saving (%)	Advantage
Conventional	3.89	-	Simple
Inverse PMV model with FF-Fuzzy[b]	2.44	37.3	Easy realize
Inverse PMV model with self tuning control	2.61	32.9	Adaptive

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