



# Intelligent system based on wavelet decomposition and neural network for predicting of fan speed for energy saving in HVAC system

Servet Soyguder

Firat University, Department of Mechanical Engineering, 23279 Elazig, Turkey

## ARTICLE INFO

### Article history:

Received 26 May 2010

Received in revised form 25 October 2010

Accepted 7 December 2010

### Keywords:

HVAC system

Energy saving

Fan motor speed predicting

Air flow control

Temperature control

Wavelet packet decomposition (WPD)

Neural network (NN)

## ABSTRACT

In this study, a heating, ventilating and air-conditioning (HVAC) system with different zones was designed and tested. Its fan motor speed and damper gap rates were controlled by two controllers (i.e. a PID controller and an intelligent controller) in real time to minimize its energy consumption. The desired temperatures were realized by variable flow-rate by considering the ambient temperature for each zone and evaporator. The PID parameters obtained in our previous theoretical work using fuzzy logic were utilized in this study. The experimental data used in this study was collected using a HVAC system built in a laboratory environment. The fan motor speed and damper gap rates were predicted using wavelet packet decomposition (WPD), entropy, and neural network (NN) techniques. WPD was used to reduce the input vector dimensions of the intelligent model. The suitable architecture of the NN model is determined after certain trial and error steps. According to test results, the developed model performance is at desirable level. Efficiency of the developed method was tested and a mean 95.62% recognition success was obtained. This model is an efficient and robust tool to predict damper gap rates and fan motor speed to minimize energy consumption of the HVAC system.

© 2010 Elsevier B.V. All rights reserved.

## 1. Introduction

In recent years, intelligent modeling studies related to HVAC system have become popular because of the rising concern about environment. The developments in intelligent methods make them possible to use in complex systems modeling. Intelligent modeling was firstly used to increase the robustness of existing models but now it is used to obtain new models. The comfort of the people in their living environment is partially dependent on the quality and temperature of air in their building. Three interrelated systems are used to provide the desired air temperature and quality. These are the ventilating system, the heating system and the air conditioning system. The purpose of a HVAC system is not only to provide thermal comfort, but also to maintain comfortable air quality. On the other hand, energy saving in this system is one of the most important issues because of its cost. Hence, it is necessary to understand the aspects of minimum energy consumption in order to design an effective HVAC system.

Many authors have employed for variable frequency drives method which is routinely used to vary pump and fan motor speed in heating, ventilating and air conditioning of buildings [1]. In these applications, speed control is used to regulate the flow of water or

air because speed adjustment is an energy efficient method of flow control. The aim of this study is to present a thermodynamic model for an air-cooled centrifugal chiller which is developed specifically to analyze how the speed control of the condenser fans influences the chiller's COP under various operating conditions [2,3]. Moreover, the other study of the same authors investigates how the use of variable speed condenser fans enables air-cooled chillers to operate more efficiently [4]. Besides, variable fan speed control is increasingly used for chiller compressors to save power when chillers are operating at part load. The power saving comes from the improved efficiency of the motors when operating at a lower speed under part-load conditions [5,6].

In the last decade, many studies were performed in HVAC systems and buildings based on intelligent methods. These researches are related to modeling HVAC systems and thermal comfort for buildings such as predictions of HVAC system parameters, process control of HVAC systems, estimating HVAC systems output parameters characteristics and humidity and temperature control of buildings. The developments in intelligent methods make them possible to use in nonlinear analysis and control. In addition to PID control of HVAC systems, the various studies using intelligent methods were presented. Many NN models were developed to predict temperature, humidity, heat transfer, optimal time, pressure coefficients and energy consumption [7–13]. Soyguder and Alli studied about the estimation of humidity and temperature in a HVAC system [7]. Kalogirou et al. discuss about estimation of pres-

E-mail addresses: [ssoyguder@firat.edu.tr](mailto:ssoyguder@firat.edu.tr), [servetsoyguder@yahoo.com](mailto:servetsoyguder@yahoo.com)

## Nomenclature

|                                  |  |
|----------------------------------|--|
| $\dot{m}_{ca}$                   | the mass flow-rate in fan channel (kg/h)                     |
| $\dot{m}_{z1a,in}$               | the mass flow-rate entered to Zone-1 (kg/h)                  |
| $\dot{m}_{z2a,in}$               | the mass flow-rate entered to Zone-2 (kg/h)                  |
| $Q$                              | convection and transmission heat (J)                         |
| $\dot{m}_{za,in} = \dot{m}_{za}$ | the mass flow-rate entered to each zone (kg/h)               |
| $C_v$                            | specific heat capacity of air at constant heat (kJ/kg K)     |
| $C_p$                            | specific heat capacity of air at constant pressure (kJ/kg K) |
| $T$                              | inner temperature (°C)                                       |
| $T_n$                            | instant temperature (°C)                                     |
| $T_{n-1}$                        | vicious circle temperature (°C)                              |
| $T_{ca,in}$                      | canal temperature (°C)                                       |
| $O_i$                            | output of ANFIS layer  |
| $A_i$                            | linguistic label   |
| $w_i$                            | firing strength of rules                                     |
| $\psi_{i,j}(x)$                  | the wavelet expansion functions                              |
| $C_{ij}$                         | expansion coefficients                                       |
| $\phi(x)$                        | scaling function   |
| $\psi_m$                         | the decomposition filter                                     |
| $P$                              | entropy  |
| $y_{pre,m}$                      | predicted value  |
| $t_{mea,m}$                      | measured value   |

sure coefficients in a naturally ventilated test room using artificial neural networks [8]. Yang et al. performed energy prediction for a building using adaptive artificial neural networks [10]. Yang et al. used application of artificial neural network to predict the optimal start time for heating system in building and HVAC system [11]. Sablani et al. developed an ANN model for calculating thermal conductivity of a variety of bakery products under a wide range of conditions of moisture content, temperature in bakery story [12]. In another study, Ben-Nakhi and Mahmoud worked about general regression neural networks (GRNN) and designed the GRNN and trained to investigate the feasibility of using this technology to optimize HVAC thermal energy storage in public buildings as well as office buildings [14]. Consequently, many studies about artificial neural network and intelligent method can be mentioned [15–19].

In this study, based on the above literature the required fan motor speed to minimize energy consumption and the required damper gap rates for obtaining the desired temperatures of two different zones for each time step were found using intelligent control algorithm. The damper gap rate is also proportional with air flow rate. Besides, in this study, an intelligent system for fan motor speed and air flow control of HVAC system based on WPD-NN is presented. All simulations have shown that the proposed method is more effective and controls the systems quite well.

The outline of the present paper is as follows. In Section 2, the model of the HVAC system is presented. The design of the considered real-time HVAC system is given Section 3. Section 4 briefly describes the wavelet transform (WT), WPD and NN. In Section 5, model procedure was designed about the wavelet packet and NN structure for intelligent modeling. Then, in Section 6, the experimental and modeling results are presented. In the experiment, the fan motor speed and the damper gap rate being proportional with air flow rate have been controlled using WPD-NN. In Section 7 was discussed the strengths and weaknesses of the present study. Finally, conclusions are given in Section 8.

## 2. The model of the HVAC system

The mathematical model of the system obtained according to the thermodynamic laws. However, obtaining of the mathe-

matical model of the cooled zone by considering all parameters is quite difficult. For this reason, we consider some assumptions. More information about the assumptions can be seen in the author's other work [7]. Every testing laboratory has its own HVAC system including cooling unit, electric heater (resistance), fan, damper motors, thermocouples and evaporator of refrigeration plant to maintain the temperature of the Zone-1 and Zone-2 space.

In this study differs from previous work [7], the mass flow-rate ( $\dot{m}_{ca}$ ) absorbed from the cooling unit does change because the supply fan speed is controlled for energy saving. At the same time, the mass flow-rate of the air entering to the zones changes depending on the temperatures of the zones. The continuously variations of the input mass flow-rate ( $\dot{m}_{z1a,in}$ ) Zone-1 and ( $\dot{m}_{z2a,in}$ ) Zone-2 are realized by regulating the gap rates of dampers into the entrances of zone-channels, depending on the control output signals. The continuity equation of the controlled system can be found as:

$$\dot{m}_{ca} = \dot{m}_{z1a,in} + \dot{m}_{z2a,in} + \dot{m}_{sva,out} \quad (1)$$

The mass flow-rate ( $\dot{m}_{sva,out}$ ) in Eq. (1) belongs to the safety valve discharging the excessive air coming from the zones.

Fig. 1 shows the schematic diagram of the modeled system in this study. The heat transfer from the outside to the system can be stated as:

$$\frac{dT}{dt} = \frac{Q + \dot{m}_{za} \cdot C_p (T_{ca,in} - T_n)}{\dot{m}_{za} \cdot C_v} \quad (2)$$

More information about HVAC system model can be seen in the author's other work [7].

## 3. The design of the considered real-time HVAC system

In this experimental study, the cooling process was performed for the two zones having the different properties as shown in Fig. 2(a and b). The volume of the each zone has 0.5 m<sup>3</sup>. The all surface areas of Zone-1 were isolated with the isolation materials (strafor) while those of Zone-2 were not. The aim of this choice is to clearly see the steady-state differences of reference temperatures. The cooled air transfer has been realized from the main channel having the supply fan to the region of Zone-1 and Zone-2 as seen in Fig. 2(a and b). The channel flow cross-section area is 0.02 m<sup>2</sup>. The 0° position of the damper (opening angle ( $\theta$ )) is the full open position and the system has the maximum air mass flow-rate. Maximum air mass flow rate is 50 kg/h for the 0° position of the damper (opening angle ( $\theta$ )). Air mass flow rate changes as direct proportional of opening angles ( $\theta$ ) between the 0° position of the damper and the 90° position of the damper. At the same time, air mass flow rate changes as direct proportional of fan motor speed. Furthermore, fan motor speed is dependent on evaporator temperature, as seen from the block diagram in Fig. 3. The 90° position of the damper is the closed position of the damper and the cooled air cannot pass through the zones. Air mass flow rate is controlled by a stepper-driven throttle damper-valve. More information about the design of the considered real-time HVAC system can be seen in the author's other work [7].

In testing real-time HVAC system, the air compressor and the evaporator were used for cooling the system and the required air flow was supplied by controlled of the dampers placed on the entrance ducts of each zone. There are the damper motors in the entrances of the each zone, controlled by intelligent control algorithm, as seen from the block diagram in Fig. 3. The air supply fan first absorbs 5 °C air from the evaporator, then sends air to the zones. In this study, the fan motor speed is also controlled by intelligent

متن کامل مقاله

دریافت فوری ←

**ISI**Articles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات