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# Self-tuning dynamic models of HVAC system components

Nabil Nassif [a,*], Samir Moujaes [a], Mohammed Zaheeruddin [b]

[a] Department of Mechanical Engineering, University of Nevada Las Vegas UNLV, USA
[b] Department of Building, Civil & Environmental Engineering, Concordia University, Canada

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ABSTRACT

A great majority of modern buildings are equipped with Energy Management and Control Systems (EMCS) which monitor and collect operating data from different components of heating ventilating and air conditioning (HVAC) systems. Models derived and tuned by using the collected data can be incorporated into the EMCS for online prediction of the system performance. To that end, HVAC component models with self-tuning parameters were developed and validated in this paper. The model parameters were tuned online by using a genetic algorithm which minimizes the error between measured and estimated performance data. The developed models included: a zone temperature model, return air enthalpy/humidity and $CO_2$ concentration models, a cooling and heating coil model, and a fan model. The study also includes tools for estimating the thermal and ventilation loads. The models were validated against real data gathered from an existing HVAC system. The validation results show that the component models augmented with an online parameter tuner, significantly improved the accuracy of predicted outputs. The use of such models offers several advantages such as designing better real-time control, optimization of overall system performance, and online fault detection.



## 1. Introduction

Several papers have been published in the past few years describing methods for minimizing the energy costs associated with the operation of heating ventilating and air conditioning (HVAC) systems in commercial buildings. One of the effective ways of achieving energy efficiency has been to install Energy Management Control Systems (EMCS) in buildings to optimize HVAC system operation while maintaining indoor environmental conditions to meet comfort and functional needs [1]. The EMCS include control strategies that adjust optimal set points and operating modes to minimize overall system energy use [2–4]. In addition, the EMCS provides the opportunity to tune effectively the parameters of the local-loop controllers [5]. These measures when properly implemented reduce energy use, enhance comfort, and increase component life. Another important application is the fault detection and diagnosis. The advanced EMCS can detect and diagnose the faulty equipment and recommend specific maintenance actions (component level) and detect abnormal energy consumption in buildings (whole-building level) [6,7].

The single most important factor in the design of efficient EMCS is the need for accurate dynamic models of HVAC systems. Depending on the type of energy management functions and the accuracy required, the models can vary from simple to more detailed. However, it is of practical importance to develop simple, yet accurate and reliable models to better capture the real dynamic behavior of the subsystems and overall system over the entire operating range. In general, models can be grouped into two types [8]: forward models and data-driven models. Forward models may need detailed physical information which may not always be available. On the other hand, the accuracy of the data-driven models could be an issue when they work outside the training range. A pure black box model, totally dependent on the experimental data, is also not likely to be robust enough. Therefore, physical considerations must be included to make the system models more robust [9].

To that end, dynamic models of HVAC components with capability for online tuning of parameters are proposed in this paper. These models ensure more reliability and accuracy. The structure of the model consists of a simple physical model to represent the system, a set of tuning parameters integrated into the model to improve accuracy and a means to intelligently update the parameters online with the measured data of the system. When the model parameters take their default values of zeros, the models revert to the initial physical models. The model parameters are periodically adjusted online by an intelligent optimization

* Corresponding author at: Engineer at Building Energy Solutions and Technology Inc., 3910 South I.H. 35, Ste 225 Austin, Texas 78704 USA. Tel.: +1 214 893 5734.
*E-mail address:* nnassif@bes-tech.net (N. Nassif).

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method such as a genetic algorithm to reduce the error between measured and predicted data.

This paper covers the models required for the design of controllers and supervisory control strategies. The models include: a zone temperature model, return air enthalpy/humidity and $CO_2$ concentration models, a cooling and heating coil model, and a fan model. The physical aspects of these models are covered in several studies [10–14]. Also, in a previous study a recursive least squares method combined with energy balance approach was employed for the identification of system parameters [15]. However, in this paper, the parameters to be tuned on line are clearly identified and incorporated into the models to improve accuracy of predictions. The models developed in this paper can be used for different applications. However, depending on the application, the inputs and the outputs of the models have to be clearly defined. The inputs of the models for a specific application may become outputs in other application. Thus, the validation and discussion presented in this paper focuses on control and optimal operation applications. The proposed models are validated against real data gathered from an existing HVAC system.

## 2. HVAC and EMC system configuration

Fig. 1 shows a schematic diagram of a typical HVAC system and EMCS. Included in this schematic are the proposed self-tuning models and how they interact within the overall system. A typical HVAC system that uses variable air volume (VAV) control is illustrated in Fig. 1. It consists mainly of (i) the return and supply fans, (ii) the outdoor, discharge, and recirculation dampers, (iii) the air handling unit (AHU) with components such as filter and cooling and heating coils, (iv) the pressure-independent VAV terminal boxes, and (v) the local-loop controllers (i.e. $C_1$, $C_2$, and $C_3$). The supply air temperature is controlled by the controller ($C_1$). The duct static pressure is controlled by the controller ($C_2$). The zone air temperature is controlled by the controller ($C_3$).

The EMCS collects the measured data "real data" from components or subsystems. At the same time the models integrated into the EMCS compute outputs from which a set of "estimated data" is obtained. The parameters of the models are tuned by a genetic algorithm (GA) at each sample time such that the error between the real and estimated data is minimized. It is expected that the model with updated parameters will better match the real behavior of the subsystems and overall system. Since the model is always tuned by using online real data, the optimal values that produce the best estimated performance may lead to the best performance. If the models are used in the design of optimal control strategy, the operation sequence is as follows. At each time interval (e.g. 10 min), the genetic algorithm is used for tuning the model parameters by reducing the error between measured and estimated sample data *S* (real and estimated data) taken from previous periods. The dynamic component models are then used for determining optimal set points and PI controller parameters for the next operating interval *J* (e.g. next 10 min).

## 3. Genetic algorithm for tuning model parameters

Given a set of measured data (MD) and estimated data (ED) for a sample *S*, the model parameters can be tuned with respect to the

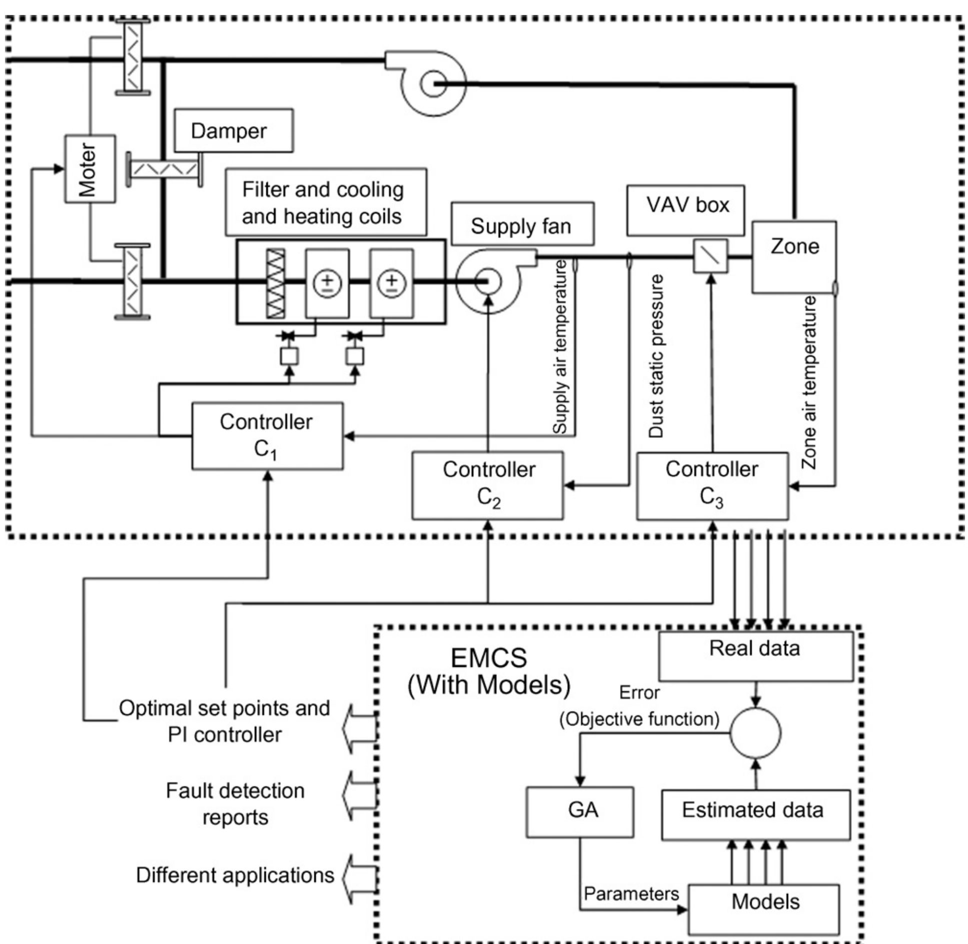


**Fig. 1.** Typical HVAC system and EMCS along with the proposed models.