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Neural networks based predictive control for thermal comfort and energy savings in public buildings

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ABSTRACT

The paper addresses the problem of controlling a Heating Ventilation and Air Conditioning (HVAC) system with the purpose of achieving a desired thermal comfort level and energy savings. The formulation uses the thermal comfort, assessed using the predicted mean vote (PMV) index, as a restriction and minimises the energy spent to comply with it. This results in the maintenance of thermal comfort and on the minimisation of energy, which in most conditions are conflicting goals requiring an optimisation method to find appropriate solutions over time. A discrete model-based predictive control methodology is applied, consisting of three major components: the predictive models, implemented by radial basis function neural networks identified by means of a multi-objective genetic algorithm; the cost function that will be optimised to minimise energy consumption and maintain thermal comfort; and the optimisation method, a discrete branch and bound approach. Each component will be described, with special emphasis on a fast and accurate computation of the PMV indices. Experimental results obtained within different rooms in a building of the University of Algarve will be presented, both in summer and winter conditions, demonstrating the feasibility and performance of the approach. Energy savings resulting from the application of the method are estimated to be greater than 50%.

1. Introduction

In European Union (EU) countries, primary energy consumption in buildings represents about 40% of the total energy consumption and, with variations from country to country, half of this energy is spent for indoor climate conditioning [1–3]. It is estimated that the use of efficient energy management systems in buildings can save up to 8% of the energy consumption in the entire EU [4]. Around 83% of the EU dwellings were constructed before 1990 and about 50% of them before 1970 [1]. Therefore it is of fundamental importance to control efficiently the existing HVAC systems, in order to decrease energy usage and increase compliance with the European Directive (2010/31/EU) on the energy performance of buildings [3].

The use of Artificial Neural Networks (ANNs) in various applications related with energy management in buildings has been increasing significantly over the recent years. Within this area, ANNs have been mainly applied in several aspects of HVAC control methodologies [5–11], and in forecasting energy consumption [12–20].

The authors have advocated, in past publications [21,22], the use of model based predictive control (MBPC) with the purpose of efficiently controlling existing HVAC systems in large public buildings. The present paper is the natural follow-up of this past work, where a remote, wired data acquisition system was set-up in a secondary school in the South of Portugal. The performance of physical models, based on energy and mass balance integral-differential equations were evaluated against black-box, neural network models for the purpose of modelling the inside air temperature. It was found that the role of these two different types of models is complementary, and not competing. While physical models can be used in the phase of the project of buildings, and to assess the consequences of possible buildings modifications, data-driven models such as neural networks should be used for the on-line control of HVAC systems. Simulations showed the potential of MBPC for the control of air-conditioned systems, indicating both the better regulation and the energy savings obtained.

This article is organised as follows. The experimental setup is described in Section 2. As a PMV formulation is employed, its computation is discussed in Section 3. To implement the MBPC strategy, several neural network models are used. Their design is briefly addressed in Section 4. Section 5 describes the branch & bound (BB)

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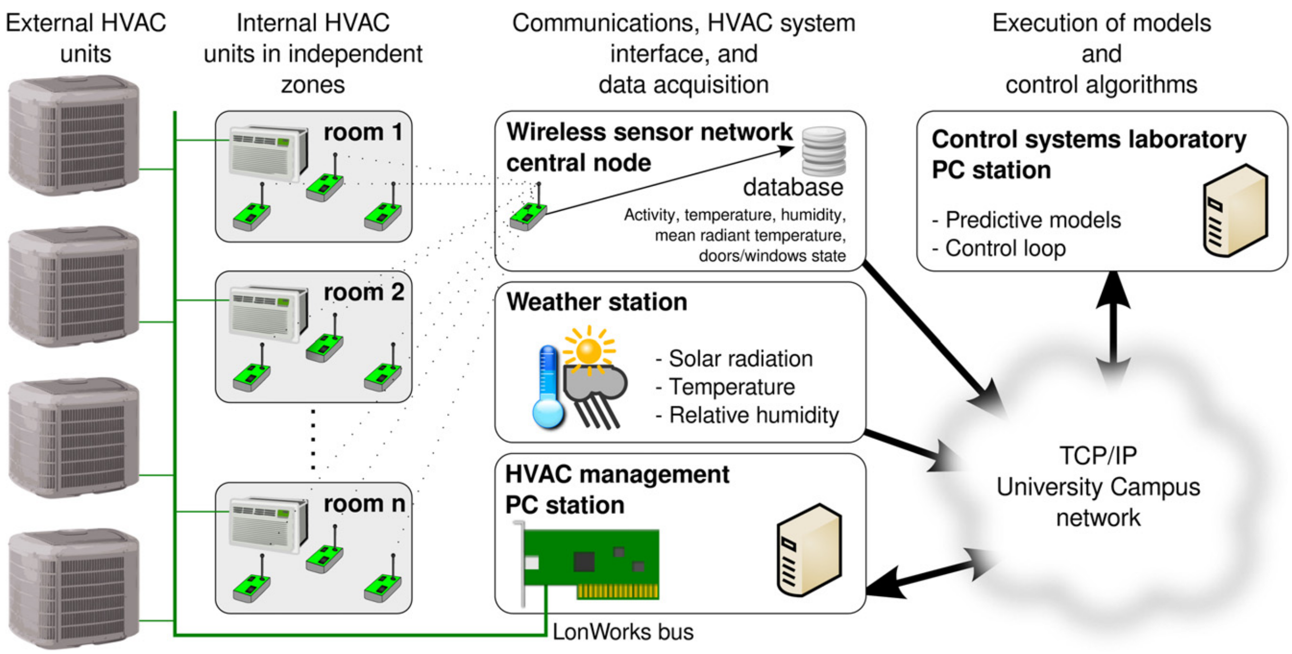

Fig. 1. Overview of the experimental set up used.

search technique that is employed to implement the MBPC, which in turn is formulated in Section 6. Several experiments are then presented in Section 7, both in summer and winter conditions. The paper ends with conclusions and a description of future work.

2. Experimental setup

HVAC control experiments were conducted in three areas of one building used by the Faculty of Sciences & Technology of the University of Algarve, in the south of Portugal. In total, 16 locations (labs, offices, corridors) are now equipped with data acquisition devices and their internal HVAC units may be independently controlled with new algorithms, and monitored. For the work that is going to be presented, four rooms were used, denoted by the letters A, B, C, and D. Rooms A and B are adjacent with walls facing west and north (only A). Room C shares the same corridor with A and B and has walls exposed to the north and east. These three rooms are on the second floor. Finally, room D is directly below room C with walls exposed to the north and east.

A weather station located in the campus provides air temperature (T_{ao}), air humidity (H_{ao}), and global solar radiation (R_{sg}) measurements. All the elements involved are connected to the TCP/IP network, enabling a PC station in the control systems laboratory to monitor and control any of the rooms. Fig. 1 provides an illustration of the system integration.

2.1. Wireless sensor networks

WSNs are rapidly gaining popularity, and are being used in a vast spectrum of applications. One of the most active area being building automation [23,24]. Each of the rooms where the experiments were conducted has WSN nodes with sensors to monitor the air temperature (T_{ai}), air humidity (H_{ai}), globe temperature (T_g), the state of windows and doors (open/closed), and movement using a passive infra-red activity monitor. T_g is measured by means of a black globe thermometer [25] and its measurement is then used to determine the mean radiant temperature, T_{mr} [26].

The WSNs have a star topology, where each unit is collecting information once per minute and sending it to a central node with storage and database capabilities. Each node consists of one Tmote Sky platform connected to the required sensors. This platform is an IEEE 802.15.4 standard compliant device that uses the TinyOS [27] operating system.

In each room one WSN node is installed in the wall, nearly 1.75 m above the floor, which measures T_{ai} and H_{ai} using SHT11 sensors from Sensirion. Approximately in the middle of the room, at a height of roughly 2 m above the floor (for security reasons), the black globe thermometer is installed. It consists of a mate black painted sphere with a diameter of 125 mm with a Tmote (and its temperature sensing device) at its centre. Plastic was used instead of copper, which is more commonly found in this application, because it was easily available, but also because according to [26] it overcomes an undesirable high time constant that appears when copper is employed. Infra-red sensors are installed at one corner of the room to monitor activity. Digital information, both from the magnetic switches in doors and windows and from the movement detector are wired to one of the existing WSN nodes.

2.2. HVAC system

The HVAC system used in the experiments is composed of 3 independent Mitsubishi Variable Refrigerant Flow (VRF) systems, each one with an outdoor air cooled inverter compressor unit (denoted in the sequel as outdoor unit), located on the building roof, connected to ceiling concealed ducted indoor units (denoted as interior units). In each independent room there is at least one internal unit, with its own wall controller. The system can be centrally managed by a PC management station to which all the units are connected via a LonWorks communication bus. This station is able to monitor and control many aspects of all the HVAC system, through the Mitsubishi LMAP02 interface [28]. Those of major interest for the experiments are: specifying a temperature set-point for a given unit, switching the internal unit on or off, and disabling the local controller so the occupants cannot operate the internal unit while experiments are being conducted.

The model of the interior units used in the experiments described in this paper is the PEFY-P63VMM and the model of the outdoor units is the PUHY-250YMF-C.