Characterisation of Thermal Inertia in University Buildings Using Continuous Temperature Monitoring Data

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Abstract

The article presents a methodology for analysing the thermal behaviour of buildings and HVAC systems using temperature data. Thermal inertia was assessed by calculating the rate of indoor temperature increase (°C/h) during the heating period (5–9 a.m.) with MATLAB, to improve HVAC scheduling, enhancing energy efficiency, IEQ, and grid interaction.

Introduction

In tertiary buildings, heating, ventilation and air conditioning (HVAC) systems account for a significant proportion of total energy consumption and can account for approximately half of total building consumption [1]. Therefore, optimal control of these systems is essential to maintain satisfactory indoor environment quality (IEQ) in individual rooms with minimum HVAC energy use [2]. To this end, the integration of the Internet of Things (IoT) in building automation systems (BAS) [3], including sensors, actuators, intelligent control, networking and communication, and software platforms, has great potential for energy savings in buildings.

Materials and methods

The University of Zaragoza has opted for an IoT infrastructure to monitor the indoor temperature of a large number of spaces in its different buildings. There are currently more than 1500 sensors in 63 buildings on 6 different campuses, most of them wireless with LoRaWAN technology and others wired from the automation system (WinCC).

A methodology has been proposed to analyse the behaviour of the University of Zaragoza buildings and their HVAC systems in heating mode, with a view to proposing improvements in their management based on the temperature records.

The buildings of the University of Zaragoza are generally occupied from 8 am to 8 pm, when the HVAC systems must guarantee a comfortable temperature. As a result, the systems are activated in the early morning before occupants arrive, since they are deactivated overnight. Currently, the schedules are scriptmed based on weather forecasts made 24 to 48 hours in advance and are applied uniformly across all buildings. To evaluate the possibility of establishing an HVAC switch-on schedule adapted to the thermal behaviour of each building, and to estimate how far in advance the HVAC systems should be switched on to achieve comfort temperatures at opening, the thermal inertia of the buildings and HVAC installations has been characterised. For this purpose, a MATLAB script has been developed. This script facilitates the calculation of the indoor temperature rise slopes (°C/h) during the heating systems' switch-on period, which occurs between 5 and 9 a.m (See Fig. 1).

The developed script performs initial data processing by interpolating the temperature values at fixed 10-minute intervals. It then detects periods of temperature increase and calculates the slopes for each room when the HVAC systems are switched on. This is done by smoothing the temperature signal with a moving average filter and calculating the temperature gradient between successive values (ΔT). If this difference is greater than a set value (ΔT_{min} of 0.05 °C), the values fall between 5 a.m. and 9 a.m. (HVAC start-up range) and there is a minimum of 8 consecutive high temperature delta records, a study band is considered. For each study band the script fits the temperature data to a line and calculates the slope.

Results and discussion

Clear variations in slope values were observed between the different buildings monitored, but also, to a lesser extent, within the same building and from day to day.

Variations between spaces on the same day and building, i.e., under similar weather conditions, can be attributed to multiple factors, including the spatial location within the building, such as orientation and floor level with respect to solar irradiation and wind incidence, the nature of enclosures, the HVAC system, and random events. It is notable that the behaviour of the HVAC system exhibits significant variations when the space is situated at the beginning or end of a hydraulic circuit. Furthermore, the presence of disparate technologies within a space, such as water or air HVAC systems, can also lead to significant variations in behaviour. Even in instances where the HVAC technology is uniform, additional factors, including the dimensions of the terminal units and variations in regulation, such as the degree of valve opening or the power settings of fans, can also contribute to the observed variations.

Regarding the **variations in slopes over time** within the same space, it has been observed that, in many cases, they correlate with indoor and outdoor temperatures and therefore vary throughout the week.

The reasons for the **differing behaviours of buildings** and variations in slopes between buildings are as follows: the ratio between the available HVAC thermal power and the thermal demand of the building, the type of HVAC systems or the use of the installation.

The average value of the slopes per building in the winter of 2023-24 has been calculated as a first approximation, and it has been shown that there are clear differences between the buildings of the university, with the slopes ranging between 0.3 and 3 °C/h on a monthly average.

Based on this study, using slope calculations, a new methodology is proposed to dynamically and in real-time determine the start time of the HVAC systems, which could be automatically implemented in the building management system (SCADA). Given a target indoor temperature and the slope value, the system could calculate the appropriate time to start the HVAC systems based on the average indoor temperature from the sensors set as the building's reference. Since it has been observed that the slope value is not unique but is typically correlated with both indoor and outdoor temperatures at start-up and with the day of the week, the future approach involves conducting multivariable mathematical correlations to calculate the slope values more accurately. In addition to the slope value, another important aspect to consider when determining the start time is the time lag between the increase in supply air temperature at start-up and the indoor temperature.

Conclusions

Thanks to the development of a methodology for calculating the indoor temperature rise gradients (°C/h) in the heating system activation range, it has become clear that there are significant differences in the behaviour of the buildings of the University of Zaragoza, since the slopes vary between 0.3 and 3 °C/h on a monthly average, depending on the building. At present, the switching-on schedules for HVAC systems is based on weather forecasts, without considering the thermal behaviour of each building. Based on this work, it is proposed to establish different HVAC switch-on times for each building or zone within the building, improving energy efficiency and thermal comfort. Given a target indoor temperature and the slope value for each zone of the building, the system could calculate the appropriate time to start the HVAC systems, covering both primary (production) and secondary (distribution) equipment.

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FIGURES

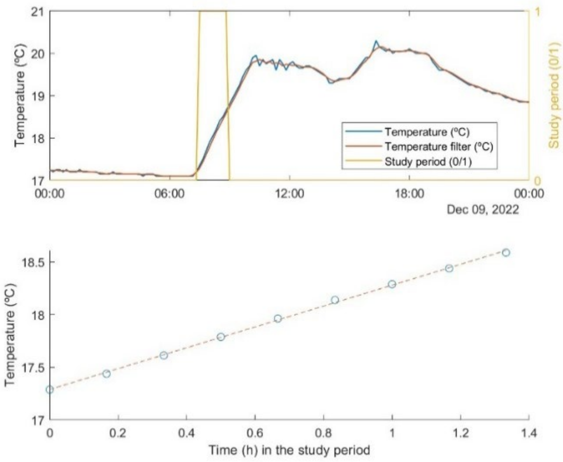

Fig. 1. a) Temperature (°C) and study area for one day. b) Linear fit of the temperature (°C) in the study area