Demo Abstract: A toolkit for low-cost thermal comfort sensing

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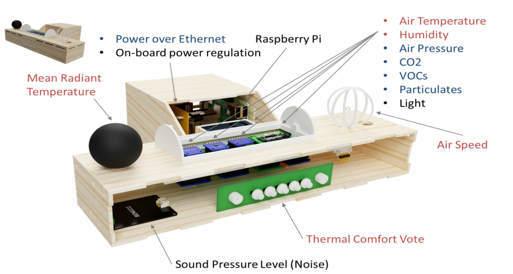

Figure 1: V2 of the thermal comfort sensing device

ABSTRACT

Why is it that we can have standards on how to achieve comfort [5] and advanced building control systems to implement these standards, yet water cooler 'discussions' about how hot, cold, or generally uncomfortable it is, seem to form a backbone to modern office life [8]? In the UK, domestic space and water heating alone was approximately 80% of the country's total final energy in 2017 [9]. Through our heating and cooling infrastructures, we are consuming significant amounts of energy and pumping out growing amounts of carbon, only to achieve a state of further discontentment. Are we approaching this all wrong? To reduce our consumption significantly, we need new methods of understanding and achieving thermal comfort. To help achieve these new methods, this paper argues we need to look again at how we are currently collecting thermal comfort data.

CCS CONCEPTS

• **Hardware → Impact on the environment**; *Temperature monitoring*.

KEYWORDS

Thermal Comfort, Indoor Air Quality, Continuous Monitoring, Building Performance, Sensors, Measurement

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1 INTRODUCTION

Four environmental and two personal parameters usually quantify thermal comfort. The environmental parameters are airspeed, humidity and temperature, as well as the radiant temperature of the surrounding area. The personal parameters are how insulating the clothes you have on are, and your metabolic rate, i.e. how much heat your body is producing. There are plenty of other factors, but these were found to be the most significant by Fanger [2] during his seminal thermal comfort study. These parameters are the core inputs used to calculate the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) thermal comfort scores. Even alternative methodologies such as Adaptive Thermal Comfort [3], still rely on most of the same parameters.

As such, thermal comfort studies revolve around measuring these parameters. Interviews, diaries or image capture are typically used to quantify the two personal factors; these parameters are not the focus of this work though. For the environmental parameters, there are generally two approaches:

Longitudinal studies such as Rupp et al. [7], which look at the same location over a period of time generally using laboratory-grade sensing and logging equipment. The equipment cost restricts the studies to a longitudinal format and usually consist of the equipment being taken to various participants at regular intervals to take readings.

Secondly, cross-sectional studies such as Ranjan et al. [6], look at multiple locations at the same time. To reduce costs, they usually make one or more of the following assumptions: Radiant temperature is the same as the air temperature, humidity is insignificant, and airspeed is both insignificant and constant.

These assumptions are often incorrect, due to factors such as intermittent heating strategies, solar gain, open windows, movement of people, and engineering of spaces for different quantities of people and different uses than in actuality.

2 A THIRD APPROACH

Thanks to falling costs of sensors it is now possible to perform combined longitudinal and cross-sectional studies, albeit with sensors that are potentially less accurate. Do the benefits of this outweigh the accuracy reduction or are lower-cost sensors and equipment not consistent or accurate enough?

The main potential benefits are:

- Understanding of how thermal comfort changes throughout the day with the patterns and rhythms of the space, e.g. day to day lifestyle and practices, as well as externalities such as rapidly changing weather conditions. These externalities can cause a difference between people's perceived and measured levels of thermal comfort.
- Systems typically only use the single parameter of air temperature to control thermal comfort. Measuring and controlling more parameters has the potential to provide improved or at least the same levels of comfort, but using less energy.
- Longitudinal studies are not able to look at the micro-climates found within office environments. Hot and cold spots are known to be sources of tension [1], and issues surrounding ownership of windows and radiators [8] compound this further. By not considering these localised effects, our buildings are actively working against the social dynamics causing discomfort.

In thermal comfort measures such as PMV, the personal parameters of clothing and metabolic rate are significantly weighted, yet they are inherently imprecise to measure. Why then do we focus so much on achieving high levels of accuracy for the environmental parameters? What do we lose by going down this third route, and how accurate do sensors need to be to achieve a representative measure of thermal comfort still?

3 DEVICE DESIGN

V1 of the prototype device suffered from problems with the heat generated by the microprocessor networking components placing a non-consistent offset on the temperature sensors. The current V2 (Figure 1), overcame these temperature-related issues and has been used in some preliminary deployments on a university campus.

The initial scope of the device was to measure the four environmental thermal comfort parameters. This scope was later expanded to include sensors for Indoor Air Quality (IAQ) research, as this is an area on which the authors' team is beginning to focus. The device has been designed to be a testbed for various low-cost thermal comfort and IAQ sensors as well as a research toolkit. Most off the shelf sensors communications are either digital via an i2c or UART bus, or analogue via a voltage or resistive output. The device is designed to be modular both in software and hardware and can handle sensors using any of the above communication protocols. Hardware modularity is currently limited, but it can accept sensors with various pin configurations; this will be improved in the next version of the sensor PCB. For now, development has been undertaken using a selection of common sensors that met our accuracy, cost and availability requirements.

Other than the sensors, the device consists of a PCB to integrate the sensor modules, POE, power regulation and a Raspberry Pi microprocessor; see Figure 1. The Pi reads the sensor data and inserts it into a MySQL database in batches. Visualisation and interrogation of the data is through a Grafana interface.

3.1 Existing toolkits

SAMBA is a recently released toolkit from the Indoor Environmental Quality Lab at the University of Sydney. It measures similar parameters and was designed for "continuous, real-time measurements of indoor environmental quality parameters from occupants' work desks" [4]. The main differentiator between the two devices is that the one described in this paper is developed on open source principles. It is intended to allow the measurement of thermal comfort and indoor air quality by the community at large, with the additional benefit of being open to future standards, sensors, and integration with future toolkits.

4 INITIAL FINDINGS

The device has been deployed for a couple of short periods to get real-world feedback on the prototype packaging. Despite it not being intentionally placed to investigate a problem, it has identified one. The deployment space had been causing regular discomfort to the occupants. The room's air temperature was assumed to be low, but this was shown not to be the case. Instead, the airspeed was shown to be significantly higher than expected. Following this up with the university's energy manager, it was found that the room's ventilation system had never been commissioned correctly.

5 FUTURE WORK

Future work looks to run experiments to benchmark the accuracy needed to achieve a representative measure of thermal comfort. Following this, we intend to investigate one or more of the three potential benefits of low-cost sensors identified above.

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