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Poster Abstract: Occupant-driven Diagnostic Bayesian Networks: Incorporating Subjective Feedback for Resilient Operation

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Abstract

This paper presents a Diagnostic Bayesian Network (DBN) for whole-building fault detection and diagnosis (FDD) incorporating occupant feedback as potential symptoms of faulty operation and occupant behaviors as potential faults in building performance. The methodology is applied on a seven-floor office building in Delft, the Netherlands, and the DBN’s fault isolation capabilities for three different levels of information are compared.

CCS Concepts

• **Computer systems organization** → **Sensors and actuators**; • **Human-centered computing**; • **Software and its engineering**;

Keywords

Fault Detection and Diagnosis (FDD), Whole building HVAC systems, Occupant behavior, Thermal comfort, Indoor Air Quality

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1 Introduction

Diagnostic Bayesian Networks (DBN) are a promising solution for whole-building fault detection and diagnosis (FDD) due to their robustness to uncertainty, scalability and flexibility [3]. They have proven to be reliable at detecting cross-level faults in whole building systems [1] and able to detect control and component faults in spite of faulty sensors [5]. As part of the *Brains for Buildings* project, work has been carried out on the development of DBN libraries for various building system components [6], their experimental validation [9] and real-time implementation [8] in Air Handling Units (AHU), and the development of whole-building DBNs [5].

A key challenge in DBNs is the need to define adequate baselines for “normal” operation and reliable thresholds to distinguish it from “faulty” operation [3]. These parameters are typically defined based on expert knowledge, design specifications and control documents, however, these documents might often be outdated or incomplete



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[5]. Furthermore, these specifications might not match the desired indoor air quality (IAQ) during operation, as real building occupants’ preferences might deviate from designers’ expectations. Incorporating humans as sensors in whole building FDD can therefore help to ensure desired IAQ conditions are maintained [4]. However, the integration of occupant behaviors into DBNs has mostly been done at the component scale [2].

In this paper, an existing DBN for whole-building FDD in a real office building [5] is expanded to incorporate building occupants’ feedback as potential symptoms for inadequate system operation and their self-reported behaviors as potential faults. The DBN’s ability to detect faults for three different levels of additional information is shown.

2 Methodology

A DBN for whole building system FDD for a case study office building in Delft, the Netherlands, has previously been developed, validated using experimental data, and tested during operation [5].

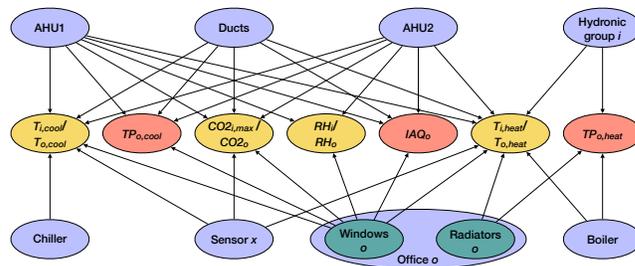


Figure 1: Simplified schematic of the DBN for the case study building. Heating and cooling modes are shown as separate nodes. *i*: building zone (East, West); *o*: each individual office.

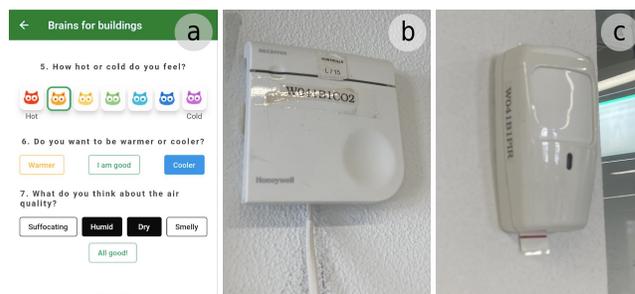


Figure 2: Smartphone application used for feedback collection (a), temperature, humidity and CO₂ sensor set (b) and PIR sensor used to detect occupant presence (c).

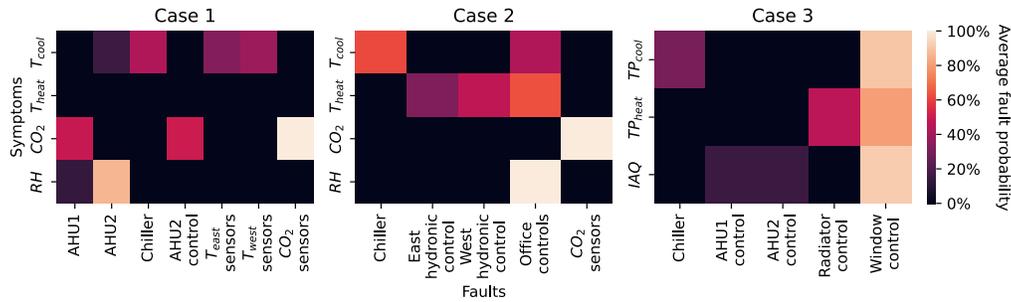


Figure 3: Average fault probability for each fault leading to a comfort-related symptom during timesteps where occupants expressed discomfort are considered for each of the DBN cases. Faults that were not detected are omitted.

A detailed analysis of this DBN is beyond the scope of this paper, and therefore a simplified version is shown in Fig. 1, which only includes the symptoms and faults that directly relate to occupant comfort and the faults that can cause them.

To assess occupants’ satisfaction in the case study building, 15 participants were recruited and requested to fill out surveys on their behaviors and comfort perception through a smartphone application [7] during a two-month period in September–November 2024 (Fig. 2a). In each participant’s office, sensors were installed to collect the air temperature, humidity, CO₂ concentration and occupant presence every 5 minutes (Fig. 2b,c). For each office, two sets of each sensor were deployed, and the average value was used.

These additional sensor measurements were used to define office-level comfort-related symptoms (deviations in the reference values for indoor comfort from the building’s documentation) and sensor faults (deviations with respect to the CO₂ measurements from the building management systems –BMS–). Occupants’ comfort-related feedback was used to define symptoms (inadequate air quality IAQ_o in office o , unmet thermal preference during the heating/cooling mode $TP_{o,heat}/TP_{o,cool}$) whereas their self-reported window and radiator states were used to define potential faults in behavior.

DBN performance was tested with three different levels of information. In *Case 1*, only data from the BMS are considered, and symptoms and faults are aggregated by Zone (East, West). In *Case 2*, sensor data from each office is added, but behavior faults are still grouped into generic Office o faults. In *Case 3*, self-reported data is added, while subjective feedback is included as a symptom and self-reported behaviors as faults. Symptoms and faults in Cases 1 and 2 are shown in Fig. 1 in yellow and purple, respectively. Additional symptoms and faults in Case 3 are shown in red and green.

3 Preliminary results

The DBN’s ability to detect faults in the building systems during periods where individual occupants expressed discomfort was explored. Fig. 3 shows the average probabilities for different faults affecting comfort-related symptoms in each of the three cases. In Case 1, since only system faults are defined, deviations in comfort-related parameters are mostly related to building systems (AHUs, chiller, sensors). In Case 2, the addition of generic office-level controls provides an additional potential fault leading to deviations in relative humidity. In Case 3, rather than detecting deviations in measurements, symptoms are defined by occupants’ self-reported

preferences. Here, occupant discomfort is more strongly associated to occupants’ inadequate operation of windows rather than building system faults. The full DBN does incorporate both system- and occupant-related symptoms, and work is ongoing on the relative roles of each of these on fault detection in the case study building.

4 Discussion and Future Work

The proposed methodology to incorporate occupant feedback and behavior into FDD appears to be a promising avenue to uncovering the role occupants can play in resilient building system operation. Preliminary results show that occupant behaviors might be able to explain perceived discomfort in the case study building, though further analysis needs to be carried out on the relative roles of faults in building systems and occupant behaviors. Work is ongoing in incorporating personalized comfort models to the DBN for FDD during periods when no feedback was collected.

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