Monitoring temperature variability inside a healthcare facility during an extreme heat event using low-cost sensors

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Abstract: Climate change is causing more frequent extreme heat events (EHEs). Healthcare facilities serve individuals susceptible to adverse health outcomes from heat exposure. This study describes temperature variability inside and outside of an older inpatient healthcare facility in Vancouver, British Columbia (BC), Canada during an unprecedented EHE in 2021. Low-cost sensors were installed outside (N=2) and inside (N=7) of the large healthcare facility including on the roof, outside a second-floor window, in the basement, on the ground floor, and on the fourth (top) floor. Sensors measured temperature every minute during the 2021 EHE. These time series data were compared across sensors to assess temperature variability throughout the facility during the EHE. Outdoor temperatures at the facility reached 47.6 ℃. Though the building has central air conditioning, indoor temperatures as high as 32.2 ℃ were recorded in a fourth-floor office. The maximum temperature in a patient room was 27.6 ℃. Some ground-floor and basement areas experienced no elevated temperatures during the EHE. These findings demonstrate how temperatures may vary considerably across a single healthcare facility during periods of extreme heat. Our findings illustrate the benefits of actively monitoring temperatures throughout such facilities to understand heat exposure in different areas. We explore how this information can help healthcare providers make real-time decisions to protect patients and staff during EHEs.

Keywords: Extreme heat event (EHE); temperature; healthcare facility; heat exposure; low-cost sensors

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Introduction

Individual extreme heat events (EHEs) can be associated with hundreds to thousands of excess deaths (1) and higher rates of emergency department visits (2). Since the 1950s, climate change has led to more frequent and severe EHEs globally, and they are expected to become more common in upcoming decades. To protect public health, it is important to develop a strong understanding of the risks associated with EHEs, particularly in facilities occupied by people who are susceptible to experiencing adverse health outcomes from exposure to high temperatures.

Certain individual-level characteristics are associated with increased susceptibility to the health effects of EHEs. For example, older age, disabilities, and other pre-existing conditions put individuals at elevated risk of heat-related illness and death during EHEs (3). Healthcare facilities house patients who may be particularly susceptible to the impacts of extreme heat, so it is important to understand how temperatures within these facilities are affected by EHEs. Healthcare workers may have additional risk factors that make them more vulnerable to heat exposure, such as performing physically demanding tasks while wearing

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personal protective equipment that may reduce their ability to shed heat. Indoor temperatures experienced throughout a healthcare facility may vary depending on the use of mechanical cooling (i.e., air conditioning), the floor, and the size and orientation of the windows (4-6). Variability in temperatures may be particularly pronounced in older facilities that were constructed under obsolete (or non-existent) building codes and may be more likely to have outdated cooling systems (7,8). However, there is limited published information on how indoor temperatures are affected by and change during EHEs at healthcare facilities where people may be particularly susceptible to heat.

The aim of this study was to explore the range of temperatures experienced by patients and staff inside an older healthcare facility in Vancouver, British Columbia (BC) during an unprecedented EHE in the summer of 2021. We examine temperature time series data from low-cost air quality sensors co-located inside and outside of this facility as well as data from a nearby weather monitoring station. Our objectives were to describe temperature variation during the EHE: (I) across multiple locations inside the healthcare facility; (II) between sensors inside and outside of the facility; and (III) between the sensors and a nearby weather monitoring station.

Methods

Study context

Vancouver has a temperate climate, with historical [1971–2000] maximum (max.) daily temperatures in June approximately 14–24 ℃ (9). In late June 2021, BC experienced an unprecedented period of extreme hot weather which resulted in temperature anomalies 16–20 ℃ above season norms. Analyses early after this event concluded that this was an EHE that would have been virtually impossible without human-induced climate change (10). In this study, the EHE period was defined as 24 June to 02 July, 2021 because this was the period in which temperatures were elevated above season norms (11) and corresponds with previous reports on the health impacts of this EHE (12,13).

The study site was a large inpatient rehabilitation center in Vancouver. The building was constructed in 1972 and has four floors and a basement. Services on the ground floor include physio- and occupational therapy, cafeterias, and offices while floors 2–4 contain all patient wards. The basement houses maintenance rooms, storage, and manufacturing facilities. The building has central air conditioning and operable windows. Satellite imaging (Google, California) from June 2021 shows a moderate amount of green space and trees around the building which may provide some shading to the northwest and southeast corners. However, no sensors were located in those areas of the facility (*Figure 1*).

Air temperature sensors

Nine Air Quality Egg sensors (EGGs) (Wicked Device, New York) were installed at the facility in August 2020 as part of another study on air quality (14). Two EGGs were installed outdoors—one on the fourth-floor roof and one outside a second-floor window—and seven were installed indoors in the basement (N=2), on the ground floor (N=2), and on the fourth floor (N=3). In the basement, one was installed near the elevator and one in a side hallway. On the ground floor, one was installed in a central therapy room and one in the lobby. On the fourth floor, one was installed near the elevator, one in a patient room, and one in an office. EGGs recorded temperatures in one-minute intervals during the EHE. The temperature sensors (Sensirion SHT35) are accurate to 0.2 ℃ and have an operating range of −40 to 125 ℃.

Nearby air monitoring station

We compared EGG measurements to data from a nearby weather station located less than four kilometers away from the study site, operated by the Metro Vancouver Regional District (15). This station was chosen because it (I) was the nearest weather station to our study site; (II) was a similar distance to the coast; and (III) was used in the previous study on air quality at this facility (14). Hourly temperature data was available from this weather station.

Descriptive statistics

Average temperatures were calculated: (I) individually for each EGG; (II) across all EGGs on the same floor; and (III) across all indoor and outdoor EGGs separately. Averages were computed for each day and for the entire EHE. Means were compared among sensors using either a two-sample *t*-test or analysis of variance (ANOVA) with follow-up Tukey *post-hoc* test, as appropriate for comparison of two or more means.

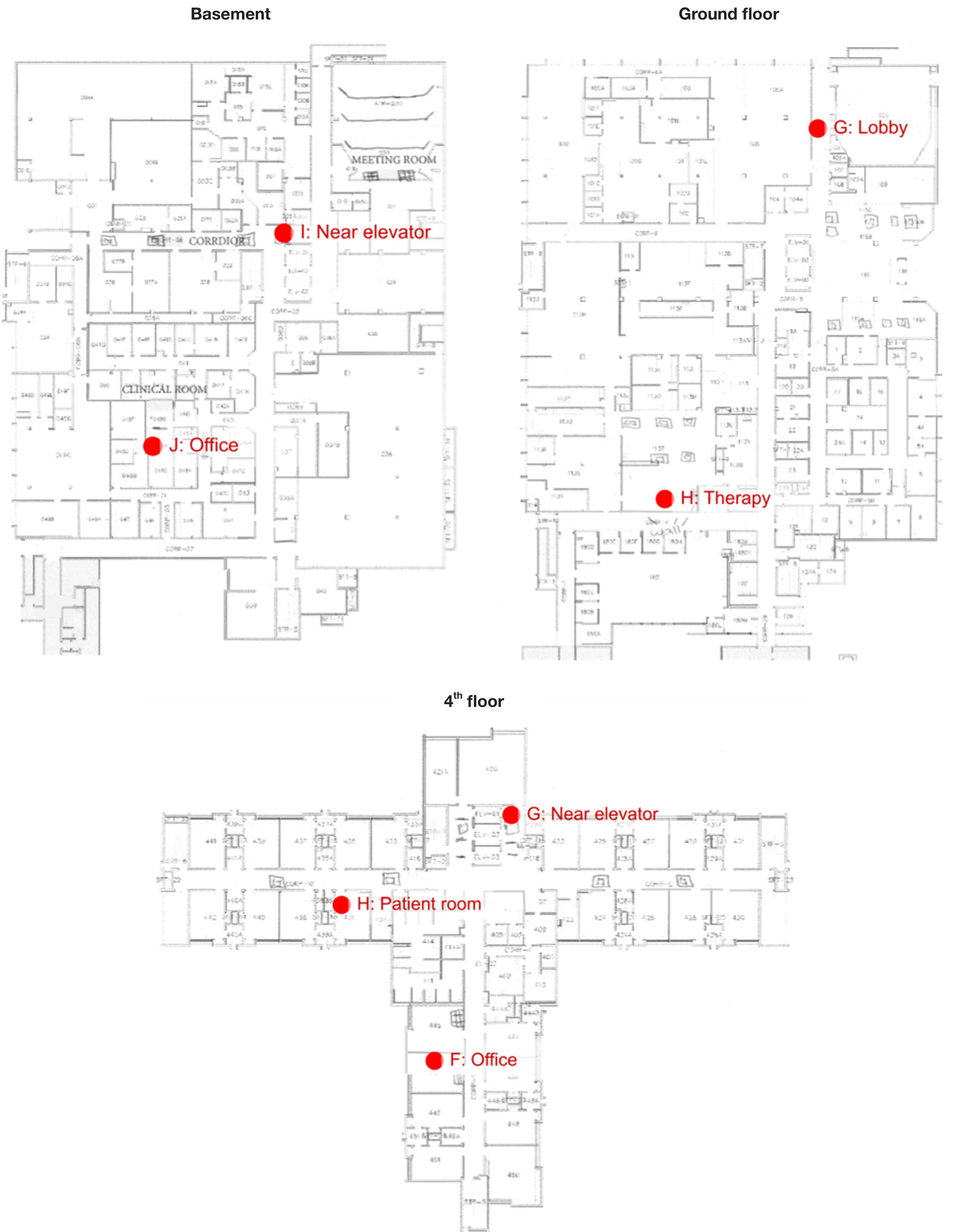

Figure 1 Map of locations of all indoor sensors. Map showing location of indoor temperature sensors in basement, main floor, and fourth (top) floor.

Results

Outdoor versus indoor temperatures

Outdoor temperatures during the EHE at the facility were higher than those recorded indoors and at the nearby weather station (*Figure 2*; *Table 1*). Outdoor temperatures recorded at the facility reached a max. of 47.6 ℃ around 16:00 at the EGG outside the second-floor window. The mean temperature during the EHE across both outdoor EGGs was 27.2 ℃ and the minimum (min.) was 15.9 ℃, which was recorded on the fourth-floor roof. Indoor temperatures across all EGGs reached their peak approximately three hours after the outdoor peak (min.: 20.1 ℃, mean: 23.6 ℃, max.: 32.2 ℃). Temperatures at the nearby weather station reached their max. at the same time as the outdoor EGGs but were up to 10.4 ℃ lower than the outdoor EGGs (min.: 16.1 ℃; mean: 25.3 ℃; max.: 37.2 ℃). The mean temperature across all indoor EGGs (23.6 ℃) was significantly ($P<0.001$) lower than both the mean temperature across outdoor EGGs (27.2 ℃) and the mean temperature at the nearby weather station (25.3 ℃).

Variability between floors

Indoor temperatures varied between floors (*Figure 2*). Temperatures among the three EGGs on the fourth floor were most affected by the EHE, with the sensor in the fourth-floor office reaching a max. temperature of 32.2 ℃ on 27 June. The mean across all sensors on the fourth floor was 24.9 ℃ and the min. was 22.6 ℃ in the patient room. The EGGs on the ground floor (min.: 20.1 ℃, mean: 22.8 ℃, max.: 26.0 ℃) and the basement (min.: 21.1 ℃, mean: 22.5 ℃, max.: 25.9 ℃) never recorded temperatures higher than 26 ℃. Average daily temperatures across all EGGs on same floor were all significantly different between floors ($P<0.001$).

Variability between rooms on the same floor

Rooms on the same floor were also affected differently by the EHE (*Figure 2*), such that average daily temperatures were all significantly different among EGGs on the same floor ($P<0.001$). In the basement, the EGG located by the elevator and the loading bay door increased in temperature during the hottest periods of the day (min.: 22.0 ℃, mean: 23.3 ℃, max.: 25.9 ℃), while the EGG located away from the elevator was unaffected (min.: 21.1 ℃, mean: 21.7 ℃, max.: 22.3 ℃). On the ground floor, the lobby was the most impacted by the EHE with temperature increasing from 24 June until declining with outdoor temperature after 29 June (min.: 22.8 ℃, mean: 24.2 ℃, max.: 26.0 ℃). In comparison, the ground-floor therapy room has its own climate control system and had lower max. temperatures during the EHE (min.: 20.1 ℃, mean: 21.5 ℃, max.: 25.4 ℃) than it did in the week before (min.: 19.9 ℃, mean: 21.5 ℃, max.: 25.6 ℃) and after the event (min.: 20.1 ℃, mean: 21.5 ℃, max.: 25.7 ℃).

The top floor of the building is shaped like a cross, with one arm extending in each cardinal direction (*Figure 1*). Temperatures on this floor increased steadily during the EHE, with the EGG in a west-facing office in the south arm having the most extreme highs and lows (min.: 23.0 ℃, mean: 25.2 ℃, max.: 32.2 ℃). The EGG near the fourth-floor elevator (min.: 22.9 ℃, mean: 24.8 ℃, max.: 28.2 ℃) was located away from major exterior walls (*Figure 1*). The third EGG on this floor was located inside of a patient room and had the lowest temperatures (min.: 22.6 ℃, mean: 24.7 ℃, max.: 27.6 ℃).

Discussion

In this study we described air temperature outside and inside a large older inpatient healthcare facility in BC during an unprecedented EHE in the summer of 2021. We found that indoor temperatures remained substantially lower than outdoor temperatures, but that temperature varied considerably between floors and between locations on the same floor, despite central air conditioning.

Overall, this study highlights how indoor temperatures may vary across a single healthcare facility during an EHE. There are many potential explanations for why we observed different temperatures throughout this facility. For example, the fourth (top) floor was markedly hotter than the basement and ground floor. This is consistent with previous research which has found increasing temperatures with higher floors (16,17) and may result from cumulative heat transfer upwards from lower floors and solar gain through the roof (18). There was also variation between rooms on the same floor. For instance, the fourth-floor office with a west-facing window reached temperatures 4.5 ℃ hotter than the max. temperature in the fourth-floor patient room with a south-facing window. Factors affecting different indoor temperatures are complex and may be the result of interactions between occupant behavior, mechanical cooling, window size and cardinal orientation, room size, building material, and building age (4-6). Lower daily max.

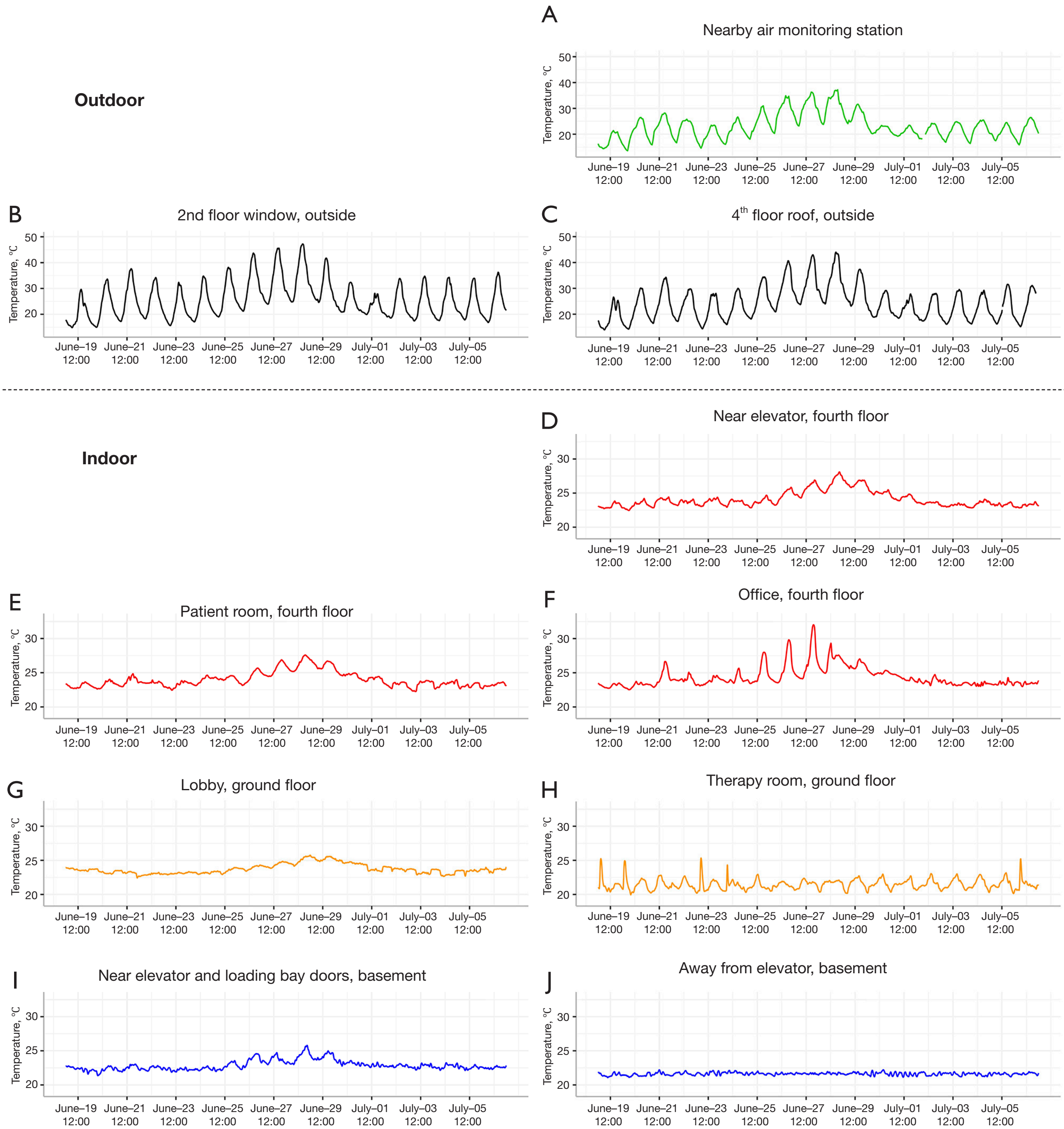

Figure 2 Time-series of temperature data recorded by each temperature sensor and nearby air monitoring station. Temperatures recorded by each temperature sensor, smoothed with a rolling one-hour average, as well as those recorded by a nearby air monitoring station. Top section (A-C) contains the sensor from the nearby air monitoring system and the two sensors placed on the facility roof. Bottom section (D-J) contains all sensors placed inside the facility.

Table 1 Descriptive statistics of temperatures recorded by each temperature sensor at a healthcare facility and a nearby weather monitoring station in British Columbia, Canada during the 2021 EHE

Location	Mean (range, SD) (℃)	Date maximum temperature (time of day)
Outdoors		
Nearby weather station	25.3 (16.1–37.2, 5.17)	2021-06-28 (19:00)
2nd floor window	28.0 (17.0–47.6, 7.27)	2021-06-28 (15:54)
4th floor roof	26.5 (15.9–44.4, 6.71)	2021-06-28 (16:50)
4th floor		
Office	25.2 (23.0–32.2, 1.67)	2021-06-27 (18:42)
By elevator	24.8 (22.9–28.2, 1.25)	2021-06-28 (20:11)
Patient room	24.7 (22.6–27.6, 1.15)	2021-06-28 (18:28)
Ground floor		
Lobby	24.2 (22.8–26.0, 0.73)	2021-06-28 (23:09)
Therapy	21.5 (20.1–25.4, 0.65)	2021-06-24 (06:22)
Basement		
By elevator	23.3 (22.0–25.9, 0.79)	2021-06-28 (20:07)
Away from elevator	21.7 (21.1–22.3, 0.20)	2021-06-30 (15:17)

EHE, extreme heat event; SD, standard deviation.

temperatures at the nearby weather station compared with the outdoor sensors at the facility may reflect outdoor sensor placement (e.g., in full sun, on a black rooftop surface), or differences in the urban heat island effect (19,20). These results suggest that areas within the same building may experience different temperatures during EHEs due to differing designs, surroundings, and behaviours of users (4,17,20). The differences in involved factors can be difficult to model across different buildings because they change over time and space (21,22), but their impacts on temperature can easily be measured and monitored in real-time.

Although most studies have focused on the impacts of hot outdoor temperatures, there is a growing body of evidence demonstrating indoor temperature thresholds and exposure times at which adverse health impacts, such as heat strain, heat stress, sleep disturbance, fatigue, and headache may start becoming more likely among susceptible populations (23). Recent work (24,25) monitoring core body temperatures, blood pressure, and heart rate in older adults in controlled laboratory settings have reported that sustained exposure (≥8 hours) to temperatures between 26 and 31 ℃ may pose a risk in some adults, while sustained exposure to temperatures over 31 ℃ should be avoided by susceptible populations. The ASHRAE guidelines for temperature in non-surgical rooms, which consider not only patient safety, but also infection control, and occupant satisfaction, are even lower, at 21–24 ℃ (26,27). In this study, temperatures on the fourth floor where patients were housed exceeded all these temperature thresholds, potentially exposing susceptible people to dangerous temperatures.

The exact health risks associated with specific indoor temperatures are not fully established for different individuals and the effects of outdoor temperatures on those indoor temperatures may vary widely between different locations in the same building. As such, this work highlights the importance of monitoring temperatures in real-time during EHEs, especially in older healthcare facilities where potentially susceptible patients housed in different parts of the same building may be exposed to very different temperatures. Simple interventions such as highly visible digital thermometers could be potentially lifesaving. Such measurements can help staff make decisions about moving patients into cooler areas of the building if temperatures reach potentially dangerous levels. Where moving patients is not feasible, this information may also help prioritize areas for placement of portable mechanical cooling devices.

This study had several limitations. First, we did not have information on the behaviours of room occupants (e.g., opening windows, closing blinds) or on the specific reasons why different rooms may have been hotter than others, such as more detailed information about the building's central air conditioning system. Second, the generalizability of our results is limited because we only examined temperatures in a single facility. Although this facility had central air conditioning, we still observed significant variation between floors and between rooms on the same floor. Buildings without air conditioning or newer buildings with recently installed heating, ventilation, and air conditioning (HVAC) systems may experience significantly more or less temperature variability, respectively, which should be explored in future research. Finally, these EGGs were installed as a part of another study to understand wildfire smoke infiltration. As a result, we have limited information on why specific locations were chosen and on differences between locations. Future research should deploy more sensors and collect more detailed information on differences between rooms and occupant behaviors to more fully understand the effect of extreme heat within a given facility.

Conclusions

The 2021 EHE in BC affected temperatures across an older inpatient healthcare building, with impacts varying between floors and between rooms on the same floor. This study demonstrates the utility of actively monitoring temperatures in multiple locations across older healthcare facilities to understand how people located in different parts of the building are exposed to heat in real-time. This information can be used by healthcare providers to make real-time decisions to protect the health of their patients and staff during EHEs.

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jhmhp.amegroups.com/article/view/10.21037/jhmhp-23-81/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study did not involve collecting data from participants, so it was not necessary to obtain informed consent.

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