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Indoor air quality and thermal comfort for elderly residents in Houston TX—a case study

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ABSTRACT

The elderly population is more vulnerable to poor indoor environmental quality. They also spend a larger portion of their time indoors than the general public, further exacerbating the associated health risks. As part of a larger study which aims to understand the health risks for the elderly population resulting from extreme heat events in Houston, TX, this study gathered empirical data on thermal comfort and air quality in existing assisted living facilities and in individual homes of the elderly. We made continuous measurements of indoor dry-bulb temperature, relative humidity, carbon dioxide (CO_2) levels and occupancy status in 25 buildings during summer months in 2016 and 2017. Then, using the measured data, we calculated the percentage of hours in which the thermal discomfort index or CO2 levels were above healthy thresholds for each site. Our results show that the indoor discomfort index and/or CO2 level exceeded the safe thresholds for at least 5% of the time in two-thirds of the buildings tested. Considering that research suggests more extreme summer weather in this region in the future, the results of this study highlight the need to consider changes in building management and occupant behavior as well as targeted improvements in the building stock to minimise adverse health impacts. In addition, the results also highlight a potential trade-off between thermal comfort and air quality in these building; air-tightening of the buildings will result in better thermal comfort at the expense of higher CO2 levels, especially in buildings with a higher number of occupants.

KEYWORDS

Indoor air quality; Carbon Dioxide; Thermal Comfort; Senior Living Facilities; Warm Humid Climates

INTRODUCTION

In the United States, the majority of people, especially older Americans, spend ~90% of their time indoors (Klepeis et al., 2001). As a result, there is a growing awareness that much of the exposure to unhealthy environmental conditions may occur indoors. For example, Chan et al. found that a healthy person in a poorly ventilated indoor environment was 3.8 times more likely to suffer from a heat-related condition compared to outdoors (Chan et al., 2001). Sensitivity to heat and air pollution is equally important. Older adults are more sensitive than the general population to heat because the ability to regulate body temperature and physiologically adapt to the heat lessens with age (Kim et al., 2012; Luber and McGeehin, 2008). Likewise, older adults may experience more adverse health effects than the general population to air pollution as respiratory function declines with age (Wang et al., 2010). For example, exposure to moderate to high levels of carbon dioxide (CO2), with its well-documented negative impacts on cognitive function (Allen et al., 2016; Satish et al., 2012), may be more detrimental to the elderly than other age groups. Therefore, considering the population ageing in the U.S (Wiener and Tilly, 2002), there is a growing interest in understanding the indoor environmental quality to which the elderly are exposed. Hence, this study focuses on indoor CO2 levels and thermal comfort in a sample of buildings with elderly occupants in Houston, TX, the largest city in Texas and the fourth largest city in the United States. We performed continuous measurements of CO2, dry-bulb temperature, and relative humidity in a sample of homes over summer months of 2016, and 2017. Post-processing the data and interpreting it using applicable metrics revealed a general picture of the indoor environment in the sample homes.

METHODS

Measuring indoor environment variables

We had ongoing measurements of CO2, dry-bulb temperature, relative humidity, and occupancy status in a sample of 25 buildings during summers of 2016 (6 buildings) and 2017 (19 buildings). These buildings were either individual homes, or small assisted living facilities and were selected to represent different locations and income levels. In each building, a set of two to four HOBO MX1102 loggers (Figure1) were installed at various locations to record environmental parameters. The measured variables were recorded in at least two rooms (namely, a bedroom and the living room) in each building. We made regular visits to each site to calibrate CO_2 sensors to outdoor conditions (~400 ppm). As demonstrated in Figure 1, to the extent possible, we tried to avoid placing sensors near non-human sources of CO2 (e.g., plants) or heat sources (e.g., electric appliances). Occupancy status was recorded via HOBO UX90-005 Occupancy/Light Data Loggers and was used to filter out the unoccupied hours during which no exposure took place.

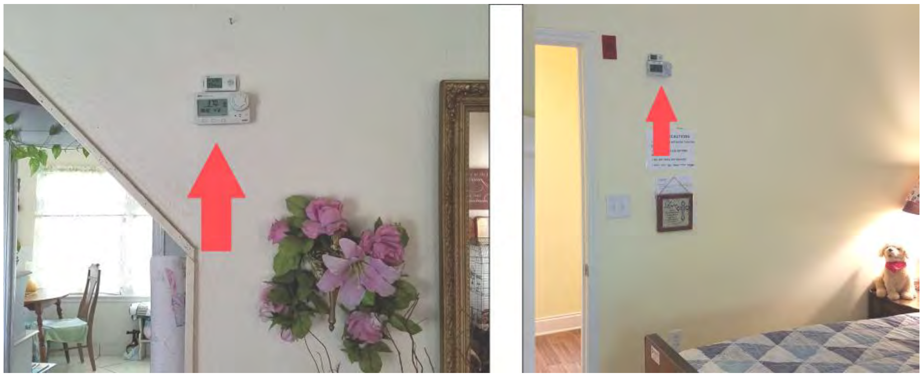

Figure 1. Sensor installation in sample buildings. Photo credit: Peter Chen, Houston Health Department

Post-processing the data

To better represent the data from long-term measurements, we calculated metrics for each site based on available thresholds. While there are numerous studies, guidelines, and thresholds for assessing indoor thermal comfort, most of them are not applicable for our purpose. The reason is that the zone of homeothermy (within which body can maintain constant core temperatures) is broader than the zone of thermal comfort (within which individuals report satisfaction with the thermal environment (Bianca, 1968). From the limited available guidance for generating suitable metrics of indoor overheating in residential settings, we selected the Discomfort Index (DI), the average of dry-bulb and wet-bulb temperatures. The DI metric has been suggested as a potential surrogate for overheating by Epstein and Moran (2006), and Holmes et al. (2016). We used the following equation to calculate the wet-bulb temperature which is needed to derive DI (Stull, 2011):

$$T_{wb} = T_a \operatorname{atan}[0.151977\ (RH\%+18.313659)^{1/2}] + \operatorname{atan}(T_a + RH\%) - \operatorname{atan}(RH\% - 1.676331) + 0.00391838(RH\%)^{3/2} \operatorname{atan}(0.023101RH\%) - 4.686035 \qquad (1)$$

Here, T_{wb} is the wet-bulb temperature (˚C), T_a is the dry-bulb temperature (˚C), and RH is the relative humidity. Regarding the overheating threshold, we assumed a DI index of 24 ˚C, over which "the heat load is moderately heavy and individuals would feel very hot"(Epstein and Moran, 2006). At two extremes of relative humidity, a DI of 24 ˚C is associated with dry-bulb temperatures of 36.5 ˚C (at RH=0%) and 24 ˚C (at RH=100%), exceeding almost all thermal comfort thresholds commonly used. This shows that a DI threshold of 24 ˚C is considered as an upper limit for the zone of homeothermy instead of the zone of thermal comfort. For CO2 levels, we considered a threshold of 1200 ppm. According to Allen et al. (2016) the decline in cognitive ability (even under typical activity levels) is easily observed above this threshold. It should be mentioned that for both parameters, the thresholds we selected are reported for the general public. The fact that elderly are more vulnerable to heat and CO2 will make the results presented here conservative.

RESULTS

We calculated the total number of hours that DI or CO2 were above the defined thresholds. An important consideration is that we did not have sensors logging data at all sites simultaneously. However, since all measurements took place over summer months (for at least one month in each location), the general outdoor conditions were similar enough that a side by side comparison of all buildings is still valid. Figure 2 shows the percentage of hours above thresholds for both DI and CO2 for all 25 buildings.

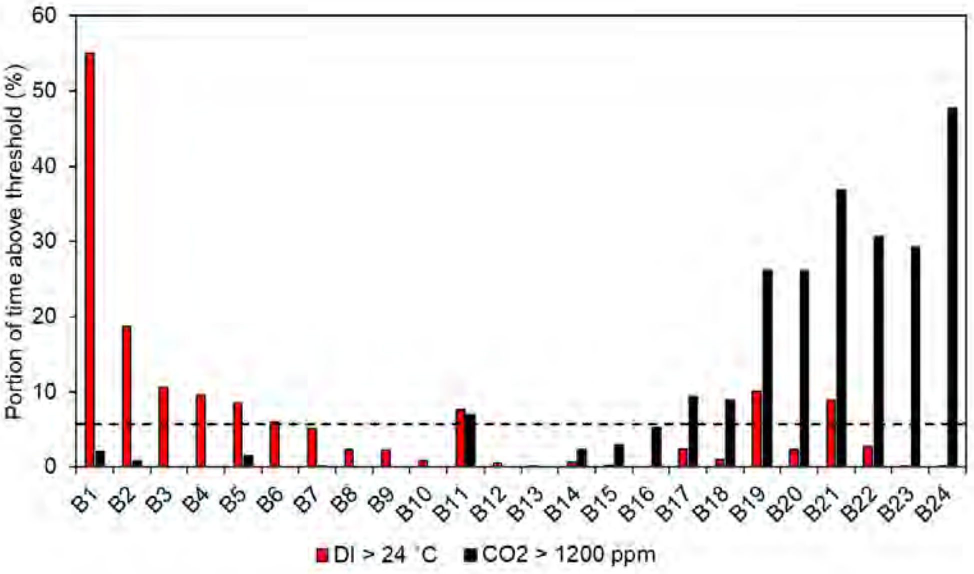

Figure 2. Summertime DI and CO2 levels inside sample buildings. Data from authors' measurements over the summer months of 2016 and 2017. Dotted, horizontal line indicates that safe thresholds were exceeded 5% of the time.

According to the Chartered Institute of Building Service Engineers (McLeod et al., 2013), buildings are considered to experience long-term overheating if they exceed the safe thresholds for more than 5% of the time. As the data suggests, DI and/or CO2 exceed the safe thresholds for more than 5% of the recorded period in 15 out of the 25 buildings. Notably, in this graph, an inverse relationship is observable between high CO2 levels and overheating. Generally, homes with high DI values seem to have low CO2 levels and vice versa.

DISCUSSION

The results presented here highlight the fact that a considerable portion (almost a third) of the sample buildings of elderly residents in Houston, TX are overheating during summer months. Considering the health implications of heat, especially for the elderly, as well as the predicted warming in Houston due to local (urban heat island effect) or global (climate change) signals (Georgescu et al., 2014), the observed conditions could be regarded as a significant public health issue. Notably, all these buildings had air conditioning. According to the U.S. Census Bureau, more than 99% percent of buildings constructed over the last three decades in the southern U.S. were equipped with AC. Hence, our sample represents the general building stock of the region with respect to AC prevalence. However, existence of AC equipment does not guarantee its effective operation. For example, building #1, the building with most overheated hours in our sample, had AC. However, based on our post-measurement surveys, the AC system was not functioning well, and the residents do not have the financial resources to properly maintain or repair it. In addition to this, the loss of power during outages is another mechanism that can lead to severe overheating. Hurricane Harvey, which happened during our measurement campaign, caused at least 5 of our sample buildings to lose power. While in this instance, the relatively low outdoor temperatures during and subsequent to Hurricane Harvey (a maximum outdoor temperature of 24 ˚C), as well as completely overcast skies, helped maintain indoor conditions below overheat levels, the outcome could have been different if the power outage occurred under a different scenario. A recent example of this happened during Hurricane Irma in Florida where 8 senior citizens died in a nursing home because of the resulting power outage and AC loss (Reisner et al., 2017). We believe that this is mostly due to the overdependence of the current building stock on AC technology. Lightweight construction with minimum regard for passive mitigation strategies lead to buildings that are highly vulnerable to extreme heat, power outages, and climate change (Baniassadi and Sailor, 2018; Nahlik et al., 2016; Sailor, 2014). The other important aspect, emphasized by the measurements, is the role of ventilation, namely, window-opening. As seen in Figure 2, there is an observable inverse relation between overheating and CO2. In general, residents of buildings that have difficulty maintaining thermal comfort, would resort to ventilation by opening the windows. However, while this mitigates indoor CO2 levels which are largely controlled indoor sources, it can increase exposure to outdoor pollutants such as ozone, its secondary bi-products, and particulate matter. Therefore, not having proper running AC not only leads to overheating, but can also indirectly increase exposure to outdoor pollutants. On the other hand, more air-tight buildings in our study with functioning AC, exhibited consistently comfortable indoor thermal conditions, but in some instances experienced high CO2 levels. Building number 24 is an extreme example of this. This building was a senior living facility with 10 elderly residents and full-time staff. This led to very high CO2 levels as the managing personnel did not operate the windows. Notably, this building was categorized as a facility whose residents are cognitively impaired (e.g., diagnosed with Dementia-Related Disorders).

CONCLUSIONS

In this study, we used long term measurements of CO2 levels and thermal comfort conditions in 25 buildings with elderly residents in Houston, TX. Our post-processing of the measured data showed that at least a two-thirds of sample buildings exceeded the CO2 threshold of 1200 ppm or were overheated for at least 5% of the measurement period. These results suggest that many elderly citizens, in particular, those with limited financial resources, are exposed to indoor environments that potentially adversely affect their health and well-being. In addition, the observed inverse relation between overheating and high CO2 levels suggests that window opening is a strategy consistently used by occupants in overheated homes. While this helps curb indoor CO2 levels, it exposes occupants to more outdoor pollutants. Considering predictions that suggest a more extreme climate in Houston in the coming decades, and a building stock that is highly dependent on AC, the situation is likely to worsen. Future research should focus on developing easy-to-implement and market-ready building construction and operation strategies to reduce the dependency of buildings on AC and increase indoor air quality.

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