

# Indoor air and environmental quality in social housing dwellings in Australia

Shamila Haddad <sup>\*,1</sup>, Afroditi Synnefa <sup>1</sup>, Riccardo Paolini <sup>1</sup>, and Mattheos Santamouris <sup>1,2</sup>

*1 Faculty of Built Environment, University of New South Wales, Sydney, Australia*

*2 Anita Lawrence Chair in High Performance Architecture*

*\* Corresponding author: s.haddad@unsw.edu.au*

## ABSTRACT

This study aims to assess the indoor thermal and environmental quality of low-income households in New South Wales, Australia. It adds evidence-based findings on the performance of residential buildings and contributes to improving the indoor environmental quality of social housing. The research presented in this paper involved subjective and objective evaluation of indoor air and environmental quality. The objective method included long-term monitoring of air temperature, relative humidity, and carbon dioxide during winter and summer 2018/2019, whereas the subjective method involved assessing occupants' feedback about the indoor environmental quality. Physical observation of the indoor and outdoor conditions of each home was carried out on the same day of the questionnaire survey. Over 100 social housing households in the Greater Sydney area participated in this study. The characteristics of the specific population group are presented in this paper including details of energy bills, health, and indoor comfort. It further discusses issues related to the impact of urban overheating on indoor environmental conditions. Lower satisfaction rate with the thermal environment and poor indoor environmental quality affect health and quality of life of residents living in social housing. The minimum indoor air temperature recorded was about 5 °C during winter 2018 and the maximum indoor air temperature reached 39.8 °C in summer 2019. The mean thermal sensation vote increases by 1 point per 4.8 °C increase in the room indoor air temperature. The residents who participated in this study have an upper acceptable indoor air temperature of about 26 °C for 80 % satisfaction. This study highlights the need to improve both building quality and outdoor local climate. Acting on only one of the two sides is not enough to achieve nearly zero energy buildings in Australian climates, considering the predicted extreme weather conditions in future. Therefore, advanced mitigation and adaptation technologies are needed to improve the quality of low-income households, promotes health, and reduce energy for heating and cooling.

## KEYWORDS

Energy poverty, Indoor air quality, Social housing, Indoor environmental quality

## 1 INTRODUCTION

There are more than 3 million people (13.2 % of the population) living below the poverty line in Australia, after taking account of their housing costs (Bradbury et al., 2018). The poverty rate is higher among children under the age of 15 (17.3 % of all children) and youth between the ages of 15 and 24 (13.9 %). The term energy poverty is used to describe a situation of a household not able to satisfy the necessary energy services in the residence (Bouzarovski-Buzar, 2011). Energy poverty, or struggling to meet energy needs, has become the subject of attention in Australia, with the rising cost of energy concerning all Australians. Low-income large-family households, most exposed to the risk of energy poverty, live in the struggle-town suburbs of Australian biggest cities (Hogan and Salt, 2017). Energy poverty has a significant

impact on the quality of life, affects indoor comfort levels in energy-poor houses, influences social attainment, has a negative effect on residents' health, and results in a significant increase of the seasonal mortality and morbidity (Santamouris and Kolokotsa, 2015). Low-income families, pensioners, and indigenous Australians have faced increasing difficulty in paying energy bills and ultimately achieving the required indoor environmental conditions. Lack of ventilation, inadequate insulation, poor indoor air quality, presence of internal condensation, mould, and damp are associated with illnesses like bronchitis, asthma, influenza, heart diseases, arthritis, migraine, as well as social and mental health problems such as depression and anxiety (World Health Organization, 2007). Further, extreme weather events have a significant impact on the quality of life, energy use, and health of urban residents (Santamouris and Kolokotsa, 2015). The low-income vulnerable population is particularly affected by the local and global climate change and energy poverty. Summertime indoor environmental conditions in low-income households lead to thermal discomfort and heat stress, especially during heat waves. Non-satisfactory levels of indoor environmental quality may cause health problems and increase the mortality rate. A recent study shows the lack of affordable housing options and rental stress in Sydney, where 90 % of low-income earners paid more than a third of their income on rent (Troy et al., 2019). It demonstrates additional challenges for people who need social and affordable housing. Despite the importance of the topic, very little is known about the specific penalties and the impact of extreme weather conditions in Australian low-income population. Additionally, there is little empirical evidence about the indoor air and environmental quality of social housing in Australia. This paper is part of a larger study which aims to assess the living conditions of the low-income population where health, energy consumption, as well as indoor environmental quality are considered. Energy efficiency measures for low-income housing require a deep knowledge of the actual conditions of social housing dwellings and residents. This paper investigates thermal comfort, indoor air quality, residents' satisfaction, housing quality and characteristics, health, and energy penalties related to the low-income population in New South Wales, Australia.

## **2 DATA COLLECTION PROCEDURE**

This study was performed in public, community, and social housing dwellings occupied by residents in need of affordable rental housing. A total of 109 residents participated in the questionnaire survey and 106 households proceeded with the indoor air and environmental quality monitoring campaign. Selected households represent the social housing stock in Sydney including a combination of one-story, multi-storey, single family, multifamily, with distinct characteristics (e.g., size, construction characteristics, age) and locations including coastal and inland areas. This study mainly focused on residences in Sydney metropolitan area; however, it was further extended to western regional cities, namely Dubbo, Bathurst, and Orange, due to the microclimate characteristics and reported higher ambient temperatures in the western areas (Santamouris et al., 2017). In this study, 51.4 % and 41.3 % of participating residents were living in public and community housing, respectively. The remaining 7 % corresponds to low-income households with private rental housing.

### **2.1 Indoor data measurement protocol and questionnaire survey**

A monitoring campaign was performed to obtain environmental data and air quality in the dwellings. The indoor air temperature ( $T_a$ ), relative humidity (RH), and carbon dioxide ( $CO_2$ ) were continuously recorded from May 2018 to February 2019 using Indoor Air Quality Eggs version 2 Model D (Wicked Device LLC, New York). The sensors were placed in a well-ventilated position away from direct sunlight and excessive moisture exposure in the living rooms, where occupants spent most of their time during the day. Measurements were recorded

with a one-minute interval and then averaged over 30 minutes for analysis. Data was recorded and manually downloaded due to limited access to a wireless network in the social housing dwellings and financial concerns of low-income residents who participated in this study. The air quality Eggs were installed in 83 residences. However, due to concerns of the remaining 23 residents about electricity usage and risk of interruptions due to accidental interference of people or power outage, 106 Logtag® TRIX-16 temperature recorders were also added in all dwellings. These temperature sensors have a built-in battery, a resolution of 0.1 °C and an accuracy of  $\pm 0.5$  °C. Thus, air quality data was obtained in 83 residences, while 23 households were only monitored for the indoor air temperature. Fieldwork procedures combined measurements of physical variables of the residences with survey of subjective responses, which records subjects' perceptions of the thermal environment, energy bills, quality of the building envelope and indoor thermal and environmental condition (e.g., presence of mould), other features of the building and energy profile (number of people sharing the household, time spent at home), and residents' health conditions and behaviours. Furthermore, the ASHRAE seven-point scale (ASHRAE 55, 2017) was used to measure residents' thermal sensation on 'right here, right now' basis during summer 2019, which records subjects' perceptions of the immediate thermal environment.

## 2.2 Characteristics of the household and dwellings in the study

The pooled responses from 109 respondents involve data for a total of 200 people living in the social housing residences. According to 2016 census data, the average age of the NSW and greater Sydney population was close to 38 and 36 years (Australian Bureau of Statistics, 2016), while the average age of participants in this study was 45 years. Figure 1 (a) shows the distribution of different age groups. The total population size is made up of 76 (38 %) males and 124 (62 %) females. Of all residents, 45 % were aged between 18 and 60 years, 35 % were aged over 60 years, and 22 % below 18 years (Figure 1(b)). Then, 18 % of the total population in this study were employed, while the remaining population were unemployed or inactive (16 %), students (28 %), and retired people and disability pensioners (39 %).

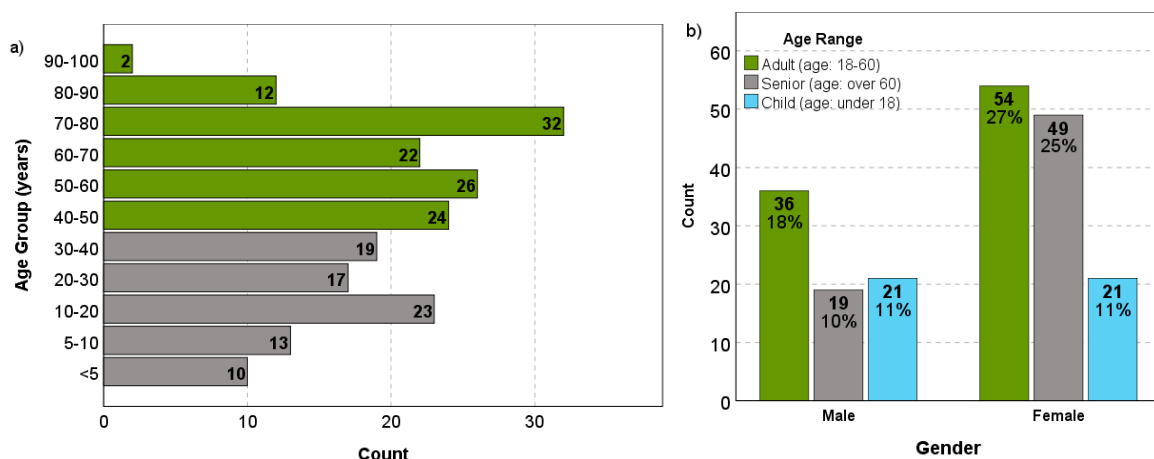


Figure 1: Characteristics of the household in this study: distribution of (a) age group; and (b) gender.

The average household size was of 1.8 people, with 54 % of participating households composed by only one person, while in 32 % and 14 % of cases the size was of two and over three persons per household, respectively. The average declared household fortnightly income value in 2018 was \$1076 per household and \$600 per person. The average electricity bills per quarter per household and per person were \$271 and \$151, respectively. All surveyed dwellings were rental housing with the average construction year of 1975-2000. Only 25% of residences were built

after 2000. The total floor area of the residences varied from 24 m<sup>2</sup> to 135 m<sup>2</sup> with an average of approximately 70 m<sup>2</sup>. 63 % of participating dwellings were apartment units and 37 % were detached or semi-detached houses. All participating residences had single glazing windows and reported to have poor insulation. While 45 % of residents did not know if their dwelling was insulated, 27 % of households reported some forms of insulations in their homes. According to the Australian Bureau of Statistics (2012), social housing renters are twice as likely to be living in un-insulated homes, when compared to owner-occupied residences. Mould and condensation were reported in 42 % of dwellings participated in this study. Mould and condensation primarily occurred in bedrooms (40 %) and wet areas namely bathroom, laundry, kitchen (38 %), 17 % happened in the living rooms, and 5 % in all rooms. Social housing residents may face difficulties to solve the mould and condensation problems. Mould is particularly important because it may affect people with health conditions namely allergies, asthma, weakened immune systems, chronic, obstructive, and allergic lung diseases (State Government of Victoria, 2019). During the winter period, 69 % of residents used a portable electric heating system, while 22 % did not have any heating system. A fireplace or gas heaters were used in 10 % of the surveyed buildings. During the summer months, 90 % of families used a portable fan or evaporative cooling system, 7 % a split system, and 3 % had no cooling system.

### **3 RESULTS**

#### **3.1 Results from the subjective survey**

The participating residents spent on average 18 hours per day at home, which highlights the importance of indoor environmental quality on social housing residents particularly the age group of over 60 years who spent an average of 20 hours a day at home. Families with a fortnightly income above \$1,500 (13 % of total sample size), were composed by higher number of residents per household and paid higher rates for the electricity bills (up to an average of \$500 per quarter) compared to families with lower-income rates. Very low-income families, with an average resident size of about two persons, paid approximately \$200 per quarter for their electricity bills. Social housing residents may face several problems including social, economic, and physical barriers to prevent chronic disease. About 28 % of all residents reported psychological disorder. Of all residents who reported mental health or psychological problems, 38% had a fortnightly income in the range between \$600 and \$1000. Depression and anxiety (76 %) were the most common psychological disorders among participating residents. Previous research has shown that low indoor temperatures have an adverse psychosocial impact including depression and stress (Critchley et al., 2007; Thomson and Snell, 2013). Non-proper levels of indoor daylight or bad window view increase the probability of depression by 60 % and 40 %, respectively (World Health Organization, 2007). Further, people living in houses with mould, present a 60 % higher trend for depression than residents of dwellings without mould problems (World Health Organization, 2007). More than half of the residents reported health problems. Within different age groups who have reported health problems, a higher percentage of seniors aged over 60 (27 %) reported health problems compared to adults (20.5 %), and children (6 %). Airway and blood diseases were the most common health problems in this study. When airway disease, allergy, and asthmatic symptoms are combined, it accounts for 32 % of all reported disease. Further, 32 % of residents were obese or very overweight, while only 4% were underweight. Residents were asked to report any hospital admission during summer months 2019. It was found that 25 % of hospital admissions in summer 2019 were associated with excess heat inside the residences. Then, 23 % of all residents involved in this study were smoking 2 to 35 cigarettes per day with an average of about 6 cigarettes smoked inside their dwelling.

### 3.2 Analysis of indoor air quality and thermal environment

The CO<sub>2</sub> concentration trespassed the recommended threshold of 1000 ppm (ASHRAE 62.1, 2016) and 850 ppm (Australian Building Codes Board ABCB, 2018) in several investigated buildings particularly during winter and the mid-season. The CO<sub>2</sub> concentration exceeded 1000 ppm and 2000 ppm in 78 % and 24 % of buildings monitored with the air quality Egg sensors, respectively. While CO<sub>2</sub> level exceeded 3000 ppm in the participating buildings, the documented indoor weekly mean concentrations of CO<sub>2</sub> in typical Australian dwelling are 527 ± 121 ppm in Winter/Spring and 544 ± 121 ppm in Summer/Autumn (Cheng et al., 2010).

Figure 3 shows the indoor air temperature profile in a sample of monitored residences in Western Sydney, which highlights the periods when indoor conditions were outside the comfort range (red dotted lines). The minimum recorded indoor air temperature in all dwellings ranged from 4.9 °C to 19.3 °C with an average of 13.5 °C. The minimum air temperature fell below 10 °C in 20 % of the monitored buildings. The average relative humidity ranged from 42 % to 68 % during the monitoring period. The maximum indoor air temperature recorded during the summer period, December 2018 to February 2019, was 39.8 °C while the average indoor maximum temperature was 32.6 ± 3.0 °C.

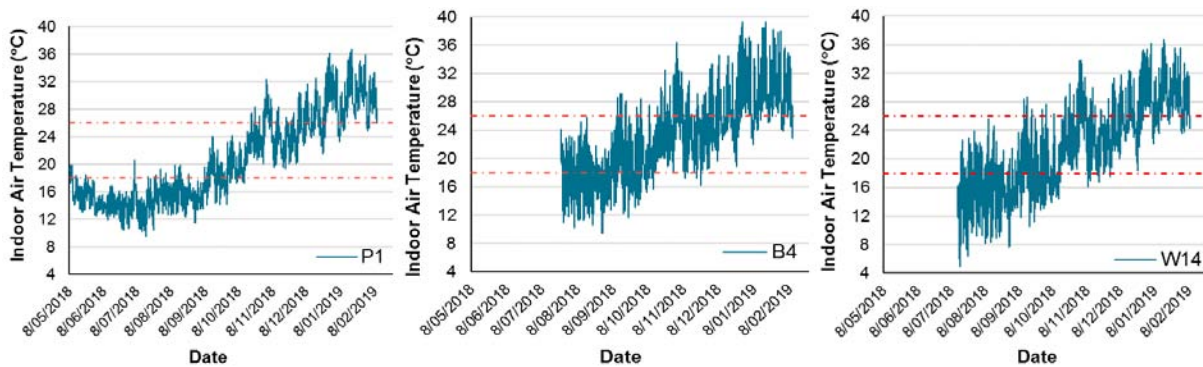


Figure 3: Indoor air temperature profile in three residences (the red dotted lines represent the comfort range)

Figure 4 shows the locations of the monitored buildings and the spatial distribution of the recorded maximum indoor air temperature. Inverse Distance Weighted (IDW) interpolation technique was used to generate the spatial patterns of maximum indoor air temperature based on the assumption that the nearest points surrounding a selected location have more influence on the prediction than those that are farther away. The IDW interpolation technique weights the points being evaluated based on the distance from the sampled location; the weight is a function of inverse distance (Philip and Watson, 1982).

The distribution of the maximum indoor air temperature in the monitored dwellings during summer was consistent with the distribution of outdoor climate in Greater Sydney, where Western Sydney frequently presents 7-10 °C hotter than in coastal suburbs (Santamouris et al., 2017). This highlights the need for improved quality of social housing dwellings to provide comfort and avoid heat-related mortality and morbidity during heatwaves and extreme climatic condition in the future.

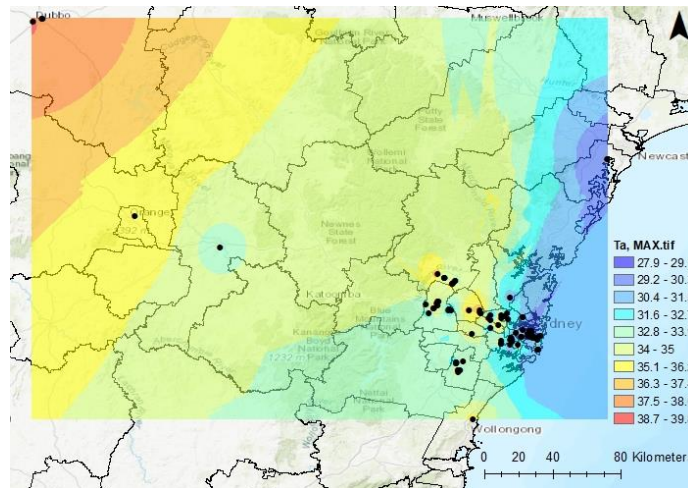


Figure 4: Maximum indoor air temperature distribution map

Based on the results of the right-here-right-now thermal sensation survey during summer 2019, the acceptable range of temperature for occupants is derived. The acceptable range is the comfort temperature band within which most people are comfortable. To find the empirical limits of acceptable thermal environments for 80 % satisfaction (ASHRAE 55, 2017), the indoor temperature was calculated for the mean thermal sensation votes (TSV) of  $\pm 0.85$ . However, because the mean TSV points fall on the warm side of neutral, i.e. central category of the ASHRAE scale, this study focuses on upper limits of the comfort zone which corresponds to  $TSV = +0.85$ . Occupants' mean TSVs within each  $0.5\text{ }^{\circ}\text{C}$  indoor air temperature bin were calculated and plotted in Figure 5. Because the data was binned, the linear regression model was weighted according to the number of occupants making up each mean vote within each  $0.5\text{ }^{\circ}\text{C}$  bin. The regression slope is a measure of sensitivity to temperature change and demonstrates how much the thermal comfort vote increases per  $1\text{ }^{\circ}\text{C}$  rise in operative temperature (Humphreys et al., 2007). It is inversely proportional to the adaptability of the building occupants. Since no data on the mean radiant temperature is available in this study, we only focused on the air temperature. The regression equation suggests that the mean thermal sensation unit increases 1 point per  $4.8\text{ }^{\circ}\text{C}$  increase in the room indoor air temperature. The dwellers participated in this study have an upper acceptable indoor air temperature of  $25.8\text{ }^{\circ}\text{C}$  (when  $TSV = +0.85$ ).

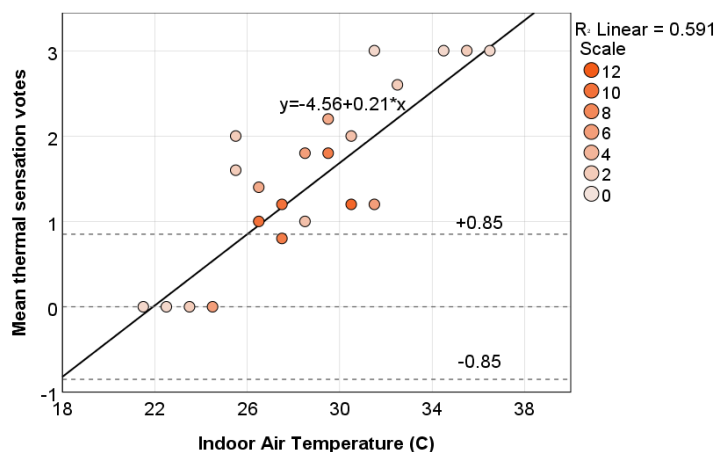


Figure 5: Weighted linear regression analysis of mean thermal sensation votes against air temperature

The most cost effective and efficient technologies that need to be used for Australian low-income households include improvements in the dwellings' envelope, passive heating and

cooling techniques, and improvement of the building services and energy management. Further, it should be attempted to improve the low-income neighbourhoods' microclimate by increasing the green spaces and using reflective materials for pavements and roofs to mitigate urban overheating particularly in western suburbs.

#### **4 CONCLUSION**

This paper presents the current indoor condition of low-income social housing residences in NSW and reports problems associated with health, comfort, and energy. Occupants' responses to the survey give information on the challenges of the low-income population in securing the required levels of the energy services in their dwellings. Monitoring of 106 low and very low-income houses during the winter and mid-season of 2018 and summer of 2019 in Greater Sydney has shown that the indoor air temperature is much lower and higher than the minimum and maximum threshold values set for comfort and health purposes, respectively. In most of the participating residences during winter 2018, long spells of low indoor temperatures are recorded which were much below the internationally accepted conditions. The minimum indoor air temperature recorded was about 5 °C during winter 2018 and the maximum indoor air temperature reached 39.8 °C in summer 2019. Summer-time indoor air temperature in many of the residences located in Western Sydney largely exceeded the comfort limits. The maximum indoor air temperatures were higher in western areas compared to those observed in eastern suburbs. As it concerns indoor air quality, many of the investigated dwellings exceeded the recommended threshold with CO<sub>2</sub> trespassing the limit of 1000 ppm, particularly during winter and mid-season when there was a limited rate of ventilation. The results of thermal comfort assessment showed that occupants adapted to slightly larger indoor temperature band (with the upper acceptability limit of 26 °C), highlighting the importance of the availability of controls that would enable them to adjust their indoor environment based on their preferences. Despite adaptability of social housing residents, indoor air temperature during cold and warm seasons exceeded the comfort zone limits and this led to a higher rate of dissatisfaction during cold and warm seasons. This highlights the importance of building design and adaptation techniques to improve the quality of building envelope and passive design strategies to reduce the need for active heating and cooling system in social housing residences. Future research should focus on analysing a larger sample of social housing and survey a larger number of occupants to generalize the results of this research.

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