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Overheating Risks and Impacts on Occupant Well-Being of Covid Lock-down in UK Apartment Blocks

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Abstract

Overheating in buildings is increasing in both domestic and commercial situations. This arises from a combination of climate change, urban heat island effect, and the ways in which buildings are used. In climates which already experience hot climates the provision of air conditioning can help reduce impacts. In more temperate climates reliance is more likely to be on natural ventilation and fans. The benefits of these can be limited in cities due to noise and pollution/dust infiltration. An important impact of the Covid pandemic was to drive the urban population to inhabit dwellings for even longer periods in indoor environments, because of needs for isolation or curfews. Occupancy patterns also shifted to include greater residence during warmer daytime hours. These factors substantially increased the risk of excessive temperatures and health impacts on occupants during the summer season. Increased morbidity and even deaths can result yet there is little guidance available. The research described in this paper uses computer simulations of typical building arrangements to identify risks and contributing factors. Reference to standard guidance in the UK is made for comparison though the concerns are important for many other countries. Awareness of the problem can lead to better future guidance.

Keywords: overheating, dwellings, apartments, Covid, UK

1 Introduction

The potential for overheating in residential buildings is increasing across the globe. The problem is not just confined to hot climates but can occur in almost any location due to the general process of global warming and the increased variations in extremes.

The problems can be exacerbated by the increasing urbanisation of populations driven to live in increasingly small spaces by the cost of real estate. The urbanisation also brings additional problems which can restrict access to and value of natural ventilation. This is a particular problem in areas with significant external noise or air pollution. Further difficulties arise when these initial and underlying problems are exacerbated by general heat island phenomena and more specifically during periods of extreme weather. An example of this was the heat wave across Europe in 2003 in which many thousands of excess deaths were recorded and even in the UK between hundreds to thousands of additional deaths (Steadman, 2004). A timely reminder has been the heat wave in western Canada and the United States in June 2021 (BBC, 2021).

The global pandemic caused by the outbreak of the Covid coronavirus disease (2019-nCoV), first spotted in 2019 but not fully recognised until early 2020, has placed further and at times pressures on the situation. Residents of many countries were advised or forced by law to stay indoors for long periods of the day (Sandford, 2020) and over the course of this pandemic almost all the world's population has been affected in some way. As a result, many dwellings were occupied for longer periods of the day and by a greater number of people than would normally be expected, particularly during daytime hours when external environmental conditions are hottest. One of the key building types that was considered to be most at risk is that of the densely occupied apartment block where the options for cooling in a temperate climate would be limited by lack of access to air conditioning (which is uncommon is such situations) and by the lack of natural ventilation potential or other means to lose heat. Ventilation in such high-rise situations can also be limited due to security feature that reduce the openable area of windows either because of risk of falling for children or because of concerns for burglaries. Some of the potential for overheating has been previously recognised (Mulville and Stravoravdis, 2016).

Taken together these factors indicate a potential for a perfect storm of negative conditions and a set of circumstances which had the potential to create serious health risks to occupants above and beyond those linked to the Covid disease itself.

2 Regulatory Standards

Taking the UK as an example of a temperate climate and a residential building stock that is largely un-airconditioned, substantial risks might be anticipated. There are a number of regulatory standards but the main legislative impact comes from the Building Regulations. In the last 2 years there has been a more rapid development of Government sponsored research and policy evolution to the overheating risk which will be liked to new tools and analysis. See for example MHCLG, 2019, however there is still risk thar the Building Regulations will not adequately address overheating. Although since 2019 options have begun to evolve though it was only in January 2021 that consultation process for Building Regulations change was commenced (UK Gov, 2021).

For a number of years, the main means of understanding risks from overheating and how to account for them have come from Technical Memoranda published by the Chartered Institution of Building Services Engineers (CIBSE) or from similar profession or public bodies in other countries. This is also an area in which the academic research community has been active through such organisations as the NCEUB (Network for Comfort and Energy Use in Buildings) and its associated series of Windsor Conferences (NCEUB, 2021). The emergence of the Adaptive Comfort Model has been useful as a means to assess more clearly real building situations with real occupants and particularly with natural ventilation operational. The background to the topic and thorough discussion of issues is provide in Nicol, Humphreys and Roaf (2012), but this is not employed in assessment of the topic.

The key linked guides relevant to the research carried out to produce this paper are: TM52: The Limits of Thermal Comfort: Avoiding Overheating in European Buildings (CIBSE, 2013); TM59: Design methodology for the assessment of overheating risk in homes (CIBSE 2017); and for calculation/simulation purposes TM48: Use of Climate Change Data in Building Simulation (CIBSE, 2009).

From these, there are two key criteria to consider: Criterion A for living rooms, kitchens and bedrooms requires that the internal temperature does not exceed a defined comfort temperature by 1 °C or more for more than 3% of occupied hours over the summer period (1 May to 30 September) – the temperature value being and undefined value for discomfort point. Criterion B for bedrooms requires that the internal temperature between 10 pm and 7 am does not exceed 26 °C for more than 1% of hours in the year. These still leave gaps in understanding.

The standards and Technical Memoranda governing overheating have raised a number of criticisms since there require a combination of exceedance of a specific value of temperature and the period of exceedance. They say much less about the degree of overheating, however these are the most relevant options at present.

There is also a focus which is not helpful given the arguments mentioned above, that the main room for consideration with specific values of maximum temperature is the bedroom. This represents a somewhat outdated understanding of the problem in which daytime and other room overheating was considered less important.

There are also assumptions about the maximum number of people likely to be resident in a dwelling and the amount of time they are likely to spend in different areas. In the case of the Covid pandemic such assumptions may be incorrect.

There are currently proposals to bring overheating risk within the proposed Future Buildings Standard which would be enacted through Building Regulations however several groups have levelled criticisms against this due to lack of specifics (Lowe and Gardiner, 2021). The situation is currently in a state of flux and at the time research commenced much more comparative data was required which prompted the research of which this paper is a part.

2 Methods of Research

2.1 Thermal simulation

Given the urgency of the evolving pandemic and also because of the difficulties of monitoring conditions in-situ an approach to analysis making use of thermal simulation programmes was undertaken. This involved using DesignBuilder and EnergyPlus calculation systems to analyse typical apartment dwellings. Although a number of simulation programmes already included options to determine overheating risk it was concluded after a number of test simulations that these did not adequately represent the contemporary situation or allow sufficient flexibility to consider situations outside the normal circumstances. Also simply advising that a design is likely to lead to discomfort did not fully realise the potential or need to discriminate for the main causative factors or where balance points might lie. Although the thermal model was not directly validated in this study there is ample evidence to suggest it is suitable (DesignBuilder, 2021) and the authors have experience of using it for analysis of apartments in warm climates (Dang and Pitts, 2021 and Le and Pitts, 2021). Factors incorporated into the analyses are below.

2.2 Locations

The intention of the research was to focus on conditions and situations in the UK and more specifically in England since the Budling Regulations and typical construction practices would be similar. Three cities representing different exposures to climate were selected: London (51.5N, 0.1W), Manchester (53.5N, 2.2W) and Newcastle (55N, 1.6W).

2.3 Weather data

Weather data were required not only for the three sites but also for two time periods so as to allow analysis of contemporary conditions but also to discover if global climate change and warming conditions would increase the risk and by how much.

Data were obtained from two sources: firstly, for contemporary conditions from the CIBSE from whom data and licenses for use were obtained at cost – since no more recent data were available, the time period 1961-1990 DSY values were chosen. Secondly for the climate change scenarios data were downloaded from the University of Exeter – Centre for Energy and the Environment in the form of 'future weather files' (University of Exeter, 2021). The future weather data was chosen to be 2050 50percentile high emissions scenario

2.4 Apartment types

The analysis was based around considering typical apartments built as part of multi-storey blocks. To examine whether the heigh above ground would have an impact the floor level 2 and the floor level one below the roof were considered separately. In all cases the apartments were surrounded on each side by other similar apartments or by corridors and each had just one external wall.

Two basic apartment types were chosen: a one-bedroom apartment occupied by two people and consisting of a bedroom and a living room with kitchen and bathroom adjacent. A two-bedroom apartment was also chosen with 4 occupants representing a family situation. In each case the bedroom and living spaces would be assessed separately. Figures 1 and 2 illustrate some of the key features of the apartments and their position. Figures 3 and 4 show layout and dimensional details of the example one and two bed apartments.

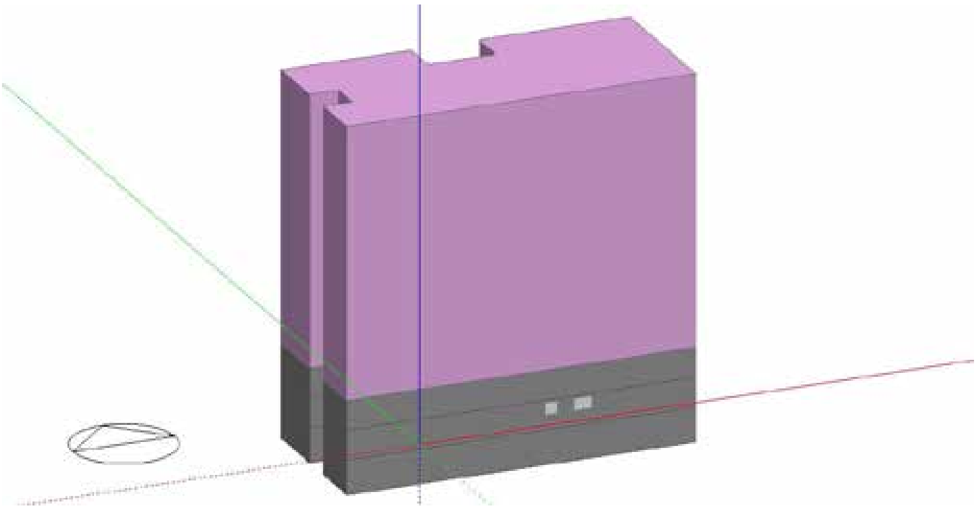

Figure 1. Whole apartment block showing typical position of apartment windows on floor 2.

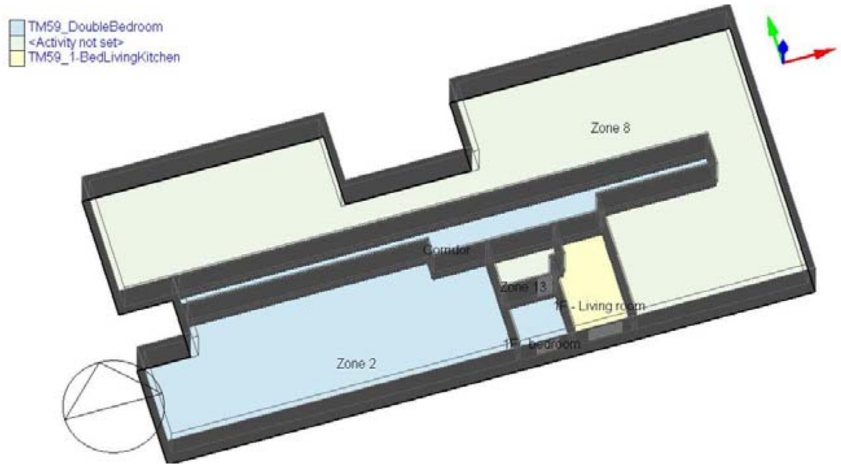

Figure 2. Apartment block typical floor level showing examples of one- and two-bed apartments.

Figure 3. Layout and dimensions of 1 bed apartment used in the study

Figure 4. Layout and dimensions of 2 bed apartment used in the study

2.4 Construction features

The one bed apartment had an openable window in the living room and bedroom room; the two-bed apartment had an openable window in each bedroom and two windows in the main living space (each window was 1.2mx1.2m) with a modest free opening area of 10% (set according to typical safety standards. Other air leakage (other than openable windows) was determined from data found in TM23 (CIBSE, 2000).

Two types of construction were examined a lightweight version with 200mm of insulation and a heavyweight version with exposed structure and 100mm insulation representing an older style of design.

In order to compare orientations, the apartments were each set in a rotated version of the apartment block to face north, south, east and west.

2.5 Other variables

Occupancy rates were created to represent typical conditions of use of living spaces and bedrooms assuming the Covid confinement was in place – so 100% values for the whole period with occupants moving between living and sleeping areas at defined times. Typical other heat gains were derived from TM59 (CIBSE, 2017) for each room type and for heat gain from lights etc.

In total the different variable led to the calculation of 1920 different combinations of rooms and conditions.

Table 1. Summary of main variables investigated in parametric study.

Parameter	Variations included	Comments
Location	3 city locations in the UK: London, Manchester, Newcastle	Spread was from South to North in England
Date for climatic data variables	Two variations: recent measured climate data (1961-1990 DSY) and predicted 2050 data according to 50 %(pctl) high emissions scenario	Data from 1961-1990 is a little old but relatively complete; 2050 high emissions scenario was chosen to represent testing future conditions
Apartment types	Two variations: 1-bedroom (2 occupants) living room, kitchen, bathroom; 2-bedrooms (4 occupants) living room, kitchen, bathroom.	Typical variations from studies of apartment blocks
Location of apartment in block	Two variations: top floor and lower mid-floor	Chosen to assess variation in fabric heat flows
Window variations	One openable window in each bedroom;	Each window 1.2m x 1.2m, 10% opening area in line with examples
Construction variations	Lightweight and steel frame (fast response to energy flows), Heavyweight concrete slab (slow response)	Main variation was depth of insulation and type of structural components
Air leakage	Estimated from data using CIBSE TM23	
Orientation	4 principal directions N, S, E, W	
Occupancy	TM59 complex and simple Generally 100% occupancy used – but variation in location of people moved between living and bedrooms	Due to need for staying at home/isolation with covid, longer periods of occupancy than normal used
Heat Gains	Calculated from glazing and internal gains (people/equipment)	Numbers used taken from TM59 and CIBSE data

2.6 Assumptions

The first assumption is that the DesignBuilder modelling software is suitable for the task using EnergyPlus calculation engine. The authors believe this is a reasonable assumption based on other studies and verification of the model published in the public domain.

Suitable weather data for Manchester was only available for the airport rather than city centre location – this will have had some impact but since the original premise was to consider a variety of climates, this means that a variety and spread of locations is still presented but will not be representative of Manchester city centre

3 Results and Analysis

The analytical approaches developed and applied in this paper arise from an extended periods of research into hot and warm climates with dwellings exhibiting arrange of features related to overheating (Dang & Pitts, 2018; Dang and Pitts, 2020; Dang and Pitts, 2021, Le and Pitts, 2021, Pitts, 2013; and Pitts, Dang & Ransom-Jones, 2019).

In several of these studies understanding of warm/hot environments was undertaken combining measurements of on-site environmental parameters in warm climates and of building occupant reactions. This information was then used to inform theoretical analyses and to develop in some cases methods of choosing appropriate building techniques or technologies to match to the climate and human needs.

The following paragraphs summarise the outcomes under a number of significant influencing features that were investigated in the parametric simulation study.

Impact of current vs future weather

The thermal environment in all living spaces of the two apartment types is warmer in the future weather scenario as might be expected. The average percentage of 'discomfort' hours (>28°C for living rooms and >26°C for bedrooms) and 'may experience discomfort' (>25-28°C for living rooms and >23-26°C for bedrooms) are more than 20% and 10% of total hours, respectively.

Impact of Floor position (level 2 and top floor)

The thermal condition in apartments located on level 2 is cooler than those on the top floor due to the impact of solar heat gain. The average discomfort hours in living rooms and bedrooms on the top floor is higher by over 15%. Combining with the effect of orientation, the uncomfortable temperatures in those rooms of top-floor apartments facing north are higher, by up to 25%. The reason may be a combination of solar radiation and lack of wind induced ventilation.

Impact of Insulation thickness (100 and 200mm)

The increase of thermal insulation thickness results in the indoor environmental being warmer with an increase of approximately 5% in unsatisfactory thermal temperatures.

Impact of Orientation (south, north, east, and west)

The average discomfort hours in apartments facing east are higher by 10% compared to apartments oriented to north. The average discomfort hours in apartments facing south are higher by 5% compared to apartments oriented to north.

The average environmental conditions of west facing and north facing apartments is similar – this is a little unexpected but seems to arise from the specific combination of circumstances

Based on the total calculated discomfort hours (>28°C for living rooms and >26°C for bedrooms) and 'may be uncomfortable' hours, the ascending discomfort level by the building orientation is West, North, South, and East (for lower apartments) and West, South, East, North (for upper apartments).

The highest and lowest percentage of uncomfortable or comfortable hours are found in eastern apartments.

The most extreme hot temperatures are found in south facing apartments.

Although the heat gain combined by internal and external sources is higher in rooms facing west, particularly after late noon; in the consideration of all 4 orientations, the air flow rate of west facing rooms is the highest probably due to the availability of prevailing winds from that direction. Therefore, the percentage of discomfort hours for west facing apartments in these circumstances are the lowest.

Impact of Occupancy pattern (using simple TM59 and complex TM59 analyses)

With the setting of TM59 occupancy pattern, the average thermal environment in apartments is warmer when applying to the simple version of TM59. The average variation between 'discomfort' and 'may be uncomfortable' operative temperature is 17% and 2%, respectively.

The vulnerability for human comfort to overheating risk is different between room types and floor levels.

For living rooms, the percentage of 'uncomfortable' operative temperature hours (>28°C) is higher by 31% in rooms simulated with the TM59 occupancy pattern. For 'may be uncomfortable' conditions, the difference is 1%.

For the bedrooms tested by TM59 pattern, the percentage of 'discomfort' (>26°C) and 'may be uncomfortable' (>23-26°C) hours increases less than in the living room with a reduction of 4%.

Impact of Location (London, Manchester, and Newcastle)

The indoor thermal environment of apartments in London is the most vulnerable to human discomfort than in apartments in the other two locations.

Comparing the discomfort condition of apartments located in London, Manchester, and Newcastle, the number of uncomfortable occupied hours in summer in London is the highest with 59%, which figure is much more than 42% and 49% in apartments in Manchester and Newcastle, respectively.

Considering the 'may be uncomfortable' hours of apartments between different locations, their percentage in apartments in Manchester and Newcastle are higher by around 7-9% in relative to apartments in London.

It should be borne in mind that the local climate (temperature and wind patterns) and the urban condition are involved in controlling the thermal environment in apartments located in different cities. In addition, the urban pattern (airport - Manchester or city centre – London and Newcastle) may affect the thermal environment inside buildings.

Impact of considering CIBSE TM59 (applied for vulnerable occupants)

This related specifically to the conditions: (a) For living rooms, kitchens and bedrooms: the number of hours during which DT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 per cent of occupied hours. (CIBSE TM52 Criterion 1: Hours of exceedance).

(b) For bedrooms only: to guarantee comfort during the sleeping hours the operative temperature in the bedroom from 10 pm to 7 am shall not exceed 26 °C for more than 1% of annual hours. (Note: 1% of the annual hours between 22:00 and 07:00 for bedrooms is 32 hours, so 33 or more hours above 26 °C will be recorded as a fail).
Using the criteria of TM59 to evaluate the overheating risk in domestic buildings, all cases tested for various variables are failed, which means that the percentage of summer occupied hours over 28°C and 26°C operative temperatures for living rooms and bedrooms are higher than 1%. Using cases of conditions (current weather year, in London, Level 2, 100mm insulation, Simple TM59) under the percentage of hours outside of the criterion (a) is 68% in the living room and 46% in the bedroom.
The occupancy pattern clearly affects the TM59 outputs and the overheating risk of living rooms and bedrooms rise by 25% and 7% when applying the TM59 occupancy distribution for simulations.

4 Discussion and conclusions

4.1 Summary

The material presented in this paper provides a summary of a wide range of investigated combinations of buildings, location, weather and occupants. The key points in section 3 therefore serve to illustrate some findings of interest these are now identified below.

- Using TM59 standards for vulnerable occupants all sets of parameter variations failed the standard.
- Overheating risk with significant discomfort is likely in all situations with future weather data used, potentially 20% of hours during the broad summer period investigated.
- Top floor apartments suffer significantly higher time periods of overheating risk (+15%) compared to lower-level apartments due to exposure to solar radiation.
- High insulation/lightweight scenario increases overheating in summer due to limiting of heat loss and potentially less thermal capacity (further work required).
- Overall highest temperatures were calculated for south facing apartment.
- The impact of occupancy patterns affected results and requires deeper investigation.
- There are several complexities in comparing impacts of using different assessment criteria from the technical memoranda and this needs further examination in future studies

4.2 Limitations

The research involved the use of an establish thermal model/simulation to assess a number of variables and their likely impacts on internal conditions of apartments. No separate independent verification of the results has yet occurred but the authors believe it is reasonable to carry out such an analysis so as to derive differential data based on the parametric variations. The more complete validation of specific circumstances will be part of a further study.
Weather data for Manchester was available in the form required only for the airport location whereas for London and Newcastle these data related to urban centres. Whilst this is not ideal it was not the purpose of the study to compare specific types of sites but rather to gain information from south to north and for different conditions. The research matched to this need quite adequately.

4.3 Further work

Further data-mining of the extensive simulation files is currently being undertaken and there is a hope to extends to more locations and situations.
There is also a need to combine with better knowledge and understanding of the human reaction to discomfort and heat stress, which as is well documented in the case of thermal comfort, can vary considerable from individual to individual. Other opportunities ought also to be explored to optimise the value of understanding exposure to overheating, this is because in a number of heatwaves the rates of morbidity and death have increased. This seems to be because building occupants gradually succumbed to the hyperthermia without fully realising their predicament. This may have been made worse when more elderly or less-mobile residents were left on their own by other family members due a combination of holidays, remoteness of location, or simply lack of awareness of the situation. A better set of regulations along with predictive techniques would enhance design understanding for new and refurbished buildings and also perhaps permit installation of 'early-warning' equipment or devices for at-risk residents.
The importance of understanding overheating risk is high not just for countries and climates located close to the equator but also for all situations in which a combination of circumstances can lead to problems for building occupants. Occupants of buildings in traditionally temperate and often regarded as comfortable climates can still experience problems whether by way of extreme climate conditions or because of abnormal circumstances.
There is a need for contemporary and future weather data to be more freely available so that it can be incorporated into new and emerging analyses and processes.
What is clear is that though the impacts of the Covid pandemic may recede the risks to health from overheating are only likely to rise.

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