Achieving a better understanding of air infiltration when assessing overheating in multi-residential dwellings

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Abstract

In temperate climates the prediction of indoor temperatures using Building Performance Simulation (BPS) is thought to be highly sensitive to assumptions regarding convective and radiative heat transfer processes. This paper investigates whether the way in which infiltration is modelled may be exerting a pronounced effect on the results of overheating studies. An EnergyPlus model, of a dwelling in a multi-residential building in London, was created to investigate the influence of infiltration and exfiltration pathway assumptions on the prediction of overheating. Baseline modelling based on the application of the TM59 methodology to an existing building was compared to scenarios using best practice dynamic modelling procedures. The findings were compared to empirical data and show that the indoor temperatures are highly sensitive to how the infiltration airflow network is modelled.
The results of this study provide practical guidance for modellers and building designers on what aspects to consider when creating energy models to ensure more reliable outcomes. Implementation of these findings is considered crucial for the further development of TM59 and similar overheating assessment methodologies) where reliable results are central to informing robust designs

Keywords

Overheating risk assessment, Airflow network (AFN), infiltration, exfiltration, Building performance simulation

1.0 Introduction

Technical Memorandum (TM) 59: Design methodology for the assessment of overheating risk in homes (1) was published by the Chartered Institute of Building Services Engineers (CIBSE) in April 2017. The aim of this document was to standardise the assessment methodology used when determining the risks of overheating in UK dwellings; with the intention that adherence to this guidance, “should play a key role in limiting overheating risks in new and refurbished homes” (1). In an earlier study of the TM59 methodology it was shown that in the context of modern energy efficient homes, in an urban UK context (which are often characterised by large glazed areas, restricted purge ventilation capacity, and a lack of shading devices), it may be impossible to fulfil the requirements set out in CIBSE TM59 without recourse to mechanical cooling (2). This study also highlighted the role that ventilation, orientation and the building's surroundings play in the discrepancy between TM59 predictions and monitored data (2). The present paper builds on this previous work and investigates the specific issue of modelling infiltration and exfiltration in multi-residential buildings, with the main objectives of this study being as follows:

i. To propose different scenarios for addressing infiltration and exfiltration more robustly in multi-residential buildings with communal corridors.
ii. To demonstrate the importance of modelling infiltration as a contributing factor in reducing the discrepancy observed between simulations and reality
iii. To propose how the current TM59 (or any other simulation-based overheating) methodology for addressing infiltration and exfiltration could be improved, with the aim of achieving more consistent and robust outcomes.

2.0 Understanding infiltration and exfiltration

Air infiltration occurs when air moves into a building or a zone within a building. Whilst air exfiltration occurs when air moves out of a building or zone. Air flow is caused by pressure differences between the inside and the outside of a building, and when differences exist internally between zones. Differences in air pressure may be caused by wind, buoyancy effects, zonal temperature differences and mechanical fan pressure (e.g. due to MVHR). Air enters buildings via large openings such as through open windows and doors but also through vents and ductwork and via small cracks and crevices within the building envelope. The geometry and location of the ingress and egress points will influence the type of airflow.

A previous calibration study on a test facility in Germany showed that accurate modelling of ventilation and infiltration had a significant impact in improving modelling predictions compared to a simplified approach using averaged (i.e. constant) flow rates to represent infiltration (3). In another study by (4) parameters such as crack dimensions, wind-induced pressure coefficients, mechanical ventilation flow rates and ratios between convective and radiative heat gains were investigated. The authors identified wind pressure coefficients as highly sensitive when analysing observed internal temperature differences.
When capturing infiltration in Building Performance Simulation (BPS), such as EnergyPlus for example, ambient air is assumed to be immediately mixed with the zone air (5). In the most common procedure, the specified infiltration quantity is apportioned, on the basis of volumetric air changes per hour (ACH), to each zone in the model and included in the zone air heat balance using the outside temperature at the current simulation time step. EnergyPlus contains three models for modelling infiltration; (i) the Design Flow Rate; (ii) the effective leakage area and (iii) the flow coefficient model. The former is based on environmental conditions modifying a design flow rate; the latter two are from the ASHRAE Handbook of Fundamentals (2001 Chapter 26; 2005 Chapter 27). The latter two infiltration models are more suitable for 'smaller residential-type buildings' (14). These models have been derived from physical models where buildings are represented as single zones and are therefore unsuitable for large multizone buildings. Furthermore, these models cannot be applied to dwellings with more than three floors (15).

Once air infiltrates the building from the outside (via cracks or openings) it is important to understand how the air moves around the different zones and where it eventually goes to, since this will influence the mass transfer of heat throughout the building. Some simulation software packages offer the possibility to include airflow networks (AFN). AFNs allow the simulation of multizone airflows driven by wind or by a forced air distribution system (5). These utilities are useful when a posterior knowledge of air flow paths is available but difficult to implement *a priori* with any certainty when the influence of occupant behaviour (e.g. window and door opening patterns, use of draft excluders, fans etc,) is unknown.

Another widely available simulation tool offers the ApacheHVAC and the Macro flow. The latter accounts for wind or stack driven natural ventilation, mixed mode ventilation, as well as detailed wind driven modelling of infiltration via crack and flow coefficients. The software manual however cautions with respect to the use of Macro flow, that “it is very calculation intensive”. The use of Macro flow is only recommended when “explicit modelling of pressure differences is needed to drive air movement in the model”. For all other environments with mechanically forced airflow, the software provider recommends using ApacheHVAC only.

The CIBSE TM59 overheating assessment methodology recommends capturing the modelled ventilation strategy in detail (including window openings, assumed infiltration rates and any mechanical supply/extract flow rates). In section 3.5 *infiltration and mechanical ventilation* TM59 refers to CIBSE Guide A (6) for more details on infiltration rates and noise design limits. TM59 states that “the infiltration and the mechanical ventilation rate should be set for every zone based on what is specifically designed for normal, acoustically compliant modes of operation.” It provides empirical values for air infiltration rates for rooms in different building types (e.g. offices, schools, dwellings etc) based on the building type, number of storeys and broadly defined air permeability standards (e.g. Part L 2002, Part L 2005, leaky, etc) as well as building size (6). Despite the complexity of air flow paths in large multi-zone buildings there are no details regarding how the inter-zonal ingress or egress of air should be treated. This is particularly relevant where flats are located adjacent to corridors, where air might infiltrate from or exfiltrate into. This is an important consideration in the thermal modelling of flats adjacent to corridors, particularly those containing communal pipework, where the exchange of heat through the mass transfer of air between the corridor and the flat is currently being ignored. Section 3.9 of TM59 proposes a treatment for including corridors in simulation practices, however the mass transfer between the corridor and flat is therein ignored. This is by virtue of the fact that only conductive heat transfer through the fabric elements (i.e. no airflow network) between a corridor and the adjacent flats is described in TM59. This means that the mass transfer of air driven by pressure differences across the corridor/ flat boundary and including any openings and their surrounding cracks is ignored.

Overall, the determination of time dependent rates of air infiltration and exfiltration and the characterisation of transient interzonal airflow network pathways is complicated and subject to significant uncertainty. To demonstrate the importance of this in the context of overheating risk analysis, this paper examines the implications of modelling infiltration and exfiltration of an energy-efficient flat and its communal corridor by considering four different scenarios.

3.0 Methodology

3.1 Case study building and monitored data

A second-floor flat located in a multiple occupancy residential building (constructed according to Part L1A 2010 building regulations) located in London, was investigated based on the application of TM59 to an existing multi-residential dwelling . The exterior walls are of brick cavity construction and all of the apertures are double glazed. Furthermore, all the openable windows open inwards and are equipped with safety restrictors. The thermal properties and air flow data of the monitored flats are presented in (2). Background ventilation in the flat is achieved through a whole house Mechanical Ventilation with Heat Recovery (MVHR) unit and hot water is provided by a Heat Interface Unit (HIU). This unit also provides space heating through a secondary circuit linked to a distribution manifold (n.b. space heating was turned off during the monitoring period). A detailed description of the above systems can be found in (7).

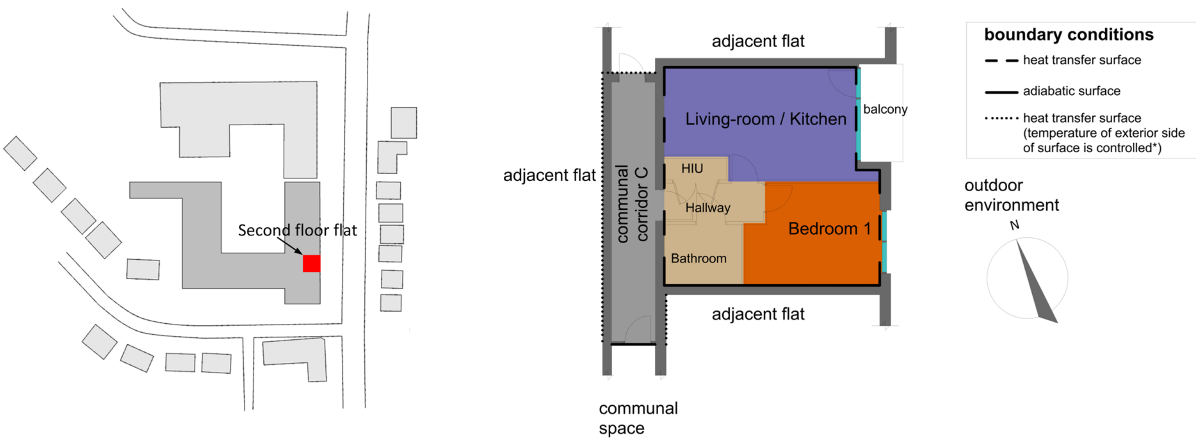

Figure 1 Arrangement of building showing the location (left) and plan of the flat comprising of and 6 thermal zones (right).

This single-bedroom flat (Figure 1) has an internal floor area of 46m^2 and is located on the second floor of the building. The flat has only one exterior façade, which is east facing. The north and south sides adjoin other flats whilst the west side is adjacent to a communal corridor.
The monitoring of the flats took place in October 2015; with the intention of assessing the prevalence of chronic overheating outside the summer period. For a detailed description of the monitoring protocol and all monitored parameters refer to (7). In this study, measurements of dry bulb (T_{db}) and globe thermometer temperature (T_g) were utilised (Table 1). Measurements of globe temperature were taken at 1.1 m above floor level to assist in estimating operative temperatures.

Monitored parameter	Room type	Flat
Dry bulb Temperature (°C)	Living-room/Kitchen	✓
	Bedroom	✓

Globe Thermometer Temperature [1](°C)	Living-room/Kitchen	✓
	Bedroom	×
Supply rates (l/s)	Living-room/Kitchen	✓
	Bedroom	✓
Extract rates (l/s)	Living-room/Kitchen	✓
	Bathroom	✓

Table 1 – Monitored data used in this study

3.2 Modelling assumptions

For the simulation using BPS, a bespoke weather file was created (2). A weather file depicting the actual weather conditions during the monitoring period was essential for the comparison of the simulated data with the monitored data. This was created by gathering data for the time period October 1 to November 4 of 2015 from the Met Office MIDAS database (9). Dry bulb temperature, dew point temperature, relative humidity, global horizontal radiation, wind direction and speed data were retrieved from the Kew Gardens weather station (51.48N, 0.19W) located approximately 11 km south-west of the monitored development. The missing, atmospheric pressure and total sky cover, weather parameters were obtained from the Northolt weather station (51.55N, 0.41W) located approximately 15 km west of the monitored flats. The opaque sky cover in the absence of recorded values was estimated by assuming 50% of the total sky cover (10). The components of the global horizontal radiation (i.e. direct normal and diffuse horizontal radiation) are essential inputs in a weather file for building simulations and were estimated using a subprogram of the daylighting analysis software Daysim (11).

For the purpose of model discretization, it was assumed that no heat transfer takes place between the flat and the space above and below; only the inside face of the ceiling and floor exchanges heat with the modelled zone. Where the surface temperatures are assumed to be adiabatic, i.e. the internal surface temperature and external surface temperature are identical. The temperature of the exterior face of the corridor wall (i.e. interior face of neighbouring flat's wall) is calculated according to Eqn 1.

$$T_{average} = \sum(T_{surface} * A_{surface}) / \sum(A_{surface}) \quad \text{(Eqn 1.)}$$

Where,

$T =$ temperature of interior face of the adjacent wall[2] (°C)

$A =$ surface area of wall sections belonging to different thermal zones of the adjacent flat in contact with the communal corridor (m^2)

[1] Measurements were undertaken in the Living rooms of the flat

[2] Note: the temperature of the interior face of the wall is the face in contact with the flats and not in contact with the corridor.

In relation to the operation of the MVHR unit, supply and extract rates for individual rooms were obtained from flow rates measured during the detailed monitoring of the flats (see table 2). The MVHR unit was in operation throughout the monitoring period. The whole dwelling ventilation rate was found to satisfy the minimum requirements specified by Approved Document F – Ventilation (13).

The MVHR unit was modelled in EnergyPlus using the *Zone Ventilation: Design Flow Rate* object in conjunction with the *Zone Mixing object* to represent the transfer of air from supply zones (e.g. living and bedrooms) to extract zones (e.g. bathrooms).
In terms of the ventilation rate in the communal corridors, in the absence of any measured data, ventilation flow rates were estimated according to CIBSE Guide A (see Table 2), where the specified design value is 10 l/s/p. In order to calculate the total flow rate in the corridor zone an occupancy density equal to 0.0196 p/m^2 was used (based on the values used in the National Calculation Method[3] (NCM) (which is based on a BRE estimate).

Room	Flat	Communal corridor	Source	Notes
Supply rates (l/s)				
Living-room	15.6		Monitored value	
Bedroom1	4.9		Monitored value	
Extract rates (l/s)		10	CIBSE A	People density was assumed equal to 0.0196; a BRE estimate
Bathroom	7.9		Monitored value	
Kitchen	12.6		Monitored value	

Table 2 –Ventilation rates (monitored data) in different zones for the flat

3.3 Infiltration scenarios

In the following section four different modelling scenarios were used to analyse the impact of infiltration and exfiltration pathways, as well as air movement through the flat. The DSP models were created using the widely used freeware EnergyPlus. The Infiltration value (ach) for the flat was derived from the SAP reports taking into account the results of individual air permeability tests and the number of sheltered sides (i.e. external walls not in contact with the outside air) of the dwellings; the infiltration rate was set to 0.26ach for all scenarios. Zonal infiltration rates were then predicted using the *Zone Infiltration: Design Flow Rate object* in EnergyPlus by assuming the same value for all thermal zones.

[3] NCM is a procedure for demonstrating compliance with Building Regulations. Available at http://www.uk-ncm.org.uk/ [last visited: 31/08/18]

3.3.1 Base case: uniform infiltration

In a previous paper the results of an EnergyPlus model were presented that was created following the TM59 procedure (2). This model represents the flat as shown in Figure 1 but does not include any information on occupancy (as it was empty during the monitoring period) and uses the more realistic onsite weather data. In this regard, the study differs from a direct application of TM59 (where the latter provides clear input requirements for occupancy profiles and climate data). In this paper this model is used to form the 'base-case' scenario which can be directly compared to the empirical data gathered on-site. The base case model assumes a fixed level of infiltration which was taken directly from the SAP report (although in reality greater uncertainty will exist, and the ADL compliance threshold is likely to be used during design stage modelling). The infiltration is equal to 0.26ach (a value which notionally applies to the whole flat) hence, in the model this value is used in all of the thermal zones. The base case model therefore assumes uniform infiltration in all spaces and no air from the corridor is assumed to enter to the flat.
In addition to the base case, three scenarios will be modelled.

3.3.2 Scenario 1: the AFN network

The first scenario is similar to the base case and infiltration is assumed to occur uniformly in each zone using air supplied from the external air temperature node, whilst the MVHR is continuously on for background ventilation. Additionally, instead of using simple ventilation objects, the Simple Infiltration/Ventilation objects have been replaced with the Airflow Network (AFN) model. The impact of wind is therefore taken into account via the custom-made weather file that includes wind data. Figure 2 shows the AFN model for the flat.

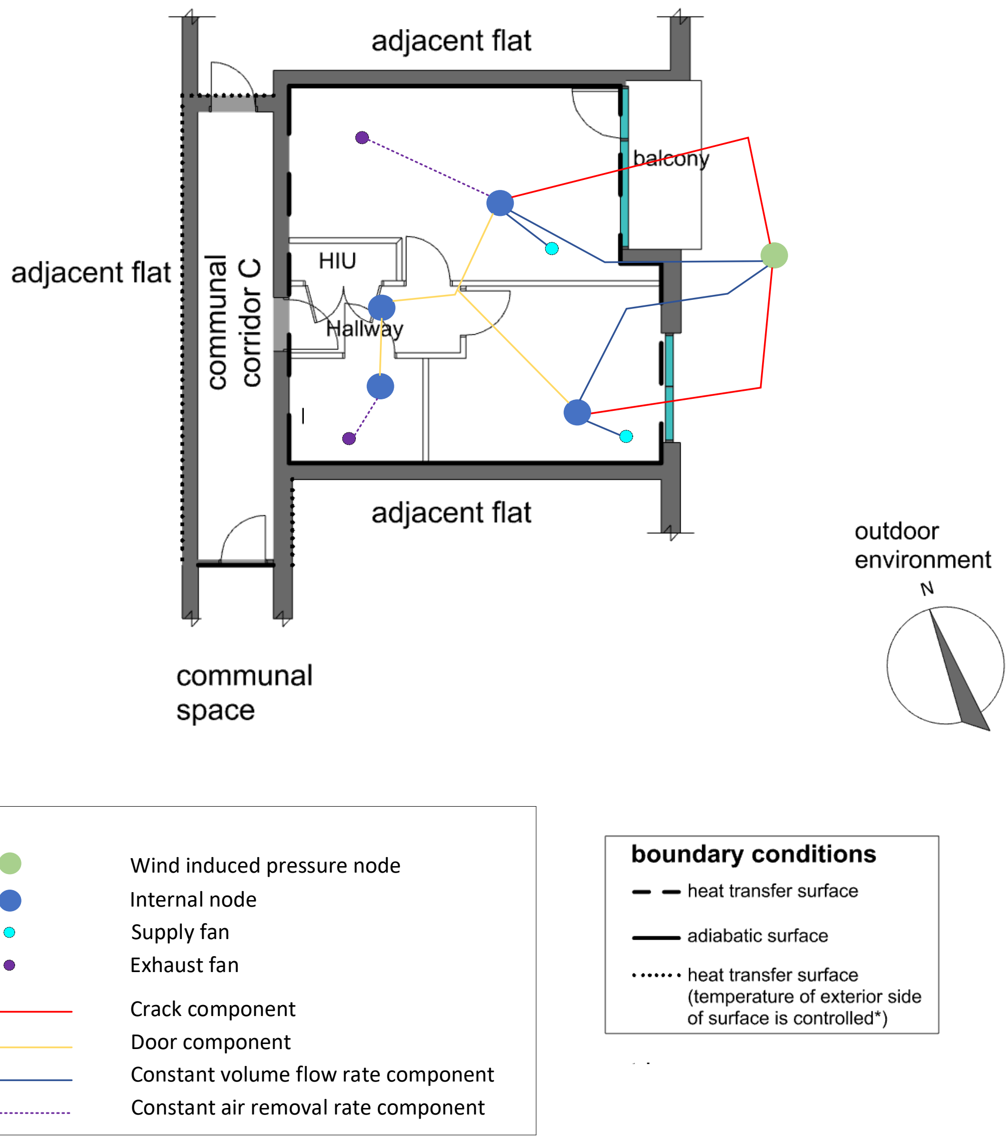

Figure 2 Airflow Network (AFN) Model of the flat

The following objects in EnergyPlus have been used to represent the AFN assumed in scenario 1:
(a) *AirflowNetwork:MultiZone:Surface:EffectiveLeakageArea* for the exterior walls of the flat: This numeric field (Table 3) is used to input the effective leakage area in square meters. The effective leakage area is used to characterize openings for infiltration calculations (ASHRAE Handbook of Fundamentals, 1997, pp 25).

Surface	Effective Leakage Area (m2)
Living-room - exterior wall	0.001222827
Bedroom - exterior wall	0.001169764
Frame of door in bedroom	0.0012
Frame of door in living-room	0.0012
Frame of door in bathroom	0.0012

Note: In terms of the frames, ASHRAE provides a value for the effective leakage area (ELA) per item; this is why all of these values are identical. In terms of the walls, the many digits are due to the units; in ASHRAE ELA values are given in cm^2/m^2 but EnergyPlus requires to insert values in m^2.

Table 3 – Effective leakage area as entered in the EnergyPlus model

(b) AirflowNetwork:MultiZone:Component:DetailedOpening for specifying the properties of air flow through windows and doors (window, door and glass door heat transfer sub-surfaces) when they are closed or open. In the model, the windows and external doors are always closed (since the flat was unoccupied) and the interior doors assumed to be always open. The doors are modelled as non-pivoted, with opening dimensions of 2.10m x 0.9m for the doors in the bedroom and in the living-room and 2.1m x 1.0m in the bathroom. The degree of opening is assumed to be 100% open.

(c) *AirflowNetwork:MultiZone:Component:ZoneExhaustFan* for specifying the properties of air flow through an exterior heat transfer surface with a zone exhaust fan. The zone exhaust fan turns on or off based on the availability schedule. When the exhaust fan mass flow rate is greater than zero, the airflow network model treats this object as a constant volume fan. If the fan is turned off (based on the schedule) the model treats this object as a crack. The zone exhaust fan runs 24/7. The exhaust fan mass flow rate is 0.0126 m^3/s in the living-room and kitchen. The maximum Flow Rate field is set to 0.0079 m^3/s [4] in the bathroom (these flow rates are derived at 20°C and 101,325 Pa [5],whilst the actual flow rate fluctuates slightly based on the actual temperature and pressure conditions).

3.3.3 Scenario 2: zero infiltration

Scenario 2 is intended to illustrate the effect of internal infiltration from the corridor coupled with exfiltration from the external wall of the flat. To model this through-flow effect simple ventilation objects are used (with no AFN). As in the base case, a *ZoneInfiltration:DesignFlowRate* object (with a value of 0.26 ach) is used. However, in this case zero infiltration from the outside is assumed. A ventilation rate equal to 10 l/s per person with an occupant density equal to roughly 0.02 people/m^2 is assigned to the communal corridor (see Table 2). The corridor air is assumed to come directly from the outside into the corridor. Using the *Zone:Mixing object* this air is then transferred from the communal corridor into the hallway; where half of this air

[4] Note that this was not set to comply with the Part F requirement of 8 l/s for continuous extract in bathrooms. As the monitored supply and extract rates are not equal, the extract rates were reduced in order to have an equilibrium. Part F (table 5.1a) states that the total extract rate should be at least equal to the total supply rate which is satisfied using the above flow rate.

[5] This refers to standard temperature and pressure conditions. However, the actual flow rates that will be calculated by the program correspond to the actual conditions.

then enters the bedroom whilst the other half enters the living-room/kitchen (as shown in Figure 3). Each of these two zones has an exhaust fan extracting air to the outside.

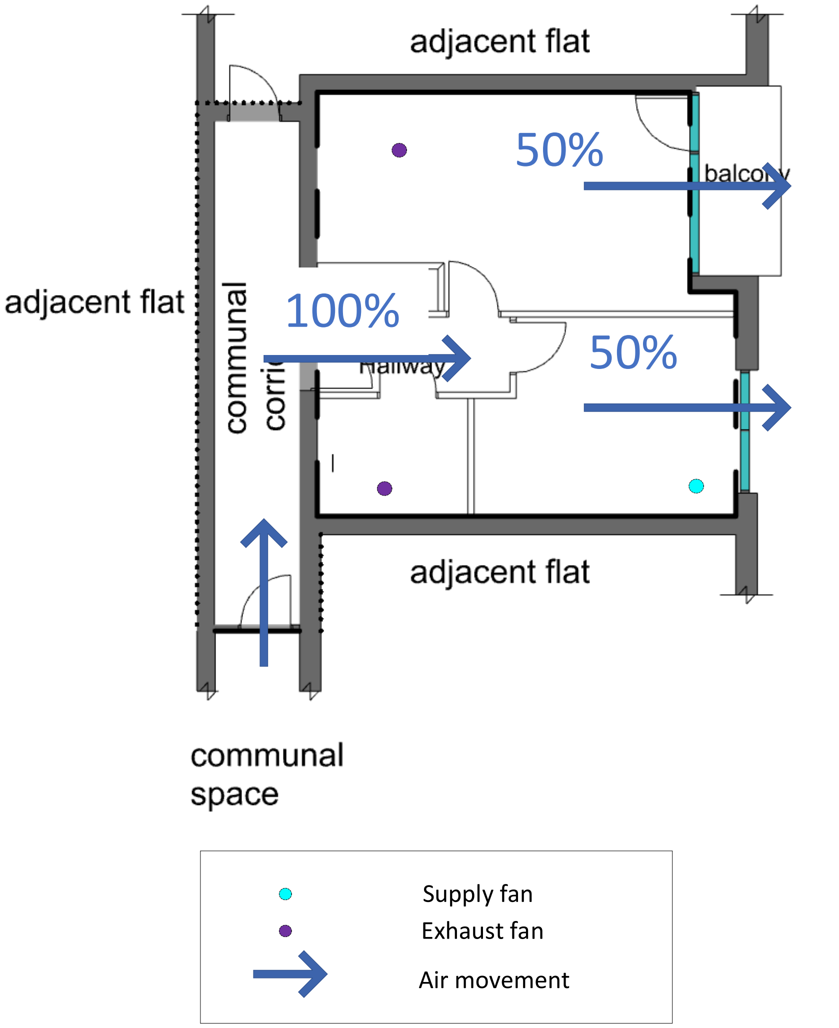

Figure 3 – Overview scenario 2

3.3.4 Scenario 3: as Scenario 2 but without corridor

The final scenario 3 is similar to scenario 2 but with the difference that the geometry of the corridor has been removed in the model (Figure 4). The object *Other:Side:Coefficients* has been used (for the flat's surfaces adjacent to the corridor) to control the temperature of these surfaces. The temperatures of these surfaces are calculated based on the monitored air temperatures of the communal corridor which have been ascribed to the model and their film coefficient[6]. All the air from the communal corridor (which is at a temperature equal to the monitored one) is assumed to enter the flat via the hallway, which is implemented (using the *Zone:Mixing object*.

[6] the combined convective/ radiative coefficient based on which the surface temperature is calculated (7.7 W/m2/K for vertical walls and horizontal heat flow.

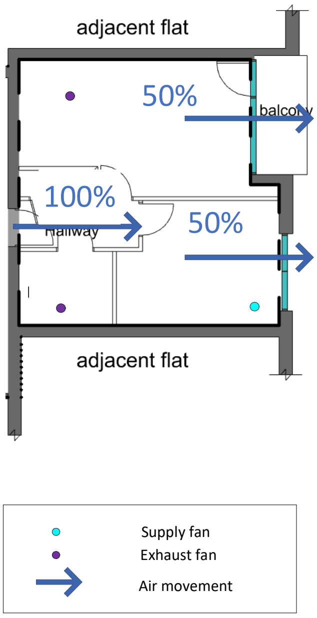

Figure 4 – Overview scenario 3

3.3.5 Summary

Four BPS models were created, to investigate the influence of distinct infiltration pathways on the thermal performance of a modern low-energy flat located in London. All models apart from scenario 1 (AFN) ascribed the infiltration design flow rate using the *ZoneVentilation:DesignFlowRate* (0.26 ach). Scenario 1 and 3 used the *DesignSpecification:OutdoorAir* only for the hallway in order to override the temperature of the air with the monitored data.

4.0 Results

Figure 5 shows the comparison of the simulated data to monitored data using the mechanically ventilated criteria and using a custom weather for the period from 01/10 to 03/11. Note that the difference in solar radiation transmitted in the living room/ kitchen and the bedroom in Figure 4 is due to the localised shading caused by the balcony and the vertical walls in the living-room.

There is a gap between the EnergyPlus simulations and reality where the measured indoor temperatures are considerably higher than the simulated ones. The RMSE is equal to 3.7 °C and 2.7 °C for the living-room/kitchen and bedroom respectively. In addition, a similar pattern is noticed in terms of diurnal temperature fluctuations; where the average-maximum monitored variation is 1.3 °C and the predicted one is 2.2 °C for the living-room/kitchen. For the bedroom the respective values are 2.4 °C and 3.0 °C. Finally, the empirical data recorded 3 and 10 hours above 26 °C in the living-room/kitchen and bedroom respectively whilst at the same time the simulations predicted just 0 and 1 hour above the CIBSE threshold in the same rooms.

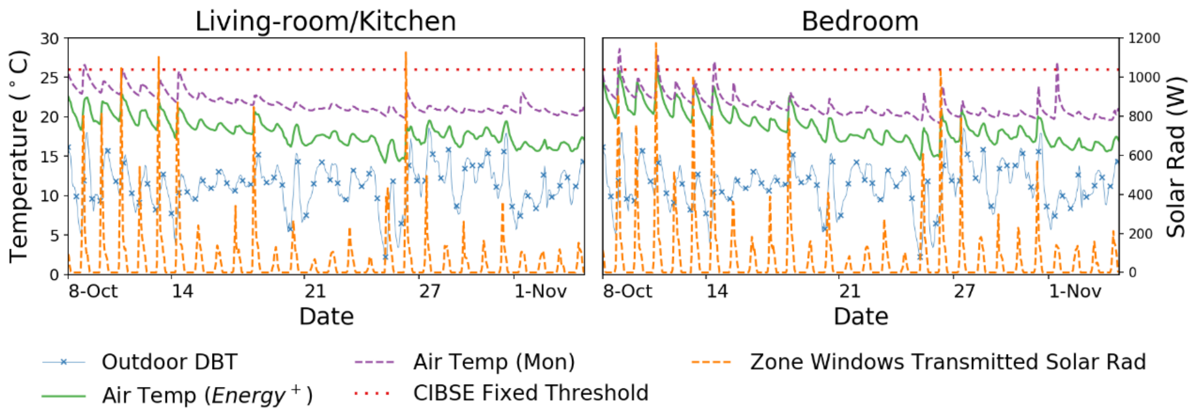

Figure 5 - Monitored outdoor air temperature and incident solar radiation on exterior wall, monitored and simulated base case indoor air temperature, and CIBSE threshold value between 01/10/15 to 03/11/15 with outdoor temperature and solar radiation from the custom weather file

In order to understand the gap between monitored and modelled data (as shown in Figure 5) better, Figure 6- 8 show the different infiltration and exfiltration scenarios as explained in section 3.3. Note that all Root Mean Square Error (RMSE) and the Mean Bias Error (MBE) values are summarized in Table 4 to indicate the prediction errors. All scenarios demonstrate significant differences with scenario 2 being closest to the monitored temperatures. Figure 6 shows that all scenarios under predict the indoor air temperature in the living room.

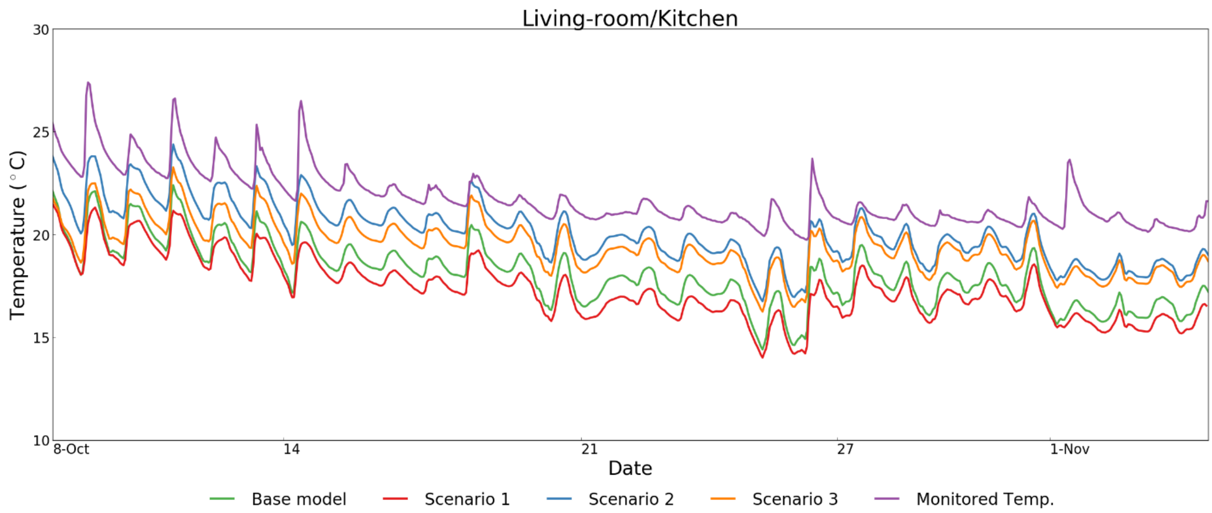

Figure 6 – Living-room and kitchen: Monitored indoor air temperature of the flat in comparison to simulated data from base model in comparison to three scenarios.

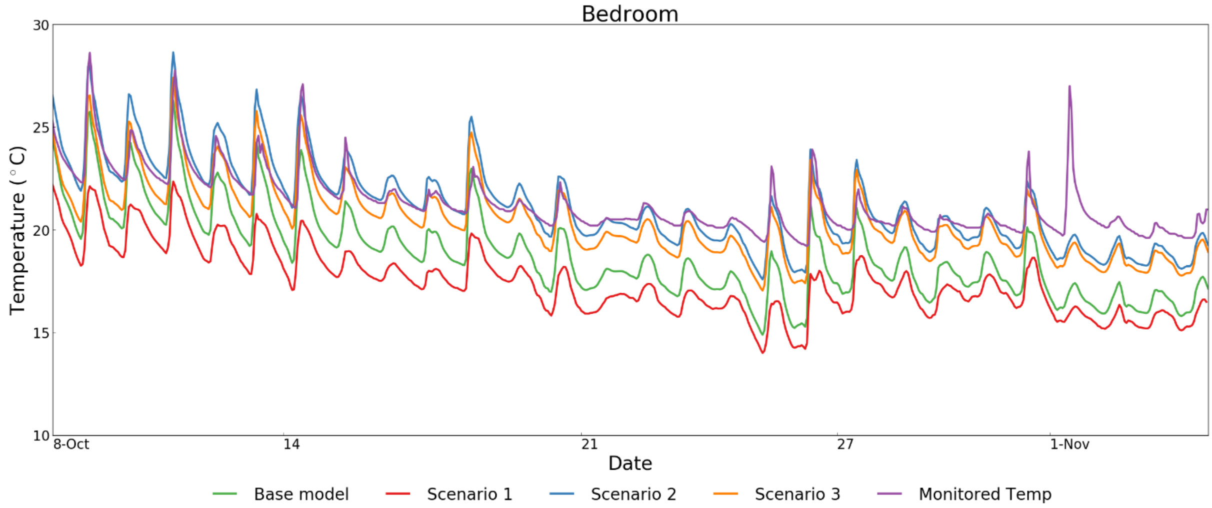

Figure 7 – Bedroom: Monitored indoor air temperature of the flat in comparison to simulated data from base model in comparison to three scenarios.

In Figure 7 the bedroom temperatures using the monitored data and the different scenarios are summarized. It is shown that scenario2 is also the closest to the indoor temperature for the bedroom. There is a good correlation at the beginning of the monitored period where the gap between the measured and modelled data is nearly closed.

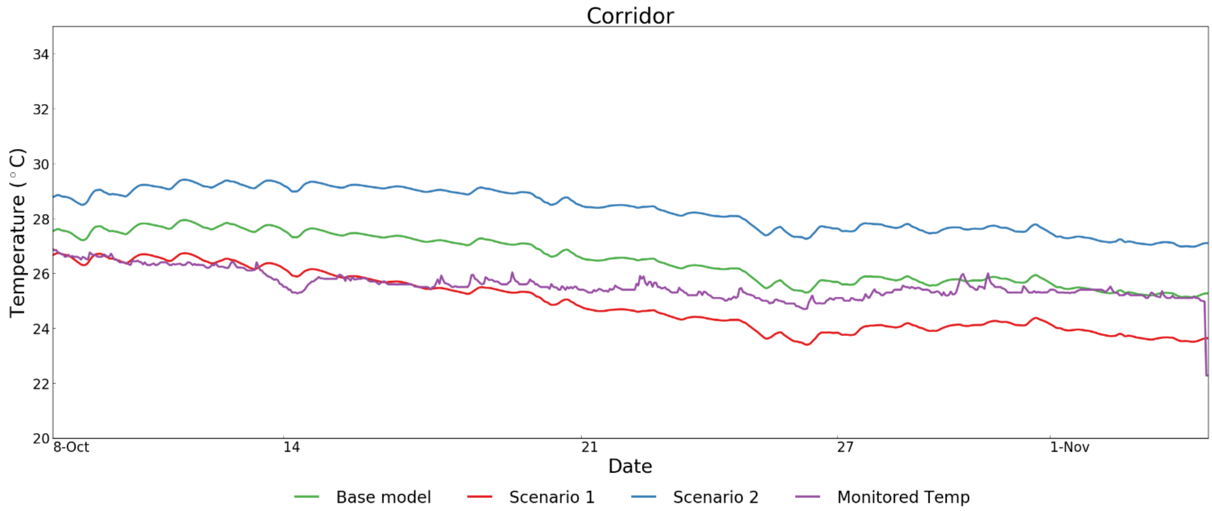

Figure 8 – Corridor: Monitored indoor air temperature in comparison to simulated data from base model in comparison to three scenarios.

Figure 8 shows the monitored corridor temperature in comparison to the base model and scenarios 1 and 2. Scenario 3 is not included in this graphic as no corridor is modelled (that is because the temperature of the monitored data is directly assigned to the surface temperature of the flat). The figure demonstrates that the base model and scenario 2 overpredict the temperature that was monitored in the corridor. A common trend in all of the scenarios is that they overestimate the downward trend of

the data due to the seasonality, which is evidenced much more subtly in the monitored data.
Table 4 summarizes all RMSE and MBE errors of the base case model and the three scenarios for the difference zones.

Table 4 RMSE and MBE for the base model and the three scenarios for the Living-room/Kitchen, the Bedroom and the communal Corridor

Statistical measure	**Base model**	**Scenario 1**	**Scenario 2**	**Scenario 3**
RMSE (°C)				
Living-room/Kitchen	3.8	4.4	1.7	2.3
Bedroom	2.8	3.9	1.2	1.3
Corridor	1.4	1.0	3.3	-
MBE (%)				
Living-room/Kitchen	-20.8	-25.7	-7.7	-11.6
Bedroom	-14.7	-22.5	-0.8	-4.5
Corridor	4.5	-2.8	12.6	-

5.0 Discussion

Overall the results show that distinctly different indoor air temperatures are predicted when the TM59 base case scenario was compared to three different infiltration scenarios. This implies that the way in which infiltration and exfiltration are modelled, as well as the rate of heat loss to/from the corridor, significantly influences the temperature in the flat. The results (including the limitations) will be summarized in the following.
In relation to zonal level infiltration rates, the dwelling level infiltration rate was assigned equitably on a floor area basis to each zone (for the base case and scenarios 2 and 3). In reality, it is likely that the infiltration rates will be much higher in zones that border the external façade and/or contain openings (such as windows and doors) in their external fabric; since these are exposed to greater pressure differences. However, in the absence of more detailed zonal level data this phenomenon cannot be accurately ascribed.

5.1 Summary

In the bedroom, living room and kitchen scenario 1 (AFN-using external infiltration only) demonstrates the highest deviation from the predictions. This is followed by the base case model which approximates current modelling practices on a real-building. As no air transfer with the corridor is modelled in these two settings, this implies that there is strong coupling with the outside air.
In the bedroom, scenario 2 is very much in line with the monitored data, closely followed by scenario 3. However, in scenario 2 the air temperature in the corridors is very different from the monitored data (Figure 8) where the corridor temperature is overpredicted by 2°C (the respective MBE value is 12.6%). Scenario 3 uses the monitored data of the corridor and assigns it directly to the flat and thus no over-prediction of the corridor temperature occurs. Similarly, in the kitchen, scenario 2 and 3 perform much closer to the real performance of the building.

Scenario 3 (assigning the actual corridor air temperature to the infiltration air mass) is the most realistic to the actual condition (as it uses the correct driving temperatures and thus, it is the model based most closely on the reality). However, the gap in relation to zonal temperatures inside the flat is slightly bigger than compared to scenario 2. This discrepancy is assumed to be caused by other uncertainties contributing the gap between monitored and modelled data.
Some of the peaks (e.g. 1st November) in the monitored internal temperatures are not picked up by the modelled data. Figure 5 indicates a slight peak in outside temperature and solar radiation. Both the living room and bedroom follow the same diurnal trend with visible solar impacts in the morning. The modelled temperatures at night-time drop more significantly in all of the modelled scenarios than in the monitored data. However, this does not appear to be so evident during the middle of the monitoring period. A general trend can be noticed, i.e. the model is very sensitive to outside air temperature (see ~24th October). In reality the MVHR due to its internal wall location (and poorly insulated extended intake ductwork) is delivering air which is constantly pre-warmed by heat exchanged with the surrounding ceiling void throughout the monitored period (7). Since this provides the continuous background air supply the flat is effectively decoupled from the external diurnal variations even when the MVHR is operating in bypass mode.
In terms of the corridors: scenario 1 (AFN) under predicts the indoor air temperature, whilst the base-case and scenario 2 over estimate the corridor air temperature. Scenario 3 is identical to the monitored data since this is being fed to the model. In all cases the seasonality trend in the corridor data is overestimated which points to the discretisation of the corridor model in contrast to the thermal inertia of the actual building.
Overall, the scenarios used have illustrated that the corridor and flat temperatures are highly sensitive to how the airflow network is modelled. Scenario 2 shows the closest fit to the measured temperatures in the flat however in this scenario the corridor temperatures were much higher than those monitored. Whilst scenario 3 gave similar results and was based on using the known air temperature of the corridor, however in practise during a design stage modelling process this information would be unavailable.

5.2 Limitations

As with all research, limitations exist. One of the limitations is the absence of information in respect of actual ventilation and infiltration flow rates and pathways within and between the corridors and the flats. The relatively short duration of the monitoring period (approximately one month) limits the extent to which the influence of seasonality can be tracked through the data. Regarding the simulation inputs and modelling, no detailed construction data was available for the floors and roofs; typical constructions were therefore assumed using the information available (e.g. overall depth of construction elements) and material properties as specified in the architectural drawings.

6.0 Conclusions

This study has demonstrated the importance of modelling both infiltration and exfiltration, between adjacent zones, in order to capture the mass transfer of heat, particularly in complex multi-storey, multi-residential buildings. The current practice of apportioning equal volumes of ambient air to account for infiltration in each zone of a model is overly simplistic and unrealistic. In reality, when carrying out modelling *a* *priori* at the design stage complete and accurate information is unavailable, and it is impossible to know how closely the eventual reality is being approximated. This paper however shows the need for a model infiltration sensitivity assessment requirement for TM59 and similar simulation-based assessment methods. The research has also highlighted a need for a better empirical understanding of the internal air movement in multi-storey multi-residential buildings

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