Department of Mechanical and Aerospace Engineering

A Study of the Challenges Accompanied with IoT Services

Author: Abdelkarim Mahmoud Mohamed Abdelkarim

Supervisor: Professor Joe Clarke

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Abstract

This study presents an analyses of the effect of building physics on the deployment of IoT services and the impact on the alternative placement of sensors for these services. Three different approaches were used for this analysis, an empirical approach, a simplified simulation approach and a more detailed air flow simulation approach. Calibration factors were derived for alternative placements for the sensor for a case study of a hypothermia alarm system and two building types were simulated that represent the majority of the buildings currently in the UK. Then a more detailed simulation was done using air flow simulation to compare it to the more simplified approach. It was found that it was possible to calibrate a sensor in a heavy built room using a simplified approach to simulation but it proves challenging for a light built room. An air flow simulation proved more accurate and provide a better insight for sensor placement.

Acknowledgements

I would like to thank Professor Joe Clarke for his continuous and tireless support throughout my project it has been a rich experience being supervised by you and hope to carry on the lessons I learnt in my future research and endevours. I would also like to thank Dr Jon Hand for his support and guidance on the ESP-r. Last but not least Dr Paul Touhy has showed us selfless support throughout this Master's program so again many thanks for your support.

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Chapter 1: Background and objectives

1.1 Background

Today in this digital age, the world around us is changing fast with things becoming more and more automated. People are expecting that everyday tasks become easier and automated for a better way of living. This gave the rise to deploy and install various types of electronic devices such as sensors and actuators to control various tasks such as lighting, heating or even watering your garden. Services are being built around this need to deliver a service of value to the customer, for controlling a task or monitoring an environment remotely with electronic devices connected to the internet. These devices are now commonly known as Internet of things (IOT) devices.

Internet of things (IOT) devices and services are anticipated to contribute £81 billion to the UK’s economy by 2020, with the majority of the research and development being in the area of healthcare and power. Most of the income forecasted to be in the area of energy efficiency [1]. Although forecasts have previously predicted a wide adoption of IOT devices and services these predictions have not materialised. Some barriers and challenges resulted in the slow deployment of IoT devices namely consumer awareness, lack of interoperability, cost, unclear benefits, complicated sourcing and installation, usability and operability problems, data security & privacy and operability concerns [2].

In this project an empirical and simulation base analysis was done to understand the challenges of deploying sensors in the built environment and possible solutions were suggested. Some of the available IoT services include the following.

Wellbeing IoT Services

The UK is an aging population with almost a fifth over 65 which increases the strain on the NHS to provide health care services [3]. This has given rise to the need for IoT healthcare systems to be used in monitoring the elderly and vulnerable patients from the comfort of their homes to reduce the stress on the NHS. Currently in the UK over 80 businesses are currently working on healthcare and social care to provide IoT solutions [1]. Current wellbeing-related services include:

- A vital signs service by Sensium comprising of wearable patches that monitor the vital signs of venerable patients after being discharged from the hospital. Health professionals can be alerted if there is a deterioration in the patients' health to be aided in a timely manner [4].
- A motion detector by eFridgeMagnet that uses a small IoT motion detector device with a magnet that is fixed to the fridge and lets the relative of an elderly person know through an SMS message when they open the fridge in the morning.[5]
- An elderly monitoring service by Canary Care provides elderly monitoring using a number of motion sensors, heat sensors and light sensors. Using these sensors it is possible to monitor the buildings temperature and the movement pattern of the elderly person and drive useful analytics such as bathroom visits, sleeping pattern, door use and nurse visits using a card based door access control systems. Relatives can see these analytics through an application.[6]
- Another monitoring system by Tunstall Healthcare that provides a portfolio of devices to monitor patients and elderly from their homes. Solutions are designed for specific application requirements using connected devices, hubs, applications and networks. Some of the connected medical devices include blood pressure monitors, ECG machines, blood glucose and bed-based epilepsy sensors. Other care related devices include carbon monoxide sensors, gas sensors, bed occupancy. Panic buttons and nurse calling devices are also among the devices that could be connected.[7]

Energy IoT Services

The issue of sensor placement is also important in relation to energy use monitoring. Achieving energy efficiency in buildings is in the heart of meeting the targets of carbon reduction set in the Paris Accord and with buildings contributing to the carbon emissions by almost 30% it is vital to think of new ways of achieving this through smart homes and connected building energy monitoring systems [1]. Current energy monitoring systems include:

- Vantage Point Technologies is a web based systems that uses connected sensors and switches to monitor the energy consumption of devices and allows for good analytics to be driven from this data by comparing device performance in facilities and buildings.[8]
- PurrMetrix uses an array of sensors deployed across a space or building to provide a comprehensive heat map of the conditioned space in the building. It uses heat, light and co2 sensors to collect data of the air quality lighting and temperature. The system is cloud based and has strong graphical analytical tools to assist in diagnosis, decision making and retrofitting of buildings.[9]
- Shepherd is a company that provides a service of monitoring chillers, boilers and other utilities to provide a real time insight on their performance. It alerts the facility manager if there is a degradation in the performance of the utility before it breaks down completely providing an early warning.[10]

In each case, sensors are require to be judicially placed to capture the condition that dictate the service. Such placement is highly problematic in practice for a number of reasons including: Cold air drifts, heat sources, ventilation and air tightness of windows which all result in Temperature variations in the space that is monitored. This is the issue explored in this thesis.

1.2 Related Work

There are many challenges facing the deployment of an IoT systems in the built environment such as Privacy & Security, deployment Cost, and Complexity of Installation. This thesis addresses the last challenge because limited research has gone into the sensor placement in relation to the building physics, most of the current research on the IoT systems has gone into the networking and topologies of the systems, the issues relating to big data analysis and the privacy and security of these systems. But the core of any system is to get correct data first then comes its value of the analytics.

Zhimin et al. work showed the use of computational fluid dynamics coupled with building energy simulation to study optimum sensor placement and more efficient HVAC for an office building. He suggested that the placement of the sensor close to the return air opening is not optimum and did not reflect the actual thermal comfort experienced by the occupants [14]. Although this study investigated the optimum sensor placement for HVAC control it did not address the problem of variation in building types and its effect on sensor placement. Yoganathan et al. discussed in his study the possibility of a data driven approach for an optimum sensor placemen. In this study sensors were placed in an office environment and data was collected for April, May and June then the data was analysed and clusters were formed to see which sensors were a good representative of the environment with minimal information loss. Then the optimum positions were chosen and readings were validated [15]. This study did not consider all seasons and was done in the summer period which leaves an ambiguity regarding the sensor placement all year round moreover for IoT systems to prevail the solution must be easy and fast, deploying numerous sensors and collecting the data for a long period of time then deciding the optimum position for the sensors may not be practical and cannot be seen as a solution for future deployment of IoT sensors.

1.3 Objectives

- To study the effect of building physics on different sensor placements in a room.
- To derive a suitable calibration factor for a sensor placed on a wall so that in could represent the area where the occupant mostly stays.
- To study the effect of different building types on the calibration
- To study the effect of different building types on the on the amount of readings required for a case study service
- To compare a detailed air flow simulation to a more simplified approach of simulation.

Chapter 2: Research method

The present work adopted empirical and simulation-based approaches to evaluate the impact of alternative sensor placings on the quality of the information supplied by a particular service.

Empirical approach

To identify the challenges accompanied with the deployment of sensors it was first necessary to examine and identify these issues through a real deployment of wireless sensors in the built environment. This was done through the deployment of four wireless sensors connected to a central digital LCD screen. All sensors were place in the same place for an hour then they were calibrated to display the same temperature. Two environments were experimented as follows:

a) **Office Environment**: For the office environment a case study of an office in the James Weir building in the University of Strathclyde was use. Sensors were placed at four different positions as shown in Figure 1 and the readings were noted.

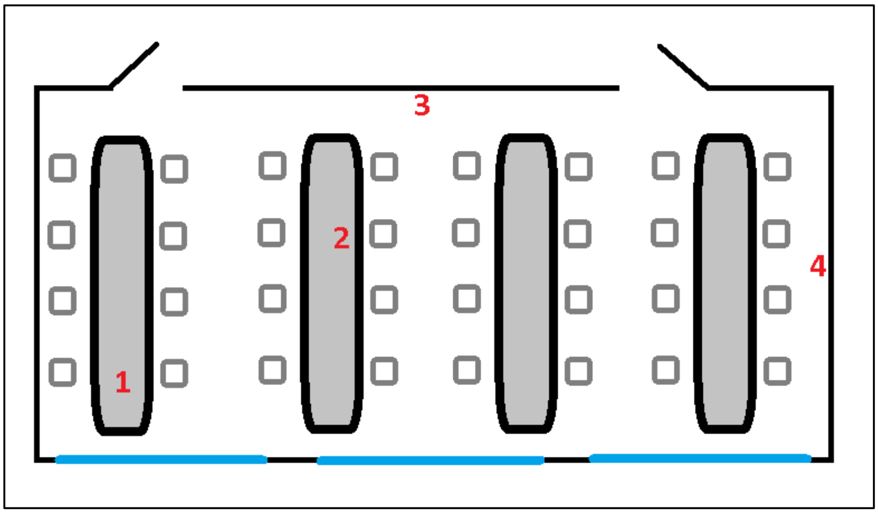

Figure (1): Sensor positions in the office.

This Figure illustrates the positions of the temperature sensors. The first position was set close to the window, the second position was placed close to the centre of the office on top of the desk, the third position was set on the top wall and final position was on the right wall.

b) Residential environment: For this environment a typical living room was chosen to undergo the monitoring of the temperature. The sensors were again positioned in four different places as shown in Figure 2 and their temperature was noted. Readings were taken in the early morning, midday and at night.

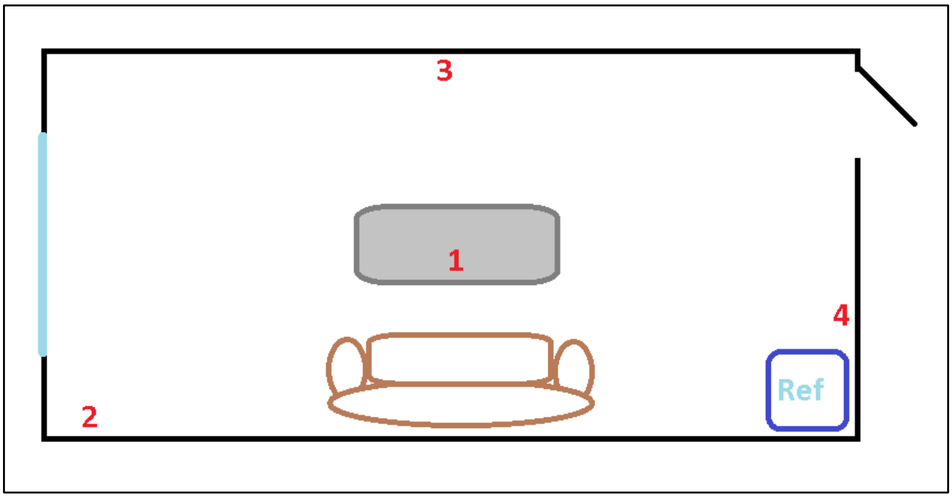

Figure (2): Sensor positions in the living room.

As it can be seen, a typical living room was used for this empirical analysis with the window to the left of the Figure facing east. There is a sofa and a coffee table in the middle of the room and a refrigerator at the corner. The first sensor was placed on the coffee table, the second sensor was placed close to the window, the third sensor was placed at the wall opposite to the sofa and the fourth sensor was placed on the wall near the refrigerator.

Simulation approach

After the analysis of the empirical data was completed further analysis was done to examine solutions for the challenges found. To do this a mathematical model of a living room was made to represent a typical living room. This was done through the dynamic modelling tool ESP-r.

For this purpose a case study of an IoT service was designed and tested in the virtual environment. The IoT service that was going to be examined was a potential hypothermia alarm for elderly people to alert his/her relatives if the temperature in the house fell below 16 C.

For this service a typical living room was designed with two exterior walls and two interior walls and a window facing south as shown in Figure 3.

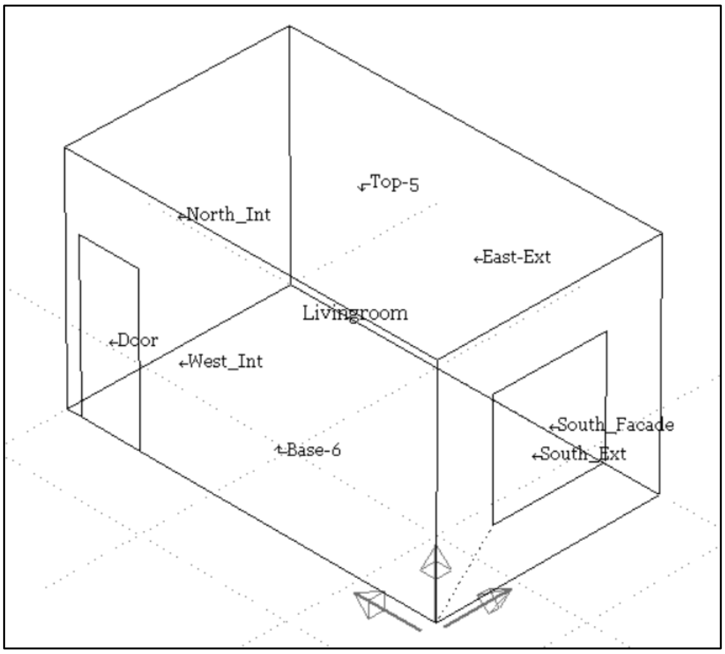

Figure (3): The living room model.

This model was made to represent a typical Scottish living room with one elderly citizen stays and the assumptions of the casual gains and ventilation are all as listed in Table 1.

Table (1): casual gain & ventilation assumptions.

	Casual gain	
Type	Sensible Heat Gain	Latent Heat Gain
Lighting	7 W/m^2	-
Equipment	200 W	-
Occupancy	75 W	45 W
	Ventilation	
	10 /s	

Construction: for the construction two types of walls were used to simulate the effect of a heavy built construction and a light built construction. Post 1919 the majority of wall build in Scotland were cavity brick walls but as of 2016 more than 70% of these cavity walls were filled with insulating foam, this type of wall construction was used to simulate the heavy built construction. In the past 20 years the majority of frame constructed houses was made from timber, so this was used for the light weight construction [16]. These two wall constructions where chosen as they both represent a great deal of the construction in Scotland and the UK as a whole.

The internal walls are made of breeze blocks with plaster on both sides for the heavy built construction and for the light constriction it was made of insulating material with gypsum board on both sides. The glazing used consists of two 6mm glass layers separated by a 12mm air gap.

- **Weather Profile:** for a weather profile it was necessary to choose one with a reasonably cold winter for the purpose of the case study. So the weather profile of a typical Scottish city was chosen and the dry bulb temperature of the weather profile can be seen in Figure (5).

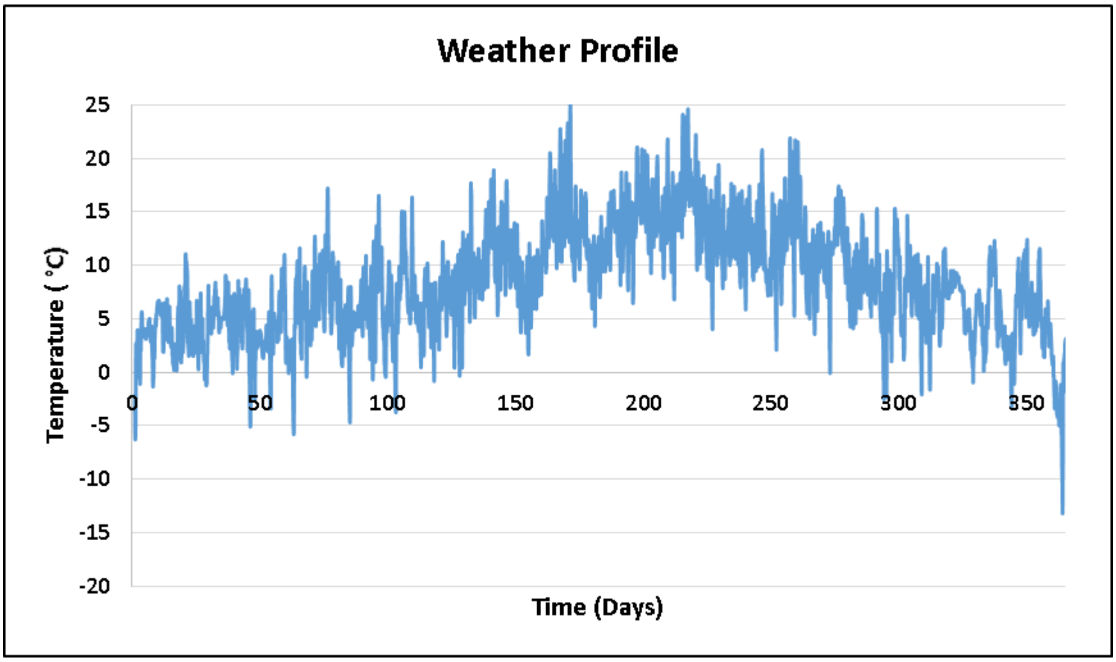

Figure (4): Shows the weather profile

It can be seen from Figure (4) that there is a clear winter with average temperatures ranging from 5-7 C with some dips below 0 C, this is suitable for this analysis of a hypothermia alert and the weather profile is similar to statistical average temperatures in Scottish cities.

ESP-r simulation directives

The ESP-r simulations were configured to deliver the spatial and temporal variation in environmental conditions. This required the invocation of ESP-r's air movement capability by establishing a CFD model as shown in Figure 5.

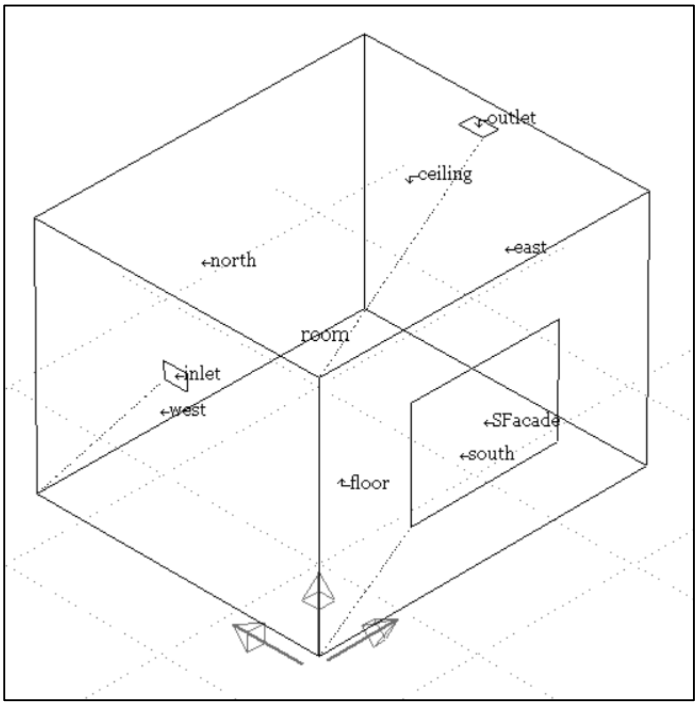

Figure (5): CFD Simulation Room Model

This allows a comparison between simplified and informed approaches to sensor deployment.

The model for the room can be seen in Figure 5 which demonstrates the room with a south facing window and an inlet opening for the ventilation and also an exhaust opening for the outlet. The model also has a heater that is not shown in the Figure below which is placed on the north wall with a heating capacity of 2000W.

Figure (6) illustrates how the model is divided into blocks and the results shown in the CFD section will show the temperature and air velocity in each block. It is also worth noting that for the purpose of this CFD simulation the ventilation rate was taken to be 50L/s with the inlet being a constant volume fan and the outlet being an air flow opening.

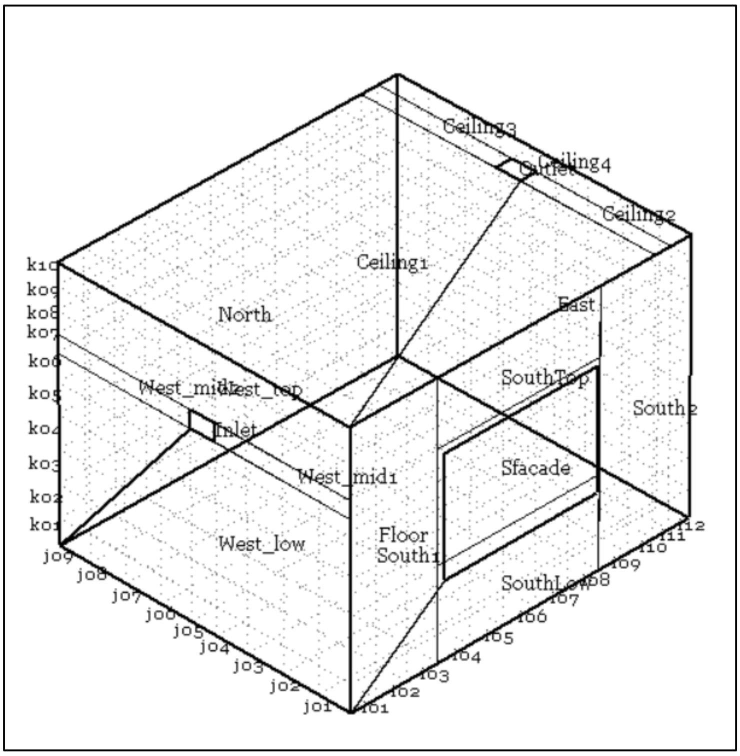

Figure (6): Model Division blocks

All the model information can be seen in appendix A and B.

Chapter 3: Results

This chapter presents the results and discussion of the study for the different approaches.

3.1 Findings from the empirical study

Office Environment

Before the start of the room simulation it was necessary to perform an experimental analysis of the deployment of the sensors. As mention earlier sensor 1 was placed on the desks which is close to the window facing west, sensor 2 was placed on a desk in the centre of the office, sensor 3 was placed on the east wall just beside the thermostat of the air conditioning system and finally sensor 4 was placed on the south wall. The sensors were read simultaneously and the readings noted as seen in Table (1).

Table (2): Temperatures measured in a plan office space.

Time	1) Near Window	2) Centre	3) East interior wall	4) South Interior wall
13:00	20.6	22.8	23.1	23.3
13:20	21.2	22.8	23.2	23.3
13:40	21.0	22.4	23.2	23.3
14:00	20.9	22.4	23.3	23.3

Results show that the temperatures of both 3 and 4 remained around 23.3 C throughout the whole period where as the sensors 1 and 2 were varying which shows that placing a sensor on the east wall will not accurately represent the comfort of the employee. It is also worth noting that the internal walls were heavy built which explains why there temperature remained roughly stable and suggests that the sensor was measuring the laminar air layer close to the wall.

One other point that was noticed was that there was no distributed ventilation system only one large duct at one end of the plan office this could explain the variation in air temperature.

Also when putting one sensor on top of the desk and the other at a lower level close to the floor it was noticed that there is a difference of 2 C with the lower one being colder. It can also be seen from Table (1) that sensor 1 which is placed on a desk close to the window was very variable and colder than both the sensors on the wall and in the centre, this would be linked to the windows which are typically not air tight.

From this experiment some challenges became very clear, for instance if an IoT service was to measure the comfort of the employees in such a setup, because employees in thermal comfort perform better [13], a difficult question would be where to place the sensor. Placing the sensor on the wall will not represent the comfort for the desks on the centre or near the window. So the other solution would remain either to put a sensor on each desk which will result in higher costs and larger amounts of data or place the sensor at one spot and then calibrate it to represent other places in the plan office. The latter would be more advantageous if it was implemented and to test its possibility a simulation of a building model was performed in the next section to test different methods of calibration.

In the next section the results and discussion of a similar experiment but in a residential environment are seen.

Residential Environment

In this experiment a typical living room was used and sensors were placed as mentioned previously with sensor number one in the centre of the room on top of the coffee table, sensor number two on the wall facing east close to the window, sensor number three opposite to the coffee table on the wall and the last sensor on the wall near the refrigerator. Readings were taken at three different day times, in the morning, midday and at night. The readings can be seen in Table (2)

Table (3): Living Room Temperature

Time	1) Centre	2) Near Window	3) Wall	4) Ref
7:00	25.2	26.7	24.9	27.0
7:20	25.1	26.5	24.9	27.1
7:40	25.2	26.4	25.0	27.1
8:00	25.0	26.4	25.1	26.9
12:00	26.2	25.1	25.9	26.7
12:20	26.1	25.3	25.7	26.9
12:40	26.4	25.0	25.8	27.0
13:00	26.3	24.8	25.6	27.2
23:00	25.8	23.4	25.5	26.4
23:20	25.7	23.1	25.2	26.6
23:40	25.8	23.2	25.2	26.3
00:00	25.5	23.0	25.0	26.4

What is first noticed from the results in table (2) is that the temperature of the sensor near the refrigerator is always higher than the rest of the room and this was expected as the results confirm that placing a sensor close to a refrigerator will give a temperature that is not true for the rest of the room this could be said about other appliances as well. When placing a temperature sensor it is considered good practice to place the sensor away from a potential heat source such as a TV or a stove.

From the morning readings it can be seen that the temperature of the sensor near the window is higher than the rest of the room although it is not exposed to the sunlight, this would be because the window is facing east so in the morning that wall is getting a great deal of sunlight heating up the wall facing east, that’s why the sensor is reading a high temperature while the air temperature outside was in the high teens. It can also be noticed that the temperature difference between the wall and the centre of the room is not high.

At midday the sun has moved from the east window the temperature of the sensor close to the window has dropped. It is also noticed that the temperature difference between the wall and the room has increased which shows that if a calibration factor is to be set to represent the centre of the room it must be dynamic.

At night the temperature of the sensor close to the window drops further as the outside temperature drops, it is also worse noting that the wall of the window is the only exterior wall in the room. The temperature of the wall is also cooler than the centre of the room.

Another condition that was tested was putting a fan in the room which resulted in the temperature of the wall and centre being almost the same this shows that if the air in the room was turbulent then there is no need for calibration as the air will be well mixed. But the temperature of the window sensor and near the refrigerator remained colder and hotter respectively than the temperature of the room.

From this experiment some of the challenges that were found was that if a calibration factor was to be applied it needs to be in some way dynamic as the results show that a calibration in the morning will not work in midday and vies versa. This will be discussed in the next section with different calibration methods suggested and then tested to see if they are applicable.

3.2 Findings from the simulation study for hypothermia

As seen in the literature one of the main barriers hindering the uptake of smart homes and e-services is the complexity accompanied with installing the sensors for different applications. A case study of an e-service was modelled to identify possible solutions and measures to be used.

The e-service in hand is a monitoring system for elderly to alert his relatives of a possible hypothermia due to a drop in air temperature of his house in winter.

A typical Scottish living room size of $15m^2$ [12] was modelled with two walls facing the exterior and two internal walls.

In this simplified approach to the simulation it was assumed that the air temperature was the same in the whole room and that the temperature measured by the sensors placed on the walls is the same as the wall temperature itself. It is also assumed that the each wall has the same temperature throughout.

The first part of the analysis was done for a heavy built living room with a cavity wall which has been insulated by filling the cavity with foam insulation.

The first challenge would be where to place the temperature sensor? To accurately measure the temperature for a hypothermia alert the sensor must be as close as possible to the person to give a realistic measure of the air temperature around him but this poses another issue of accidently dropping or damaging the device. So the sensor must be place close to the person but not too close to risk dropping or damaging the device and stopping the monitoring process. In the Figure 7 below a winter week in January was modelled to see the temperatures in the living room.

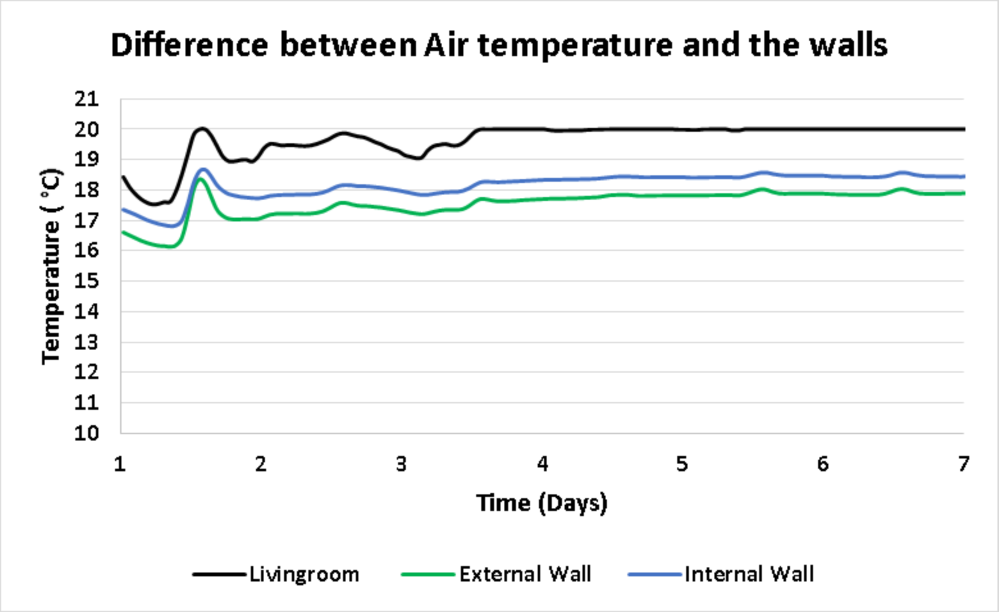

Figure (7): Air & walls Temperature Difference for heavy built room

As the results in Figure 7 show that there is a significant temperature difference between the air temperature measured and the temperature of the walls. The external wall is a bit colder than the internal wall as a result of being exposed to the environment. For an optimum placement of the sensor it would be placed on the wall closest to were the elderly person usually stays within the living room and then the readings from the sensors should be calibrated to give a temperature closer to what he is experiencing. Assuming that the sensor was placed on the internal wall a calibration factor was derived. Figure 8 below shows the difference in temperature between the internal wall and the air temperature in the winter month of January and February.

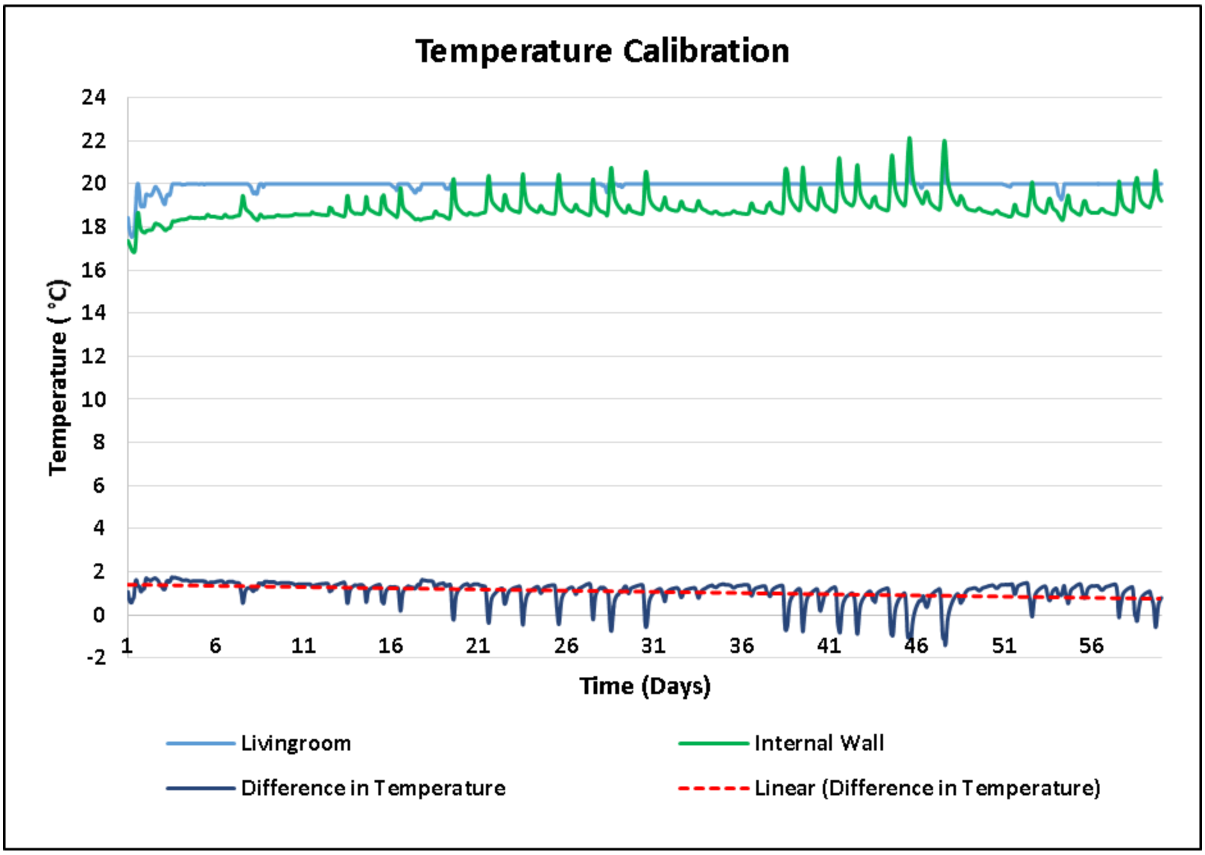

Figure (8): Shows the difference in temperature between the internal wall and the air temperature for January and February.

As it can be seen in Figure 8 there is no single calibration factor that can be used at all times and it is highly variable. But in this specific application were only a drop in temperature is to be reported a calibration factor could be derived to estimate the temperature experienced by the elderly person. From Figure 8 it can be seen that at the beginning of January the difference in temperature is about 1.8 C º but going on to the end of February it is seen that the difference drops to about 1 C º which shows that in the beginning of the winter a higher calibration factor is needed than that in the days leading to spring. Figure 9 below shows the application of a single calibration for the winter month of January and February.

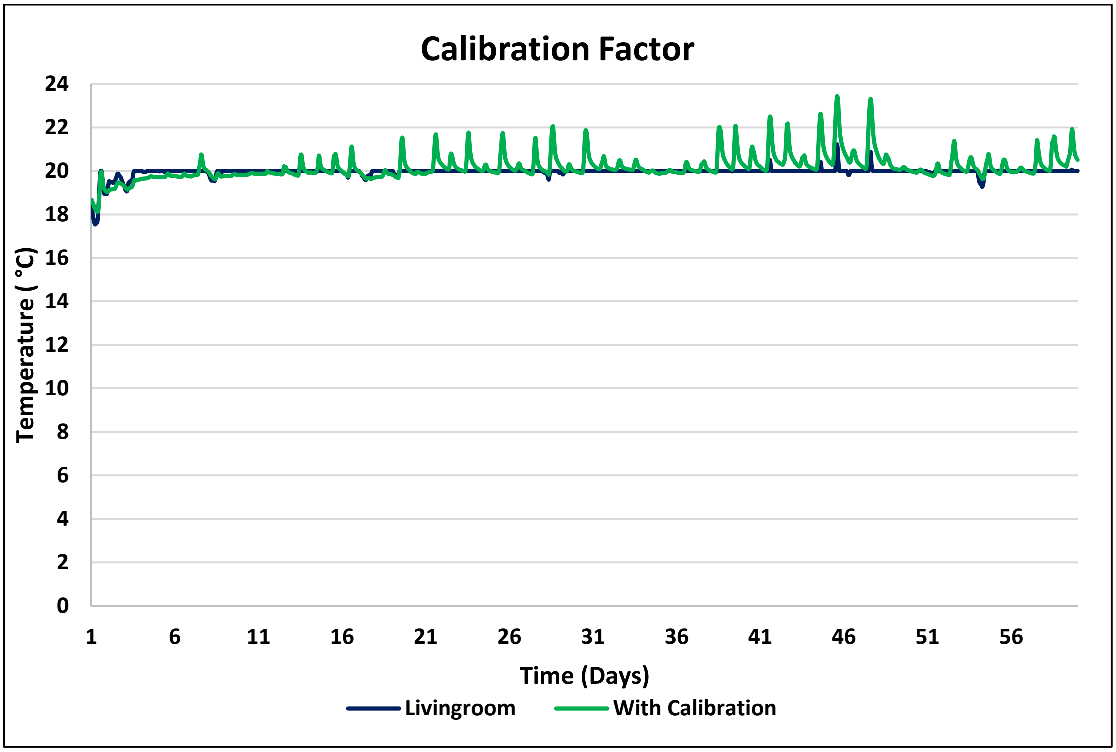

Figure (9): Calibration of 1.3 C º added.

Single Calibration Factor:

After adding the calibration factor of 1.3 C º shown in Figure 9 it can be seen that the temperature roughly matches the air temperature of the room with some peaks that are higher. This might be a typical approach adopted by an installation technician were he places the sensors at different locations in the building then weighting for an hour or two to set the calibration of the sensor. Unfortunately this approach might be very miss leading and could lead to a reading that is further away for the required depending on the time of the year that the calibration was made. In figure 10 below the annual temperature of both the air and wall can be seen for the whole year.

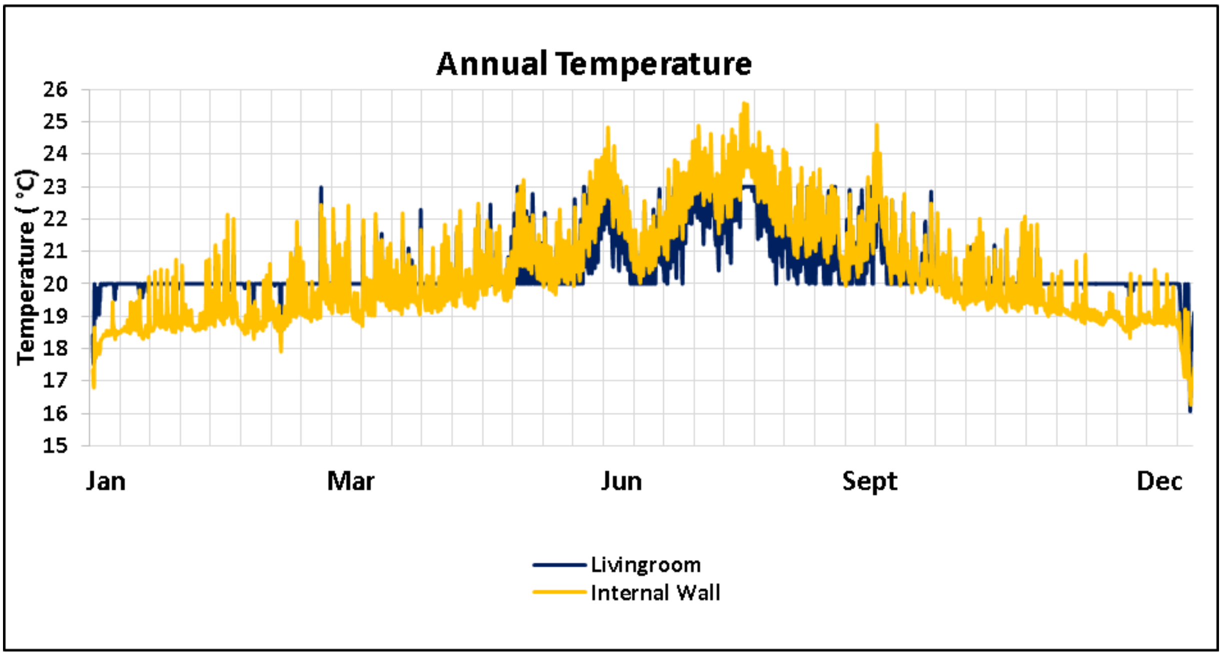

Figure (10): Shows the Temperature of the internal

Wall and the air temperature for the year

From Figure (10) it can be seen that the a positive calibration factor is needed in the winter and a negative calibration factor is needed in the summer which means if the calibration in figure 3 was applied it will further offset the temperature reading in the summer .Different calibrations are needed because walls are usually colder than the indoor air temperature in the winter and are hotter in the summer this was reported by L. Zhu et al in his study of the performance of the thermal mass of walls, he also reported that in the transition month of April and October the wall temperatures are closer to the air temperature which is similar to the results of this simulation and the walls in his analysis were precast concrete with insulation in the middle of the cast wall which is also similar to the insulated cavity wall used in this analysis [17]. So the need arises for a dynamic calibration factor for the whole year to accommodate for the winter, summer and transition month. Figure 11 below shows the application of a dynamic calibration factor using a polynomial trend line.

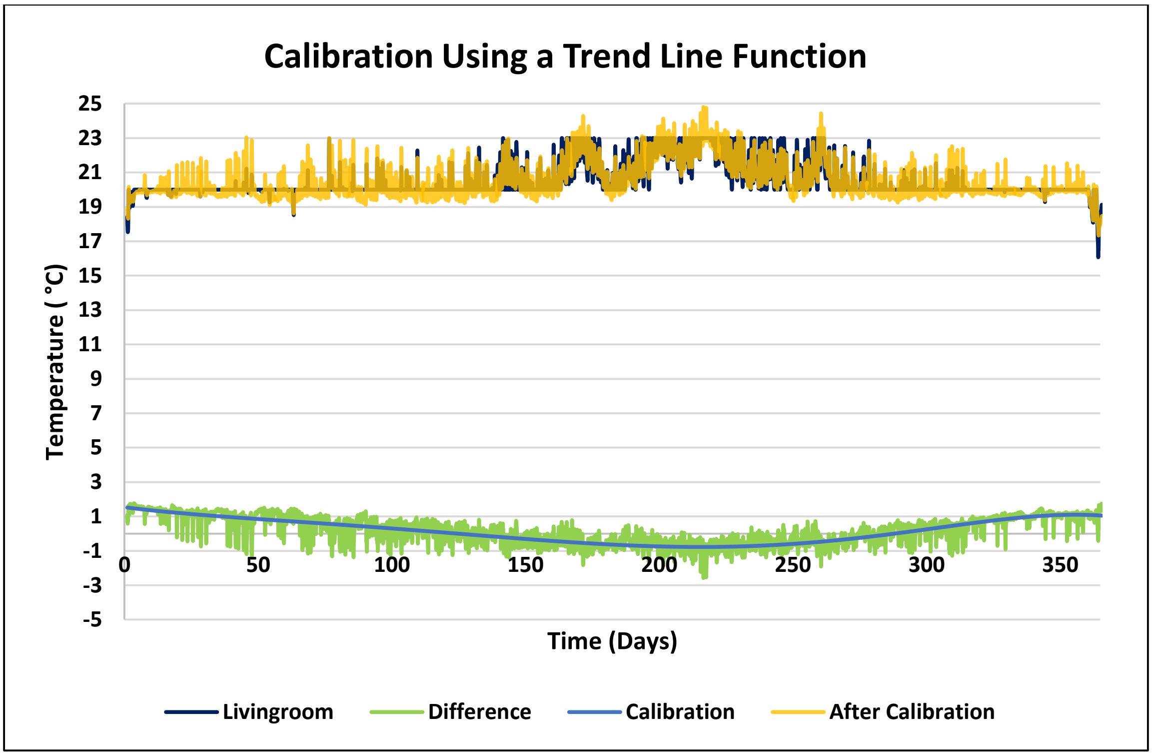

Figure (11): Shows the sensor reading after calibration

by a polynomial trend line equation.

Polynomial Trend Line Calibration:

As shown in Figure (11) a polynomial trend line was made for the difference in temperature between the air temperature and the wall sensor, this was then used as a calibration factor. As it can be seen that the trend line follows the behaviour of the walls at the different times of the year with a positive value in the winter, a negative value in the summer and a near zero value during the transition month. This result suggests that applying a trend line calibration was more accurate and closely follows the air temperature. All of the previous analysis was done using an insulated cavity wall, in the next section the effect of a light built wooden frame building on the calibration factor was studied.

Effect of Building type on calibration:

Although the overall temperature difference between the air temperature and the sensor on the interior wall could be roughly calibrated in case of the heavy built room for this specific application, caution must be taken when designing such a service as it would be installed in a wide variety of building types which will intern have different thermal behaviours. This gives the rise to different calibrations which will be discussed in this section by analysing a light built room.

In figure 12 below the air and wall temperatures are shown for a light built room with a wooden frame construction. What can be noticed is that both temperatures are very highly variable compared to the heavy built room analysed earlier. This behaviour of a light built wall was reported by L. Zhu et al in his study were he compared the performance of conventional wooden frame wall to a heavy build concrete wall [17]. It can also be noticed that the difference in temperature between the wall and the air is quite high, this will have great implications on the calibration of the sensor as the previous approach will not be viable. This gives rise to the need of a more detailed simulation using ESP-r CFD air flow simulation which is presented in the last section of this chapter.

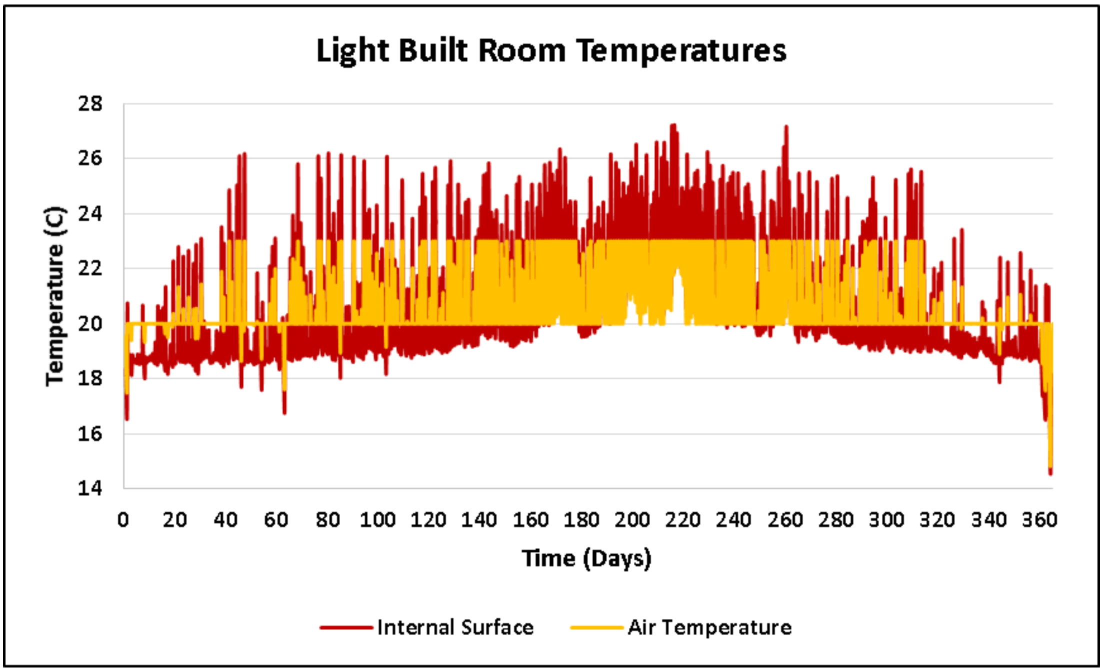

Figure (12): Air & wall temperatures in a light built room

This thermal behaviour will also affect the number of reading the are taken from the sensor as a building with a temperature that changes rapidly will require a greater number of reading for the IoT service in hand, were as a heavy built room would require a lower number of reading to be taken. In the next section the amount of data transfer will be discussed.

Amount of Data Transfer by IoT Systems

The number of readings taken and the amount of data transferred is crucial as this is one of the challenges facing IoT systems. If every household has several connected devices this amounts to trillions of devices connected to the internet, which will result in unprecedented amounts of data being transmitted. Currently there is no infrastructure to support this amount of data, so solutions must be made to decrease the amount of data transfer to the minimum.

For the IoT Service in hand a question must be answered.

How often should readings be taken? This is a question that faces many e-services as it has a high impact on the quality of the service that is being provided, on one hand and on the other hand it affects the amount of data being collected, transferred, stored and processed. A fine balance should be made between providing a good service and decreasing the amount of data. In this case study a number of solution are going to be suggested.

Figure 13 shows the percentage difference in measured temperature at 6 minutes intervals, that is to say that the sensor is read 10 times per hour and the graph represents the difference from the previous temperature for the whole year.

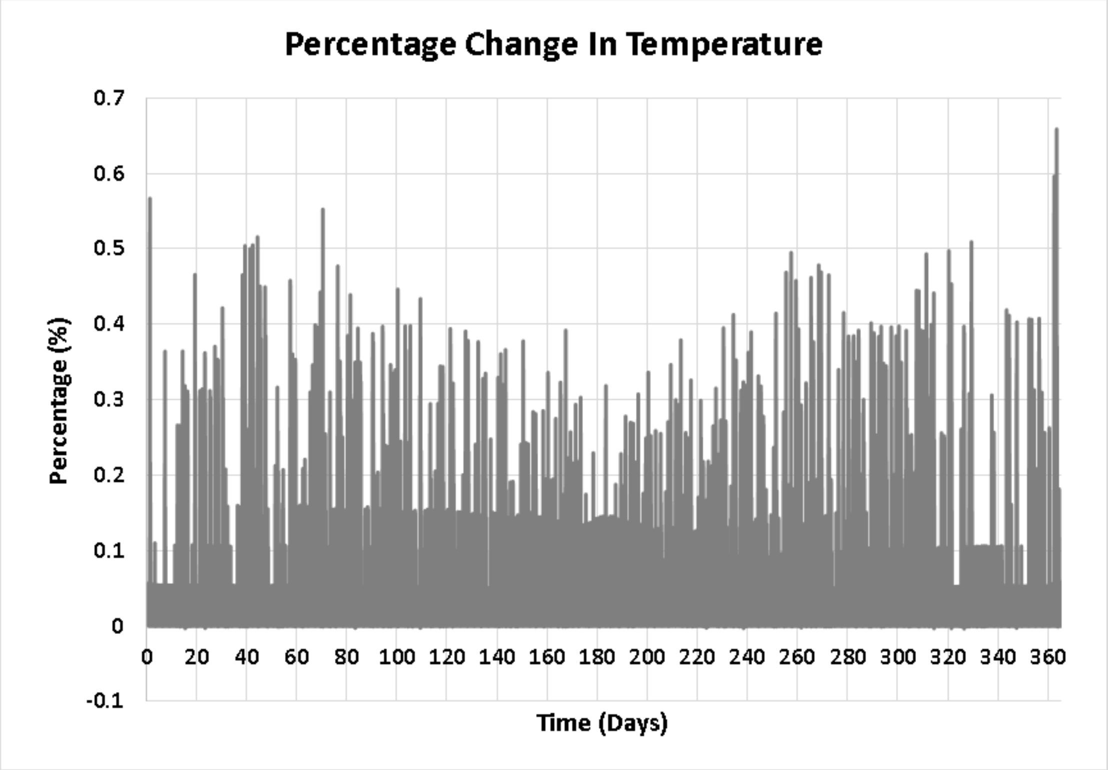

Figure (13): Percentage Change in Temperature.

It can be seen than on average the temperature does not change more than 0.5% and the maximum temperature difference was 0.12 °C showing that this is a suitable rate to read the sensor. But as this IoT service is for the elderly another scenario should be tested in case that the elderly person opens the window wide open and forgets to close it or maybe unable to close it for any reason this can be seen in Figure 14.

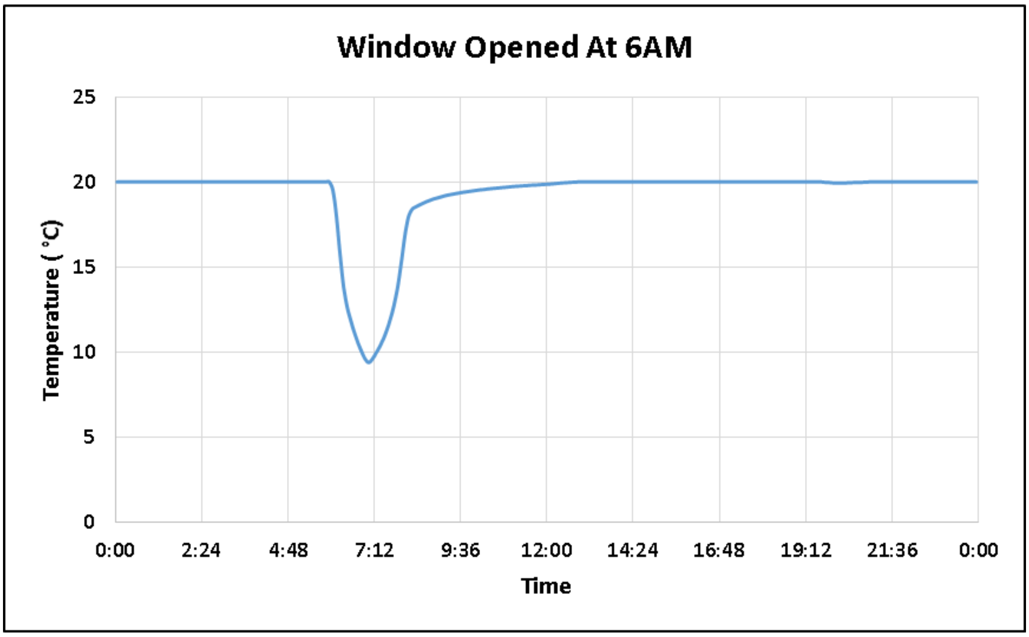

Figure (14): Living room temperature when Window was opened at 6AM

Shown in Figure 14 is the simulation of a case were the window of the living room was opened for an hour at 6:00AM. It can be seen that the temperature drop was very dramatic and for an alarm to be set after 6 minutes from opening the window could be very dangerous. In figure 15 below the percentage change in temperature for this scenario is shown.

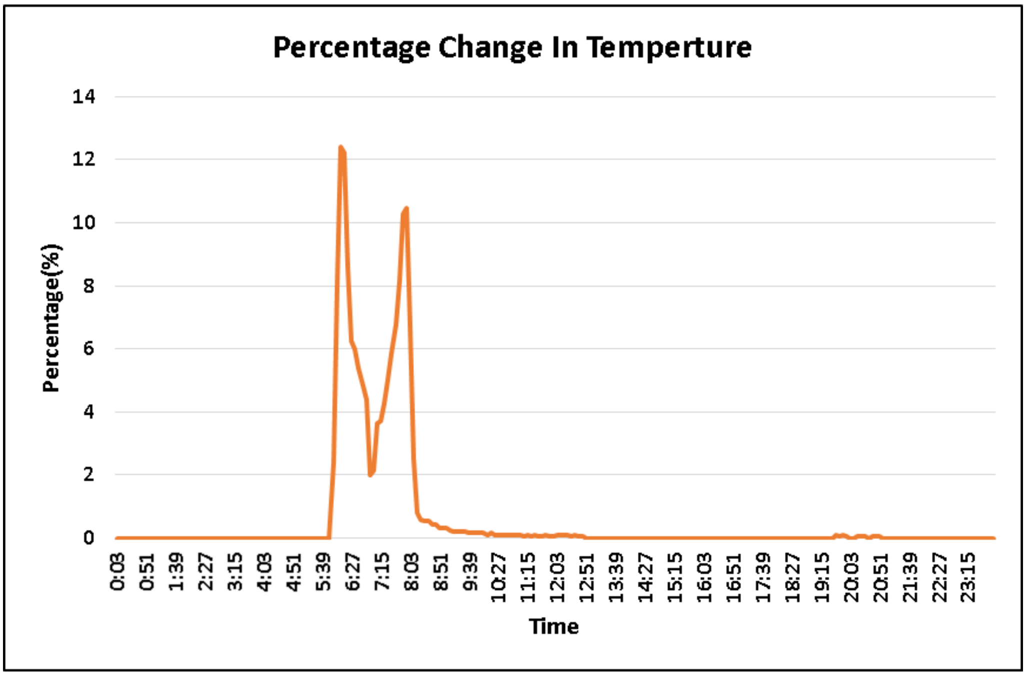

Figure (15): Shows the percentage change in temperature when widow was opened

From Figure 15 it can be seen that the rate of change was over 12% which is quite high and will deem this rate of sensor reading unsuitable for this application. But on the other hand if a higher rate was used for instance 30 second interval this will result in almost 173,000 readings per day which is an enormous amount of data.

This could be tackled by changing the way readings are taken in the first place, instead of reading the sensor every fixed time interval it would be more rational to have a sensor that reports only a change in temperature. This could also be set to a certain threshold so in this application the sensor will report the reading when there is a change of temperature of 0.5 ºC.

This will enormously decrease the amount of data used while at the same time not compromising the quality of service being offered.

In the next section a more detailed approach to the building simulation is discussed.

CFD Air Flow Simulation

Adopting a simplified approach to the simulation of a building does come with its drawback but it depend upon the IoT service and the required accuracy of measurement and the implications of having in accurate data. For instance an IoT service that measures the moisture content of the soil in your garden might not be as crucial as a service that measures the vital signs of your elderly parent that is why a detailed analysis for the optimum sensor placement is of paramount importance in a service such as the one in hand.

To understand better the complexity of this task a similar living room model was setup on ESP-r to demonstrate the airflow inside a typical living room. In figure 16 below a slice of the air flow through the centre of the room can be seen with the inlet ventilation on the top left of the diagram and the outlet is shown on the roof on the top right side. The temperatures here are quite cold as they represent switching on the heater after a cold night and is suitable to analysis the offset of temperatures at different positions in the room.

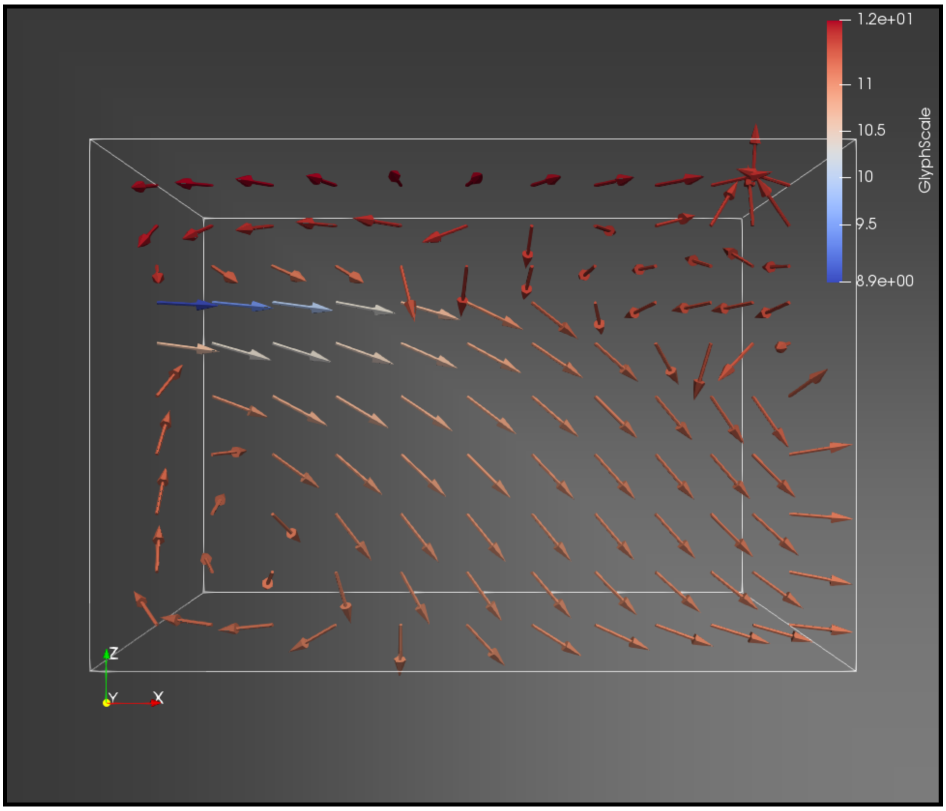

Figure (16): Air flow Slice of the centre of the room

As the results from figure 16 show that cold air from the inlet of the ventilation is much colder than the room temperature and drops to the ground and hot air stays in the top of the room and is extracted by the outlet. This result shows that if a sensor was to be placed on the ceiling of the room it will be greatly offset from the actual temperature being experienced by the elderly person also placing the sensor near the outlet in this case may not be the optimum placement and will also be offset this result is similar to the findings by Zhimin et al. in his study [14].
In figure17 below a slice of the air flow near the north wall is show.

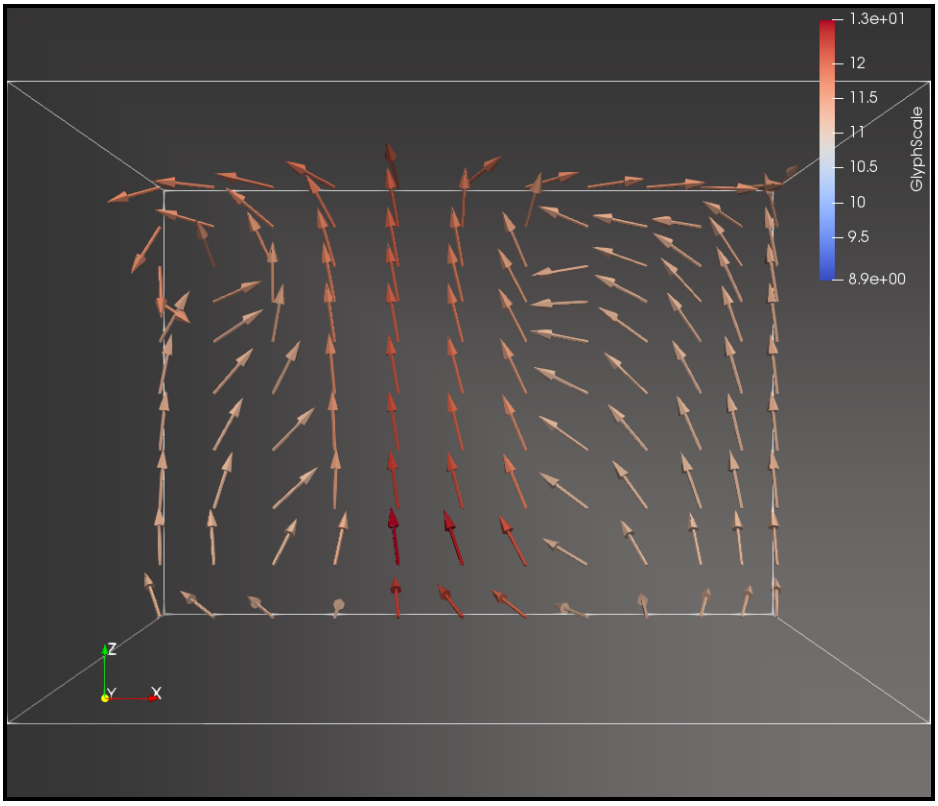

Figure (17): Air flow Slice of the heater on the North wall

As it can be seen from this figure 18 that the hot air from the heater rises to the ceiling and that the temperature in the wall is not uniform as it was assumed in the previous section, this also supports the findings from the empirical approach that placing a sensor near a heat source is not best practice. In figure 18 below a detailed heat map of the centre of the room is demonstrated.

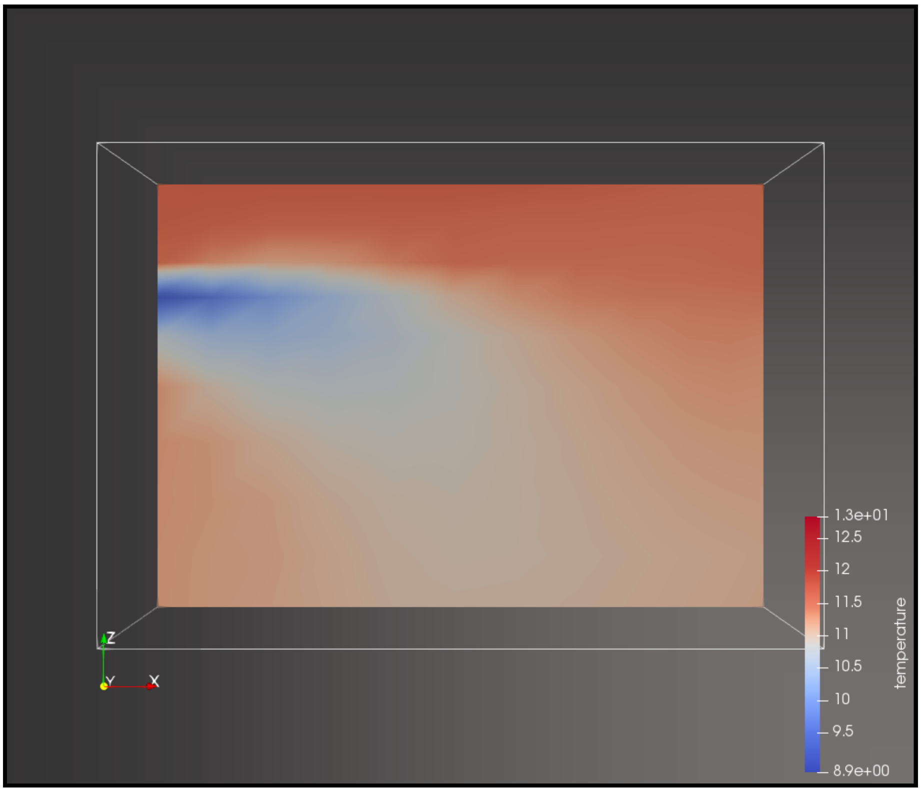

Figure (18): shows the heat map of the centre of the room.

From figure 18 it can be seen that the area where it could be expected that a sofa would be placed and the elderly person might be sitting is colder than the rest of the room and for a sensor to reflect an accurate measurement of the temperature it must be placed at the correct height as it can be seen from the figure that there is a variation in temperature at different heights this was also noticed in the empirical study that was discussed earlier. In figures 19 a, b & c below the detailed heat map of the heights of 2.7m, 2m & 1m respectively are shown.

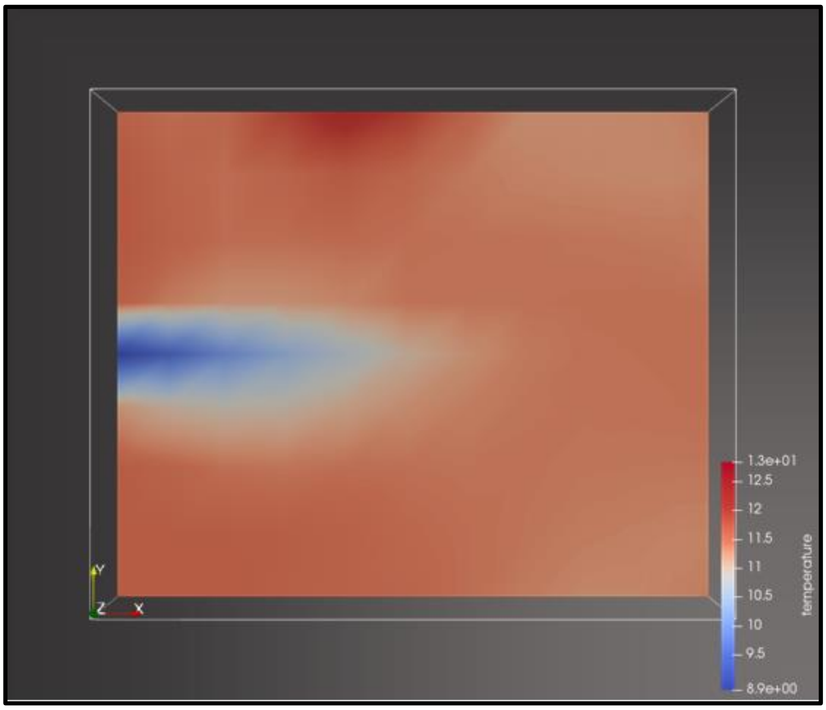

Figure (19a): Heat map at 2.7m

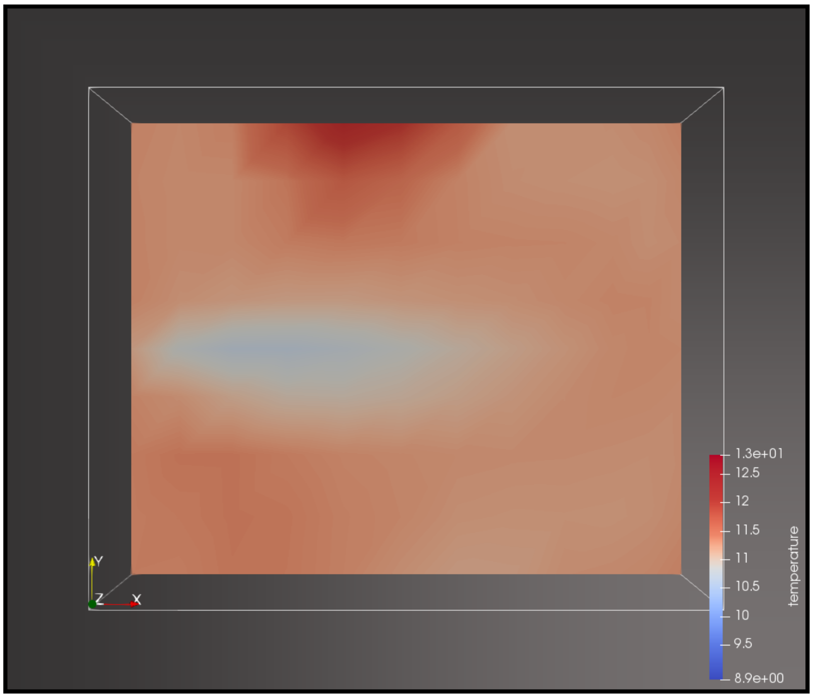

Figure (19b): Heat map at 2m

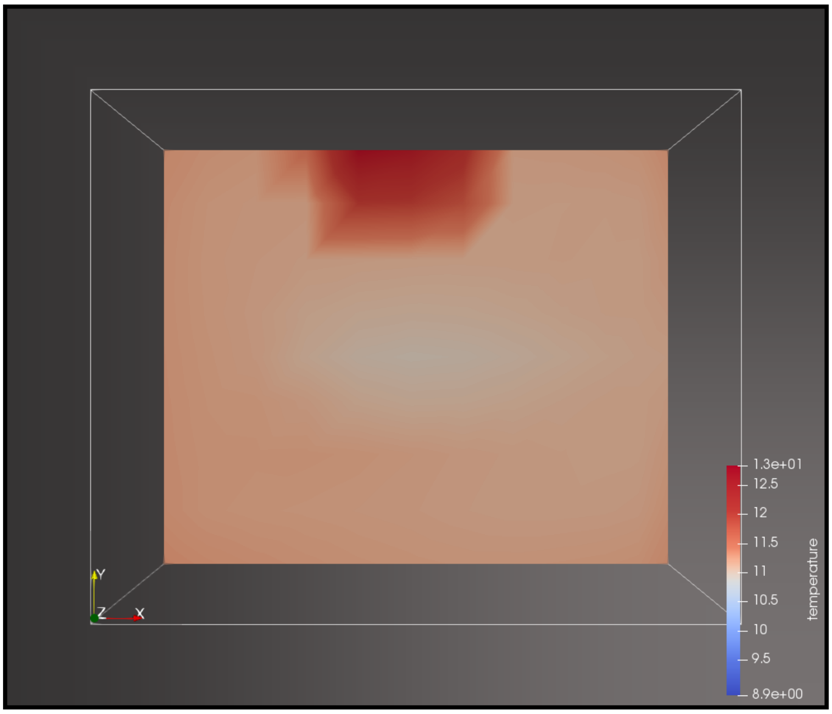

Figure (19c): Heat map at 1m

As it can be seen from figure 19a that at this height the room's temperature ranges from 8.9 C to more than 13 C which is a significant difference with the highest being directly over the heater and the lowest value being in front of the inlet. As the air flows down from the inlet it can be seen from figure 19b that the cold air from outside starts to mix with the warmer air of the room and the gradient of temperature becomes less. Finally from figure 19c it can be seen that the cold air is almost mixed but is still colder than the average room temperature by about 1C.

These results suggest that taking a simplified approach to the simulation of the room for an IoT service might be misleading and the quality of the information supplied by such a service might be jeopardized by a mere misplacement of the sensor and on the other hand a well-informed placement of the sensors could be achieve by using air flow simulation. Moreover this air flow simulation was done in the winter but further research is to be done to have a comprehensive assessment of the optimum placement.

Chapter 4: Conclusions and Findings

In this chapter the main findings of this study are presented along with the conclusions and future work.

Key Findings

Optimum placement of sensors in building indoor environment is of paramount importance to ensure a good quality of service in the world of IoT systems. Some studies suggested different approaches to sensor placement [14, 15] but their study was either not comprehensive to assess the thermal behaviour at different time of the year or their solution was a lengthy procedure that required a long period to deploy the sensor. This study address the thermal behaviour of buildings at different times of the year in relation to sensor calibration to represent an optimum placement and data transfer. It also compares a simplified simulation approach to a detailed approach with regard to sensor placement. Based on the results and analysis of this study the following key findings are summarized below:

- A calibration factor to represent an optimum placement of the sensor when it is not safe to place the sensor at that location is possible but is more suitable for a heavy built room because the air temperature is somewhat close to the temperature of the wall.
- A single calibration for the whole year could be far from the actual temperature depending on the time of the year the calibration was made.
- A dynamic calibration factor that changes with the time of the year gives a better representative of the temperature required than a single calibration.
- It is quite difficult to establish a calibration factor for a sensor placed on a light built wall to represent the air temperature thus a more detailed simulation is needed in this case.
- A higher rate of sensor readings is needed for a light built room compared to a heavy built room.

- A simplified approach to the building simulation could be misleading compared to a more detailed airflow simulation but it goes back to the level of accuracy needed for the specific application of IoT service.
- A detailed airflow simulation could be a faster and more accurate approach to sensor placement compared to the solutions presented in the literature [15].

Conclusion

This study presents an analyses of the effect of building physics on the deployment of IoT services and the impact on the alternative placement of its sensors. Three different approaches were used for this analysis, an empirical approach, a simplified simulation approach and a more detailed air flow simulation approach. Calibration factories were derived for alternative placements for the sensor for a case study of a hypothermia alarm system and two building types were simulated that represent the majority of the buildings currently in the UK. Then a more detailed simulation was using air flow simulation was done to compare it to the simplified approach of simulation. It was found that it was possible to calibrate a sensor in a heavy built room using a simplified approach to simulation but it proves challenging for a light built room. An air flow simulation proved more accurate and its results were comparable to the results presented in the literature [14]. These findings give an insight to the placement of sensors for IoT services and can have important implications for future researchers and practitioners.

Future Work

In this study only one winter day was simulated in the detailed airflow simulation further research is required to get a comprehensive view of the behaviour of the building at different times of the year.

More over for a fast and accurate deployment of IoT services it is suggested that a data base for the available building stock types is to be modelled and become available for the companies that provide IoT services. This will allow for an accurate and fast placement of sensor with only minor tweaks to each model to represent the equipment in the house hold and maybe the occupancy a detailed model of each house would be very easy and fast to attain. This might be a far more practical solution than what was suggested in the literature [14] and could allow for deployment within hours.

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Appendices

Appendix A: QA report for simplified simulation

Synopsis

Synopsis of the model Hyperthermia monitering defined in Hyperthermia.cfg generated on Sat Aug 25 00:46:06 2018. Associated notes are in ..\doc\Hyperthermia.log

The model is located at latitude 55.90 with a longitude difference of -4.10 from the local time meridian (east +ve). The year used in simulations is 2007 and weekends occur on Saturday and Sunday.

The site exposure is typical city centre and the ground reflectance is 0.20.

Simulationist name: not yet defined

Simulationist telephone: not yet defined

Simulationist address: not yet defined

Simulationist city: not yet defined

Simulationist postcode: not yet defined

The climate is: ABERDEEN/DYCE - GBR and is held in: GBR_Aberdeen.Dyce with hour centred solar data.

standard annual weather: GBR_Aberdeen.Dyce

Calculated ground temp at 0.5m depth

4.1933 3.7788 4.5139 5.6643 8.6733 10.995 12.562 13.038 12.226 10.423 8.0140 5.7786

Calculated ground temp at 1.0m depth

4.7597 4.1918 4.6877 5.6293 8.2751 10.434 11.992 12.615 12.067 10.563 8.4231 6.3409

Calculated ground temp at 2.0m depth

```
5.7185  4.9799  5.1307  5.7418  7.7552  9.5753  11.031  11.813  11.646  10.624  8.9638
7.2037
Calculated ground temp at 4.0m depth
6.9810  6.2236  6.0580  6.2871  7.4267  8.6529  9.7771  10.560  10.743  10.299  9.3246
8.1339

An Integrated Performance View is incomplete or missing.

Databases associated with the model:
 standard pressure distr: pressc.db1
 standard materials     : material.db4.a
 standard constructions : multicon.db4
 standard plant comp    : plantc.db1
 standard event profiles: profiles.db2.a
 standard optical prop  : optics.db2
 standard UK NCM data   : SBEM.db1
 standard predefined obj: predefined.db1
 standard mould isopleth: mould.db1
```

```
The model includes ideal controls as follows:
Control description:
no overall control description supplied

Zones control includes  1 functions.
no zone control description supplied
Details of control loops referenced in the model:

 The sensor for function  1 senses the temperature of the current zone.
 The actuator for function  1 is air point of the current zone
There have been  1 periods of validity defined during the year.
```

```
 Control is valid Mon-01-Jan to Mon-31-Dec, 2007 with  1 periods.
 Per|Start|Sensing  |Actuating  | Control law description
   1  0.00 db temp   > flux      basic control: max heating capacity 400.0W min heating
capacity 0.0W max cooling capacity 1000.0W min cooling capacity 0.0W. Heating
setpoint
20.00C cooling setpoint 23.00C.

 Zone to contol loop linkages:
 zone ( 1) Livingroom   << control  1
```

```
ID Zone        Volume|         Surface
   Name        m^3   | No. Opaque  Transp  ~Floor
 1 Livingroom     45.0   8    75.8     2.2     15.0  Livingroom describes a
   all           45.    8     76.      2.     15.



 Zone Livingroom ( 1) is composed of 8 surfaces and 16 vertices.
 It encloses a volume of 45.0m^3 of space, with a total surface
 area of 78.0m^2 & approx floor area of 15.0m^2
 Livingroom describes a
 There is 24.000m2 of exposed surface area, 24.000m2 of which is vertical.
 Outside walls are 145.00 % of floor area & average U of 0.314 & UA of 6.8390
 Glazing is 15.000 % of floor & 9.3750 % facade with average U of 2.811 & UA of
6.3240
 Ground contact is 100.00 % of floor area & average U of 0.652 & perimeter 8.0000

 A summary of the surfaces in Livingroom( 1) follows:

 Sur| Area  |Azim|Elev| surface    |    geometry               | construction |environment
    | m^2   |deg |deg | name       |optical|locat| use          | name         |other side
```

```
  1  6.75    180.   0. South_Ext    OPAQUE   VERT -      -      Filled_Cavit ||< external
  2  15.0     90.   0. East-Ext     OPAQUE   VERT -      -      Filled_Cavit ||< external
  3  9.00      0.   0. North_Int    OPAQUE   VERT -      -      intern_wall  ||< identical
environment
  4  13.3    270.   0. West_Int     OPAQUE   VERT -      -      intern_wall  ||< identical
environment
  5  15.0      0.  90. Top-5        OPAQUE   CEIL -      -       roof_1      ||< identical
environment
  6  15.0      0. -90. Base-6       OPAQUE   FLOR -      -      ground_1.6m  ||< ground
profile  1
  7  2.25    180.   0. South_Facade DCF7671_ VERT C-WINDOW CLOSED   dbl_glz
||< external
  8  1.68    270.   0. Door         OPAQUE   VERT DOOR    CLOSED   int_doors    ||<
identical environment
```

```
 All surfaces will receive diffuse insolation (if shading not calculated).
 No shading analysis requested.
 No insolation analysis requested.
```

```
 Air schedule notes:
no infiltration or venitlation notes (yet)
 Control: no control of air flow

Scheduled air infiltration and ventilation:
Daytype    Period    Infiltration     Ventilation     From Source
          id Hours   Rate ac/h m3/s   Rate ac/h m3/s  Zone DegC
weekdays   1  0 - 24    1.00  0.0125    0.00  0.0000   0     0.00
saturday   1  0 -  6    1.00  0.0125    0.00  0.0000   0     0.00
```

```
saturday   2  6 -  7    1.00  0.0125    0.00  0.0000   0     0.00
saturday   3  7 - 24    1.00  0.0125    0.00  0.0000   0     0.00
sunday     1  0 - 24    1.00  0.0125    0.00  0.0000   0     0.00
holiday    1  0 - 24    1.00  0.0125    0.00  0.0000   0     0.00

Notes:
no casual gain notes (yet)

Daytype   Gain Label     Type    Unit Period Sensible  Latent     Radiant    Convec
         No.                     Hours Magn.(W)  Magn.(W)   Fraction   Fraction
weekdays    1 lighting   lighting  m2p  0-24     6.0      0.0       0.30       0.70
weekdays    2 Occupants  people    W    0-24     75.0     45.0      0.60       0.40

saturday    1 lighting   lighting  m2p  0-24     6.0      0.0       0.30       0.70
saturday    2 Occupants  people    W    0-24     75.0     45.0      0.40       0.60

sunday      1 lighting   lighting  m2p  0-24     6.0      0.0       0.60       0.40
sunday      2 Occupants  people    W    0-24     75.0     45.0      0.40       0.60

holiday     1 lighting   lighting  m2p  0-24     6.0      0.0       0.60       0.40
holiday     2 Occupants  people    W    0-24     75.0     45.0      0.40       0.60
```

Project floor area is 15.000m2, wall area is 21.750m2, window area is 2.2500m2.
Sloped roof area is 0.00m2, flat roof area is 0.00m2, skylight area is 0.00m2.
In contact with ground 15.000m2.
There is 24.000m2 of outside surface area, 24.000m2 of which is vertical.

Outside walls are 145.00 % of floor area & average U of 0.314 & UA of 6.8390 & max MLC thickness 0.324

```
 Glazing is 15.000 % of floor & 9.3750 % facade with average U of 2.811 & UA of
6.3240
 Ground contact is 100.00 % of floor area & average U of 0.652 & perimeter 8.0000 &
max MLC thickness 1.600
 CIBSE ground beta! 3.750 dt 2.686 Ufleft 0.207 Ufright 1.684 Uf 0.349 R extra @
virtual layer 1.330
```

```
 Multi-layer constructions used:

 Details of opaque construction: intern_wall and overall thickness  0.174

 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
      |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
 Ext    12.0     0.180   800.   837. 0.91 0.60     9.  0.07   9.6 perlite plasterboard : Perlite
plasterboard (inorganic-porous)
    2  150.0     0.440  1500.   650. 0.90 0.65    15.  0.34 225.0 breeze block : Breeze block
(inorganic-porous)
 Int    12.0     0.180   800.   837. 0.91 0.60     9.  0.07   9.6 perlite plasterboard : Perlite
plasterboard (inorganic-porous)
 ISO 6946 U values (horiz/upward/downward heat flow)=   1.552   1.628   1.461
(partition)  1.362
 Weight per m^2 of this construction 244.20

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  1.53
 External surface admittance Y=  3.10  w=  1.71 decrement factor f=  0.68  phi=  0.91
surface factor f=  0.68  phi=  0.91
 Partition admittance Y=  3.46  w=  2.75 surface factor f=  0.74  phi=  1.44
 Total area of intern_wall is     22.32

 Details of opaque construction: int_doors and overall thickness  0.025
```

```
 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
      |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
    1   25.0     0.190   700.  2390. 0.90 0.65    12.  0.13  17.5 oak : Oak (radial cut)
 ISO 6946 U values (horiz/upward/downward heat flow)=   3.316    3.682    2.928
(partition)  2.554
 Weight per m^2 of this construction  17.50

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  3.21
 External surface admittance Y=  3.33  w=  0.61 decrement factor f=  0.61  phi=  0.40
surface factor f=  0.61  phi=  0.40
 Partition admittance Y=  1.21  w=  5.38 surface factor f=  0.99  phi=  0.56
 Total area of int_doors is      1.68

 Details of transparent construction: dbl_glz with DCF7671_06nb optics and overall
thickness  0.024

 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
      |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
 Ext      6.0      0.760  2710.    837. 0.83 0.05 19200.  0.01  16.3 plate glass : Plate glass
with placeholder single layer optics
    2   12.0     0.000     0.     0. 0.99 0.99     1.  0.17   0.0 air  0.17 0.17 0.17
 Int      6.0      0.760  2710.    837. 0.83 0.05 19200.  0.01  16.3 plate glass : Plate glass
with placeholder single layer optics
 ISO 6946 U values (horiz/upward/downward heat flow)=   2.811    3.069    2.527
(partition)  2.243
 Weight per m^2 of this construction  32.53

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  2.73
 External surface admittance Y=  2.81  w=  0.63 decrement factor f=  0.67  phi=  0.31
surface factor f=  0.67  phi=  0.31
 Partition admittance Y=  0.82  w=  5.64 surface factor f=  1.00  phi=  0.38
```

```
 Clear float 76/71,     6mm, no blind: with id of: DCF7671_06nb
 with 3 layers [including air gaps] and visible trn: 0.76
 Direct transmission @ 0, 40, 55, 70, 80 deg
   0.611 0.583 0.534 0.384 0.170
 Layer| absorption @ 0, 40, 55, 70, 80 deg
    1  0.157 0.172 0.185 0.201 0.202
    2  0.001 0.002 0.003 0.004 0.005
    3  0.117 0.124 0.127 0.112 0.077
 Total area of dbl_glz is      2.25

 Details of opaque construction: roof_1 and overall thickness  0.120

 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
      |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
 Ext     12.0     0.190   960.   837. 0.90 0.90    15.  0.06  11.5 roofing felt : Roofing felt
(impermeable)
    2    50.0     0.380  1200.   653. 0.90 0.65     6.  0.13  60.0 light mix concrete : Light
mix concrete (inorganic-porous)
    3    50.0     0.000     0.      0. 0.99 0.99     1.  0.17   0.1 air  0.17 0.17 0.17
 Int      8.0     0.380  1120.   840. 0.90 0.60    12.  0.02   9.0 ceiling (plaster) : Ceiling
(plaster) (inorganic-porous)
 ISO 6946 U values (horiz/upward/downward heat flow)=   1.799   1.902   1.678
(partition)  1.548
 Weight per m^2 of this construction  80.54

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  1.77
 External surface admittance Y=  2.02  w=  1.20 decrement factor f=  0.77  phi=  0.37
surface factor f=  0.77  phi=  0.37
 Partition admittance Y=  1.41  w=  4.87 surface factor f=  0.96  phi=  0.64
 Total area of roof_1 is     15.00

 Details of opaque construction: ground_1.6m and overall thickness  1.600
```

```
 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
     |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
 Ext   250.0     1.280  1460.   879. 0.90 0.85     5.  0.20 365.0 earth std : Common_earth
    2  250.0     1.280  1460.   879. 0.90 0.85     5.  0.20 365.0 earth std : Common_earth
    3  250.0     1.280  1460.   879. 0.90 0.85     5.  0.20 365.0 earth std : Common_earth
    4  250.0     1.280  1460.   879. 0.90 0.85     5.  0.20 365.0 earth std : Common_earth
    5  250.0     1.280  1460.   879. 0.90 0.85     5.  0.20 365.0 earth std : Common_earth
    6  250.0     1.280  1460.   879. 0.90 0.85     5.  0.20 365.0 earth std : Common_earth
 Int   100.0    0.520  2050.   184. 0.90 0.85     2.  0.19 205.0 gravel based : Gravel based
(non-hygroscopic)
 ISO  6946  U  values  (horiz/upward/downward  heat  flow)=   0.652    0.665    0.635
(partition)  0.616
 Weight per m^2 of this construction2395.00

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  0.65
 External surface admittance Y=  3.01  w=  1.21 decrement factor f=  0.67  phi=  0.65
surface factor f=  0.67  phi=  0.65
 Partition admittance Y=  3.01  w=  1.21 surface factor f=  0.67  phi=  0.65
 Total area of ground_1.6m is      15.00

 Details of opaque construction: Filled_Cavit and overall thickness  0.324

 Layer|Thick |Conduc-|Density|Specif|IR  |Solar|Diffu| R    | Kg |Description
     |(mm)  |tivity |       |heat  |emis|abs  |resis|m^2K/W| m^2|
 Ext   100.0     0.960  2000.   650. 0.90 0.93    25.  0.10 200.0 outer leaf brick : Outer
leaf brick (inorganic-porous)
    2  100.0     0.037   300.  1000. 0.90 0.60     1.  2.70  30.0 cavity wall insul : cavity
wall insulation
    3  100.0     0.620  1800.   840. 0.93 0.70    29.  0.16 180.0 inner leaf brick : Inner leaf
brick (inorganic-porous)
```

```
    4   12.5     0.500  1300.  1000. 0.91 0.50    11.  0.03  16.2 dense plaster : Dense plaster (inorganic-porous)
 Int     12.0      0.700  1400.   920. 0.91 0.70     10.  0.02  16.8 lime plaster : lime plaster from IBO PassivHaus (inorganic-porous)
 ISO 6946 U values (horiz/upward/downward heat flow)=   0.314    0.317    0.311 (partition)  0.306
 Weight per m^2 of this construction 443.05

Admittance calculations using Rsi   0.12 Rso   0.06 & Uvalue=  0.31
 External surface admittance Y=  4.73  w=  1.62 decrement factor f=  0.54  phi=  1.72 surface factor f=  0.54  phi=  1.72
 Partition admittance Y=  4.78  w=  1.59 surface factor f=  0.53  phi=  1.73
 Total area of Filled_Cavit is     21.75
```

Appendix B: QA report CFD detailed airflow simulation

Synopsis

Synopsis of the model A basic room with basic CFD with mass flow and thermal conflation defined in CFD_room_afn.cfg generated on Sat Aug 25 00:53:03 2018. Associated notes are in ../doc/CFD_room.log

The model is located at latitude 55.00 with a longitude difference of 0.00 from the local time meridian (east +ve). The year used in simulations is 2000 and weekends occur on Saturday and Sunday.
The site exposure is typical city centre and the ground reflectance is 0.20.

Simulationist name: not yet defined
Simulationist telephone: not yet defined
Simulationist address: not yet defined
Simulationist city: not yet defined
Simulationist postcode: not yet defined

The climate is: ESP test climate and is held in: clm67 with hour centred solar data.
standard annual weather: clm67
Calculated ground temp at 0.5m depth
3.0888 4.3008 6.6610 8.8949 13.123 15.349 15.963 14.834 12.227 8.9770 5.7777 3.6649
Calculated ground temp at 1.0m depth
3.6630 4.5020 6.4738 8.4398 12.343 14.560 15.374 14.612 12.434 9.5459 6.5633 4.4524
Calculated ground temp at 2.0m depth
4.7588 5.0557 6.4004 7.8990 11.149 13.226 14.259 14.027 12.542 10.298 7.7730 5.7855
Calculated ground temp at 4.0m depth

```
6.4880  6.2779  6.8663  7.7174  9.8661  11.475  12.517  12.771  12.121  10.800  9.0880
7.5409

An Integrated Performance View is incomplete or missing.

Databases associated with the model:
 standard pressure distr: pressc.db1
 standard materials      : material.db4.a
 standard constructions : C:/ESRU/esp-r/databases\multicon.db5
 standard plant comp     : plantc.db1
 standard event profiles: profiles.db2.a
 standard optical prop   : optics.db2
 standard UK NCM data    : SBEM.db1
 standard predefined obj: predefined.db1
 standard mould isopleth: mould.db1
```

```
The model includes an air flow network.

 Flow network description.

   5 nodes,   2 components,   4 connections;     wind reduction =  1.000
   # Node      Fluid   Node Type          Height Temperature    Data_1       Data_2
   1 room        air   internal & unknown    1.5000   20.000     (-)     0.000  vol   45.361
   2 west      air   boundary & wind ind   2.1500   0.0000     coef     1.000  azim 270.000
   3 roof      air   boundary & wind ind   3.0000   0.0000     coef     2.000  azim    0.000
   4 01Inlet     air   internal & known      1.5000 room         (Pa)     0.000  vol     0.000
   5 02Outlet     air   internal & known      1.5000 room         (Pa)     0.000  vol     0.000

 Component    Type C+ L+ Description

 open         110  2  0 Specific air flow opening          m = rho.f(A,dP)
```

```
 Fluid  1.0 opening area (m)  0.060


 fan           30  2  0 Constant vol. flow rate component   m = rho.a
 Fluid  1.0 flow rate (m^3/s)  0.50000E-01

   # +Node        dHght   -Node        dHght   Component       Z @+    Z @-
   1 west        -0.325   room         0.325   fan            1.825   1.825
   2 roof        -0.750   room         0.750   open           2.250   2.250
   3 west        -0.325   01Inlet      0.325   fan            1.825   1.825
   4 roof        -0.750   02Outlet     0.750   open           2.250   2.250
thermal zone to air flow node mapping:
thermal zone -> air flow node
room         -> room
```

```
ID Zone         Volume|          Surface
  Name          m^3   | No. Opaque  Transp  ~Floor
 1 room          45.4   9    77.0     0.0    15.1  room describes a basic room
  all          45.    9     77.      0.     15.


 Zone room ( 1) is composed of 9 surfaces and 20 vertices.
 It encloses a volume of 45.4m^3 of space, with a total surface
 area of 77.0m^2 & approx floor area of 15.1m^2
 room describes a basic room
 There is 36.000m2 of exposed surface area, 36.000m2 of which is vertical.
 Outside walls are 238.10 % of floor area & average U of 0.000 & UA of 0.00
 Ground contact is 100.00 % of floor area & average U of 0.000 & perimeter 12.000

 A summary of the surfaces in room( 1) follows:
```

```
 Sur| Area  |Azim|Elev| surface    |    geometry              | construction |environment
    | m^2   |deg |deg | name       |optical|locat| use        | name         |other side
  1  10.1     180.   0. south       OPAQUE   VERT -       -       extern_wall  ||< external
  2  10.8      90.   0. east        OPAQUE   VERT -       -       extern_wall  ||< external
  3  12.6       0.   0. north       OPAQUE   VERT -       -       extern_wall  ||< external
  4  10.7     270.   0. west        OPAQUE   VERT -       -       partition    ||< identical
environment
  5  15.1       0.  90. ceiling     OPAQUE   CEIL -       -       ceiling      ||< identical
environment
  6  15.1       0. -90. floor       OPAQUE   FLOR -       -       floor_1      ||< ground profile
1
  7  0.060    270.   0. inlet       OPAQUE   VERT -       -       dummy_pnls   ||< identical
environment
  8  0.060      0.  90. outlet      OPAQUE   CEIL -       -       dummy_pnls   ||< identical
environment
  9  2.52     180.   0. SFacade     OPAQUE   VERT C-WINDOW CLOSED   dbl_glz
||< external


 All surfaces will receive diffuse insolation (if shading not calculated).
 No shading analysis requested.
 No insolation analysis requested.



A CFD domain has been described for: room
Description is: A room with a CFD domain, coupled with the building simulation a
Building-CFD conflation type 1: thermal conflation

The current domain is orthogonal with:
   3 X regions
   3 Y regions
```

```
  3 Z regions
X Region   1, cells:  10, size:  3.75, power law coef: 1.100
X Region   2, cells:   1, size:  0.20, power law coef: 1.000
X Region   3, cells:   1, size:  0.25, power law coef: 1.000
  Totals          12       4.20
Y Region   1, cells:   4, size:  1.65, power law coef: 1.100
Y Region   2, cells:   1, size:  0.30, power law coef: 1.000
Y Region   3, cells:   4, size:  1.65, power law coef: 1.100
  Totals           9       3.60
Z Region  1, cells:   6, size:  2.05, power law coef: 1.100
Z Region  2, cells:   1, size:  0.20, power law coef: 1.000
Z Region  3, cells:   3, size:  0.75, power law coef: 1.000
  Totals          10       3.00

Volume Inlet is on the West face, cells:   1   1   5   5   7   7
Volume Outlet is on the High face, cells:  11  11   5   5  10  10
Volume West_low is on the West face, cells:   1   1   1   9   1   6
Volume West_mid1 is on the West face, cells:   1   1   1   4   7   7
Volume West_mid2 is on the West face, cells:   1   1   6   9   7   7
Volume West_top is on the West face, cells:   1   1   1   9   8  10
Volume Sfacade is on the South face, cells:   4   8   1   1   4   7
Volume South1 is on the South face, cells:   1   3   1   1   1  10
Volume South2 is on the South face, cells:   9  12   1   1   1  10
Volume SouthTop is on the South face, cells:   4   8   1   1   8  10
Volume SouthLow is on the South face, cells:   4   8   1   1   1   3
Volume North is on the North face, cells:   1  12   9   9   1  10
Volume East is on the East face, cells:  12  12   1   9   1  10
Volume Floor is on the Low face, cells:   1  12   1   9   1   1
Volume Ceiling1 is on the High face, cells:   1  10   1   9  10  10
Volume Ceiling2 is on the High face, cells:  11  11   1   4  10  10
Volume Ceiling3 is on the High face, cells:  11  11   6   9  10  10
Volume Ceiling4 is on the High face, cells:  12  12   1   9  10  10
```

Volume HeaterSourc is of type Source, cells: 5 7 8 9 1 2

NOTE: Face orientations (North, South, East and West) are in terms of the CFD domain only.

This does not necessarily match building geometry.

Solid boundary condition West_low is of type Temp, with temperature associated with building surface west

Solid boundary condition West_mid1 is of type Temp, with temperature associated with building surface west

Solid boundary condition West_mid2 is of type Temp, with temperature associated with building surface west

Solid boundary condition West_top is of type Temp, with temperature associated with building surface west

Solid boundary condition Sfacade is of type Temp, with temperature associated with building surface SFacade

Solid boundary condition South1 is of type Temp, with temperature associated with building surface south

Solid boundary condition South2 is of type Temp, with temperature associated with building surface south

Solid boundary condition SouthTop is of type Temp, with temperature associated with building surface south

Solid boundary condition SouthLow is of type Temp, with temperature associated with building surface south

Solid boundary condition North is of type Temp, with temperature associated with building surface north

Solid boundary condition East is of type Temp, with temperature associated with building surface east

Solid boundary condition Floor is of type Temp, with temperature associated with building surface floor

Solid boundary condition Ceiling1 is of type Temp, with temperature associated with building surface ceiling

Solid boundary condition Ceiling2 is of type Temp, with temperature associated with building surface ceiling

Solid boundary condition Ceiling3 is of type Temp, with temperature associated with building surface ceiling

Solid boundary condition Ceiling4 is of type Temp, with temperature associated with building surface ceiling

Opening Inlet is of type Velocity, conflated to mass flow connection 1

Opening Outlet is of type Velocity, conflated to mass flow connection 2

Following conflated flow network will be used

Source HeaterSourc has heat flux 200.000 W

MIT zero-equation turbulence model active

Solving buoyancy by full ideal gas law calculations, relaxation factor 0.50

Solving pressure (P), initial value 0.0000, relaxation factor 0.50, relaxation factor 2 0.10

Solving velocity in X direction (Vu), initial value 0.0010, relaxation factor 0.30, relaxation factor 2 0.10

Solving velocity in Y direction (Vv), initial value 0.0010, relaxation factor 0.30, relaxation factor 2 0.10

Solving velocity in Z direction (Vw), initial value 0.0010, relaxation factor 0.30, relaxation factor 2 0.10

Solving temperature (T), initial value 20.0000, relaxation factor 0.30, relaxation factor 2 0.20

Solving turbulence energy (k), initial value 0.0050, relaxation factor 1.00, relaxation factor 2 0.05

Solving turbulence energy dissipation rate (e), initial value 0.0050, relaxation factor 1.00, relaxation factor 2 0.05

Solving local mean age of air, initial value not used, relaxation factor not used (always 0.9)

Convergence criterion is maximum sum of residuals 0.100E+00 within 2000 iterations.

Monitoring cell is 7 5 6

Ventilation & infiltration is assessed via network analysis

and the associated network node is: room

Notes:

one dynamic person at various hours

```
Daytype   Gain Label   Type        Unit Period Sensible  Latent     Radiant    Convec
          No.                      Hours Magn.(W)  Magn.(W)   Fraction   Fraction
weekday    1 Occupt    dynamicpeoW   0- 1    0.0      0.0       0.60       0.40
weekday    2 Occupt    dynamicpeoW   1- 7   53.0      3.0       0.00       0.00
weekday    3 Occupt    dynamicpeoW   7- 8   45.0      2.0       0.00       0.00
weekday    4 Occupt    dynamicpeoW   8-10   35.0      1.0       0.00       0.00
weekday    5 Occupt    dynamicpeoW  10-11   24.0      0.0       0.00       0.00
weekday    6 Occupt    dynamicpeoW  11-24    0.0      0.0       0.60       0.40
saturday   1 Occupt    dynamicpeoW   0-24    0.0      0.0       0.60       0.40
```

Project floor area is 15.120m2, wall area is 36.000m2, window area is 0.00m2.

Sloped roof area is 0.00m2, flat roof area is 0.00m2, skylight area is 0.00m2.

In contact with ground 15.120m2.

There is 36.000m2 of outside surface area, 36.000m2 of which is vertical.

Outside walls are 238.10 % of floor area & average U of 0.000 & UA of 0.00 & max MLC thickness 0.000

Ground contact is 100.00 % of floor area & average U of 0.000 & perimeter 12.000 & max MLC thickness 0.000

CIBSE ground beta! 2.520 dt Inf Ufleft 0.000 Ufright 0.000 Uf 0.000 R extra @ virtual layer NaN

Multi-layer constructions used: