PARAMETRIC ENVIRONMENTAL DESIGN FOR LOW ENERGY HEALTHCARE FACILITY PERFORMANCE

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ABSTRACT

Increasingly challenging climatic conditions could significantly impact on the environmental performance of healthcare facilities. Current climate and environmental related challenges are complex which need to be addressed by first analysing the potential impact of climate change on building performance, and then using this to develop responsive environmental design solutions. Given the degree of complexity and the number of multiple variable parameters that need to be considered, the approach proposed by this paper is referred to as 'parametric environmental design'. The evidence to support the development of a proposed parametric environmental design framework has included related: literature review; multiple case study; post occupancy evaluation; environmental review; energy use audit; energy performance benchmarking; thermal scenario development; thermal scenario testing; focus group workshop; environmental design; and environmental monitoring. This paper focuses on the thermal scenario development and testing aspects through the use of parametric modelling and environmental simulation for thermal analysis.

The aim of this paper is to assess the potential role of parametric environmental design in facilitating low energy healthcare facility design and performance, and this will be fulfilled through the use of the following methods: literature review and tool testing for evaluation of the features and capabilities of building information modelling (BIM), and parametric modelling and environmental simulation tools that support the development of purpose-built parametric models for thermal analysis; and thermal scenario development and testing for thermal analysis of 4 purpose-built parametric models of a healthcare single bedroom for the elderly to be situated in 4 cities in England.

This paper determined that 4 purpose-built parametric models – all with the same volume, and representative of a healthcare single bedroom for the elderly (as a sample of a healthcare facility) situated in 4 cities in England – had differing heating requirements, and this necessitated active and passive environmental design strategies and controls to facilitate low(er) heating energy use. Furthermore, parametric modelling and environmental simulation as an aspect of a proposed parametric environmental design approach facilitated this assessment.

Keywords: Design; Elderly; Environmental; Facility; Healthcare; Innovation; Microclimate; Modelling; Parametric; Simulation.

1. INTRODUCTION: STATEMENT OF THE PROBLEM

The National Health Service (NHS) Sustainable Development Unit (SDU) (2008) estimates that: the NHS annual carbon footprint is approximately 18 million tonnes of CO_2 which accounts for nearly 3 percent of England's total carbon emissions; and the NHS annual energy expenditure for both electricity and heating exceeds £429 million, and is responsible for nearly 22 percent of the NHS total carbon footprint. According to Hui (2003), the amount of energy used by a facility is directly related to its climate, function, and form. In its description of the changing health landscape, the Commission for Architecture and the Built Environment (CABE) (2009, p.3) states that "[m]odern healthcare is under pressure to provide individually tailored care in safe and effective facilities [that]…must be responsive to shifting patterns of sickness, population, patient expectations, technological advances in treatments and climate change". However, current climate and environmental related challenges are complex and these need to be addressed by first, analysing the potential impact of climate change on building performance, and then using this to develop responsive environmental design solutions. CABE (2009, p.7) suggest that "…it is essential to consider weather and temperature fluctuations when designing facilities or places meant to encourage healing and good health". Given the degree of complexity and the number of multiple variable parameters that need to be considered, the approach proposed by this paper is referred to as 'parametric environmental design'.

1.1 Research Aim

The study reported on in this paper aims to assess the potential role of parametric environmental design in improving healthcare facility thermal performance, thereby facilitating low energy healthcare facility design and performance.

1.2 Research Objectives

Its objectives are to document the application of key aspects of parametric environmental design to: undertake a thermal analysis of 4 purpose-built parametric models that have the same volume, and are representative of a healthcare single bedroom for the elderly situated in 4 cities in England; review 388 digital tools in the built environment and healthcare sectors, and identify the major digital tools that have the potential to facilitate this thermal analysis study; determine the impacts of 4 England microclimates on the thermal performance of a healthcare single bedroom for the elderly; and develop appropriate environmental design strategies that could mitigate any identified impacts for low(er) heating energy use.

1.3 Research Scope and Justification

In its description of the lessons learned from the early adopters of BIM, Howell and Batcheler (2005, p.5) state that "…using a single BIM model for building performance mode[l]ling…does not provide the flexibility needed by consulting engineers to conduct a multitude of "what if" scenarios to study alternate approaches and to optimi[s]e design alternatives in order to maximi[s]e energy efficiency…". According to Howell and Batcheler (2005), despite the creation and adoption of BIM, a growing number of purpose-built models are used by the AEC (architecture, engineering, and construction) industry. The 4 purpose-built parametric models used by this study for thermal analysis are the purpose-built parametric models created by interfacing Activity DataBase (ADB), Autodesk Revit, and ECOTECT data that have the same 46.293m^3 volume, and are representative of a healthcare single bedroom for the elderly situated in 4 cities in England. The Office for National Statistics (ONS) (2009) describes the population category known as elderly or old as those aged 65 years and over. The use of 4 purpose-built parametric models by this study for thermal analysis of a healthcare single bedroom for the elderly is based on the following criteria that are related to building performance modelling and simulation, and health and social care:

- In Nayak and Prajapati (2006), it was demonstrated that the thermal analysis of a single zone room can be used as an example to determine aspects of the thermal performance of a building.
- It represents a unit of accommodation for health and social care for a vulnerable group likely to be affected by England microclimate and thermal scenarios.
- It serves as a way of ensuring that a constant volume of space is maintained for thermal analysis during this study’s initial 8 simulation runs where the variable is the England microclimate, and during this study’s final 8 simulation runs where the HVAC system was varied in comparison to that used during the initial 8 simulation runs.
- In the past 20 years there has been a quick population growth, with the elderly making up almost a quarter of the current 71.7 million population, that is, the population of the elderly in the United Kingdom (UK) is almost 17.9 million. (NHS SDU and Forum for the Future, 2009; and Office for National Statistics (ONS)).
- Increases in the UK elderly population has led to an increase in the UK population’s median age, which increased from 35 to 39 years between 1983 to 2008 and this will rise to 40 years by 2033. (Office for National Statistics (ONS), 2009).
- A significant proportion of hospital occupants are now elderly, and preserving their dignity within a hospital is a key objective (Patient UK, 2008).

The healthcare single bedroom for the elderly was used by this study for measurement of its unit of analysis, which is thermal performance.

2. RESEARCH METHOD

The central methods used for data collection and analysis during this study were:

- Literature review and tool testing for evaluation of the features and capabilities of 387 built environment sector digital tools and 1 healthcare sector digital tool with a focus on Autodesk Revit, ECOTECT, and Activity DataBase (ADB) for support in the development of purpose-built parametric models for thermal analysis.
- Thermal scenario development and testing that involved: interfacing ADB, Autodesk Revit, and ECOTECT to develop 4 purpose-built parametric models,

which all have the same volume and are representative of a healthcare single bedroom for the elderly situated in 4 cities in England, that is, Birmingham, London, Manchester, and Newcastle; and undertaking thermal analysis of these 4 purpose-built parametric models in order to determine the impacts of 4 England microclimates on the thermal performance of the healthcare single bedroom for the elderly.

The resultant knowledge will be used to develop appropriate active and passive environmental design strategies and controls that are responsive to England microclimates, and facilitate low(er) energy use in a healthcare single bedroom for the elderly. Further research will involve using a similar approach for the thermal scenario development and testing of purpose-built parametric models of healthcare rooms and buildings with the same volume that are to be situated in 57 locations in 13 countries, and these are in: Australia (x5); Canada (x3); China (x2); Germany (x2); Greece (x1); India (x1); Italy (x3); Kenya (x1); Nigeria (x1); Russia (x1); Saudi Arabia (x1); United States of America (U.S.) (x6); and UK (x30). It is anticipated that this would further determine the impacts of a country's microclimates on healthcare facility thermal performance. The evidence generated from this would contribute to the development of a parametric environmental design framework. It is anticipated such a parametric environmental design framework would include guidelines and recommendations for appropriate active and passive design solutions, strategies and controls that address the impacts of microclimates on healthcare facility thermal performance in order to facilitate their low energy use.

2.1 Review of Digital Tools in the Built Environment and Healthcare Sectors

A total of 387 digital tools in the built environment sector were reviewed, and these include Autodesk Revit, which was identified by Autodesk (2010), Howell and Batcheler (2005), and Rundell (2007) to support BIM. 384 of the 387 built environment sector digital tools reviewed form part of the U.S. Department of Energy Building Energy Software Tools Directory. These were described by the U.S. Department of Energy (2010) to be databases, spreadsheets, component and systems analyses, and whole-building energy performance simulation programs that support the evaluation of energy efficiency, renewable energy, and sustainability in buildings. The focus on these 384 digital tools was eventually narrowed down to 20 based on the criteria that these were described in Crawley et al. (2005) to be major building energy simulation analysis programs.

These 20 major building energy simulation analysis programs are: BLAST; Bsim; DeST; DOE-2.1E; ECOTECT; Ener-Win; Energy Express; Energy-10; EnergyPlus; eQUEST; ESP-r; IDA ICE; IES <VE>; HAP; HEED; PowerDomus; SUNREL; Tas; TRACE; and TRNSYS. A further 2 building energy simulation programs were reviewed, and these were described by the Building Research Establishment (BRE 2008) to be the National Calculation Method (NCM), and the Simplified Building Energy Model (SBEM) and its user interface known as iSBEM.

The review of these built environment sector digital tools subsequently led to a focus on Autodesk Revit and ECOTECT, and were identified by Autodesk (2010), Marsh (1996 and 2006), and Rundell (2007) to support BIM, and parametric modelling and environmental simulation.

The healthcare sector digital tool that was reviewed is Activity DataBase (ADB), and it was described by the Department of Health (DH) (2007 and 2009) to contain healthcare room and departmental layouts with export facility to Autodesk Revit for development into 3d building information models (BIMs).

The review of these 388 built environment and healthcare sector digital tools led to the adoption of Autodesk Revit, ECOTECT, and ADB to fulfil the objective to undertake thermal analysis of 4 purpose-built parametric models that have the same volume and represent a healthcare single bedroom for the elderly situated in 4 cities in England in order to determine England microclimate impacts on healthcare facility thermal performance.

2.1.1 The Review of Autodesk Revit

Autodesk (2010), and Rundell (2007) describe Autodesk Revit as a BIM tool that facilitates innovative building design, and permits freedom of design and fulfilment of efficiency. Howell and Batcheler (2005) describe Autodesk Revit as a BIM implementation by one of the leading providers of BIM solutions. Howell and Batcheler (2005, p.2) state that “Autodesk [Revit] is perhaps the most literal interpretation of a single BIM as a central project database”. According to DH (2007 and 2009), Autodesk Revit can be interfaced with ADB for development of ADB healthcare room and departmental layouts into 3d BIMs that can be viewed and modified in Autodesk Revit. In their description of the features and capabilities of Autodesk Revit, Autodesk (2010) and Rundell (2007) state that Autodesk Revit supports the following:

- Integration of design and work between internal and external teams.
- Accuracy and flexibility in design.
- Approximately 10% reduction in time wastage during planning and design.
- Approximately 3% savings on the cost of building projects.
- Building Information Modelling (BIM).
- Compatibility with other tools such as ADB, and ECOTECT.
- Evidence based design.
- Development of 3d BIMs of a healthcare single bedroom for the elderly by interfacing ADB related data with Autodesk Revit for 3d views and modifications.

Furthermore, the proof of concept undertaken in Osaji et al. (2009) that involved the integration of built environment and healthcare sector digital tools for improved building performance determined Autodesk Revit to be supportive of BIM, and compatible with other tools such as ADB, and ECOTECT.

2.1.2 The Review of ECOTECT

According to McLean, in Howell and Batcheler (2005, p.7), “[o]ne of the key ingredients to introducing Environmentally Sustainable Design (ESD) principles into design is technology – specifically the use of building simulation applications performing a variety of analyses with relevance to technology of Building Performance Modeling (BPM)”... Crawley et al. (2005) identifies one of such building simulation applications when it describes ECOTECT as an architectural design and analysis tool that supports parametric modelling and environmental simulation. In their description of the features and capabilities of ECOTECT, Crawley et al. (2005), Marsh (1996 and 2006), and the U.S. Department of Energy (2010) state that ECOTECT supports:

- Parametric modelling and environmental simulation.
- Certain aspects of pre-occupancy and post-occupancy building performance analysis, including thermal analysis, solar exposure, material costs, resource consumption, reverberation times, acoustic response, and lighting aspects within multiple variable parameters.
- Mapping of analysis results over building surfaces and within spaces.
- Compatibility with Autodesk Revit.
- Evidence based design.
- This study's thermal analysis of purpose-built parametric models that were developed by interfacing ADB healthcare single bedroom for the elderly data with Autodesk Revit to develop 3d BIMs, and then interfacing these 3d BIMs with ECOTECT to develop 4 purpose-built parametric models for determination of the impacts of England microclimates on healthcare facility thermal performance.

Furthermore, the proof of concept undertaken in Osaji et al. (2009) that involved the integration of built environment and healthcare sector digital tools for improved building performance determined ECOTECT to be supportive of parametric modelling and environmental simulation, and compatible with other tools such as Autodesk Revit.

2.1.3 The Review of Activity DataBase (ADB)

According to DH (2007 and 2009), ADB is an NHS DH Estates database tool containing recommendations for room specifications and components, and it assists in the briefing, design, construction, equipping, and alteration of healthcare environments and facilities. ADB is also based on current health building guidance, and contains accurate and detailed data drawn directly from the Health Building Notes (HBNs), which support the DH National Service Frameworks identifying the way care will be delivered in the future, as well as Health Technical Memoranda (HTM) publications. Holme (2009) also describes the relationship between ADB and current health building guidance when it states that the key guidance comprise HTM engineering services, HBN building design, HTM building components, and Health specific guidance notes which all feed into and support ADB. In their description of the features and capabilities of ADB, DH (2007) and DH (2009) state that ADB supports:

- Room and departmental layouts, C-Sheets, reports, 1:50, 1:200, and 2d / 3d.
- An audit trail component symbol library.
- An inbuilt graphical editor, and export facility.
- Brands, models, manufacturers and specifications.
- Extensive references to internal and external standards, including HTMs, Chartered Institution of Building Services Engineers (CIBSE) guidance, Disability Discrimination Act, etc.

Furthermore, the proof of concept undertaken in Osaji et al. (2009) that involved the integration of built environment and healthcare sector digital tools for improved building performance determined ADB to be supportive of the design of healthcare environments and facilities, and compatible with other tools such as Autodesk Revit.

2.2 Thermal Scenario Development and Testing for Determination of England Microclimate Impacts

This thermal scenario development and testing involved: interfacing ADB, Autodesk Revit, and ECOTECT to develop 4 purpose-built parametric models, which all have the same volume and are representative of a healthcare single bedroom for the elderly situated in 4 cities in England, that is, Birmingham, London, Manchester, and Newcastle; and undertaking thermal analysis of these 4 purpose-built parametric models in order to determine the impacts of 4 England microclimates on the thermal performance of the healthcare single bedroom for the elderly. Furthermore, the thermal scenario development and testing method employed by this study involved the following process:

- Thermal scenario development whereby a healthcare single bedroom for the elderly with a volume of 46.293m^3 was subjected to the microclimates of 4 cities in England, that is, Birmingham, London, Manchester, and Newcastle while operating 24 hour weekdays and weekends with single inpatient occupancy.
- Parametric modelling whereby: ADB data of a healthcare single bedroom for the elderly was interfaced with Autodesk Revit in order to generate a 3d BIM; and then this 3d BIM was interfaced with ECOTECT to create 4 purpose-built parametric models of a 46.293m^3 healthcare single bedroom for the elderly that incorporate defined parameters and variables governed by this study’s Simulation Decision Set.
- Thermal scenario testing whereby: environmental simulation was used for the thermal analysis of the 4 purpose-built parametric models of a 46.293m^3 healthcare single bedroom for the elderly when they are subjected to the microclimates of 4 cities in England, that is, Birmingham, London, Manchester, and Newcastle.

2.2.1 The Variable Parameters and Assumptions: The Simulation Decision Set

The choice of multiple variable parameters and assumptions used by this study for its thermal analysis of 4 purpose-built parametric models of a healthcare single bedroom for the elderly, which was subjected to 4 England microclimates is governed by a Simulation Decision Set that had the following criteria:

- The morphology of each of the 4 purpose-built parametric models is a cuboid.
- The height of each of the 4 purpose-built parametric models is 2.7m.
- The volume of each of the 4 purpose-built parametric models is 46.293m^3.
- The local time zone of each of the 4 purpose-built parametric models is GMT London.
- The site latitude and longitude for the 4 England microclimates are:
    a. 52.4° and -1.8° respectively for Birmingham.
    b. 51.4° and 0.0° respectively for London.

    c. 53.5° and -2.9° respectively for Manchester.
    d. 55.4° and -1.5° respectively for Newcastle.
- The building type of the 4 purpose-built parametric models is a healthcare facility.
- The local terrain of each of the 4 purpose-built parametric models is urban.
- The climate zone of each of the 4 purpose-built parametric models is temperate.
- The hours of operation are 24 hours during both weekdays and weekends.
- The design conditions include: 0.6 clo for clothing (clo); 60.0% for humidity; 0.50m/s for air speed; and 300 lux for lighting.
- The HVAC system of each of the 4 purpose-built parametric models for the initial 8 simulation runs is heating only.
- The HVAC system of each of the 4 purpose-built parametric models for the final 8 simulation runs is a mixed-mode system.
- The HVAC system efficiency of each of the 4 purpose-built parametric models is 95.0% (based on the assumption that it is relatively new).
- The thermostat range of each of the 4 purpose-built parametric models is between 18.0°C (upper band) to 26.0°C (lower band).
- The occupancy of each of the 4 purpose-built parametric models is equal to one person, that is, one elderly inpatient.
- The single elderly inpatient occupant is engaged in a level of activity that is predominantly resting (45W).
- The internal gains are 5 W/m² for sensible gain and 2 W/m² for latent gain.
- The infiltration rate is 0.50 air changes/hr for the air change rate and 0.25 air changes/hr for the wind sensitivity.
- The material assignments of each of the 4 purpose-built parametric models consist of: concrete block plaster walls; a concrete slab on-ground floor; a suspended concrete ceiling; a solid core oak timber door; and a double glazed aluminium frame window.

2.2.2 The Use of ECOTECT for Thermal Analysis of the 4 Purpose-Built Parametric Models

ECOTECT was used for development of the 4 purpose-built parametric models of a healthcare single bedroom for the elderly, and to undertake their thermal analysis using environmental simulations in order to determine the impacts of 4 England microclimates. 16 simulation runs were undertaken, that is, an initial 8 simulation runs were undertaken where the variable was the England microclimate, and a final 8 simulation runs were undertaken where the HVAC system was varied in comparison to that used during the initial 8 simulation runs. These involved the following process:

1. The Project tab was selected to open the project page for the input of project parameters that include: Project Title; Job/Reference No.; Building Type; User/Client; Weather Data File; Notes; Site Location (Latitude, Longitude, Local Time Zone); and Site Specifics (North Offset, Altitude, Local Terrain). The input parameters and variables were derived from the Simulation Decision Set that was developed for this study.
2. The Model tab was selected from the toolbar for input of the model parameters that include: Site and Location; Zone Management; and Model Settings. The input

parameters and variables were derived from the Simulation Decision Set that was developed for this study.

3. The Zone Management tab was selected from the vertical toolbar on the right-side panel of the ECOTECT interface for the creation of the zones of the 4 purpose-built parametric models of the healthcare single bedroom for the elderly. The input parameters were derived from the Simulation Decision Set that was developed for this study. The creation of the zones of each of the 4 parametric models was achieved through the following process:
   - Within the Zone Management panel on the right-side of the ECOTECT interface, Create New Zone was selected and this opened a highlighted new zone for input of a name for the created zone.
   - Within the Zone Management panel, Change Zone Settings was selected, and then Make Thermal was selected in order to assign thermal qualities to the zones of the 4 purpose-built parametric models.
   - The Zone Management tab at the bottom right-side of the Zone Management panel was left-clicked in order to access the Zone Management interface for input of parameters that include: General Settings; Thermal Properties; and Information.
   - For the General Settings: the Zone Volume Calculation Precision was set as Low Precision; About Axis was set as Z-Axis; Shadow Display was set as Shadow Colour; Hours of Operation on Weekdays was set as 24; Hours of Operation on Weekends was set as 24; Design Conditions were set as Trousers and Shirt (0.60 clo) for Clothing (clo), 60.0% for Humidity; 0.50m/s for Air Speed; and 300 lux for Lighting Level.
   - For the Thermal Properties: the HVAC System was set as Heating Only for the initial 8 simulation runs, and set as Mixed-Mode System for the final 8 simulation runs; the HVAC System Efficiency (%) was set as 95.0% based on the assumption that it is relatively new; the Thermostat Range Lower Band was set as 18.0°C while its Upper Band was set as 26.0°C; Occupancy was set as 1 for No. of People and 45W for Activity based on the assumption that the elderly inpatient is Resting; Internal Gains were set as 5 W/m^2 for Sensible Gain and 2 W/m^2 for Latent Gain; Infiltration Rate was set as 0.50 air changes/hr for Air Change Rate and 0.25 air changes/hr for Wind Sensitivity.
   - The Zone Volume of each of the 4 purpose-built parametric models was calculated by selecting the Information tab and then left-clicking the Calculate Zone Volumes tab.
   - The Selection Information tab was selected from the right-side vertical toolbar of the ECOTECT interface. From its dropdown menu, Zones and Objects were selected to ensure that their parameters corresponded to the parameters in the Simulation Decision Set, and the Zone Management interface. The Apply Changes tab located at the bottom right-side of the Selection Information panel was left-clicked to update the information.
4. The Material Assignments tab was selected from the vertical toolbar on the right-side of the ECOTECT interface for assignment of materials to the 4 purpose-built parametric models. The input parameters were derived from the Simulation Decision Set that was developed for this study. U-Value and Admittance was set as 0.200 W/m^{2}K.
5. The Analysis tab was selected from the toolbar on the left-side of the ECOTECT interface. This opened the Analysis window for calculation of the thermal analysis of the 4 purpose-built parametric models, and this involved the following process:

- Within the analysis window, the Thermal Analysis tab was selected.
- From the Thermal Calculation dropdown menu, the Monthly Loads/Discomfort option was selected.
- The Inter-Zonal Gains and Solar Radiation options were selected by ticking the boxes next to them.
- From the Highlight Zone dropdown menu, the All Visible Thermal Zones option was selected.
- Previously inputted zone settings were checked and confirmed by left-clicking the Zone Settings tab.
- Previously inputted location settings were checked and confirmed by left-clicking the Location tab.
- For Comfort Data, the Flat Comfort Bands option was selected from the dropdown menu, and the Degree Hours option was also selected.
- Previously inputted weather data settings were checked and confirmed by left-clicking the Weather Data File tab.
- The monthly heating/cooling loads for each of the 4 purpose-built parametric models were then calculated by left-clicking the Calculate tab in order to produce a graph and a table showing monthly heating and cooling loads over a 12 month period.

2.2.3 Results and Findings: Based on the Use of a Heating Only HVAC System

This study undertook the thermal analysis of 4 purpose-built parametric models of a 46.293m^3 healthcare single bedroom for the elderly when it is subjected to the impacts of 4 England microclimates. Parametric modelling and environmental simulation as an aspect of a proposed parametric environmental design approach facilitated this thermal analysis. It involved a process whereby the healthcare single bedroom for the elderly ADB data was interfaced with Autodesk Revit to create a 46.293m^3 3d BIM, then interfaced with ECOTECT to create 4 purpose-built parametric models whose thermal performances where analysed in order to determine the impacts of 4 England microclimates in Birmingham, London, Manchester, and Newcastle. The results and findings for this thermal analysis study are tabulated in Table 1.

Table 1: Results and Findings of the Thermal Analysis of a 46.293m^3 Healthcare Single Bedroom for the Elderly (HSB4E) Subjected to 4 England Microclimates

<table>
<tr><th>S/N</th><th>RESULTS</th><th>FINDINGS</th></tr>
<tr><td>1</td><td>HSB4E in Birmingham: total heating = 924.450 kWh; maximum heating = 6.159 kW at 00:00 on 15th February.</td><td rowspan="4">The HSB4E in Newcastle used the most total heating while the same HSB4E in Manchester used the 2nd most total heating.

The HSB4E in London used the least total heating while its total heating increased progressively as its location changed from England’s South East to West Midlands then North West and finally North East sub regions. Total heating for the HSB4E: in London (South East) < in Birmingham (West Midlands) < in Manchester (North West) < in Newcastle (North East).

Maximum heating for the HSB4E occurred on 4 different days between December and February while no cooling occurred over a 12 month period between January and December.</td></tr>
<tr><td>2</td><td>HSB4E in London: total heating = 797.337 kWh; maximum heating = 6.389 kW at 00:00 on 24th December.</td></tr>
<tr><td>3</td><td>HSB4E in Manchester: total heating = 935.753 kWh; maximum heating = 6.493 kW at 00:00 on 11th February.</td></tr>
<tr><td>4</td><td>HSB4E in Newcastle: total heating = 1,099.274 kWh; maximum heating = 6.716 kW at 00:00 on 13th January.</td></tr>
</table>

The 46.293m^3 healthcare single bedroom for the elderly used the most total heating in Newcastle, which is located in England's North East sub region than it did in 3 other England cities located in the North West, West Midlands, and South East sub regions. The 46.293m^3 healthcare single bedroom for the elderly also used the second most total heating in Manchester, which is located in England's North West sub region than it did in 2 other England cities located in the West Midlands, and South East.

The 46.293m^3 healthcare single bedroom for the elderly used the least total heating in London, which is located in England's South East sub region than it did in 3 other England cities located in the North East, North West, and West Midlands sub regions.

The 46.293m^3 healthcare single bedroom for the elderly in London used the least total heating while its total heating increased progressively as its location changed from England's South East to West Midlands then North West and finally North East sub regions. The total heating for the 46.293m^3 healthcare single bedroom for the elderly in London (South East) is less than in Birmingham (West Midlands), which is less than in Manchester (North West), and is less than in Newcastle (North East).

The maximum heating for the 46.293m^3 healthcare single bedroom for the elderly, which was located in 4 England cities occurred on 4 different days between December and February. However, no cooling for the 46.293m^3 healthcare single bedroom for the elderly occurred over a 12 month period between January and December.

Based on these results, the ratio of the total heating performances for the 46.293m^3 healthcare single bedroom for the elderly in London, Birmingham, Manchester, and Newcastle is 1.000 : 1.159 : 1.173 : 1.378 respectively. Therefore, it appears that a 46.293m^3 healthcare single bedroom for the elderly if located in England's:

- Newcastle would likely use 1.378 times more total heating than it would use if it was located in London.
- Manchester would likely use 1.173 times more total heating than it would use if it was located in London.
- Birmingham would likely use 1.159 times more total heating than it would use if it was located in London.

Furthermore, these thermal analysis results imply that the:

- Total heating performance differential between a 46.293m^3 healthcare single bedroom for the elderly in Newcastle and London is about 27.46%.
- Total heating performance differential between a 46.293m^3 healthcare single bedroom for the elderly in Manchester and London is about 14.79%.
- Total heating performance differential between a 46.293m^3 healthcare single bedroom for the elderly in Birmingham and London is about 13.75%.

The results of this thermal analysis study demonstrate that the microclimates of 4 cities located in 4 England sub regions, that is, West Midlands, South East, North West, and North East had 4 different impacts on the total heating performance of the 46.293m^3 healthcare single bedroom for the elderly.

2.2.4 Results and Findings: Based on the Use of a Mixed-Mode HVAC System

This study undertook the thermal analysis of 4 purpose-built parametric models of a 46.293m^3 healthcare single bedroom for the elderly when it is subjected to the impacts of 4 England microclimates. Parametric modelling and environmental simulation as an aspect of a proposed parametric environmental design approach facilitated this thermal analysis. It involved a process whereby the healthcare single bedroom for the elderly ADB data was interfaced with Autodesk Revit to create a 46.293m^3 3d BIM, then interfaced with ECOTECT to create 4 purpose-built parametric models whose thermal performances where analysed in order to determine the impacts of 4 England microclimates in Birmingham, London, Manchester, and Newcastle. The results and findings for this thermal analysis study are tabulated in Table 2.

Table 2: Results and Findings of the Thermal Analysis of a 46.293m^3 Healthcare Single Bedroom for the Elderly (HSB4E) Subjected to 4 England Microclimates

S/N	RESULTS	FINDINGS
1	**HSB4E in Birmingham: total heating = 924.092 kWh; maximum heating = 6.159 kW at 00:00 on 15th February.**	The HSB4E in Newcastle used the most total heating while the same HSB4E in Manchester used the 2nd most total heating. The HSB4E in London used the least total heating while its total heating increased progressively as its location changed from England's South East to West Midlands then North West and finally North East sub regions. Total heating for the HSB4E: in London (South East) < in Birmingham (West Midlands) < in Manchester (North West) < in Newcastle (North East). Maximum heating for the HSB4E occurred on 4 different days between December and February while no cooling occurred over a 12 month period between January and December.
2	**HSB4E in London: total heating = 797.337 kWh; maximum heating = 6.389 kW at 00:00 on 24th December.**	
3	**HSB4E in Manchester: total heating = 936.154 kWh; maximum heating = 6.493 kW at 00:00 on 11th February.**	
4	**HSB4E in Newcastle: total heating = 1,099.274 kWh; maximum heating = 6.716 kW at 00:00 on 13th January.**	

The 46.293m^3 healthcare single bedroom for the elderly used the most total heating in Newcastle, which is located in England's North East sub region than it did in 3 other England cities located in the North West, West Midlands, and South East sub regions. The 46.293m^3 healthcare single bedroom for the elderly also used the second most total heating in Manchester, which is located in England's North West sub region than it did in 2 other England cities located in the West Midlands, and South East.

The 46.293m^3 healthcare single bedroom for the elderly used the least total heating in London, which is located in England's South East sub region than it did in 3 other England cities located in the North East, North West, and West Midlands sub regions.

The 46.293m^3 healthcare single bedroom for the elderly in London used the least total heating while its total heating increased progressively as its location changed from England's South East to West Midlands then North West and finally North East sub regions. The total heating for the 46.293m^3 healthcare single bedroom for the elderly in London (South East) is less than in Birmingham (West Midlands), which is less than in Manchester (North West), and is less than in Newcastle (North East).

The maximum heating for the 46.293m^3 healthcare single bedroom for the elderly, which was located in 4 England cities occurred on 4 different days between December and February. However, no cooling for the 46.293m^3 healthcare single bedroom for the elderly occurred over a 12 month period between January and December.

Based on these results, the ratio of the total heating performances for the 46.293m^3 healthcare single bedroom for the elderly in London, Birmingham, Manchester, and Newcastle is 1.000 : 1.159 : 1.174 : 1.378 respectively. Therefore, it appears that a 46.293m^3 healthcare single bedroom for the elderly if located in England's:

- Newcastle would likely use 1.378 times more total heating than it would use if it was located in London.
- Manchester would likely use 1.174 times more total heating than it would use if it was located in London.
- Birmingham would likely use 1.159 times more total heating than it would use if it was located in London.

Furthermore, these thermal analysis results imply that the:

- Total heating performance differential between a 46.293m^3 healthcare single bedroom for the elderly in Newcastle and London is about 27.46%.
- Total heating performance differential between a 46.293m^3 healthcare single bedroom for the elderly in Manchester and London is about 14.82%.
- Total heating performance differential between a 46.293m^3 healthcare single bedroom for the elderly in Birmingham and London is about 13.71%.

The results of this thermal analysis study demonstrate that the microclimates of 4 cities located in 4 England sub regions, that is, West Midlands, South East, North West, and North East had 4 different impacts on the total heating performance of the 46.293m^3 healthcare single bedroom for the elderly.

2.2.5 The Limitations of the Thermal Analysis Study

The limitations of this thermal analysis study are described below.

- This thermal analysis study does not account for thermal and energy related inputs and outputs that are attributable to medical equipment.
- The occupancy for this study is set at one person, that is, one elderly inpatient, and this study does not account for any increase in occupancy that can occur in reality due to the presence of staff and visitors.
- Although the 4 purpose-built parametric models of a 46.293m^3 healthcare single bedroom for the elderly were developed with a similar layout and size, as well as similar parameters and variables as an actual healthcare bedroom, they do not fully represent the real world. They are limited by both their available input data and the digital tool used to run its environmental simulations for thermal analysis.
- Possible modelling discrepancies may occur which may affect thermal and cost analysis functions.

2.2.6 Discussion

As can be seen from the summary of the results and findings in Tables 1 and 2:

- The 46.293m^3 healthcare single bedroom for the elderly in Birmingham used more total heating by about 0.038% when its HVAC system was Heating Only than when it was a Mixed-Mode system.
- The 46.293m^3 healthcare single bedroom for the elderly in London used the same total heating when its HVAC system was both Heating Only and a Mixed-Mode system.
- The 46.293m^3 healthcare single bedroom for the elderly in Manchester used less total heating by about 0.042% when its HVAC system was Heating Only than when it was a Mixed-Mode system.
- The 46.293m^3 healthcare single bedroom for the elderly in Newcastle used the same total heating when its HVAC system was both Heating Only and a Mixed-Mode system.

This implies that for a 46.293m^3 healthcare single bedroom for the elderly in Birmingham, it would appear that its use of a mixed-mode HVAC system is more beneficial to its total heating performance than its use of a heating only HVAC system. However, it would appear that for a 46.293m^3 healthcare single bedroom for the elderly in Manchester, its use of a heating only HVAC system is more beneficial to its total heating performance than its use of a mixed-mode HVAC system. Furthermore, it would appear that for a 46.293m^3 healthcare single bedroom for the elderly in both London and Newcastle, its use of either a heating only HVAC system or mixed-mode HVAC system does not result in any noticeable increase or decrease in its total heating performance.

Therefore, the development of a healthcare facility, for instance, a healthcare single bedroom for the elderly to be situated in different England cities could each have differing heating requirements, which might necessitate the application of differing solutions, including active and / or passive environmental design strategies and controls.

CABE (2009, p.7) states that “[s]trategic action is required to create well-located, sustainable, high-quality healthcare buildings and green surroundings that improve the patient experience and overall health and well-being”. It describes the use of passive environmental design strategies such as thermal massing, natural ventilation and natural lighting as essential for achieving sustainable design and reducing energy use. In describing 5 design principles for sustainable building, Strong (2004) and the CIBSE Energy Efficiency in Buildings Guide (2004) state that these are: site considerations (location and weather; microclimate; site layout; orientation); built form (shape; thermal response; insulation; windows/glazing); ventilation strategy; daylighting strategy; and services strategy (plant and controls; fuels; metering). Furthermore, Strong (2004) and the CIBSE Energy Efficiency in Buildings Guide (2004) identify 3 issues that affect energy efficiency as: building envelope; building services; and human factors.

The results and findings of the thermal analysis study reported on in this paper demonstrate the importance of thermal scenario development and testing – as an aspect of a parametric environmental design concept – in fulfilling aspects of the 5 design principles for sustainable building. This is a necessity in order to effectively assess healthcare facility thermal performance, thereby facilitating its low energy design and performance. Furthermore, the results and findings of the thermal analysis study reported on in this paper also identify and demonstrate the importance of the concept of microclimates.

Keel (2010, p.55) also supports the concept of microclimates when it states that "…a hospital requires a range of carefully controlled micro-climates, each with differing heating, cooling and ventilation requirements, rather than a standard solution for the entire environment".

3. CONCLUSION: CREATION OF A PARAMETRIC ENVIRONMENTAL DESIGN FRAMEWORK

Based on the thermal analysis study undertaken by this paper, as well as a similar ongoing study that is being undertaken by the first author as part of the work of Loughborough University's Health and Care Infrastructure Research and Innovation Centre (HaCIRIC), certain findings are beginning to emerge. This paper's study has identified and demonstrated:

- The importance of the thermal scenario development and testing aspect of the parametric environmental design concept in fulfilling aspects of the 5 design principles for sustainable building.
- The importance of the concept of microclimates, and their impacts on, for instance, the thermal performance of a healthcare single bedroom for the elderly.

Further research will involve the use of a similar approach for the thermal scenario development and testing of purpose-built parametric models of healthcare rooms and buildings with the same volume that are to be situated in 57 locations in 13 countries, including in Australia, Canada, China, Germany, Greece, India, Italy, Kenya, Nigeria, Russia, Saudi Arabia, U.S., and UK. It is anticipated that this would further determine the impacts of a country's microclimates on healthcare facility thermal performance. The evidence generated will also involve learning lessons from aspects of the following: literature review; multiple case study; post occupancy evaluation; environmental review; energy use audit; energy performance benchmarking; thermal scenario development and testing through parametric modelling and environmental simulation; comparative study; focus group sessions; environmental design; and environmental monitoring.

These will contribute to the development of a parametric environmental design framework. The first author defines parametric environmental design as undertaking an integrated building design, and the control of a building's internal environment (for example, its heating and cooling, quality of air, humidity, acoustics, lighting) through the use of passive or active environmental controls, parametrics, and parametric modelling and environmental simulation.

It is anticipated such a parametric environmental design framework would include guidelines and recommendations for appropriate active and passive design solutions, strategies and controls that address the impacts of microclimates on healthcare facility thermal performance in order to facilitate their low energy use.

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