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BUILDING SIMULATION AS AN ASSISTING TOOL IN DESIGNING AN ENERGY EFFICIENT BUILDING: A CASE STUDY

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ABSTRACT

Decisions made in the very first stages of a building's design often have a significant impact on energy efficiency and internal environment of the building. Although many buildings have energy efficiency strategies embedded in their conceptual design, it is seldom that these concepts would be fully analysed at the initial design stages.

In this paper, a case study based on current IES office building is presented as an example to explore an approach, which uses building simulation technology to evaluate a variety of envelope thermal characteristics and low carbon technologies in an integrated manner at the early design stage in order to assist the delivery of a sustainable green office building with a high rating of energy performance.

To be able to achieve these aims, a building energy simulation software IES Virtual Environment (VE) is used to conduct a series of sensitivity analysis on a set of design parameters which have good prospects of influencing the building performance. The parameters include the building orientation, construction, natural ventilation scheme integrated with window type and opening area, shading devices and how they are positioned, daylighting, heating strategy.

The daylighting calculation is conducted by using the Radiance module implemented in the IES VE. Additionally, an overheating analysis is performed to examine the thermal comfort within the whole office building. Finally, the paper discusses how each parameter interacts with one another and influences they have on the building's performance to determine the effectiveness for the optimum design solutions of comfortable and energy efficient buildings.

INTRODUCTION

It is already clear that buildings have a large impact on energy consumption and CO2 emissions. It is estimated that the energy consumption share of buildings in the U.K. is about 46% of the total energy consumed, which results in the CO2 release of approximately 66 million tonnes into the atmosphere (C H Pout et.al 2002). Most of this energy use is for the provision of heating, cooling, lighting and hot water supply. One way of reducing the building energy consumption and thereby CO2 emission is to design comfortable and energy efficient buildings. Decisions made during early stages of a building design process would have substantial impact on the performance of the resulting building. Building design should be no longer merely dominated by aesthetic and functional considerations. Environmental performance based concern needs to be considered at the planning stage, which can help to deliver valuable information on the viability of a design approach.

In the UK, building performance analysis is traditionally performed by the contracted building services engineer. Often the building services engineer will be involved later in the project where many of the decisions over fabric, shape, layout, glazing and orientation have been made and fixed. Therefore by this stage the ability to utilise the most appropriate passive measures may have been heavily restricted and mechanical conditioning systems are needed to maintain occupancy comfort.

By putting analysis tools into the hands of architects and by utilising building analysis from the very first stages in a building's design, designers can make informed decisions over the best strategy and optimise the buildings performance.

With the Energy Performance Certificates (EPC's) now compulsory within the UK, there is much more of a drive for sustainable design and this is becoming more frequently a priority with clients. Building simulation enables designers to identify the key energy loads, test their strategies and compare permutations of a design strategy in order to optimise the design.

Much of a buildings energy consumption can be attributed to ensuring the building is a comfortable environment for its occupants. Heating and cooling is used to maintain comfortable temperatures, fans are used to provide ventilation preventing a build up of moisture, carbon dioxide and odours and lighting is used to ensure a visual comfort. Passive measures can be employed to reduce and even

eliminate some of these loads. By understanding what the predominant building loads are likely to be, designers are better positioned to develop strategies that best utilise passive measures.
Occupancy comfort is affected by a number of environmental factors. In a naturally ventilated building, issues with overheating and Carbon Dioxide concentration can arise where sufficient fresh air cannot be delivered through natural means alone. Overheating can be particularly problematic on buildings designed with large amounts of glazing. While glazing can assist with natural day lighting of a building it can also lead to excessive solar gains. It is therefore important that this is considered and evaluated early in the design process. An early analysis will help to establish the merits each design solution offer and help designers develop an optimum solution that meets all required criteria. Where problems with occupancy comfort can be identified early in the design process, passive or low energy solutions can be developed, tested and implemented into the final design.
In this case study a baseline building design was analysed to better understand predominant loads and performance of the building. Alternative variations intended to improve the buildings performance was then tested. The performance elements analysed include:

- Daylighting
- Energy
- Overheating

While some design changes would improve one performance element they might hinder another. Once a series of analyses are performed, an optimum solution can be selected that delivers the best overall solution for all three criteria.

METHODOLOGY

Computational simulation

The Virtual Environment (VE) v5.9.0.3 was selected to perform this case study as it allowed a single model to be used for all the required aspects of the study.
The daylighting element of the analysis required the facilities to calculate Daylight factors on the working plane. The Radiance link within the VE was utilised for this aspect of the study. In order to account for the local shading effects from surrounding trees and buildings, the Suncast module of the VE combined the Apache Simulation Engine was used. For the overheating analysis the software needed to be able to model bulk air flow within the building in order to establish the effectiveness of the proposed ventilation strategy. The Macroflo module of the VE was used in conjunction with Suncast and the Apache Simulation engine for this element of the study.

Case study building

The building chosen for this case study is the proposed “Venture Building”.
The building is a 3 storey office development located in Glasgow with an approximate office floor area of 2600m^2. The building contains an atrium through the core. The intention of the atrium is to improve natural daylighting within the building and help drive natural ventilation to the offices using buoyancy from the increased temperature in the atrium. Figure 1 shows the baseline layout for the Ground Floor. The first and second floor plans are the same, as illustrated in Figure 2.
The building is shaded by surrounding trees and other buildings. Figure 3 shows the case study building within its context.

Weather data

The weather data used in the case study was the CIBSE Test Reference Year (TRY) and Design Summer Year (DSY) 2005 datasets for Glasgow. The TRY weather file is representative of a typical year and is generated based on recordings over a 20 year period. The TRY file was used in the simulations for energy consumption. The DSY file is a one year sequence selected from the 20 year data to represent a year with a hot summer. This DSY file was used in simulations for overheating analysis in line with guidance in CIBSE Guide J 2002 and Approved Document L2A for Criterion 3 Method b overheating analysis.

Simulation inputs and assumptions

The external constructions used in all the analysis were the same as the proposed baseline building. In some scenarios analysed the internal ceilings had an exposed concrete finish rather than ceiling tiles in order to minimise overheating. The construction U-values used in the case study are shown in Table 1.

When performing the building analysis it was important to use profiles and gain characteristics that were representative of how the office would be used in reality. The NCM activity database was used as a starting point for internal gain assumptions, meanwhile an investigation which involved the analysis of the current occupancy density and equipment gains for different areas was conducted based on the current office use. The profiles used in the analysis were based on the investigation results.
For the energy analysis a minimum fresh air supply of 10 l/person/second was assumed. For the overheating study this was replaced by dynamic ventilation rates governed by the bulk air flow analysis. This was to ensure that heating loads were not artificially low due to insufficient ventilation during the heating season.

An infiltration rate of 0.1 ach was assumed for the building this was based on calculations within CIBSE TM23: 2000 for a Naturally Ventilated office built to a good practice standard.

The heating system used in each of the scenarios was the same as the proposed baseline. As there is no natural gas available on the site, electric resistance heaters are the main heat source. The WC's and showers have extract ventilation only with a specific fan power of 0.8W/l/s.

In some of the scenarios a mixed mode ventilation strategy was used. With this system air was supplied and extracted with heat recovered from the extract air at a sensible efficiency of 60%. This operated when the heat recovered exceeded the energy required to drive the system. In the mixed mode scenarios mechanical ventilation also operated between 0000 and 0800 when the room exceeded 21°C. This operation was used to purge heat stored in the exposed thermal mass and bypasses the heat exchanger. When this system was in operation it ran at a specific fan power of 1.8 W/l/s.

Simulation procedure

The process for this case study started with the architect's concept design layout for the Venture building. The initial concept of the design uses a central atrium to achieve good levels of daylighting. The atrium also serves as a driving force of a naturally ventilated building utilising the stack effect with warm air in the atrium rising through the roof. The aim of this case study is to ensure that the concept design is achieving what it set out to do and secondly optimise the design to improve its overall performance if possible.

The first stage was to build a model of the building and analyse how this baseline design would perform. At this stage reasonable assumptions were made regarding how the different parts of the building would be used. There were three main areas of the buildings performance that we were investigating at this stage.

- Daylight
- Energy
- Overheating

Two further design scenarios where the area of external glazing was increased further to provide deeper and better distributed daylight. When performing this analysis, Radiance was used to calculate the average Daylight Factor on the working plane, the area of working plane with a daylight factor greater than 5% and the area of working plane with a Daylight Factor greater than 2%. This allowed looking at the effect different window placement options had on the daylighting levels.

Following the daylighting studies, an energy analysis was performed comparing the four different glazing options. The simulations included an allowance for dimming control following the formulas set out in the National Calculation Method. Having an increased area of glazing resulted in the lighting energy going down however the heating energy increased due to increased conduction losses and reduced useful internal gains.

After the Energy analysis on the building an overheating study was performed on the building thermal comfort resulting from overheating was analysed. It was identified that under the initial conditions, overheating was an issue in many parts of the building once the glazing levels were increased from the baseline level. Passive solutions were then sought that could resolve the overheating problem without compromising on daylight levels. The passive solutions tested included exposing thermal mass in the ceiling, external shading and night ventilation.

The daylighting studies were then rerun to account for the effect the shading devices had on the daylighting levels. Energy and overheating simulations were then performed additional scenarios to quantify the impact the design changes made.

A total of 16 permutations including the baseline were completed. Table 3 summarises the differences between these design options. Once all of these simulations were completed, the merits of each solution could be compared and the best overall design solution could be chosen.

RESULTS AND DISCUSSION

Daylighting Comparison

Natural daylight is important within a building both for the visual comfort of the occupants and to limit the dependency on artificial lighting. Good Practice Guide 245, Day lighting for Architects gives guidance on daylight factors within buildings. Using these figures as a benchmark an average daylight factor between 2% and 5% was sought for each of the office spaces.

In an analysis of the baseline design, much of the space had an average Daylight factor below 2% and outside of the target range. It is also notable that the Northern office has a Daylight Factor above the target range.

The dullest points of the office were situated on the ground floor and also the Southern parts of the office. Under the baseline design the Southern office areas are segregated from the atrium.

In reviewing the baseline daylighting results we found that many areas of the building were not as well day lit as would have been hoped with the majority of the rooms achieving an average daylight factor less than 2%. The South of the building in particular was poorly daylight. This section of the office was separated from the Atrium by service areas and stair cores. It was hypothesised that re-arranging the floor plan layout would give better access to daylight from the atrium. This change in layout was the first change from Baseline design. The revised floor plans are shown in figures 7 and 8.

Glazing was also rearranged by reducing glazing on the northern elevation and increasing glazing on the other orientations. Table 4 gives a summary of the daylighting results from the additional Scenarios.

To achieve the BREAM Credit for daylighting, dual criteria must be demonstrated. These criteria are:-

- 80% of the net lettable area should have an average daylight factor greater than 2%
- A uniformity ratio of at least 0.4 or a minimum point daylight factor of at least 0.8%

An exemplary credit can also be awarded if 80% of the net lettable floor area can be shown to have a daylight factor greater than 3%.

The daylight factor criteria can be met to an exemplary level in Scenarios 3 and 4 and to a standard level in Scenario 2. The uniformity level criteria however cannot be achieved in any of the scenarios.

Energy Consumption Comparison

Making changes to improve the internal environment can result in a greater energy demand on the building. Understanding the energy usage can help the designer shape further permutations and identify that changes are most likely to reduce energy consumption.

Figures 6 and 7 illustrate the proportional makeup of the Energy Consumption for the baseline building. The equipment usage within the building will be relatively unaffected by the building design so this is excluded in Figure 7.

From these baseline results it can be seen that the dominating loads are lighting and heating. When developing potential design solutions this should be considered.

Fig 11 compares the energy consumption results for each of the scenarios analysed. It can be seen from the results that as the glazing area increases the lighting load drops however the heating load increases by an approximately equal amount. As Solar shading and thermal mass is utilised to minimise overheating the annual heating demand increases in many cases above the consumption of the baseline building. Analysis of the results showed that much of the heat lost from the building was due to ventilation losses. A mixed mode scenario allowed heat to be recovered from the exhaust air while there was a heating demand.

Overheating Comparison

As the building will not have any active cooling systems it is important that internal gains are controlled to mitigate overheating. Two benchmarks targets were used in the assessment of overheating. Those targets are:

- The percentage of occupied hours exceeding a Dry resultant Temperature of 25°C should be below 5% This target is set out in CIBSE Guide J as a means of demonstrating occupancy comfort.
- The percentage of occupied hours exceeding a Dry resultant Temperature of 28°C should be below 1%. This is the Criteria set out in the Approved Document L2A for overheating within Naturally Ventilated Buildings. Under Section 6 there is no requirement to demonstrate overheating however additional credit is given by applying a correction factor to the BER if it can be demonstrated that the building never exceeds 28°C

Figures 9 and 10 show the percentage of zones that fail to meet the overheating benchmarks. The results show that the less than 5% above 25°C is the more onerous target to meet with only one scenario achieving it. Under Section 6 there are no overheating benchmarks required to be met in order to achieve compliance.

From the results above it is relatively easily identify the best solution for a single analysis criteria, it is more difficult to find an overall best case solution. Often a scenario that performs best in one criterion will be the worst in another so a compromise that meets in the middle may be best overall.

It is important that a design that meets an acceptable standard over all the criteria analysed. An integrated performance view can assist with this selection where the merits of each design option can be compared. In Table 5 points have been awarded to each to each of the scenarios. Each Scenario received 1 – 4 points for each criterion depending on the quartile they performed in. A scoring system should be specific to the needs of the project and if one criterion is more important than other a score weighting could be applied to reflect this.

The Case Study performed indicates that out off the scenarios tested, Scenario 3e gives the best overall performance. This scenario performed in the third quartile for Daylighting and the Top Quartile for Overheating and Energy.

It is noted that the three top scoring scenarios include solutions where a mixed mode system was incorporated. Although this system requires additional fan energy in comparison to the other scenarios, this additional energy is less that the amount of heat energy that it can recover that would otherwise be lost in a Naturally Ventilated solution.

The use of this system has also helped the overheating criteria as the system can be used overnight to purge stored heat from the thermal mass. It can be seen that in Scenarios 2e and 3e the Overheating performance is among the best.

Conclusions

The Case study has shown that through changing the design at the early stages while it is most flexible, the overall performance can be improved upon. In this instance it has been shown that both daylighting levels and Energy performance can be improved upon without compromising on thermal comfort.

The study so far has helped to establish an overall solution for the building that performs better than the original concept design. It has also highlighted that there are specific locations within the building that are more prone to problems. Without a study such as this these zones may have remained as per the Baseline design and become uncomfortable spaces to occupy. This study has shown that in particular the Office space North of the core has the worst risk of overheating due to direct solar gains via the atrium. Further scenarios incorporating local shading or reduced glazing to the atrium should also help to optimise this section of the building.

There are other benefits of a mixed mode system that may not be shown in the results. In a Natural Ventilation scenario, openings may cause local discomfort which will discourage occupants from using them. This can result in a build up of stale air and carbon dioxide making the room uncomfortable for its occupants. The use of a mixed mode system can minimise drafts as air is supplied at a warmer condition distributed more evenly. Further CFD studies would allow local comfort to be analysed in greater detail.

Further studies will look into different system options as a means to minimise energy consumption. As natural gas is unavailable the use of ground source heat pumps as a low carbon solution can may allow for substantial energy savings.

Reference

C H Pout, F Mackenzie and R Bettle, Carbon Dioxide Emissions from Nondomestic buildings: 2000 and beyond, BRE Energy Technology Centre , 2002

CIBSE, Weather, Solar and Illuminance Data. Guide J Chartered Institute of Building Services Engineers, London. 2002

CIBSE 2000 TM 23, Testing Buildings for Air Leakage, Technical Memorandum No. 23, Chartered Institute of Building Services Engineers

DETR, Good Practice Guide 245, Desktop guide to daylighting – for architect

ODPM, Approved Document L2A, Conservation of fuel and power in new buildings other than dwellings, 2006, London

Table 1 Construction U-values

Construction Element	U-Value
External Walls	0.25 W/m^{2}K
Roof	0.22 W/m^{2}K
Ground Floor	0.22 W/m^{2}K
Windows	1.8 W/m^{2}K
Rooflights	1.9 W/m^{2}K
Ceiling with Void and Ceiling Tile	1.78 W/m^{2}K
Exposed Concrete Ceiling	3.7 W/m^{2}K
Atrium Internal Windows	1.7 W/m^{2}K
Atrium Internal Partition	0.55 W/m^{2}K

Table 2 Summary of template inputs

Thermal Template	Design Temperature (℃)	Equipment gain	Lighting Gain	Occupancy Density (m^2/person)	Occupants Sensible Gain	Ventilation
Office	21	15 W/m2	12 W/m2	9.09	73.2 W	10 l/person/s
Atrium	18	-	12 W/m2	-	-	Infiltration Only
W/C	18	-	12 W/m2	9.09	70 W	10 ach
Shower	18	-	12 W/m2	1 person	70 W	10 ach

Table 3 Summary of Analysis Permutations

Scenario	Percentage of Facade Glazed	Exposed Thermal Mass	External Shading	Mixed Mode (Heat Recovery / Night Purge)
Baseline	19.6 %			
Scenario 2a	26.8%			
Scenario 2b	26.8%	X		
Scenario 2c	26.8%		X	
Scenario 2d	26.8%	X	X	
Scenario 2e	26.8%	X		X
Scenario 3a	32.1 %			
Scenario 3b	32.1 %	X		
Scenario 3c	32.1 %		X	
Scenario 3d	32.1 %	X	X	
Scenario 3e	32.1 %	X		X
Scenario 4a	40%			
Scenario 4b	40%	X		
Scenario 4c	40%		X	
Scenario 4d	40%	X	X	
Scenario 4e	40%	X		X

Table 4 Summary of Daylighting Results

Scenario	Percentage of Facade Glazed	Average DF	% Area > DF 5%	% Area > DF 2%	% Area > DF 1%
Baseline	19.6 %	2.5	17.51%	39.53%	55.99%
Scenario 2 a, b & e	26.8%	3.1	22.32%	47.79%	67.51%
Scenario 2 c & d	26.8%	2.85	19.07%	43.73%	61.52%
Scenario 3 a, b & e	32.1%	3.6	23.57%	49.96%	68.74%
Scenario 3 c & d	32.1%	3.4	22%	49.32%	68.87%
Scenario 4 a, b & e	40%	4.1	30.16%	59.87%	82.22%
Scenario 4 c & d	40%	3.9	29%		

Table 5 Scenario Performance Table

Scenario	Daylighting Criteria	Overheating Criteria	Energy Criteria	Total Score
Baseline	1	4	3	8
Scenario 2a	2	2	3	7
Scenario 2b	2	3	1	6
Scenario 2c	2	3	2	7
Scenario 2d	2	4	1	7
Scenario 2e	2	4	4	10
Scenario 3a	3	1	3	7
Scenario 3b	3	3	1	7
Scenario 3c	3	2	3	8
Scenario 3d	3	3	2	8
Scenario 3e	**3**	**4**	**4**	**11**
Scenario 4a	4	1	4	9
Scenario 4b	4	1	1	6
Scenario 4c	4	1	2	7
Scenario 4d	4	2	1	7
Scenario 4e	4	2	4	10

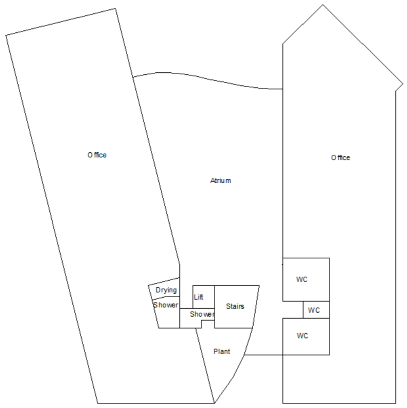

Fig.1 Baseline Design Ground Floor Plan

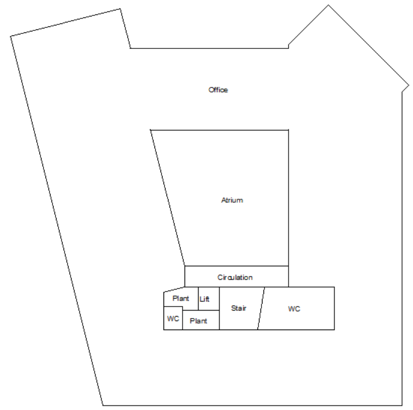

Fig.2 Baseline Design First Floor Plan

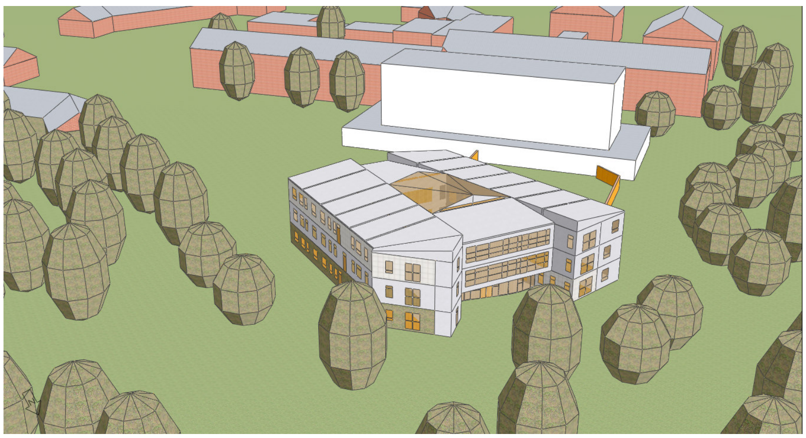

Fig.3 Axonometric view of proposed building

Fig.4 Updated Design Ground Floor Plan

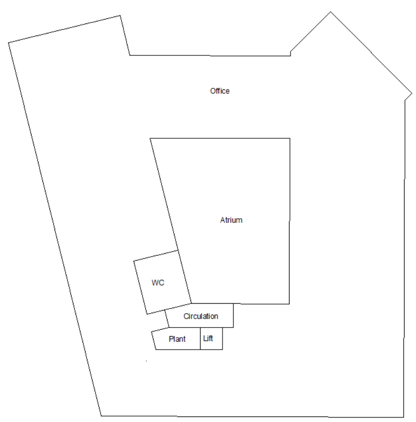

Fig.5 Updated Design First Floor Plan

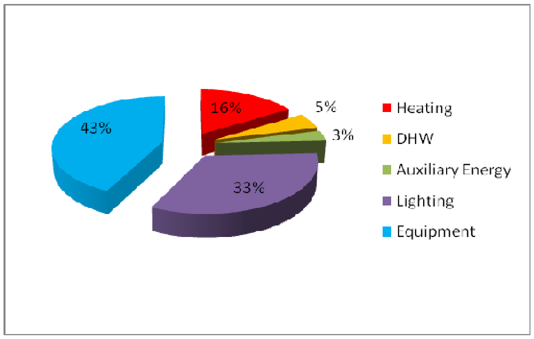

Fig.6 Baseline Energy Breakdown inc. Equipment

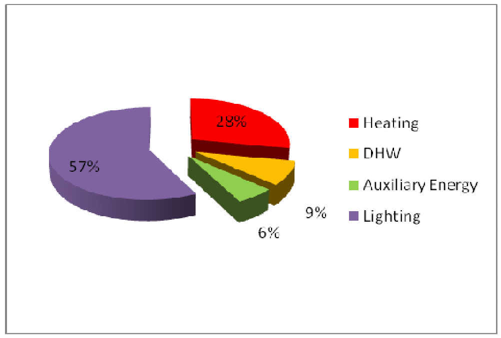

Fig.7 Baseline Energy Breakdown

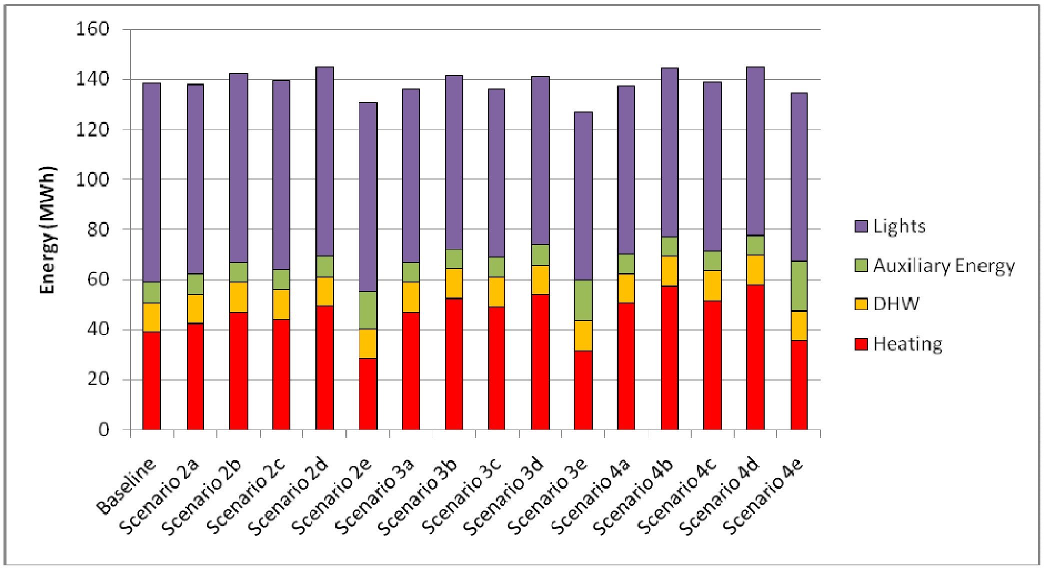

Fig.8 Energy Comparison Chart

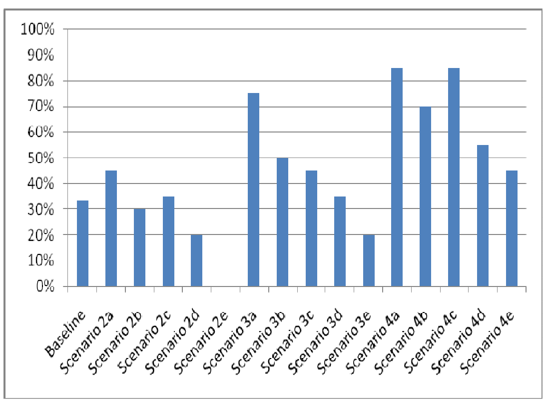

Fig 9 Percentage of office zones that fail 5% above 25℃ DRT Criteria

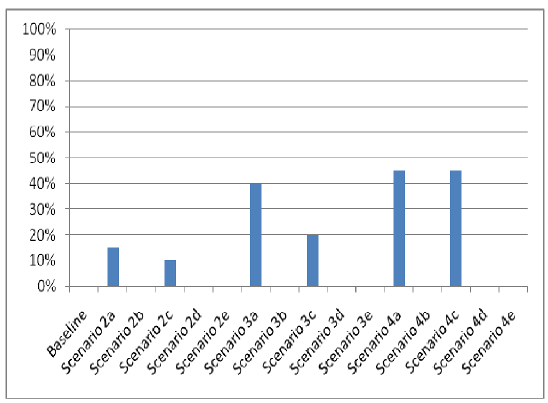

Fig 10 Percentage of office zones that fail 1% above 28℃ DRT Criteria