Considering the risk factors of reliability, maintainability and product life cycle in a Zero Carbon commercial building

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Abstract

The increased mechanisation of buildings towards the goal of achieving Zero Carbon can be expected to yield certain consequences. This paper was required to investigate the risk associated with the heavy technological load in a building designed to meet the UK 2016 target of Zero Carbon. There is significant motivation for such considerations as the creation of a Zero Carbon building can not only expected to require significantly more investment than a traditional alternative, but the long term financial and environmental benefits will be made redundant if the technologies used fail to function correctly. The case study building was taken from a study into strategies for achieving Zero Carbon performance in commercial buildings in the North West of England. Two solutions from that study were considered in terms of the reliability, maintainability and life cycle of their key sustainability related systems. The paper focuses on comparing the difference in maintenance requirements and anticipated failures between a passive design strategy and a mechanical alternative. This was carried out through building simulations that calculated both the anticipated emissions for each of the strategies and the risk of overheating within the offices themselves. Consideration was given to the potential consequences of failure, including loss of desired user environment, financial and environmental repercussions. The study demonstrated that there is a relatively high risk of additional maintenance issues and increase in components to any reliability analysis when striving for zero carbon performance. It also demonstrated that some of the more passive measures such as the increase in building fabric performance, could increase the severity of the repercussions of failure in the case of a loss of cooling. The paper reflects the need for reliability, maintainability and product life cycle to be considered a major constraint when working towards

performance improvement in buildings and in the allocation of renewable energy generation and that the approach of the building designers and their relationship with a completed building may have to change to accommodate this fully.

Keywords: reliability, maintainability, overheating, zero carbon, commercial

1. Introduction

The need to reduce the energy demand of buildings in order to lower their carbon footprint has become a key issue in modern building design. One benchmark which has received significant interest is that of a building which performs at Zero Carbon in operation. The UK government has set the target in the Part L 2010 Consultation (2009) that all new commercial buildings will achieve this level of performance by 2019 (p.6(1.9)). There are several definitions for this term however for the purpose of this paper the definition employed was that found in CIBSE Guide L (2007). It states that Zero Carbon performance in a building is achieved by a net emission of zero over a calendar year. In practice this means that all energy demand is either met via carbon neutral generation or offset by additional carbon neutral generation to an equal value of the demand (p.9).

In order to achieve this level of performance, building design strategy has been modified to place an increasing emphasis on demand reduction and on site micro-generation. In early examples of buildings which attempted to attain Zero Carbon status the methods used were often non-cohesive and employed untested or uncomplimentary technologies. Clarke et al (2008) asserted that many such attempts were found to be performing at standards well below those laid out in the original designs and simulation results. These findings are also supported by Hinnells (2008) and Glass et al (2008). As such there was perceived to be a need for a more rational and structured set of design parameters that would allow buildings to be designed to favour the reduction of demand and, if necessary, the incorporation of micro-generation in such a way as to succeed in practice. This need for a rational strategy ties the research to the demands of industry, meaning that the numerical definition of Zero Carbon performance must also come from a practical source. In the United Kingdom the emissions are assessed using the National Calculation Method (NCM) as stated in the Approved Document L2A (2006). The building design is modeled and the carbon consumption measured as the Building Emissions Rate (BER) which is then compared to a Target Emissions Rate (TER) which is found by the generation of a notional building of the same dimensions to the 2002 Building Regulations and modified by improvement factors (p.14(23)).

$$TER = C_{notional} \times (1 - \text{improvement factor}) \times (1 - \text{LZC benchmark})$$

Compliance when: BER<TER

Units of BER/TER mass of CO_2 per year per square metre useful floor space ($kg/m^2/yr$) from L2A (2006) (p.14(23)).

A second factor that is of increasing relevance is that of reliability, maintainability and product life cycles. A rational building designer must not only consider the new technologies and design strategies available to improve performance but also the repercussions. The failures observed by Clarke et al (2008) can not only be attributed to poor design methodology. The increased mechanisation of buildings and the use of generation technologies attach a new level of risk to the performance of the building while in use. Each of these new technologies used offers new points of failure and this study was conducted to assess the potential repercussions of applying a zero carbon strategy to a typical office building. The areas of interest were the implications of an increased reliance on the control of internal temperatures via mechanical means rather than by passive design choices (a byproduct of highly insulated and sealed buildings), the risks associated with micro-generation and whether these factors should influence the targets of the low impact building designer and the decision to strive for zero carbon performance.

The study employs a case study building generated within the IES Virtual Environment software which was used to explore the design choices stated above. This was done through a combination of Building Regulations compliance tests and overheating tests. The results of the testing are then examined in order to consider their impact on the reliability and maintenance demands of the building as well as the repercussions of failure.

2. Methodology

2.1 Case study

For the purpose of this study a theoretical building was created that matched the requirements of the strategies to be tested. A simple two storey shallow plan office block was selected so as to allow both a passive and mechanical ventilation strategy to be explored. The building was given a south facing orientation so as to make use of daylight for both light and heating. This method has been described as one of the few proven methods for reducing heating and lighting loads within a low impact building as observed by Andrews et al (2009). Additionally, as noted by Hinnells (2008), it is a factor which the building services engineer (who is often charged with reducing energy demand) can have little control over. The need to control this passive input is a major factor in determining whether the building will require cooling or shading, with the former being another mechanical system which must be considered and the latter a passive design choice which will not. The geometry for this model was derived from the DEFRA’s Lion House building which Jones (2009) describes as carbon neutral in operation over a year (which meets the definition of Zero Carbon within this study) through a similar design methodology of demand reduction to that employed within this study. In order to achieve Zero Carbon performance the DEFRA building used both Photovoltaic arrays and micro wind turbines to offset that demand which could not be removed. With this building being a market leader in the UK in terms of performance it was considered appropriate to use this selection of renewable energy sources as the offsetting strategy for this case study. This decision offers two points of interest. If the final performance for either strategy is approaching zero carbon then the methodology itself will be demonstrated to be successful within the capacity of what is considered currently attainable. Additionally, it offers a clear example of the type and size of renewable energy sources required when considering the additional risk that they provide as further technologies that can potentially fail.

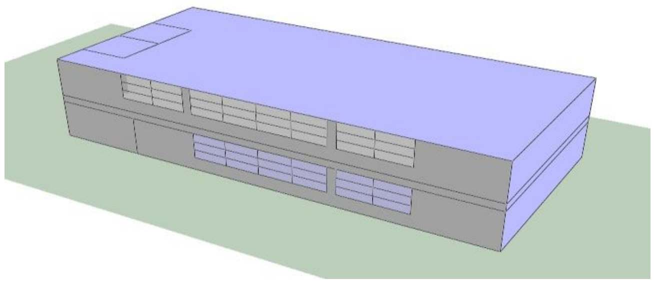

Figure 1: Basic geometry of case study for both naturally and mechanically ventilated strategies.

The image depicts the geometry employed in the case study, with the key features being a ground floor office of 278 m^2 and a first floor office of 294 m^2. Each floor is 2.7m in height with a building depth of 6m and a length of 26m. High thermal mass insulation was used due to the regular hours that the office would be occupied. These hours were assumed to be 0800 – 1800 with a one hour lead in time for heating and cooling (if in place). The building was located in the North West of England due to its part in a larger study within the area. As such the climate was represented by the Test Reference Year (TRY) for Manchester. The key parameters of the building design are included for comparison with the subsequent performance improvement measures.

Table 1: Key Parameters for the Basic Office designs with natural and mechanical ventilation strategies.

Parameters	Wall U-value W/ m^2.K	Floor U-value W/ m^2.K	Roof U-value W/ m^2.K	Glazing U-value W/ m^2.K	Heating Eff. %

Strategy					
Nat. Vent.	0.28	0.16	0.22	2.0	89
Mech. Vent.	0.28	0.16	0.22	2.0	89
Parameters Strategy	Cooling	Specific Fan Power W/(l/s)	Fuel	Air permeability @50Pa m^3 /(h. m^2)	
Nat. Vent.	No	-	Nat. Gas	5	
Mech. Vent.	Electric	2	Nat. Gas	5	

The designs within this study were assessed using the IES Virtual Environment software. This suite of building design tools offers both dynamic simulation of building performance and compliance checking using the NCM in conjunction with both dynamic simulation and empirical assessment. For the purposes of the study the dynamic simulation was employed for both the checking of regulation compliance (and as such the calculation of CO2 generation) and for the overheating tests that are integral to confirming that a building offers the required comfort level for its occupants.

The testing of the basic models revealed that both designs were compliant to L2A 2006 Building Regulations as they produced Building Emission Rates below that of the calculated Target Emission Rates. When the overheating tests were ran using the Design Summer Year (DSY) climate file (which represents a hot summer) it was found that neither mechanical ventilation nor a window opening strategy could provide sufficient cooling. CIBSE Guide A (2006) recommends that no office should be used if it experiences more than 30 hours of occupied time at over 28°C (p.1-11). As such, modifications were made to both the naturally ventilated and mechanically ventilated designs. The naturally ventilated option was provided with shading over the south facing windows in keeping with its passive design ethos. The mechanical ventilation was supplemented by simple cooling. Each design choice has its own perceived advantage, with the passive option still requiring only a heating unit for winter temperature control where the mechanical option will have a lower winter heating demand balanced by a summer cooling energy demand.

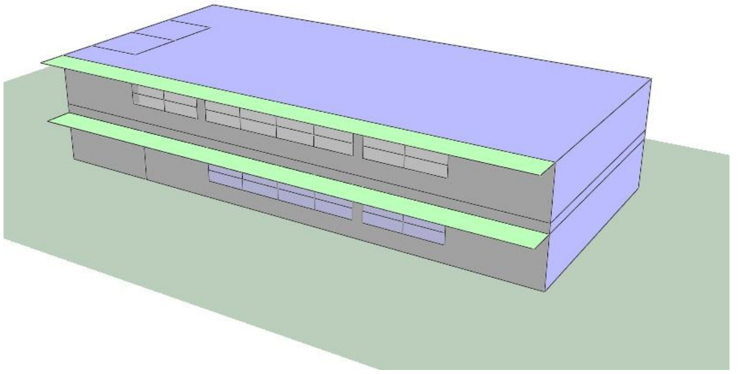

Figure 2: Modified geometry of natural ventilation solution incorporating 2m deep shading on southern windows.

2.2 Zero carbon design methodology

The study targeted the testing of the impact on reliability, maintainability and product life cycle of design improvements aimed at reducing the CO2 emissions of a building. The particular methodology used was taken from an ongoing study and focuses on establishing a maximum demand reduction before employing micro-generation. The justification for this method is itself tied to the risks associated with maintenance factors. It is also to examine the difference between the effects of improving standard design practices through better quality materials, building practices and modeling techniques and the effects of increasing the technological complexity of buildings themselves in order to offer greater control. Combined Heat-Power (CH-P) is a major driver behind the latter. The use of CH-P or even combined cooling, heat and power (CCH-P) requires a level of control over the passive inputs within a building and careful system balancing. If achieved, however, there is evidence to suggest that CCH-P, also known as tri-generation, can be a significant technology for the improvement of building performance as cited by Clarke et al (2008) and Hinnells (2008).

If it is anticipated that a building offering a spread load of heating and cooling is more suited to a CCH-P system than a natural ventilated building with no summer cooling load and (due to the risk of human error with window opening) a significantly higher winter heating load then whether the overall performance improvement is greater than the simpler building with a biogas boiler should b established. Exploring this question fits with the investigation of reliability as the failure of a more complex and less familiar system is a significant risk if the building is provided with traditional maintenance as observed by Glass et al (2008).

The naturally ventilated strategy includes parameters for window opening on the southern face which remains constant throughout all design iterations. It assumes that the windows will be opened when the internal temperature reaches 23°C and subsequently closed once the office temperatures are reduced to 19°C.

Table2: Key Parameters for the Improved Office designs with natural ventilation strategy.

Parameter Design Stage	Wall U-value W/ m^2.K	Floor U-value W/ m^2.K	Roof U-value W/ m^2.K	Glazing U-value W/ m^2.K
Lowered U-values	0.25	0.19	0.13	1.5
Extreme U-values	0.16	0.1	0.1	1.5
Reduced permeability	0.16	0.1	0.1	1.5
Biogas	0.16	0.1	0.1	1.5
CCH-P	0.16	0.1	0.1	1.5
Renewables	0.16	0.1	0.1	1.5
Parameter Design Stage	Air permeability @50Pa m^3 /(h. m^2)	Fuel Type	CCH-P	Wind Turbines and Photovoltaic Panels
Lowered U-values	5	Natural Gas	No	No
Extreme U-values	5	Natural Gas	No	No
Reduced permeability	4	Natural Gas	No	No
Biogas	4	Biogas	No	No
CCH-P	4	Biogas	Yes	No
Renewables	4	Biogas	Yes	Yes

The mechanical ventilation strategy employed no window opening so as to make maximum use of the control offered by a complete HVAC system. An additional performance improvement that was included in this strategy was that of smart metering and active controls over the internal conditions within the building. This was considered an example of an unnecessary technology in the passive focussed natural ventilation strategy. In the mechanical ventilation strategy however, it can potentially offer a more balanced heating and cooling profile that will reduce the CO2 generated by the HVAC system.

The renewable energy strategy found in both design strategies uses the same parameters as the Lion House building as discussed above. Jones (2009) states that three 15kW wind turbines and 106 m2 of photovoltaic panels were employed by this building to offset demand and equivalent systems have been included in the relevant simulations. The CCH-P system has been set to meet the demands of the heating and cooling loads rather than the electrical power demands where it provides an offsetting factor.

Table3: Key Parameters for the Improved Office designs with mechanical ventilation strategy.

Parameter Design Stage	Wall U-value W/ m^2.K	Floor U-value W/ m^2.K	Roof U-value W/ m^2.K	Glazing U-value W/ m^2.K	Air perm. @50Pa m^3 /(h. m^2)
Lowered U-values	0.25	0.19	0.13	1.5	5
Extreme U-values	0.16	0.1	0.1	1.5	5
Reduced permeability	0.16	0.1	0.1	1.5	4
Smart Metering and Controls	0.16	0.1	0.1	1.5	4
Biogas	0.16	0.1	0.1	1.5	4
CCH-P	0.16	0.1	0.1	1.5	4
Renewables	0.16	0.1	0.1	1.5	4
Parameter Design Stage	Metering and Controls	Fuel Type	CCH-P	Wind Turbines and Photovoltaic Panels	
Lowered U-values	No	Natural Gas	No	No	
Extreme U-values	No	Natural Gas	No	No	
Reduced permeability	No	Natural Gas	No	No	
Smart Metering and Controls	Yes	Natural Gas	No	No	
Biogas	Yes	Biogas	No	No	
CCH-P	Yes	Biogas	Yes	No	
Renewables	Yes	Biogas	Yes	Yes	

2.3 Testing performance

The performance of the building designs were assessed by the comparison of their respective building emissions rates at each stage of design and the consideration of the reliance that the designs had on each of the technologies. The risk of these technologies as points of failure were then considered and the examination of the consequences of key failures considered. This consideration included overheating tests of the mechanical ventilation strategy in the case of failure of the cooling system as no window opening was offered as part of the cooling and ventilation strategy. For comparison overheating tests were also conducted for the functioning naturally ventilated offices.

The motivation behind staggering the design stages rather than applying all anticipated changes has benefits for both the building designer and those considering reliability, maintainability and product lifecycle factors. For the former it prevents assumptions of significant performance improvement for a specific design due to past successes and prevents the inclusion of redundant or financially inappropriate design measures. For those considering the latter it offers the opportunity to consider the implications of system failures at key stages. The overheating tests carried out in parallel with each compliance check are of interest here as they represent the performance of the building should further system improvements fail.

3. Results

3.1 Natural ventilation method

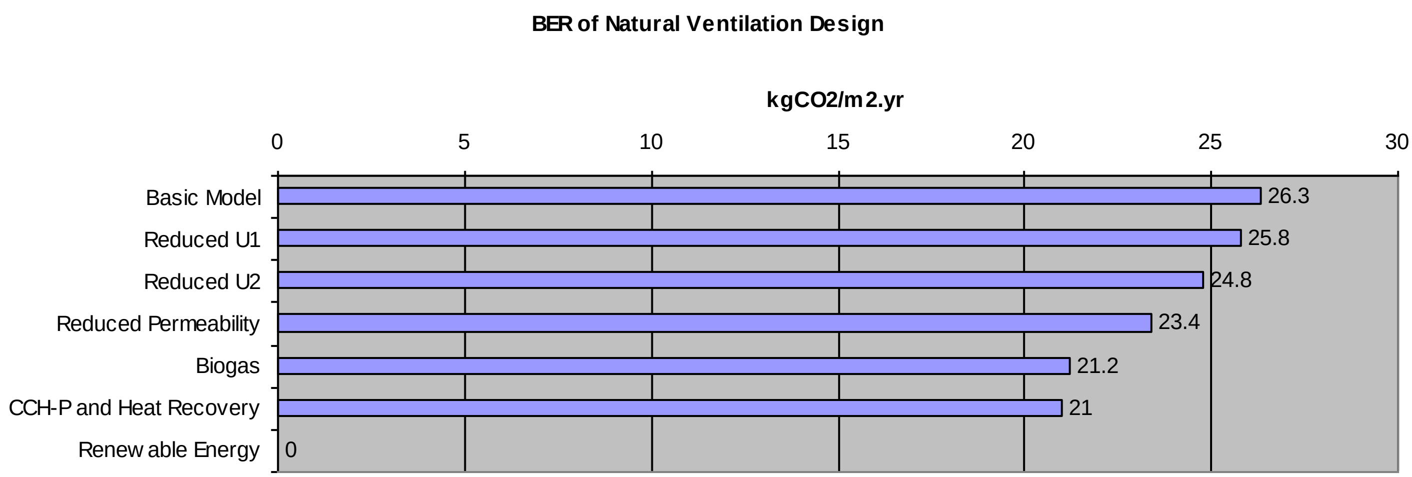

Figure 3: Building Emissions Rates of design stages of the Natural Ventilation design strategy

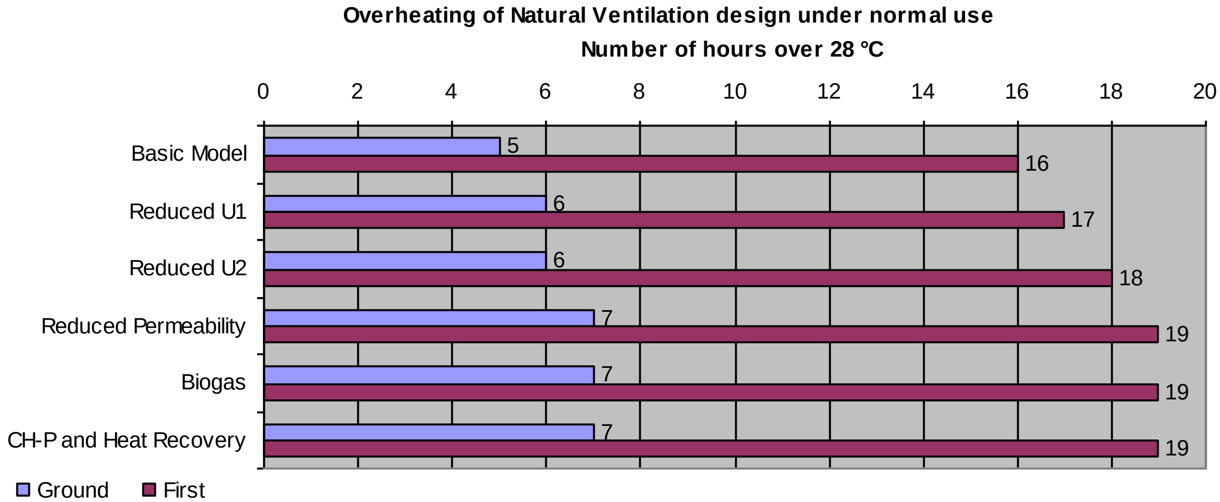

Figure 4: Overheating test for Natural Ventilation design strategy under normal use: number of hours over 28°C during occupied office hours

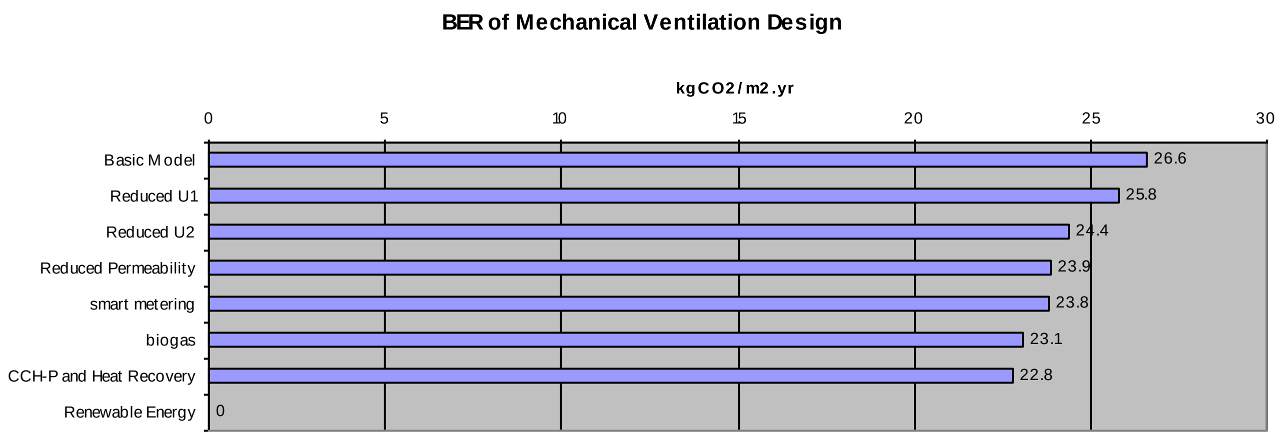

Figure 5: Building Emissions Rates of design stages of the Mechanical Ventilation design strategy

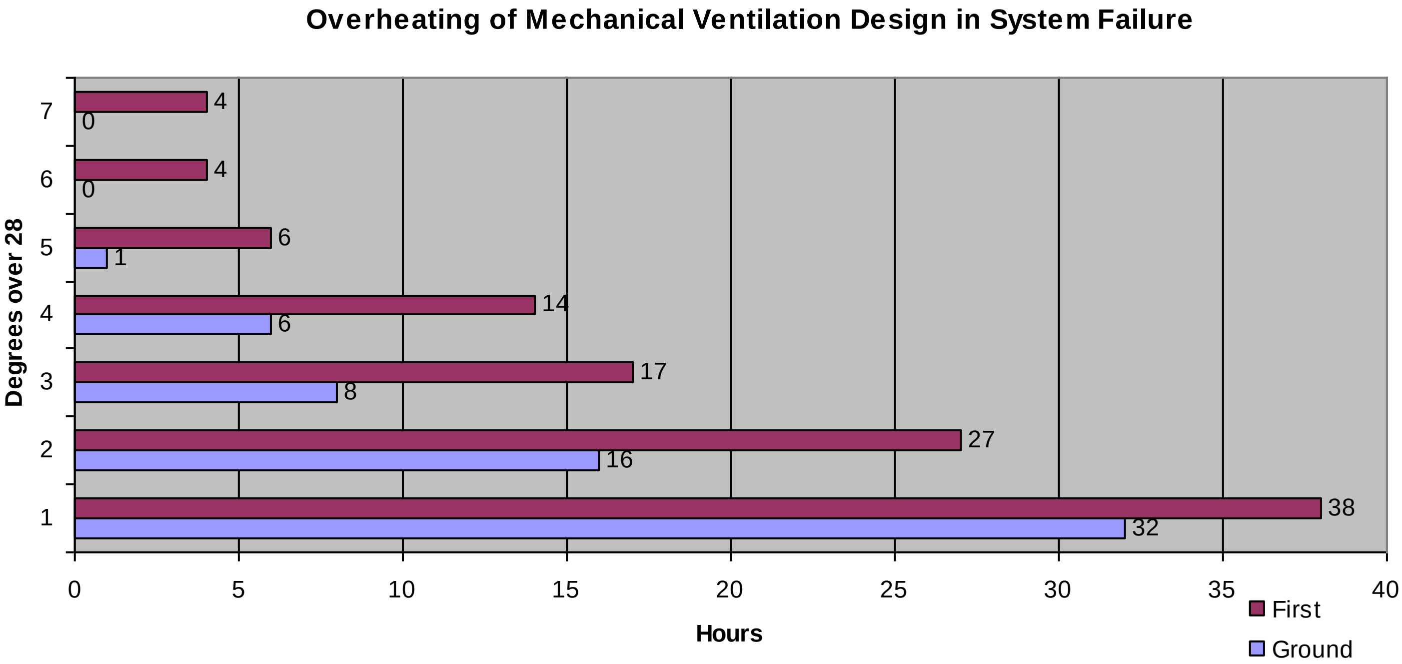

Figure 6: Overheating of final design stage of the Mechanical Ventilation design strategy: number of hours at each degree over 28°C to a maximum of 35°C

4. Discussion

4.1 Comparison of BER for design strategies

The Building Emissions Rates for the mechanical ventilation strategy does not demonstrate an improvement in the performance of the building over those of the natural ventilation strategy. In fact the performance figures suggest that a natural ventilation strategy will offer 1.8 kgCO2/m2/yr less emissions than the mechanical strategy. It should be observed, however that there are risks associated with using the natural ventilation strategy. Such a strategy has an inflexible internal condition that is built around the assumption that cooling will never be needed. Should this prove not to be the case due to unanticipated weather conditions or climate change then there may be the need for aftermarket cooling installation which has the potential to be more expensive and less integrated (and therefore efficient) than a system included in the original design. Additionally, the calculations do not account for the risk of human error and the leaving of a window open, which can have significant effects on the emissions of a building if perpetrated regularly. It can also be observed that despite the goal of balancing the demand over the year as heating and cooling, rather than heating alone, neither strategy gained a significant benefit from the inclusion of a CCH-P system in direct opposition to the suggestion put forward by Clarke et al (2008) and Hinnells (2008). It may be that a greater overall load is required to make use of such a system and make it worth the undoubted risk it poses to building performance through its complexity and requirement of expert maintenance should it fail.

4.2 Overheating analysis

The overheating analysis had its own role in the consideration of each of the design strategies. In the consideration of the natural strategy it was used to confirm that the passive design did not impact on the users as there was perceived to be some risk of overheating as the materials were improved. It can be seen in figure 4 that this is not the case and that even at its highest the overheating for both the ground floor and first floor offices is within the limit of 30 hours over 28°C per year. For the consideration of the mechanical ventilation design it was used to examine what was determined to be the greatest risk of failure and key difference between the two strategies; the loss of cooling. As can be seen in figure 6 there is significant overheating with temperatures reaching as high as 35°C in the first floor office as well as three times the total number of acceptable hours over 28°C per year. This suggests that the failure of this design measure poses a significant problem to the building users and the subsequent need for auxiliary cooling measures poses a risk to the carbon emissions performance of the building.

4.3 Reliance on renewable energy technologies

The two strategies both rely on renewable energy systems to offset four times the CO2 that has been removed through energy reduction strategies and low carbon fuels. This reliance is a major reliability and maintainability issue as these systems require specialist expertise to maintain and the impact of failure will be significant for both the cost of energy provision and the failure to meet targeted emissions rates.

5. Conclusions

The findings of these tests demonstrate the need for the consideration of reliability, maintainability and product life cycle when designing zero carbon commercial buildings. In this simple case study there is the option to focus on passive design choices; however in larger, deep plan buildings this is not available. As has been demonstrated in the testing, system balancing and the use of low carbon fuel can offer only so much performance improvement while increasing both the risk of failure and the severity of the repercussions. This leaves the Zero Carbon building designer relying on renewable energy sources in order to bridge the gap between low impact and truly carbon neutral. This is not an acceptable situation under current building practices as small scale renewable energy requires specialist maintenance and adds an upfront cost premium to the building. Added to these issues are the questions as to the level of understanding of the long term reliability and output of these technologies and their ability to perform to the expectations on which energy assessments are based.

The study demonstrates the need to focus on a change in the way building design is approached, where rather than building to the simplest or most short term cost effective standard, efforts must be made to get the best value from the emerging technologies in order to offset the repercussions of any failures. Additionally, the industry itself needs to look towards a change in its approach towards the provision of solutions and their maintenance. This will allow the successful building designs to continue to do their job of reducing emissions and prevent the shift in building design impacting on the end user.

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