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Tuohy, Paul (2009) *Regulations and robust low-carbon buildings.* Building Research and Information, 37 (4). pp. 433-445. ISSN 0961-3218

Regulations and Robust Low Carbon Buildings – Draft version.

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Keywords
Air-conditioning, Cooling, Natural ventilation, Building design, Simulation, Overheating.

Abstract

Building regulations and associated calculation methods have been rapidly evolving, driven in Europe by the EU Energy Performance of Buildings Directive.

As an example the current UK regulations are reviewed in relation to buildings that are naturally ventilated, mechanically ventilated or mechanically ventilated and cooled.

The UK regulatory energy and carbon calculations are analyzed for a standard office design with typical, best practice and advanced building fabric and systems applied and observations made on how the regulations may influence future adoption of mechanical cooling.

The criteria and calculations for demonstrating avoidance of excessive temperatures in buildings with no mechanical cooling are also explored.

It is shown that current regulatory methods can be subjective and limited in scope, for example they do not include adaptive comfort criteria or uncertainties in parameters such as occupant behaviour, climate, internal gains from equipment etc.

A design methodology is proposed that addresses these issues and provides a capability parameter to quantify robustness. This capability parameter would allow comparison of design options and provide an indication to building users of the limitations to a buildings use beyond which mitigating action would have to be taken for performance to be maintained.

1. Introduction

Naturally ventilated or hybrid ventilated buildings are common. The importance of good understanding and good practice in design and operation of these buildings is being heightened by increased local outdoor temperatures and increased focus on building energy use and associated carbon emissions. There is increased use of cooling in new buildings and it is common for existing buildings to have cooling added as a retrofit.

The building regulations across Europe have recently been updated in to align with the requirements of the EU Energy Performance of Buildings Directive (EPBD) (EU, 2002) including the requirement for Energy Performance Certificates (EPC). In the UK the carbon emissions calculation method for domestic building regulation compliance and EPC rating is SAP2005 (BRE, 2008) while for non domestic buildings the national calculation method (NCM) (BRE, 2008a) based on the monthly method of CEN standard EN13790 has been implemented in the Simplified Building

Energy Model (SBEM) which is intended to be used for the majority of buildings while dynamic simulation tools are to be used for more complex buildings.

In part due to the poor performance of existing (including recently constructed) buildings during recent warm summers and also to avoid unnecessary energy use for air-conditioning, the UK regulations now include the requirement to demonstrate that buildings without cooling will maintain comfortable temperatures during warm periods. The guidelines for how the building design is shown to comply with this requirement have also been updated.

In this paper we first explore how natural and mechanical ventilation and mechanical cooling are treated in the UK regulations and regulatory calculation methods and assess how the regulations may influence the adoption of various building service strategies including the use of mechanical cooling. We then highlight some issues with the current methods and propose a revised approach.

2. The impact of regulations on the adoption of mechanical cooling.

In order to explore the likely impact of the recently updated regulations, guidelines and methodologies on future building service strategies, the ease of compliance to the UK building regulation maximum carbon emissions criteria and the associated EPC rating was analysed for naturally ventilated, mechanically ventilated and mechanically ventilated and cooled versions of a common type of office building. Compliance to the regulatory criteria for avoidance of excessive temperatures was also analysed for the cases without mechanical cooling.

The office building used was a typical 2 storey office design situated in Scotland (figure 1). This typical office type has previously been used to assess the possible impact of future improvements in carbon emissions in regulations at the request of the Scottish Governments Building Standards division and is described in more detail elsewhere (Turner and Townsend, 2008)

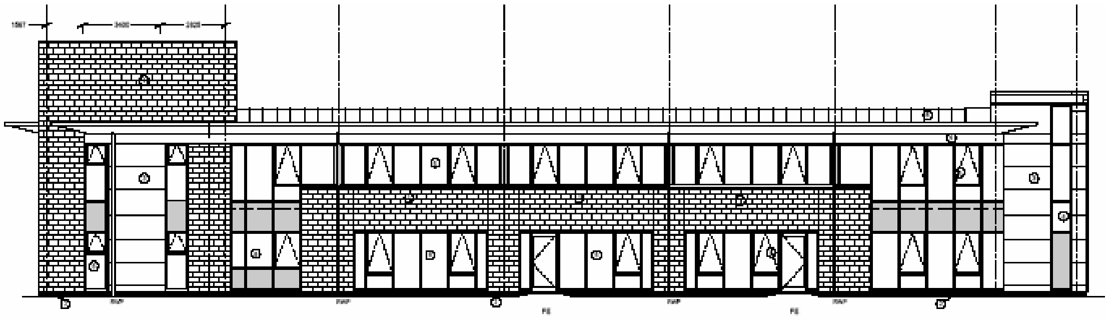

Fig.1. *The example building*

2.1 Energy and carbon performance for EPC and national building standards.

The UK's regulatory calculation tool SBEM was used to explore predictions of carbon and energy performance for naturally ventilated, mechanically ventilated and mechanically ventilated plus cooled building service strategies for the example office building. The performance was calculated for a range of building fabric and system options and then inter-comparisons made, the results were also compared against building standards and EPC rating criteria. The selection of systems and their performance parameters while somewhat subjective and not exhaustive is designed to provide insight into the representation of current practice and potential future options in the regulatory calculations.

Two levels of building insulation performance were evaluated. A ‘2007 typical’ level was defined to represent current common practice (meeting current building regulations with a wall U-value of 0.25 $W/m^2.K$) and also an ‘Advanced’ fabric level representing probable future standards (wall U-value of 0.13 $W/m^2.K$). The building fabric specifications are detailed further in table X. The Advanced fabric used here is similar to that already established in dwellings through the EU Passive House standard with many examples constructed across Europe.

Many different building services strategies can be followed, each utilising multiple systems and components which can be selected with various levels of performance. The approach taken here was to define three distinct building service strategies labelled ‘Natural Ventilation’ (NV), ‘Mechanical Ventilation’ (MV) and ‘Heating, Ventilation and Cooling’ (HVAC).

For each of these building services strategies, three levels of system and component performance were then set representing ‘2007 typical’, ‘2008 best practice’ and ‘Advanced’ performance. The 2007 typical performance level represents standard practice, meeting the current regulation requirements with acceptable quality and reasonable cost. The 2008 best practice was selected to represent the best performance systems currently readily available which would be expected to become standard practice and lower cost in future as regulations drive increased adoption. The Advanced performance represents achievable but not yet commonly available system performances which were judged to represent probable future performance. The details of systems and parameters for each service strategy are given in table Y.

The heating is through standard gas boilers in the 2007 typical cases but through heat pump technology in the improved performance cases. Ground source heat pumps are specified for NV and MV heating but a reversible air source system is assumed to supply both heating and cooling for the HVAC case. Co-efficient of performance (COP) for ground source heating was based on Government publications for currently available systems (EST, 2004) (DOE, 2001) and the EU GROUNDHIT project goal of COP >5.5. The heating efficiency (COP) values and the cooling seasonal energy efficiency rates (SEER) for the HVAC case were based on the Eurovent database (Eurovent, 2008) and manufacturers’ data (Ord, 2008).

Where there is mechanical ventilation it is specified to include heat recovery with 65% efficiency for the 2007 typical cases and 75% for the improved performance cases based on available data (CIBSE, 2001). Fan specific powers were set based on limits set in regulations (DCLG, 2006) and industry data. Duct leakages and AHU leakages for HVAC are set based on the levels specified in SBEM which are derived from CEN standards EN13779 and EN 15242 (DCLG, 2008).

Several HVAC options were explored including single duct variable air volume (VAV), variable refrigerant flow (VRF), displacement ventilation (DIS) and VRF in mixed mode (MM) but in the initial analysis the 2007 typical HVAC was selected as a VAV system, the 2008 best practice and Advanced systems were selected as VRF.

The lighting and lighting control parameter levels are similarly set based on current good practice, the best currently available or projected future potential. The SBEM lighting inputs are the installed main lighting circuit $Watts/m^2$, the lighting control type, and the display lighting type. The main circuit $Watts/m^2$ is dependent on the lamp performance (lumens/W) adjusted by the luminaire performance, the room characteristics (shape, brightness of walls etc.) and the maintenance factor (i.e. how well performance of lights and luminaries is maintained). The circuit Watts/m2 levels for 2007 typical are based on standard T8 fluorescent lamps delivering 70 lumens per watt and the minimum luminaire, maintenance and room factors for current good practice (Loe, 2003), for 2008 best practice the lamps are assumed to produce 100 lumens per watt (best currently available T5 or T8 fluorescent lamps) and the luminaries are improved to the best available, for the Advanced case the lamps are assumed to produce 200 lumens per watt which is predicted to be possible in future from either advances in fluorescent technology (DOE, 2008) or through use of LED lighting (Foster, 2005). The performance levels for controls and display lighting circuits were chosen using similar criteria.

SBEM was then used to calculate the carbon and energy performance for combinations of the fabric and system performance levels for each of the service strategies. Table Z gives a key to the labels used in the figures and Figures 2, 3 and 4 give some selected results for the NV, MV and HVAC building strategies respectively.

There are variations in regulations between the different countries of the UK, in this case we follow the Scottish conventions. The current Scottish building regulation limits are indicated on the graphs as well as the Scottish EPC rating bands (Scottish Building Standards, 2007). The Scottish Governments approach to EPC ratings is that they are based on the absolute $kgCO_2/m^2$ per year as predicted by the calculation tool, buildings with calculated emissions less that 15 $kgCO_2/m^2$ per year achieve an A rating, less than 30 $kgCO_2/m^2$ per year achieve a B rating and so on.

In terms of ratings and calculated carbon emissions for the 2007 typical fabric and systems cases (07typ), the MV building has the lowest calculated CO2 emissions while the HVAC building has the highest. The MV and NV buildings achieve C ratings while the HVAC building achieves a D. The MV performs better than the NV case due to reduced heating loads and carbon emissions associated with the ventilation system which includes heat recovery.

The regulation limit for HVAC is significantly higher than the limit for MV and NV service options. This higher limit may reflect historical surveys in which HVAC offices have higher energy use than NV offices (The Carbon Trust, 2000). Compared to these regulation limits the HVAC and MV cases both pass while the NV case is marginal.

Ratings and calculated carbon emissions for the 2007 typical fabric with 2008 best practice systems cases (08bp) for the three building service strategies is very similar with NV, MV and HVAC all achieving a B rating. This result is not consistent with the historical survey data mentioned above.

To explore further the calculated performance of the HVAC buildings, analysis was performed to compare VAV, VRF, DIS and VRF MM systems (figure 5). This showed that all of the 2007 typical fabric with 2008 best practice systems achieved a B rating but that the VRF and DIS systems perform better than the VAV. Where Advanced fabric is used rather than 2007 typical fabric the calculated performance of HVAC buildings is degraded due to the calculated higher cooling loads (compare ‘08bp VRF’ to ‘Adv VRF’). Mixed mode operation as represented in SBEM gives only a small saving in carbon emissions (a reduction of around 20% in cooling load).

The historical data showing increased energy used in fully serviced offices is due in part to the highly serviced offices having deeper floor-plans with less opportunity for daylight utilisation, less external heat loss area per unit floor area and natural ventilation opportunity, longer operating hours and higher densities of people with associated higher ventilation requirements (including humidity control in some cases) and higher equipment energy use than the surveyed naturally ventilated offices (The Carbon Trust, 2000). The higher buildings regulation carbon emissions limit applied to the HVAC strategy in this evaluation would appear not to be justified by the above mentioned factors as these factors were not explicitly varied between the HVAC, MV and NV cases. Overall the higher limit for HVAC service strategies in the regulations appears in this case to provide greater margin for the HVAC service strategy than for NV and MV approaches. The calculation results would also tend to suggest that for future regulations the same calculated CO_2 emissions rates could be applied across NV, MV and HVAC building types.

The calculated performance of the HVAC, MV and NV cases with 2008 best practice system parameters applied (08bp) all have somewhat similar calculated performance and achieve a B rating. Where survey data exists it appears to indicate that more highly serviced buildings have higher carbon emissions, possibly due to the factors discussed above but also due to the fact that more highly serviced building may tend not to run to their potential optimum performance due to issues of centralised and imperfect control, maintenance and occupant understanding. Studies of buildings in operation have found that there can be significant differences between calculated and actual energy performance (Bordass *et al.*, 2004), also surveys have found that many buildings have errors in implementation or operation which cause energy use to be higher than intended. The more novel, complex or highly serviced a building then in general the higher the risk that these problems will arise. The validation of this calculated equivalent performance for future building types should be investigated through measured data. The performance of future buildings will need to be monitored closely to avoid miss-steps.

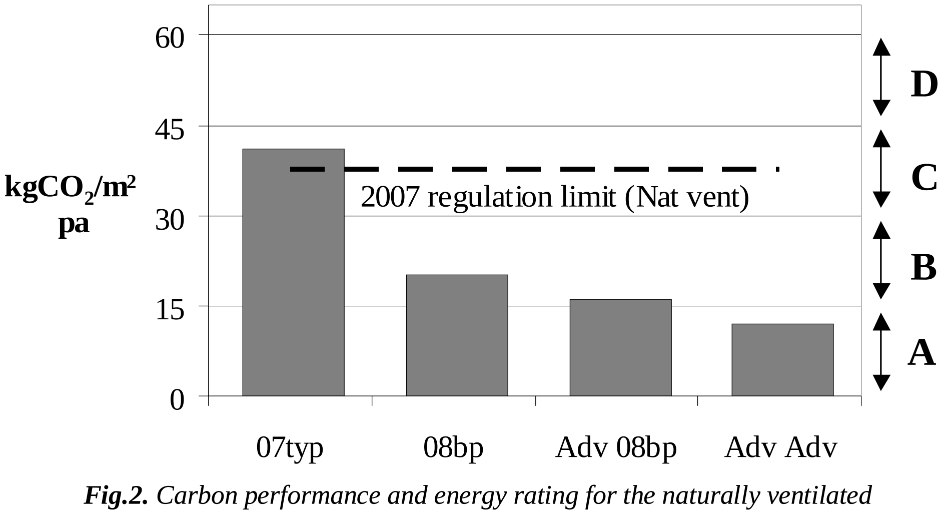

Fig.2. *Carbon performance and energy rating for the naturally ventilated (NV) design options. Detailed input parameter values are given in appendix 1.*

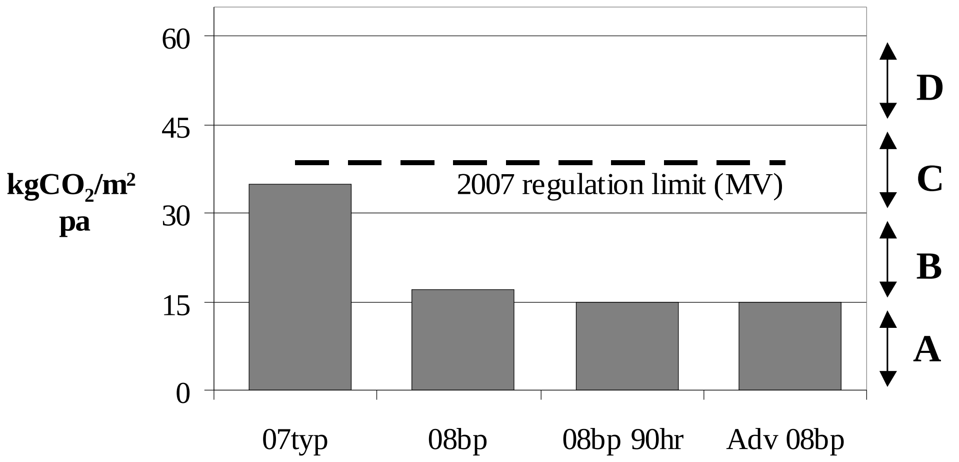

Fig.3. *Carbon performance and energy rating for the mechanically ventilated (MV) design options with heat recovery (no cooling). Detailed input parameter values are given in appendix 1.*

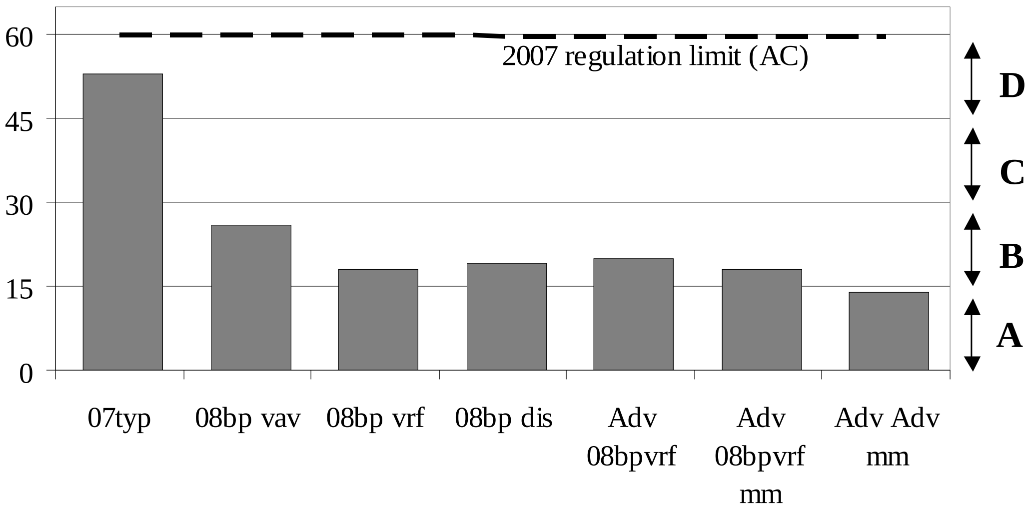

Fig.4. *Carbon performance and energy rating for the mechanically ventilated and cooled (AC) design options. Detailed input parameter values are given in appendix 1.*

2.2. Criteria for the avoidance of excessive indoor temperatures.

For the design options without mechanical cooling to meet the UK building regulations, they must be demonstrated to comply with criteria for the avoidance of excessive indoor temperatures.

Compliance can be demonstrated in a number of ways (CLG, 2008): (i) by limiting internal plus solar gains to less than 35W/m^2 as calculated in CIBSE TM37 (CIBSE, 2006), (ii) by limiting the time that internal temperatures are greater than 28^{o}C to less than 1% of occupied hours per year when tested against CIBSE Design Summer Year (CIBSE, 2003), or (iii) by using the BB101 (DfES, 2006) method for schools which requires use of the ClassVent and ClassCool tools in which CIBSE AM10 (CIBSE, 2005) calculation methods are embedded. Other more detailed methods are allowed, the CEN standards 13791 and 13792 provide the criteria all methods must meet to be considered valid (CEN, 2007, CEN, 2007a). The regulations also mention CIBSE

TM36 (CIBSE, 2005a) for further guidance for going beyond the requirements of the current regulations.

The Scottish regulations allow the calculated CO_2 emissions for regulation compliance and EPC rating to be reduced by 5% for non mechanically cooled buildings where the design temperatures achieved are always below 28^{o}C (Scottish Building Standards, 2007).

The example building described in the previous section was deemed to have complied with the regulations using the TM37 method. It is insightful to review the process used.

The TM37 gain limit of 35 W/m^2 is adjustable by location, in this case the building is in Central Scotland (between Glasgow and Edinburgh) so the limit is 45.15 W/m2 to account for the lower local outdoor temperatures.

TM37 gives two methods to estimate the internal gains: (a) using standard tables, or (b) based on detailed design assessment of the intended use of the space. The parameters for use with method (a) are tabulated in TM37 and an example of method (b) is given for an office space similar to that of the example building. The primary difference between the two methods is in the estimation of the internal gains where the standard tables contain very much higher gains than those given in the detailed design example for the office which includes some allowance for staff holidays etc.

In this case the standard table method (a) gave a Fail while the detailed design assessment method (b) gave a Pass as shown in table 1 and the building was then deemed to be compliant.

As a cross check dynamic simulation was run with the building modelled in ESP-r software (Clarke, 2001), the model included an air flow network and proportional window opening between 20 and 22^{o}C for the CIBSE Glasgow summer design year, both of the internal gains scenarios from TM37 methods (a) and (b) were included in the simulations, the results of simulations were consistent in that the reduced gains scenario (b) appeared to show compliance with less than 1% of occupied hours > 28^{o}C while the higher gain scenario (a) again failed (table 2). The dynamic simulation was carried out for both 2007 typical fabric and Advanced fabric options. The Advanced fabric option was marginally more prone to overheating by this criterion.

Table 1. *Overheating calculations for the example building (40% glazing) using the TM37 method for a standard gains scenario (method (a)) and a reduced gains scenario (method (b)).*

Method: TM37	(a)	(b)	
Solar gains	34	34	W/m2
Occupant gains	6	2.4	W/m2
Lighting gains	0	0	W/m2
Equipment gains	15	6.2	W/m2
Total gains	55	43	W/m2
Target (35*1.29)	45.15	45.15	W/m2
Pass/Fail	**FAIL**	PASS	

Table 2*. Overheating calculations for the example building using the Dynamic Simulation method (ESP-r) with the same gains scenarios as in table 2. The percentage values represent the proportion of annual occupied hours when the 28^{o}C threshold is exceeded.*

Method: Dynamic	(a)	(b)	
2007 reg fabric	8.5%	0.5%	occ hr
Advanced fabric	12.3%	0.7%	occ hr

The compliance demonstrated using the detailed design method of TM37 was due to the low internal gains assumptions. Whether these lower gains assumptions can realistically represent the performance of the building for future uses and local climate variations is not clear. In passing the regulation compliance test no indication of building robustness or the underlying design assumptions used are required to be communicated to future users of the building.

3. Some issues with the regulation compliance calculation methods.

The modelling of people, their behaviours and their equipment use is somewhat subjective and as illustrated by the differences between TM37 scenario (a) and scenario (b), the assumptions on occupancy, lighting and equipment gains can vary greatly and can have a large effect on occupant comfort and energy use.

The current building regulation compliance methods do not generally include the adaptive nature of comfort in free running naturally ventilated buildings that is well established in CEN Standard EN15251 (CEN, 2007b) and also in CIBSE Guide A (CIBSE, 2006). The adaptive criteria have been shown in occupant surveys to better represent occupant comfort (and discomfort) when compared to a fixed threshold. For warmer climates the adaptive criteria can allow significantly higher comfortable temperatures than non-adaptive criteria, particularly where ceiling fans are provided.

Occupant use of blinds and shading devices are coarsely and subjectively represented. Use of windows for ventilation and cooling is generally represented either as a fixed ventilation rate, a variable ventilation rate or, when an air-flow network is sometimes used in dynamic simulation, may be represented as some proportional window opening based on an indoor temperature. The use of ceiling fans is generally not considered in the UK. The modelling of lighting as always off in the summer period per TM37 may not be appropriate particularly where blinds have been deployed to avoid glare or direct solar heat gains. Overall the assumptions used for many of the occupant related parameters are generalised and do not relate closely to the specifics of the building being evaluated.

By allowing the designer flexibility to assess the risk of overheating based on the specifics of the planned occupancy and use of the space then no account is taken for possible change in use in future e.g. from a low occupancy low IT intended use to a high occupancy, high IT use (e.g. call-centre). Conversely if the designer was required to have all the input variables set at a worst case value then the combination of the worst cases may be totally unrealistic and could lead to an overly pessimistic conclusion.

Figure 5 illustrates graphically the risks related to specification of the criteria to be met to demonstrate avoidance of excessive temperatures. If there is no regulation criteria to be met then there is a high risk that the building will perform poorly and after some (possible very short) time in operation will require to be retro-fitted with cooling. If the criteria are over-robust and for example assume combinations of high gains and low ventilation rates etc. then there is a high risk that at the design stage the designer will specify that the building must have mechanical cooling where in fact passive measures would have been adequate. A third risk is represented on the graph as ‘NV not chosen’ which is the risk that AC will be preferred to passive measures such as shading, mass and night ventilation due to cost, logistics, perceived risk, sales or rental value, time delays or other reasons. This perceived lower risk and higher sales or rental value associated with buildings with cooling may in part be due to past experiences where non cooled buildings have not been robust in operation and uncomfortable conditions have resulted in reduced satisfaction and reduced productivity.

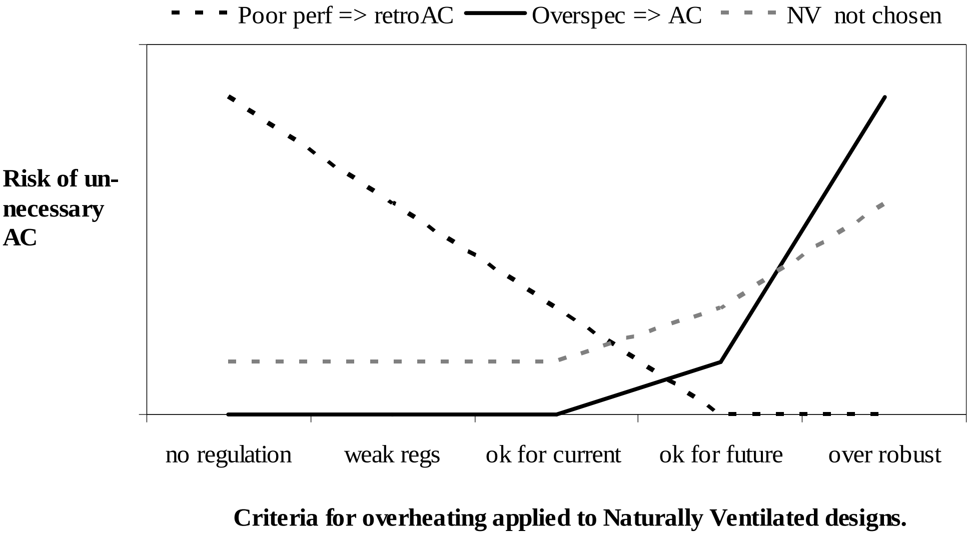

Fig.5. *Risk of un-necessary air-conditioning including risk of retrofit to poorly designed buildings, risk of AC due to over robust criteria for NV and risk that AC will be selected in preference to NV due to economic or other reasons.*

4. A proposed methodology for design of robust buildings.

The current approach could be summarised as being to calculate the building performance for a single set of pseudo worst-case input parameters and measure performance against a pass-fail criterion. A similar approach was taken in the electronics industry in the 1980’s where significant efforts were made to synthesise ‘realistic worst-case’ simulation parameter sets for creating competitive designs through avoiding the risk of an expensive design failure or the opposing risk of un-necessarily complicated, costly and un-competitive designs (Tuohy and Walton, 1986). More recently in electronics the approach has changed from this pass/fail test to an assessment of the robustness of the design to realistic variation in input parameters and the calculation of a ‘six-sigma’ capability parameter (Pyzdek, 2003). This second approach is employed in many industries and commercial organisations and would appear to have some value in the area of building design.

Here a detailed methodology is described for deriving a design capability parameter (C) for the summer comfort performance of a naturally ventilated building. This depends on robust algorithms representing occupant behaviour and representation of uncertainties in building construction, building operation and climates within dynamic simulation. The development of this methodology and the underlying behavioural models is still the subject of research and development. The capability parameter approach need not necessarily depend on conclusion of this research, it would be possible to apply based on currently available or simplified underlying models or even a combination of input parameters including some fixed values and still provide benefits. While the example developed here is for the comfort robustness of non-cooled buildings in warm conditions the same methodology could be applied to the robustness of a building design against a carbon emission target etc.

It is proposed that the comfort criteria the performance of a building in free running, naturally ventilated mode should be measured against is the adaptive comfort criteria. It is relatively simple to apply the adaptive criteria in dynamic simulation. Figure 6 and table 3 both show the summer performance relative to the adaptive criteria in the CEN standard for; (a) a south facing thermally lightweight office, (b) the same office with an external shade applied, and (c) the same office with the external shade and an exposed concrete ceiling to add thermal mass.

This simulation includes ventilation through an airflow network and window opening modelled using the Humphreys model representing occupant adaptive behaviour. More detail is given in a previous publication (Rijal *et al.*, 2007).

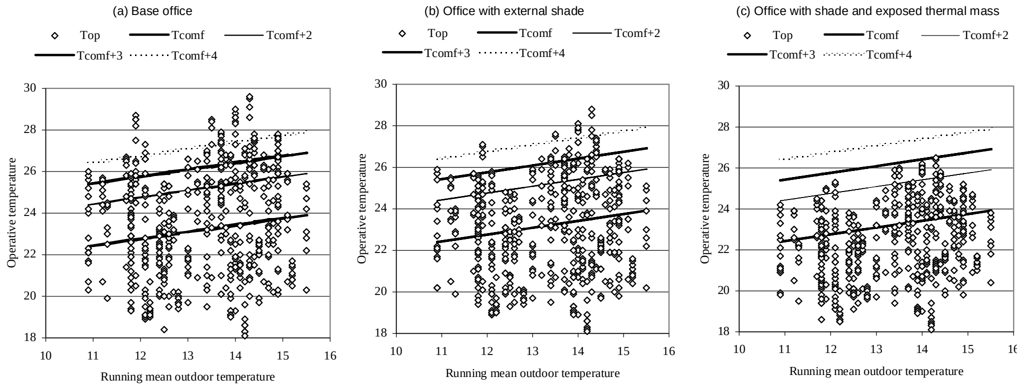

Figure 6 *The summer performance of the three office design variants is compared against the adaptive comfort criteria, the left graph (a) shows the baseline office, the center graph (b) shows the baseline office with an external shade added, the right graph (c) shows the baseline office with an external shade and an exposed concrete ceiling. All units are* ^{o}*C.*

Table 3. *Design variant results for adaptive comfort criteria*

Building design variant	**Occupied hours > Tcomf+2 (category I)**	**Occupied hours > Tcomf+3 (category II)**	**Occupied hours > Tcomf+4 (category III)**
Base case - typical south facing office.	32 %	17 %	5.5 %
Base case with external shading.	22 %	7.2%	2.3 %
Base with shading and exposed mass.	5.3 %	0	0

Modelling of the ventilation in terms of an airflow network rather than making more generalised assumptions better reflects the short time-base variation in airflow resulting from variations in wind speed and wind direction and also allows occupant window opening behaviour as well as the specifics of the ventilation openings to be directly incorporated.

The modelling of a wide range of occupant behaviours such as window opening, light and blind use and occupancy patterns is being actively developed and implemented in dynamic simulation and the available algorithms have been shown to give reasonable agreement with field survey data (Tuohy *et al.*, 2009). These occupant behavioural algorithms are generally stochastic in nature and represent the spread in occupant behaviour between more active users of adaptive opportunities and more passive users.

The variability in occupant behaviour is one uncertainty that impacts on building performance, other uncertainties are variations in internal gains, variations in climate, variability in construction parameters etc.

Uncertainty analysis is already well established in building simulation (Macdonald and Strachan, 2001). Monte-Carlo analysis can be used to generate the distribution in output parameters resulting from variation in input parameters.

The proposal here is that a building is dynamically simulated in a Monte-Carlo method for appropriate distributions representing possible variation in internal equipment and lighting gains, climate, occupancy, window opening behaviour, light and blind use etc and the resulting output distribution compared against the adaptive comfort criteria to generate a building summer comfort capability index C.

The methodology and the capability parameter is illustrated here for the simple example shown in figures 7 and 8 where performance of the thermally lightweight office for one summer day was simulated in Monte-Carlo mode with the input variation being only due to variation in window opening behaviour as described by the Humphreys algorithm (Rijal *et al.*, 2003). The maximum, minimum and mean operative temperature (Top) for each hour of that day is shown in figure 7, this illustrates possible range in temperatures due to the variation between active and passive use of the windows. The operative temperatures are shown in figure 8 normalised to the comfort temperature (Tcomf) for that day.

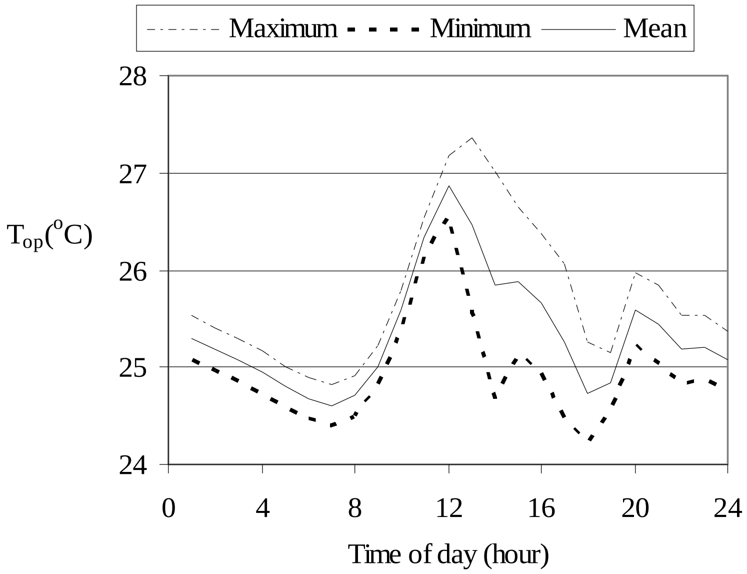

Figure 7 *The predicted range in operative temperature for a single day in summer day due to the variation in window opening behaviour represented by the stochastic nature of the Humphreys algorithm run in a Monte-Carlo mode.*

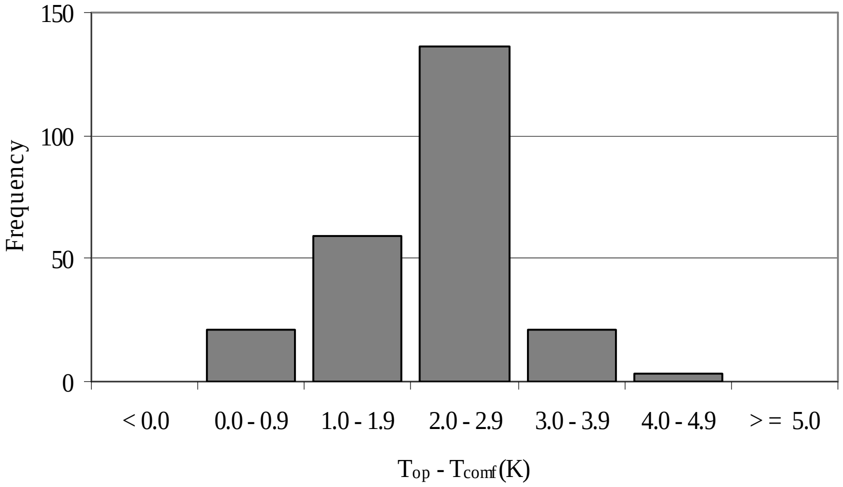

Figure 8 *The predicted distribution of the deviation from optimal thermal comfort temperature ($T_{op} - T_{comf}$) for the same summer day as in Figure 10 due to the variation in occupant behaviour as embedded in the Humphreys algorithm.*

The comfort capability (C) of the building (considering only this one day and this single source of variation) can then be calculated (Pyzdek, 2003) using the equation:

C = (specification limit – mean) / (3 x sigma)

Where for a class II building per the CEN standard (CEN, 2007b) the specification limit is Tcomf+3 and the mean and sigma are for the Top-Tcomf distribution.

In the same way, the Monte-Carlo simulation method can be applied to capture all the input parameter variations and generate an overall output distribution (Figure 9).

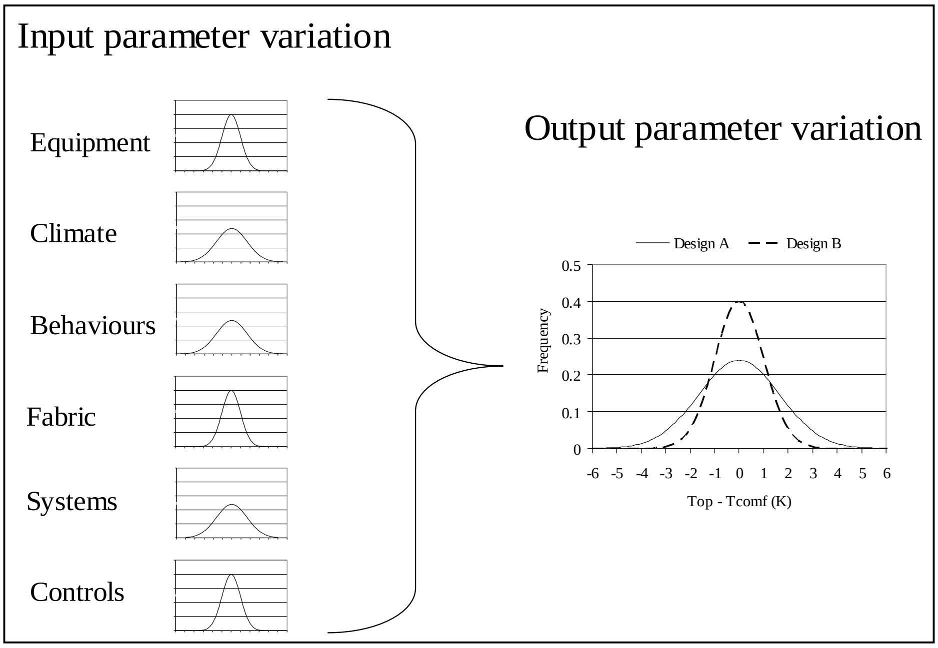

***Figure 9** The variation in input parameters combined in dynamic simulation using Monte-Carlo method to give a resulting variation in output parameters for Design A and Design B (see also Figure 10).*

Figure 10 illustrates how the performance could be analysed in this way for two different design options. This illustration shows the two design variants to have similar average performance. However option A has poor performance for some combinations of possible input parameters that may result in significant overheating while option B is clearly more robust for the same modelled distributions in patterns of use, climate, fabric etc. This type of analysis can be carried out for any of the comfort or energy use outputs from the simulation. It should also be noted that the equation given here for C is in its simplest form and that more complex statistics are applied where the distribution is not of normal form etc.

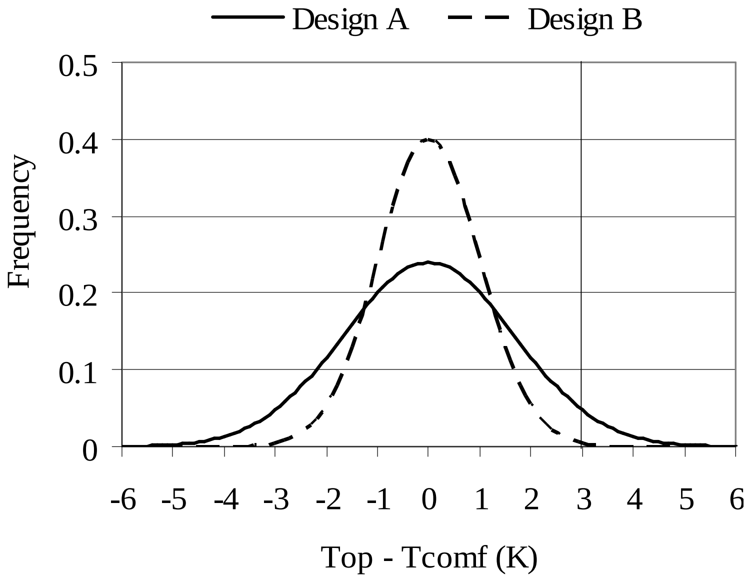

***Figure 10** Distributions representing the comfort performance of Design A and Design B for a range of input parameters representing variation in climate, internal gains, occupant behaviour, construction etc. Design A has a comfort capability of C = 0.6 when compared to the T_{comf} + 3K limit for a category II building, Design B has a comfort capability of C = 1.*

Implementation of this methodology would require the specification of standard distributions in input variables (internal gains, behaviours etc) to be modelled. These could be derived from existing survey data, climate projections etc.

The example office here which only passed the overheating criteria for a very low set of internal gains assumptions would have a lower comfort capability (C = 0.5 say) while a heavyweight, well shaded building with night ventilation in a rural location could have a higher comfort capability (C = 1.5 say).

One of the advantages of this method would be that it would allow building designs to be benchmarked and compared using a simple index in a language that has already permeated other industries. It would give building designers, specifiers or building owners a value which would relate to the capabilities of the building and the limits (maximum internal gains etc) beyond which comfortable conditions would not be guaranteed without taking action in mitigation (e.g. addition of shading or night ventilation, selection of low power IT equipment, provision of AC etc.).

Conclusions

The UK building regulations allow a fully serviced office building design to have a higher level of calculated emissions than the equivalent naturally ventilated design option however the energy rating for EPC certificate is based on the absolute emissions value and gives a better rating to the building design which demonstrates the lowest carbon emissions. With current typical levels of fabric and system performance then the naturally ventilated design in this study was a marginal fail to the current building regulations emissions criteria while the air-conditioned design was a pass. These typical designs achieved a ‘C’ rating with natural and mechanical ventilation and a ‘D’ with air conditioning including cooling. The justification of this higher limit for mechanically cooled buildings is discussed and some issues identified.

Applying current best practice systems to the typical fabric led to the naturally ventilated, mechanically ventilated and the air-conditioned designs achieving a calculated ‘B’ rating and similar calculated emissions levels. This equivalent calculated performance for the highly serviced design is discussed in the context of historical data and some questions are raised over whether this calculated performance would be achieved in practice.

The UK building regulations now have increased focus on summer overheating criteria but there are several methods of demonstrating compliance. An analysis of these methods was carried out and issues identified which could lead to a risk of un-necessary air conditioning either through implementation of air-conditioning in a building which does not require it or through the creation of a building which performs poorly and has to be subsequently air-conditioned.

The factors behind these risks are reviewed including the use of fixed rather than adaptive comfort criteria and the variation and uncertainty in occupant behaviour, building use, internal gains, fabric, climate etc.

A methodology is then proposed for assessing building performance which includes a capability parameter (C) which can be used to compare the capability of different designs and provide an indication of design quality and building robustness. This type of methodology is widely used in other industries where the quality metric has provided significant benefits over the use of pass/fail criteria. The capability of the building once quantified would serve to inform future users of the limits to building use beyond which measures would have to be taken in mitigation for performance to be maintained.

Acknowledgements

The author is grateful for the funding provided Building Market Transformation (BMT) project under the Carbon Vision Buildings (CVB) program sponsored by the UK Engineering and Physical Sciences Research Council (EPSRC) and the UK Carbon Trust.

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