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NHSScotland New Build Health Buildings DSM Modelling - SUMMARY

Prepared for:

NHS National Services Scotland

Health Facilities Scotland

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Executive Summary

HFS commissioned this study, performed by Mabbett and Associated Ltd and IES Ltd, in response to issues including space overheating and high cold water temperatures being experienced in newly built healthcare building in Scotland.

These issues have attracted the additional costs of retrofit remedial measures being taken to address the problems. HFS are concerned that whilst the building designs and the design stage modelling demonstrate the buildings comply with regulations and statutory overheating checks, there is evidence of a 'performance gap' between design predictions and actual building operation.

The hypothesis for this study was that more accurate and deeper modelling at design stage could have identified and mitigated the problems. The output of the study is to provide considered recommendations of next steps NHS could take to make improvements in the design and construction of future new buildings.

A typical example of a new build Health Centre and Hospital Ward Block was identified through a series of briefing sessions held with HFS to discuss known issues and to agree the areas to investigate as part of this pilot study.

Mabbett and Associates Ltd have extensive experience in energy management within existing healthcare buildings across Scotland and have a well-developed understanding of the engineering issues and activities that contribute to the problems experienced in new buildings.

IES Ltd are developers and expert users of the IES Virtual Environment, the market leading building simulation tool in Scotland, which has been used extensively in new healthcare projects.

IES Ltd performed baseline simulations both using UK government sourced National Calculation Method[1] (NCM) data, which is known to be used by designers for both design and compliance calculations in the absence of better data, and also using the more representative data (Improved) from the Room Data Sheet Data provided by Mabbett and Associates Ltd.

The differences between results using NCM vs Improved data show large variances both in energy and temperature predictions. Overheating risk is much more prevalent when using the Improved data and can lead to >1,000 hours of predicted overheating per year compared to 0 hours when using the NCM data.

The current 2015 Scottish Building Technical Standards have enhanced levels of thermal insulation and air tightness compared to previous versions and this means that overheating is increasingly becoming more of a potential risk, even in winter, unless design teams take steps to address this. A series of sensitivity analyses were undertaken to evaluate different scenarios such as modifying window openings, trickle ventilators and lighting energy to demonstrate how these factors can have a significant effect, and which can be selected to reduce overheating from >1,000 hours to less than <100 hours per year.

Further detailed analysis evaluated the approach to modelling a range of issues including natural ventilation and daylighting.

The results of this study clearly show that the approach to modelling can lead to healthier decisions being taken at each stage in the design process, but that NHS Scotland need to find ways to ensure that accurate input data based on real buildings is being used by designers at each stage in the design process.

[1] http://www.uk-ncm.org.uk/

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Recommendations for next steps and further actions to develop a new approach can be summarised as follows:

- **BIM process** – Create and implement design modelling procedures integrated across design team members based on more realistic input data and identify the measures that need to be considered at each stage in the Design Process, e.g. overheating
- **Design Risks** – Identify the project team member best able to mitigate known risks and responsible for providing the modelling evidence at each stage in the design process
- **Standardised Approach** – at each stage in the design of new buildings identify what analysis is needed and the format required for results to enable direct comparison across projects and analyses of similar types
- **Knowledge Base** – Create a database of design data that designers can use in their simulation modelling. Improve Designers' capabilities by making sure they have demonstrated the right modelling capabilities and verify this through auditing their analysis models at key milestone stages. For instance, project mentoring could be customised to train each team member in the analysis of particular design aspects, e.g. for the Architect (correct windows selection and daylighting) and for the M&E designer (plant sizing and ventilation controls)
- **Design Database** - NHS Scotland should gather and maintain data from their operational buildings to inform their designers and create a range of operational templates across different building types. Existing design guidelines, e.g. SHTM 04-01 on cold water may have to be revised.
- **Feedback** – Gather operational energy and associated data (e.g. space and water temperatures) from newly constructed buildings to evidence the improvements being progressed. This could involve 'Model based commissioning' which uses comparisons between models based on design and operational data in order to improve building operation.

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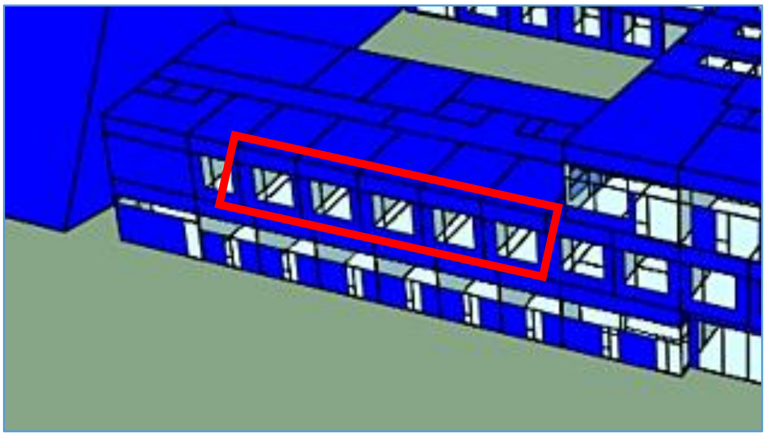
1 Introduction

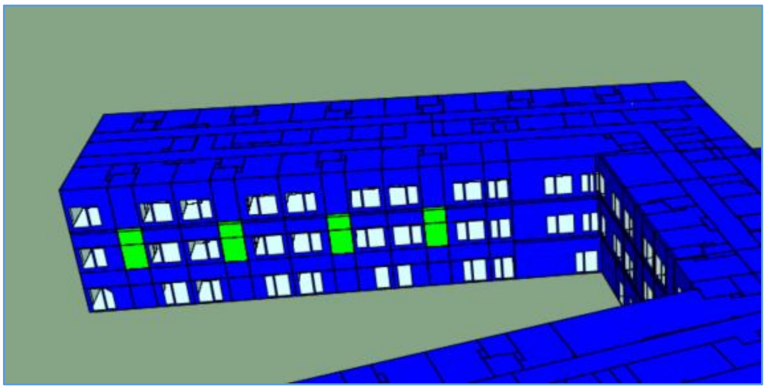
The objectives of this study were to evaluate the implication of various approaches to Dynamic Simulation Modelling (DSM) for use in the design of new build Health Centres and Hospitals in Scotland.

An ‘exemplar’ approach was used, illustrated with appropriate examples of building analysis models for both Health Centre and Hospital buildings.

Typical designs for new buildings were identified which were based on representative recently completed buildings. The models have been set to comply with the current 2015 Scottish Building Standards, which have increased levels of thermal insulation and air tightness compared to buildings built to previous versions of the Standards.



Health Centre Consulting Rooms for analysis



Hospital Ward (middle floor) for analysis

Health Centres and Hospitals have very different operational needs and one of the objectives was to use practical examples to help provide briefing information that would assist designers in understanding underlying issues that enable them to maximise the benefits derived from their analysis and improve building performance.

Various design scenarios were considered and included where agreed in the approach to these works through close cooperation between IES Ltd and Mabbett & Associates Ltd (Mabbett). Both worked together in gathering data, performing analysis and setting out the findings and recommendations resulting from this project.

Refer to accompanying report 13416 HFS Exemplars: Health Centre & Hospital Modelling Report v0 for a more detailed description of the project approach with detailed outputs from the modelling study.

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2 Modelling Scenarios

The approach taken follows a consistent methodology. This involved building baseline models and then performing a number of alternative scenario analyses to find options to improve on the baseline and optimise the design. The results reveal how designers and modellers can identify ways to reduce risks of building failure in operation, and improve environmental conditions for the occupants.

For this project two baseline models were created:

- NCM Base Case (NCM)
- Corrected Base Case (CBC)

Both the NCM Base Case and Corrected Base Case use DSM and the differences between the two relate to the specific input data.

2.1.1 NCM Base Case (NCM)

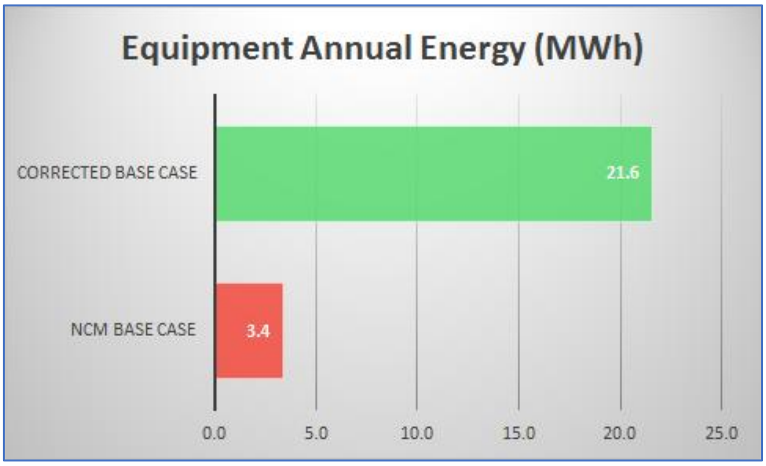
The NBC model populated with standardised operational NCM model input data is intended for Section 6 compliance calculations and for producing Energy Performance Certificates (EPC's). From experience, designers frequently use the same standardised NCM data in their design models as well for newly designed healthcare developments, both in the analysis of thermal comfort and predicting operational energy performance. It should be noted that the UK Department for Communities and Local Government (DCLG) who provide the NCM data for UK compliance assessments, clearly state that the NCM data is intended to be used for comparison, not an absolute calculation and the results of UK compliance calculations should not be regarded as the true prediction of actual energy usage.

2.1.2 Corrected Base Case (CBC)

The CBC model is instead populated with representative operational model input data for the buildings in question and is expected to more accurately reflect the true operation of a health centre and hospital based on real life experience with similar developments and as defined in detailed Room Data Sheets (RDS).

2.1.3 Assessment of NCM vs CBC

Comparing the NCM representation and more realistic CBC model demonstrates that employing NCM input data cannot be regarded as realistic for use in analysis.



Internal heat gains are one of the areas that show the greatest discrepancies which can lead to incorrect assessment of internal temperatures, which in turn lead to buildings overheating and frequently unacceptable levels of thermal comfort for occupants.

Taking the hospital bedrooms as an example, the NCM assumes that the energy consumed, and therefore heat gain to the space, will be only 3.4 MWh per annum for 20 bedrooms. The CBC, based on real world observations, is over six times higher at 21.6 MWh.

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To put the NCM assumptions in perspective, the average equipment power is equivalent to the rated power of a single Vital Signs Monitor. There are a range of other likely sources of casual heat gain such as air mattress pumps (250W), adjustable beds, TVs, mobile phones, iPad/tablets, electronics chargers, electronic cigarettes, etc.

Previous electrical demand studies by Mabbett in NHS Scotland hospitals found the figure to be up to four times higher at night and over six times higher during the day compared with the NCM data.

What is clear is that the NCM input data significantly underestimates real heat gains to the space.

In addition, no account is taken within the NCM data of non-electric causal heat gain other than people, for example hot pipework, and losses from electrical cables in adjacent voids and rooms.

With regard to lighting, although annual energy is broadly similar in the NCM, the seasonal and daily profiles are not consistent with real life experience. This can lead to overestimating heat gain at night and underestimating during the day.

With regard to people, the NCM model overestimates the heat gain to bedrooms, assuming the equivalent of two to three permanent occupants. Not only is average occupancy less in the real world, the profile changes throughout the day. This impacts on the assessment of heat gains to the space and ventilation rates that are required.

Conclusions

In use energy consumption is not well understood, which is causing a serious underestimate of heat gains to spaces in design calculations and analysis where NCM data is used. Use of NCM data in preference to more realistic, site representative data can give the impression of more favourable results but can lead to an increased risk of unsatisfactory building performance.

Using more accurate, site representative data in design analysis will enable more accurate and confident predictions for decision making, and to offset overheating in buildings.

Reducing equipment energy consumption where possible will have two benefits: reduced running costs and reduce the risk of overheating.

Recommendation

Undertake a review of in-use energy within modern Scottish hospitals and health centres to create recommended sets of load profiles for model inputs to be used by design teams. This will provide more realistic data that designers can use to identify and manage out risks in their designs, particular with regard to overheating and operational energy.

There are recently built health buildings with substantial electrical sub-metering installed that could be included within the study.

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2.1.4 Design Scenario Analysis

The design scenario modelling analysis focused primarily on modelling iterations derived from the CBC as this provides a more realistic basis for predicting ways to find operational improvements. The following settings were identified as the areas for further evaluation primarily as they had been the subject of concerns raised from previous developments and offered scope to evaluate opportunities to improve design in future developments.

Design Factor	Hospital CBC	Health Centre CBC
Window Configuration	10% openable area	10% openable area
Window Opening Control	Windows open at 24°C and outside air temperature above 10°C	Window opens at 23°C
Trickle Ventilation	On	Off
Service Void Internal Gains	Gains on & no ventilation	Gains on & no ventilation
Service Void Insulation	No	No
Weather File	GlasgowTRY05	GlasgowTRY05
Air Infiltration	0.125 ACH	0.125 ACH
Fabric	External wall U=0.2 W/m^{2}K Window U=1.6 W/m^{2}K	External wall U=0.15 W/m^{2}K Window U=1.2 and 1.6 W/m^{2}K
Glass & Shading	g-value = 0.5 & no additional shading	g-value = 0.6 & no additional shading
Lighting	As RDS	As RDS

Iterations and sensitivity tests of the design factors above were applied both individually and together to the CBC model to create a series of 'Optimised' versions as listed below.

Combined Scenarios	Hospital Bedroom	Health Centre Consulting room
Optimised 1	Window 1.12m^2 Split opening, 10.6% of Floor Area, Window Open at 24°C, Ceiling Void Gain 4ACH, Infiltration 0.125ACH, Fabric U-Value -30%, Lighting -50%	Window 0.64m^2 Split opening, 8.2% of Floor Area, Window Open at 23°C, Ceiling Void Gain 4ACH, Infiltration 0.125ACH, Fabric U-Value -30%, Lighting -50%
Optimised 2	As 1 + Trickle Vent 0.112m^2	As 1 + Trickle Vent 0.0644m^2
Optimised 3	As 2 + Ceiling Void Insulation 25mm	As 2 + Ceiling Void Insulation 25mm
Optimised 4	As 3 + G-Value 0.50 Ext. Shade 0.4	As 3 + G-Value 0.37 Ext. Shade 0.4
Optimised 5	As 4 + Glasgow-DSY2-2050 (High)	As 4 + Glasgow-DSY2-2050 (High)

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3 Overheating Analyses

Simulations were performed using the NCM, CBC and the five CBC derived 'optimised' models to predict levels of overheating. This provided a baseline comparison of overheating output predictions between the standardised NCM input data and across the range of corrected base case models.

The following table compares the modelling results with NCM defaults with those of the same model but with more realistic assumptions on internal gains and occupancy.

Scenario	Hours per annum >28°C Operative Temp[2] / Annual Peak Temp			
	Hospital		Health Centre	
	South Facing Bedroom		Consulting Room	
NCM	48	30.5°C	30	30.1°C
CBC	1,911	37.4°C	56	31.5°C
Optimised 1	234	32.7°C	42	31.1°C
Optimised 2	150	32.1°C	42	31.0°C
Optimised 3	210	33.2°C	36	30.8°C
Optimised 4	92	30.5°C	0	27.8°C
Optimised 5[3]	259	35.1°C	45	32.6°C

The results indicate that designs will meet the SHTM requirement for overheating where NCM data is used. However, changing the NCM model values for more realistic CBC values of the building in operation clearly exposes the real risks of non-compliance, and in the case of the hospital bedrooms potentially by a very large margin.

For the south facing hospital bedrooms, the rooms are at risk of overheating for nearly a quarter of the year. Peak temperature is predicted to be 7°C higher in the more realistic CBC model compared with the NCM model.

The two main drivers for this are:

- The NCM assumptions on heat gains, particularly from equipment, bear little relation to reality.
- The NCM assumes a heating set-point of 18°C as opposed to the 22 - 24°C operational requirement.

The various scenarios show that deeper analysis of design factors can lead to substantial improvements, for example in window design, external shading, and trickle ventilation.

Conclusions *If NCM input data is used for the basis of design decisions then buildings will be built that overheat in operation.*
Recommendation *Create and implement design modelling procedures integrated across design team members based on more representative input data and identify the measures that need to be considered at each stage in the Design Process, e.g. overheating.*

[2] *Operative temperature is the comfort temperature felt by humans, it is an equal split from the local air temperature and mean radiant temperature (MRT). MRT is derived from the collection of surface temperatures within the space.*

[3] *'Optimised 5' uses recently published future (i.e. predicted warmer) weather files for 2050*

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4 Non-Summer Overheating

The modelling has clearly demonstrated that in some cases overheating is likely to be almost as much a problem in winter as in summer.

The relatively high internal gains, combined with the improved fabric insulation and reduced infiltration losses due to increased airtightness, driven by current 2015 building standards, mean that when windows are closed the rooms are prone to overheat. The actual heat required to be provided by the controllable heating system on cold days is minimal when compared to older buildings. Designers increasingly need to think differently as new buildings perform very differently to older buildings.

Human behaviours about when to make the decision to open a window now have a more significant impact on overheating. For example, in a sample bedroom, if the occupant always opens the window when it gets to 24°C regardless of season, the occasions when the room exceeds 28°C is only 52 hours. However, if the occupant does not open the window unless it is above 10°C outside then the room exceeds 28°C for 4,558 hours.

The importance of accounting for human behaviours, when designing the buildings to be comfortable in winter is becoming paramount. These new buildings do not act in a way that is familiar to staff and patients in their own homes.

Conclusions *The risk of overheating needs to be considered for each month of the year, not just summer months.* *Further tightening of building regulations with regard to heat loss are likely to exacerbate this issue.* *Designers need to have an awareness of how the occupants will use the building to allow them to assess the real risks and how to mitigate them at design stage.*
Recommendation *Consider developing guidance to be issued to design teams on how they should assume that occupants will behave with regard to areas such as window opening, control of thermostats etc.* *Improve Designers' capabilities by making sure they have demonstrated the right modelling capabilities and verify this through auditing their analysis models at key milestone stages. For instance, project mentoring could be customised to each team member, e.g. for architect (e.g. correct windows selection).*

5 Implications of Mechanical and Electrical Service Design on Overheating

The preferred choice for heating most occupied rooms in hospitals is most frequently ceiling mounted radiant panels, which are selected primarily for operational reasons. This design strategy necessitates a change in conventional perimeter heating design for the circulation of water from variable temperature heating to higher constant temperature. Instead of water temperature reducing as external temperatures rise, e.g. being circulated at 30°C when its 18°C outside, it now needs to be circulated at over 70°C in order to enable the required heating.

Radiant panels result in additional heat transfer to the ceiling void compared to radiators.

It was also noted from the CFD airflow analysis that conventional radiators would perform better at mixing air across the room.

The conclusions to be drawn from this is not that radiant panels are never the correct choice, but that the wider impact from this design choice (as is true for all other design choices) must be considered.

Other examples of where heat lost from mechanical and electrical services is impacting on overheating include:

- Electrical cable sizing
- Location of drivers for LED light fittings
- Routing of hot pipework, such as heating pipes and medical gases
- Underfloor heating distribution pipework

Conclusions *The distribution pipework of heating systems and other services within buildings are ultimately acting as uncontrolled heaters which can lead to unintended overheating problems.*
Recommendation *The distribution losses of hot pipework and other services should be accounted for in models, including modelling the zone that they are contributing heat to.* *Designers should be required to consider alternative approaches to minimise uncontrolled heating, such as using lower water temperature distribution systems.*

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6 Ceiling Void Space Temperatures

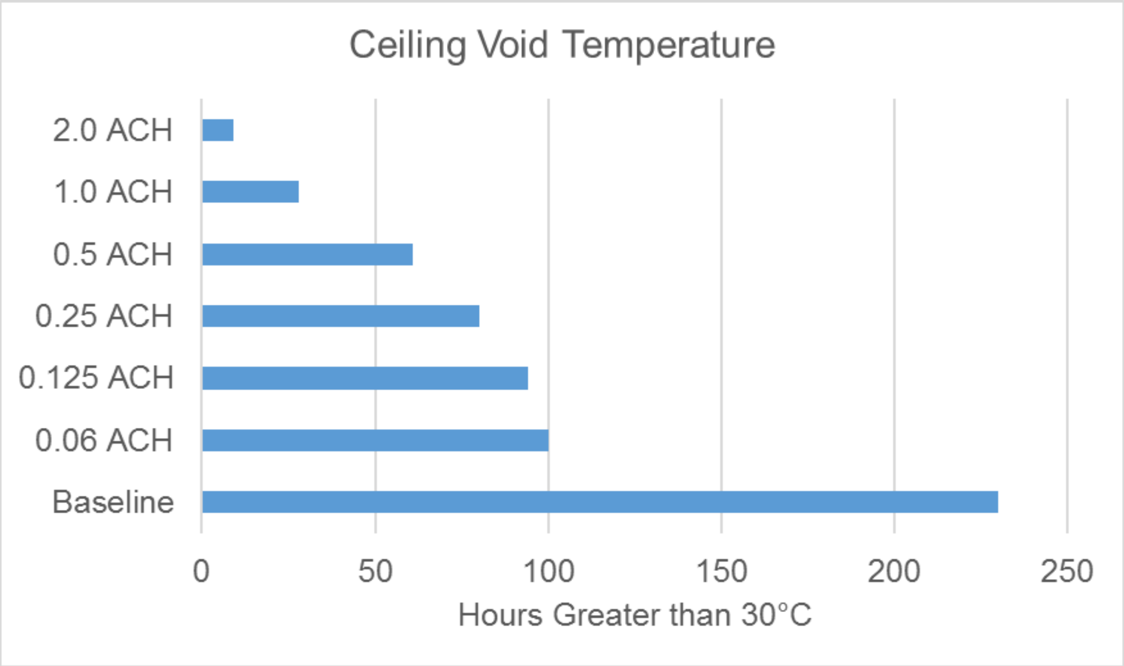
Ceiling void spaces were added to the CBC and optimised models as these are not included in the NCM compliance models. In order to help provide a more representative picture of performance the occupied space and ceiling void ought to be modelled as separate volumes, so as to correct the occupied space volume and ensure the differences in gains and conditions are taken into account. Generally design teams do not currently create separate zones for ceiling voids.

Taking the hospital bedroom ceiling voids as an example, the temperature within the space in the CBC model is always greater than 25°C, with temperatures of greater than 33°C being reached. Hot pipework distribution is usually located in ceiling voids and, despite them being insulated, this creates a source of significant heat gain into these spaces in relation to their volume.

An unventilated void has two major impacts:

- The void space will ultimately act as a "heater" to the bedroom below as it is always greater than the target room temperature.
- Any cold-water services running in these spaces are almost certain to exceed limits defined in SHTMs for most of the year.

Void space temperatures can be reduced by ventilation, however even with ventilation the void spaces are over 25°C for the majority of the year regardless of ventilation rate.



The real-world turnover of water is much lower than those given in design guides, as these are primarily used for sizing peaks not averages. The design value may be 3 to 5 times greater than the actual water demand.

Based on previous studies by Mabbett, the average water demand for Scottish hospitals is only 0.8 l/s, which is the equivalent of five taps in use at any one time. As the majority of water consumed in a hospital is likely to be in flushing toilets, showers, and use in communal areas, the actual water use per cold water tap is negligible. Previous studies have shown that water use in taps is only ~13% of the water used, if half of this is cold water that is less than 7% of water use through taps.

There are 55 cold water taps in the 20 bedroom ward block considered, more than one per occupant, as they are provided for both clinical and patient use.

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With the number of fittings in each ward block, it is unlikely that water turnover can be relied upon to maintain cold water temperatures below 25°C, let alone the ultimate target of 20°C.

This is similar in the health centre with more outlets than occupants, but with longer periods of inactivity overnight and at weekends.

With spaces that have to be maintained to over 20°C, combined with the number outlets it may no longer be possible to guarantee safe water temperatures using the conventional method of turnover and insulation.

The approach of recirculating the water and chilling it that is being recommended more regularly needs to be carefully considered. For example, if the water is chilled and circulated through the building where it returns warmer and in need of chilling once more, we have in effect installed a void space cooling system. The energy removed in cooling may then be replaced with heating, creating continuous simultaneous heating and cooling.

The most appropriate approach may be to accept that the conventional approach is no longer valid for new build properties, test new methods and approaches, decide on the best solution and advise future design teams on the preferred method. SHTM 04-01 may have to be revised depending on the solution.

The following are thoughts and ideas that would have to be tested:

- Changes to clinical requirements to reduce the number of outlets to increase turnover
- Review pipework sizes and run lengths on main routes
- Run cold water pipework external to the building where possible
- Dedicated cold-water pipe voids that can be insulated and ventilated
- Pasteurisation with regenerative heat exchange, similar to the process for pasteurising milk. The energy recovery rate can be as high as 95%.
- Recirculate cold water and use heat exchangers to reduce temperature and recover heat, example to preheat DHW cold feed or pre-heat coil in an air handling unit.
- Only supply cold water to wash hand basins
    - Removes hot DHW pipework, reducing causal heat gain from service voids
    - Increases turnover in pipework as demand that is shared between hot and cold pipes are combined in to a single pipe
    - Reduces energy costs to heat DHW. Previous studies by M&A have found that 50% to 70% of the energy that is used in DHW systems is losses.
- Alternatively, only supply hot water to wash hand basins. Consideration on how to avoid scalding
- The use of advanced water purification techniques, such as reverse osmosis
- Restricting in the type of materials that can be used in water distribution to that that inhibit the development of bacteria

Conclusions *With well insulated and air tight spaces that have to be maintained to over 20°C, combined with the low turnover of water per outlet it may no longer be possible to guarantee safe water temperatures using the conventional method of turnover and insulation.*
Recommendation *A range of innovative solutions need to be identified to ensure that designers know how to address this issue. SHTM 04-01 may have to be revised depending on the solution.*

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7 Natural Ventilation

Section 2.3 of SHTM 03-01: Part A – Design and Validation acknowledges that “as the motivating influences of natural ventilation are variable, it is almost impossible to maintain consistent flow rates and ensure that minimum ventilation rates will be achieved at all times. This variability is normally acceptable for general areas including office accommodation, general wards, staff areas, libraries rooms, dining rooms and similar areas which should, where possible, be provided with opening windows of a design that facilitates natural ventilation.”

However, Appendix 1: Recommended air-change rates includes naturally ventilated rooms with a recommendation for 6 air changes per hour for bedrooms. There is a requirement for clarity to avoid design teams interpreting Appendix 1 as minimum values for ventilation of naturally ventilated spaces.

It is difficult to provide definitive guidance for natural ventilation rates. An example of where this is handled is in the HSE booklet ‘The Storage of Flammable Liquids in Tanks’ guidance on ventilation requirements:

> ‘A high standard of natural ventilation, using high and low-level openings in the walls (typically 2.5% of the total wall and roof area) leading directly to the open air. Alternatively, permanent mechanical ventilation can be used, equivalent to at least five air changes per hour.’

The above allows the designer to provide natural ventilation, without having to prove the equivalent ACH value if mechanically ventilated.

Section 2.11 of SHTM 03-01 should be redrafted to take account of new recommended practice on assessing overheating in buildings.

The SHTM currently advises:

> *“Calculations and thermal modelling should be undertaken to ensure that during the summertime, internal temperatures in patient areas do not exceed 28ºC (dry bulb) for more than 50 hours per year taking into account the level of design risk for the application.”*

This approach has largely been superseded by CIBSE TM52: “The limits of thermal comfort: avoiding overheating in European buildings” which takes account of human behaviours in naturally ventilated buildings and how humans adapt to their surroundings. CIBSE TM52 assesses acceptable overheating by the following metrics:

- The first criterion sets a limit for the number of hours that the operative temperature can exceed the threshold comfort temperature (upper limit of the range of comfort temperature) by 1°K or more during the occupied hours of a typical non-heating season (1st May to 30th September).
- The second criterion deals with the severity of overheating within any one day, which can be as important as its frequency, the level of which is a function of both temperature rise and its duration. This criterion sets a daily limit for acceptability.
- The third criterion sets an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable.

CIBSE have recently published TM59 2017 “Design methodology for the assessment of overheating risk in homes”, elements of which may be more relevant to certain areas of healthcare buildings, such as bedrooms. For example, there are specific temperature limits specified for bedrooms during sleeping hours and for rooms with vulnerable occupants.

Consider altering the SHTM so that the designer has to undertake a TM52 or similar assessment. Instruction should also be given as to what weather files are to be used, including future weather files, and assumption on internal gains (see section 1.4).

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Conclusions *SHTM03-01: Part A – Design and Validation needs revised as it may lead to misinterpretation of requirements with regard to natural ventilation and acceptable rooms temperatures, leading to it be erroneously dismissed as a viable option.*
Recommendation *Redraft Appendix 1 to avoid ambiguity in targets for natural ventilation and Section 2.11 to take account of new practices in assessing overheating in buildings.*

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8 Space Ventilators

Building Regulations require the installation of space ventilators, also referred to as ‘trickle vents’, in addition to openable windows, however they must be possible to close to avoid the permanent event of draughts.

A bedroom or consulting room with good air tightness needs the equivalent of four standard 400 mm wide Space Ventilators or eight standard 240 mm wide Space Ventilators. It is unlikely that occupants would open and close four to eight Space Ventilators to control their environment, therefore alternative practices would be required.

The modelling exercise shows that if natural ventilation is active before temperatures start to rise, the risk of overheating is significantly reduced.

In hospital bedrooms the number of surrounding areas with permanent mechanical ventilation, such as en-suites, ultimately means that they are ventilated by a mixed mode system. Permanent trickle ventilators, or alternative local additional permanent openings, would encourage the flow of air from the outside rather than from the warm corridors.

Conclusions *Space ventilators are an important part of any natural ventilation design. Human behaviour has to be considered at design stage on how these would be used when the building is in operation.*
Recommendation *Consider adding the requirement for permanently open or automatic ventilators, designed to avoid draughts.*

9 Daylighting

Daylight Factor (DF) has traditionally been the industry standard daylight metric and been used for BREEAM points scoring. DF is calculated as a ‘snapshot’ for an overcast sky and does not include for direct sunlight which is a significant limiting factor when testing true performance.

Daylight capture was assessed for the bedroom space against the four standard orientations to test the sensitivity of harnessing natural daylight. The more recently developed Climate Based Daylighting Modelling (CBDM) approach was used to compare the two approaches. CBDM models the annual illuminance performance and includes the impact of seasonal solar position, solar intensity, cloud cover and building form. Attributes such as shades, surrounding topography and buildings, plus window layout and glass type are all factors that are tested with this approach.

The more detailed analysis approach mean that modellers need to understand how to build their models to achieve the correct results. This now also involves additional modelling detail including adjacent buildings and window recesses.

Glass Transmittance = 70%	North	South	East	West
DF average	3.64	3.46	3.64	3.47
Annual Average Illuminance for Occupied Period	296.71	978.94	658.43	616.08

The CBDM approach details the clear differences between each orientation whereas DF identifies little change. The impact is DF provides a poorer representation of the expected demands on the building in terms of managing sunlight and how to maximise its capture when beneficial and likewise prevent too much sunlight when levels are high so visual comfort is the best possible for occupants, much in the same manner thermal comfort is managed for the space.

Conclusions
The conventional method of using daylight factor to assess the benefit of natural daylight is crude compared to new modelling based approaches.

Recommendation
CBDM should be considered as the new standard in daylight modelling approach to measure daylight capture and this extends to its ability to filter the hours of analysis. This approach would assess when daylight is actually being used and analysis can define more accurate benchmarks when assessing design scenarios.

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10 Comparing In-Use Energy to the Design Stage

As the designer can never truly know how a building will be used and operated throughout its life, the predicted energy performance can only ever be at best an approximation based on experiential assumptions. How close the figure is to real world is dependent on how good the design team is at gathering the best data they can.

Sub-metering is often cited as a method of separating non-building related energy so that the building can be assessed against the design figures. However, all equipment electrical consumption ends up as heat, which can influence heating, cooling and ventilation.

If ventilation is by natural means, heating performance is predicated based on assessment of reasonable occupant behaviours.

Research has shown that even for a simple two room model, the percentage discrepancy between simulation and laboratory test for temperature can vary up to 14%.

The most advanced approach has been developed by the Efficiency Valuation Organization, with their International Performance Measurement & Verification Protocol Concepts and Options for Determining Energy Savings in New Construction. Their method has been in development since 1994 and has been used throughout the world, with thousands of trained Certified Measurement & Verification Professionals.

Their advice is that whole building comparison should only be used "for projects which do not require a high level of savings accuracy and where there are existing buildings available for comparison which are physically and operationally similar … even then, the potential for error renders this option suitable for only the most cursory M&V programs".

A detailed simulation approach, also known as Model Based Commissioning can be used, and this can be successful if a reliable design stage model has been created. Operational data can be gathered from metering and BMS platforms and used to compare predictions with real operations. However, it should be noted that detailed M&V can be an intensive exercise and buildings are often unstable in their first year or two of operation such that that "frequent post-commissioning re-verification of operational status and the associated potential to perform is usually necessary."

Conclusions *M&V using a model based commissioning approach may be useful in areas thought to have stable operations.*
Recommendation *This is an area to develop to ensure that design operation can be realised in the finished building. Once designers are creating reliable models of buildings they can be used to fine tune the operation.*

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11 In-Use Energy

The modelling results demonstrate the bedroom requirement for heating is negligible, even in winter, peaking at £3 per month to heat all of the bedrooms in December. The bedrooms are ultimately heated by uncontrolled casual gains, including heat loss from the heating distribution pipework. Included is the influence of limited window opening to prevent local discomfort due to the cold draughts from the large internal to external temperature difference.

Any improvement to building fabric through lower U-values has a negligible impact on heating energy, and may actually lead to higher consumption due to windows opened to deal with overheating when the internal to external temperature difference is substantial.

The main requirement for heating will be for tempering fresh air to mechanically ventilated spaces, providing heating to naturally ventilated rooms if the windows are open on cold winter days and maintaining circulation losses within the distribution pipework.

As NHS buildings are primarily designed based on the clinical function requirements, there are limits as to where continuous reductions can be made.

Conclusions *Future reductions in limits for energy and carbon in new buildings, such as improved U-values, stipulated by building standards may show reductions in the NCM compliance model, but these are unlikely to lead to real world savings. In fact, it may actually lead to higher heating consumption than a building with lower levels of thermal insulation.*
Recommendation *Use accurate modelling to identify how best to control each building, use sensitivity analysis to fine tune this and also use a soft landings approach to feed real performance data back into the model to compare predicted with actual operation.*

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12 Application of Dynamic Simulation Models

The findings of this study clearly show that modelling results are not only a result of the modelling process but are fundamentally a result of the input data.

Increasingly public sector and other clients are requiring BIM standards to apply to the drawings produced by their Project Design teams. A DSM model is as much part of BIM as any drawing and is potentially an even more valuable asset during design and into building operation.

DSM models at design stage are used primarily to reduce risk by evidencing design decisions. DSM models can be used at any stage in the building lifecycle as the design evolves to build complexity and detail and improve data at each stage.

The level of modelling complexity needs to be pitched at the right level at each stage and layers of data can be added as the design evolves. At early stages the DSM model can be used to optimise a window opening strategy and at later stages for sizing plant and equipment. More complex models can also be used to predict maximum demands and energy utilisation profiles, whilst at commissioning and operational stages they can be used to validate controls and for fault detection.

Too often incorrect or insufficient modelling means that opportunities for natural ventilation are not realised and retrofit cooling is needed because designers have used NCM input data to incorrectly determine the overheating risk which has then missed opportunities to solve the overheating issue by passive means.

Heating and cooling plant (including all the ancillary components such as fans, pumps, pipework, ductwork and switchgear) is frequently oversized due to the use of out of date 'rules of thumb' or steady state calculations. Advances in Building Standards mean that historic challenges of under heating are less of an issue in today's well insulated, and tightly sealed buildings. On the other hand, overheating is now more prevalent as heat loss has been reduced and designers need to predict and mitigate these issues right from the early stages of design, for example by using DSM modelling techniques.

Models can be used as a communication tool to visually convey when and how a building interacts with solar gain, and to quantify in a visual way what risks need to be addressed. These can include issues as diverse as overheating, natural ventilation, daylight utilisation as well as compliance with building standards by using different versions of the same building model.

Modern technology enables competent and motivated designers to perform hundreds, potentially thousands, of simulation in batches in less time than they would have taken to run a handful in the past. Results can be automatically generated in prescribed formats and design teams can work collaboratively across their BIM platforms to streamline and avoid duplication of effort by sharing the data in their respective workflows. This enables exceptional results to be identified and investigated further, to check and mentor designers for an efficient modelling process.

Standardised templates can be created for use and customisation across similar buildings within a portfolio.

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Conclusions *Modelling results are not only a result of the modelling process but are fundamentally a result of the input data.* *DSM, if utilised correctly, can be used to make changes early in the building design process to avoid more costly building service led solutions.*
Recommendation *Identify a protocol for use of DSM models to obtain maximum value at each stage in the building lifecycle. Through training and provision of approved templates improve consistency of modelling to mitigate risks of buildings failing in operation for reasons that could easily have been predicted.* *Provide a methodology, and where possible analysis templates, for designers to use. Ensure modellers have achieve and demonstrate the suitable levels of competence. Check modelling input and outputs to ensure standards are maintained.*

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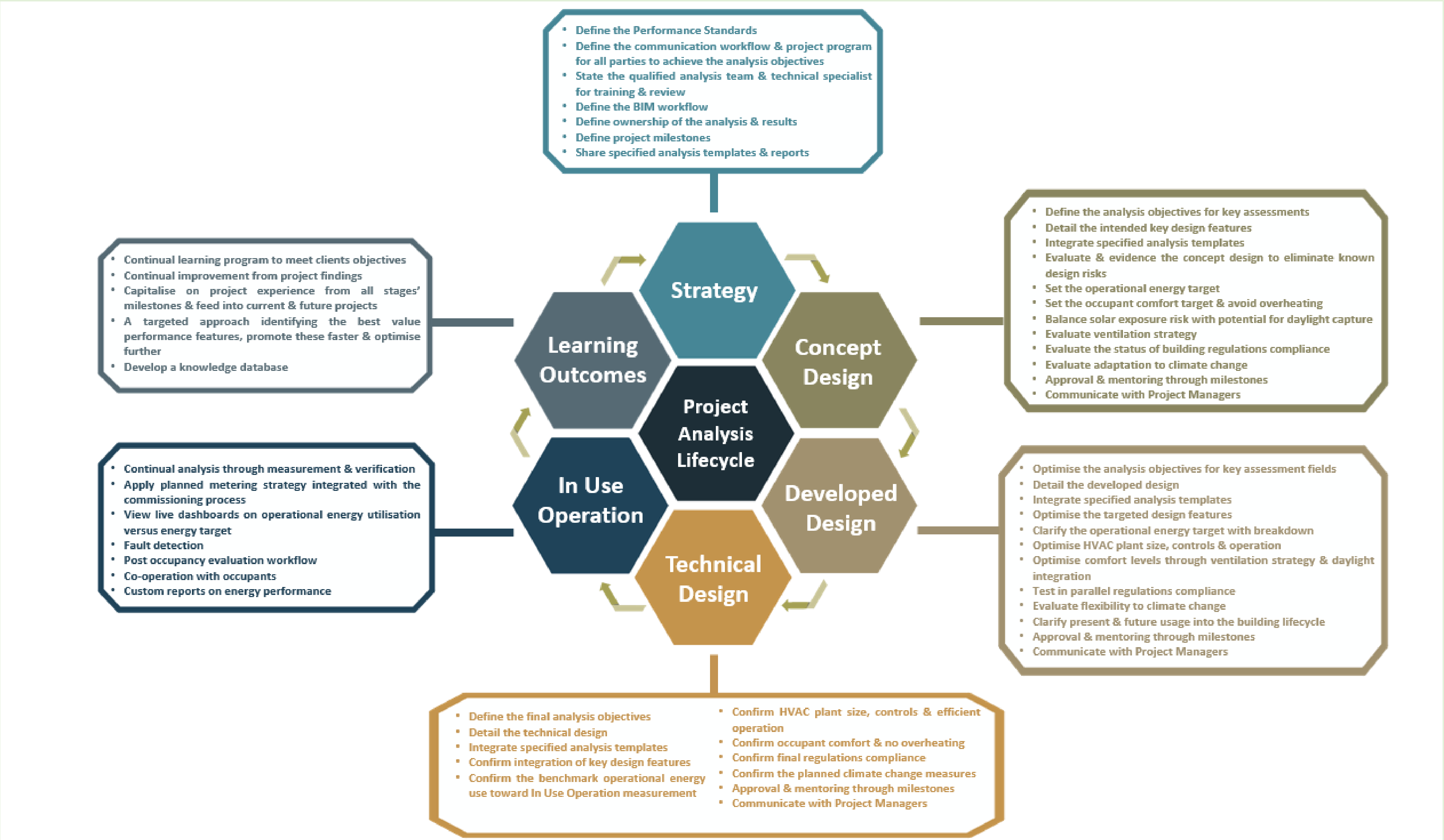
The use of common BIM and analysis platforms enables deliverables to be defined at each stage in the building lifecycle:



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