HEAT

Hospital Environmental Appraisal for Thermal-comfort

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# Overview

## What is HEAT?

HEAT refers to Hospital Environmental Appraisal for Thermal-comfort. It is an evidence-based design tool created based on 52 pieces of research evidence that seeks to enhance decision-making related to patient thermal comfort (PTC) issues in inpatient wards. The framework of the tool is based on eight essential design domains that are; design flexibility, coordination, adaptive opportunities

, temperature ranges, activity level, external shading, building monitoring and airstream. Eight non-technical statements are driven from design domains to address common PTC issues. Hence, each statement provides a list of design recommendations to inform a variety of solutions that would be considered at several design phases.

## Who should use HEAT?

HEAT is best used by healthcare planners, architects, MEP engineers (mechanical, electrical, plumping), facility managers and project managers to optimise the PTC demands by applying and testing a variety of design solutions through several design stages. It could be also used to convince stakeholders of the value of selected design interventions on PTC with clear trade-off designs opportunities.

## What are the benefits of using HEAT?

HEAT is a useful tool that can be used to share knowledge and information related to PTC, as its structure consists of eight multidisciplinary aspects (design domains) related to external building design and indoor environmental quality (IEQ). This information can be considered from the strategic definition of the project to post-occupancy for improvement of such a design scheme.

## What are the HEAT features?

PTC requirements are consolidated into design recommendations that can be used by designers to enhance decisions during the development of a design scheme. It has a flexible interface that may be used for different projects. HEAT features three interfaces, each having a particular approach that reports an average score based on the available information and intended use. The tool shares the same information and levels of detail among all approaches and the only difference is the scoring system.

## What is required?

To use HEAT, design documents are needed to assess the design scheme such as drawings, calculated heating/cooling loads, utilisation rates of inpatient wards, energy auditing, (if the building is occupied), post-occupancy evaluation (POE) from previous projects, satisfaction surveys completed by patients and project and facility managers’ reports, etc. This is all information needed to facilitate use of the tool in an effective manner. These documents give the design team a wide understanding of all key aspects that affect the hospital thermal environment to see if conflicts appear later.

## At what phases of design should the HEAT be used?

HEAT offers a multitude of information at several design phases starting from strategic definition until post-occupancy. It provides design guidance that may be integrated into the cycle design process and implemented in variety of hospital contexts either nationally or internationally.

# HEAT Instructions

HEAT is a Microsoft Excel spreadsheet and contains six internal sheets; Read me, approach 1, approach 2, approach 3, summary and an evidence database (detailed in section 6). The use of each sheet is detailed as follows:

## Spreadsheets

### ‘READ ME’

The read me sheet gives the design team a quick snap-shot how to use HEAT according project stage and focus of interest. Three approaches are briefly described in order to pick the most appropriate approach that suits the project’s goal(s). In advance, the project goal(s) can be discussed earlier, and then a particular approach may be selected.

### Approach 1

This approach can be used to evaluate an existing design scheme as it provides extra information on how the design quality is enhanced in terms of a patient’s thermal environment. It can also be used as an informative guide that covers the main aspects of the thermal environment and to check if the design brief considered these demands to enhance their decision-making to PTC issues. These design recommendations appear as guided text under each statement in Approach 1 and help for a better understanding of that particular statement. In addition, it adds more detailed information to achieving a realistic score.

### Approach 2

In this approach, the designers can have two scores for each statement – the baseline score allows the design team to rate the current design scheme based on design recommendations provided by the tool, while there is an empty box for suggestions made by the design team to improve the design statement (domain). After that the designers can rate the statement again including the suggestions that they made. At the end there are two total scores: the baseline score and the improved score. Significant differences can be noted if designers suggest adding/amending any design recommendation based on the available resources and building codes in selected countries. In approach 2, those design interventions help to provide examples for a design team to improve baseline conditions based on the available alternatives in each design scheme and especially specific-climate contexts.

### Approach 3

The uniqueness of Approach 3 allows each statement to have a separate average score. This can be done by rating each design recommendation from 1–6 on the Likert scale under each statement. Designers have the option to select ‘unable to score’ if the suggested design recommendation does not fit into their design scheme for any reason, and it would then be excluded from the calculated score for that statement. Another vital feature of this approach is that designers can add their suggestions or accessible design solutions under ‘option’ based on the current situation or common practices in a country, without any limitations. The tool is flexible, and there can be up to three additional options that are not mentioned in the original design recommendations. These options can be rated too, which will reflect on the average score of the particular statement.

### Summary

The design team reports the most suitable approach and how its results can be incorporated in the current design scheme or can enhance several decisions related to PTC. Also, it should mention how points of weakness can be overcome by designers and the additional work required in cases where suggestions are made.

## HEAT accessible features

Selected features were employed on the sheets to facilitate use of the tool and enhance its usability and readability:

* Design domains were matched individual statements and its relevant design issue.
* Hyperlinks next to statements allow access to supporting evidence from evidence database.
* Guidance layer (design recommendations) under each statement with expand & collapse icon allows detailed information to be displayed or hidden, which offers a spectrum of design recommendations that support the accomplishment of the certain statement.
* An option to record notes for each statement is also available.
* Radar chart in Approach 3 to show the average score of each domain and to visualise any deficiency at any design domain that had a low score, expressing 6 as maximum and 0 as minimum.

# HEAT statements

### 1 Design Flexibility

**Stat 1. The design is sufficiently flexible to accommodate inpatients’ conflicting and varied thermal needs during all design phases and takes into account patient circumstances.**

Optimally flexible designed patient rooms should be able to accommodate an often-conflicting variety of patient thermal environments needs concerning; i) the severity of their medical conditions, ii) demographic differences of vulnerable and elderly, iii) patients with reduced metabolic rates (low mobility). Examples of flexible design are:

* The HVAC system should be capable of intelligently monitoring the supply and return air temperature by correcting (adding or removing moisture to/from the air) the indoor relative humidity (Rh) percentage before it strays out of the acceptable range (30-60%).
* Isolation rooms can be used as a regular patient room when needed by enabling the HVAC system to switch between positive, negative and equal pressurisation.
* Patient rooms must have an HVAC risk assessment that maintains the thermal environment in case of system failure or maintenance.
* Ensuring inpatient variety of thermal comfort demands are explained clearly in the design brief alongside the code requirements.

### 2 Coordination

**Stat 2. A high level of coordination between architects and MEP engineers should be retained through design development to ensure no compromise related to inpatient thermal requirements occurs.**

Close coordination is recommended in patient rooms, as a compromise to any design intervention or requirement is highly expected due to a clear divide between MEP (mechanical, electrical, and plumbing) engineers and architects’ tasks despite overlaps and trade-offs involving both disciplines. **Examples of high level of coordination are:**

* Architects and healthcare planners should work closely with MEP engineers to ensure the delivery of patient thermal requirements through the design process.
* A large amount of MEP items being added to a patient room needs to be orgainsed without affecting the thermal environment.
* Compromise can happen at the technical design stage due to system prerequisites or unforeseen trade-offs although they may be planned during the early design stages.

### 3 Adaptive opportunities

**Stat 3. Patients can adapt their rooms via various means, such as by opening or closing windows and using curtains.**

Several adaptive and passive methods help patients to adapt with the indoor environment in order to obtain fresh air and to change the room’s temperature. Examples of adaptive and passive design strategies:

* Sufficient partially openable windows (up to 180 mm), note: windows are not openable in places like mental facilities and countries that have extreme climates as they cannot maintain the indoor quality by the HVAC equipment.
* Curtains/blinds can be automatic, so patients have fully automatic control from their beds to reduce direct solar radiation.
* Portable heaters made accessible to the patient bed, particularly during cold seasons.
* Opportunities for thermal adaptation should be outlined in case of double- or multi-occupancy beds based on building heating/cooling system or external conditions. In multi-bed rooms during winter, there is a chance for stored heat into a room, because generally, the heating (radiators) is on at a set temperature that will be comfortable for some patients but not for all.

### 4 Temperature Range

**Stat 4. The design of the inpatient room should be resilient over a feasible range of internal set temperatures without compromising the acceptable indoor air quality limits.**

The temperature within patient rooms has set points over a practical range due to patient personal and medical preferences and needs. The current temperature range for patient rooms as classified in ASHRAE 170-17 Ventilation of Health Care Facilities is 21-24C. (This excludes isolated rooms as they have different requirements like negative pressure and several infection control criteria). Examples of adaptive and passive design strategies:

* The proposed temperature range can be extended to ±5 ˚C from setpoint (e.g. 20-25 ˚C). Concomitantly, it should maintain the balance between temperature and indoor air quality (IAQ) parameters such as relative humidity, air change rate, carbon dioxide and monoxide levels within inpatient rooms.
* The design of the HVAC system should be capable of offering this margin to control the temperature by patients without trespassing the limits.
* This range is controlled by a separate thermostat that is either portable or wall-mounted to allow more control of the temperature in the space.
* The thermostat must be positioned away from direct sunlight to avoid false temperature readings.

### 5 Activity Level

**Stat 5. Increasing a patient’s activity levels generates internal body heat. The design, therefore, allows patients to walk around and spend time outside their room.**

The design should allow patients to increase their activity levels if their current medical condition is stable. The design facilitates access to an allocated outdoor area from the inpatient ward zone. Examples of design to increase patient activity levels:

* Indoor spaces are dedicated for social interaction.
* The outdoor area is best oriented to face south or north, and solely for patient use.
* The design of corridors should avoid any overlap between public access areas (lifts and stairs for staff and services) and patient routes.
* These areas are essential, especially in mental health wards for patients who are hospitalised for long periods alongside a risk-assessed plan to ensure their safety.
* Indoor spaces are necessary especially if outdoor ones are impossible to be included within existing hospitals or where regulations restricting this type of use exist.

### 6 External Shading

**Stat 6. Any external shading strategy should be optimised for different orientations of each façade of the building to ascertain its efficiency in reducing the adverse effects of the external climate.**

External shading device(s) (either adaptive or fixed) should be designed for each façade orientation exposed to solar radiation, thus reducing the heating and cooling loads while providing adequate thermal and visual environment. Examples of external shading strategies:

* Selected shading devices (canopies, louvres, vertical fin, and vertical/horizontal blades) should be optimised by orientation and local sun-paths through dynamic simulation that includes all building fabric characteristics (i.e. walls, windows and roof materials).
* The window-to-wall ratio of patient rooms should be specified to minimise excessive solar gains and to avoid glare whenever possible where external shading devices have not been used.
* Shading needs to be especially considered for inpatient wards facing any orientation that has an excessive solar gain due to site restriction.

### 7 Building Monitoring

**Stat 7. Highly efficient building monitoring systems (BMS) should be considered to control indoor environments in inpatient rooms.**

BMS can provide comprehensive auditing facilities for monitoring the parameters related to the thermal environment and IAQ such as indoor temperature, mean radiant temperature, relative humidity, air velocity, air change rate (ACH), and indirect parameters such as daylight. Examples of BMS benefits:

* 7.1. BMS data are used to correlate patient demographics information (e.g. age group and health condition) to thermal environment parameters to show patient satisfaction limits.
* 7.2. It can be used to monitor the system efficiency all the time and particularly peak hours/days/seasons.
* 7.3. It provides medical staff information about particular patient rooms that may benefit from more detailed monitoring.

### 8 Airstream

**Stat 8. The airstream outlet from grilles or diffusers supplying the patient room should be located away from patient beds to minimise draught and discomfort conditions.**

Supply and extract schemes should be located within ideal locations and positions. Examples of airstream outlet positions and locations:

* The diffusers should be positioned away from the patient’s head (if positioned vertically) and positioned away from the patient’s bed (if positioned horizontally) so to minimise draughts and to avoid patients’ feeling uncomfortable due to the HVAC equipment.
* As grilles and diffusers respond to other technical devices in the room, the design should make explicit what takes priority, and the ductwork should enable this hierarchy.
* Standardising the layout of patient rooms helps to ensure that diffusers are located consistently in an ideal place.
* Low-velocity supply air outlets should comply with Group A, D, E classified in chapter 20 of the 2017 ASHRAE Handbook—Fundamentals.
* Whenever diffusers are too far from the bed, the influx of the air has to be increased to maintain adequate comfort levels.

# Scoring system

## How to use HEAT?

HEAT is most effective if two rounds of assessment are conducted; one for the lead individual designers and the other as a discussion with the whole design team to identify and resolve any deficiencies. The discussion can be in the form of evaluation focus groups or workshops to identify key areas that require improvement and to reveal trade-off designs and conflicts that occur or expected as a result of implementing design solutions in the tool. The projects design priorities need to be clearly defined to effectively facilitate these in-depth discussions.

## 6-point Likert agreement scale

HEAT adopts a six-point Likert scale (expressing the level of agreement) to aid in determining the applicability of a statement:

* Completely disagree (1)
* Mostly disagree (2)
* Slightly disagree (3)
* Slightly agree (4)
* Mostly agree (5)
* Completely agree (6)
* Unable to score

The ‘unable to score’ is used if insufficient information or no supporting documents are provided for specific statements. It may be noted that when users select ‘unable to score’ for a statement, that particular statement is excluded and does not affect the total score. The use of each of the approaches followed by its average score is detailed in 4.3.

## How to calculate average scoring per approach?

### Approach 1

Eight statements, each statement has a score from 1—6 then all scores will be summed and divide the total score on the number of statements, which are 8.

### Approach 2

Eight statements, each statement has a baseline and improved score to be rated from 1—6 then all scores will be summed and divide the total score on the number of statements. At the end two average scores presented for this approach; baseline and improved, respectively.

### Approach 3

Approach 3 is more specific, eight statements, each statement has listed several design recommendations to be rated from 1—6, the score of these recommendations will be summed and divided by number of recommendations. So, each statement will have its own average score and the result of approach 3 is visualised on radar chart.

# HEAT Interface

### Approach 1

*(only single statement is shown for each approach due to space limit)*

Graphical user interface, text, application

Description automatically generated

### Approach 2

*(only single statement is shown for each approach due to space limit)*

Graphical user interface, text, application, email

Description automatically generated

### Approach 3

*(only single statement is shown for each approach due to space limit)*

Graphical user interface, text, application

Description automatically generated

A picture containing text

Description automatically generated

# Evidence database

The evidence database is linked to all HEAT statements and can be accessed from the same Excel Spreadsheet. Design teams can refer to the database if they wish to see how research findings are converted into practical summaries or for research purposes. Excel spreadsheets related to HEAT can be accessed from the University of Bath Research Data Archive on at <https://doi.org/10.15125/BATH-00000>

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Year | Source | Design domain | Evidence level | Findings related to thermal comfort/Practical summary | Link | Bibliographic information |
| 1 | 2016 | Research | Design flexibility | 3 | **n= 49 occupants including 30 patients, C.l = 95%**   * PMV mismatched the actual thermal sensation for patients which was on warm side. * An inadequacy of PMV model for patient population is proved. * Females are sensitive to the thermal environment as they reported uncomfortably hot and cold conditions more than males. * Gender and age must be accounted when thermal environment is assessed. | <https://www.sciencedirect.com/science/article/abs/pii/S0003687015000472?via%3Dihub> | Del Ferraro, S., Iavicoli, S., Russo, S., & Molinaro, V. (2015). A field study on thermal comfort in an Italian hospital considering differences in gender and age. *Applied Ergonomics*, *50*, 177–184. <https://doi.org/10.1016/j.apergo.2015.03.014> |
| 2 | 2016 | Research | Design flexibility | 8 | **n= 60 full publications, review paper**   * Existing thermal comfort standards are not suitable for patient population in healthcare facilities. * Indoor environments parameters, particularly thermal environment has influence on several aspects; well-being, safety, work conditions, sleep quality, patient satisfaction and health status of all occupants. | <https://eprints.qut.edu.au/108842/3/108842.pdf> | Salonen, H., Kurnitski, J., Kosonen, R., Hellgren, U.-M., Lappalainen, S., Peltokorpi, A., Morawska, L. (2016). The effects of the thermal environment on occupants’ responses in health care facilities: A literature review. In *9th International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings (IAQVEC2016), 23-26 October2016, Songdo, Incheon, Republic of Korea*. |
| 3 | 2008 | Research | Design flexibility | 2 | **n= 81 occupants including 36 patients, C.l = 95%**   * Very low humidity levels were found in hospitals which led to promote the spread of influenza viruses. * After humidifiers installed, humidity levels reach the optimum range while patients’ perceptions didn’t significantly change to thermal environment. * Setting humidifiers in patient rooms is a sufficient approach to overcome the issues of lower humidity levels especially during the winter. | <https://www.sciencedirect.com/science/article/abs/pii/S0003687007000592?via%3Dihub> | Hashiguchi, N., Hirakawa, M., Tochihara, Y., Kaji, Y., & Karaki, C. (2008). Effects of setting up of humidifiers on thermal conditions and subjective responses of patients and staff in a hospital during winter. Applied Ergonomics, 39(2), 158–165. <https://doi.org/10.1016/j.apergo.2007.05.009> |
| 4 | 2012 | Research | Design flexibility | 1 | * Patients prefer a warmer thermal environment than neutral sensations. * Type of medications can affect patients’ metabolism. * ﻿Several conditions are most likely to increase as a result of cold (uncomfortable sensation) such as; inattentiveness, * Shivering, restlessness, aggravate pain, muscular and joint tension and overall patient dissatisfaction. * Patients hypothermia can be prevented by using active warming devices instead of beddings covering. These devices better to be installed above patients for more performance. * Exceeding acceptable humidity would increase the growth of bacteria and thermal discomfort while lower levels can cause blood coagulation, skin and nose drying, throat irritation and respiratory problems. * International standards have recommended levels of relative humidity from 30% to 60%. | <https://www.sciencedirect.com/science/article/abs/pii/S1364032112002377?via%3Dihub> | Khodakarami, J., & Nasrollahi, N. (2012). Thermal comfort in hospitals - A literature review. *Renewable and Sustainable Energy Reviews*, *16*(6), 4071–4077. <https://doi.org/10.1016/j.rser.2012.03.054> |
| 5 | 2008 | Research | Design flexibility | 4 | **A review paper of evidence-based healthcare design**   * It was evident from multiple rigorous studies that single-bed room has major impact in improving health outcomes. | <https://journals.sagepub.com/doi/10.1177/193758670800100306> | Ulrich, R. S., Zimring, C., Zhu, X., DuBose, J., Seo, H.-B., Choi, Y.-S., … Joseph, A. (2008). A Review of the Research Literature on Evidence-Based Healthcare Design. *HERD: Health Environments Research & Design Journal*, *1*(3), 61–125. [https://doi.org/10.1177/193758670800100306](https://doi.org/10.1177%2F193758670800100306) |
| 6 | 2007 | Research | Design flexibility | 2 | **n= 927 patients,** **confidence interval (C.l) = 95%**   * Physical strength had a significant impact on patients’ thermal sensations while gender, age and acclimatisation showed no effect. * Frail patients expected a warmer indoor environment. * The thermal neutral effective temperature (ET\*) is about 0.3 °C higher for frail patients than vigorous. * A difference of 1.5 °C in winter and 0.8 °C in summer was found in the preferred effective temperature between the frail and vigorous population, respectively. * Indoor temperature ranges were determined using TSV and TPV scales. A vicinity of 20.7–26.2 C ET\* is close to the range from ASHRAE-55 between 20.3–26.7 ﻿°C ET\* for all year. * Range 21.4– 25.8 1°C ET\* estimated by TPV was narrow to comfort range suggested by ASHRAE-55. | <https://www.sciencedirect.com/science/article/abs/pii/S0360132306002083?via%3Dihub> | Hwang, R. L., Lin, T. P., Cheng, M. J., & Chien, J. H. (2007). Patient thermal comfort requirement for hospital environments in Taiwan. *Building and Environment*, *42*(8), 2980–2987. <https://doi.org/10.1016/j.buildenv.2006.07.035> |
| 7 | 2013 | Research | Design flexibility | 2 | **n= 3 medical wards, confidence interval (C.l) = 95%**   * Low thermal satisfaction levels correlate with profiles of higher temperatures. For example, the staff is more thermally unsatisfied with the wards that have higher temperature values (Paediatrics). In comparison, the patients tend to be more contented with wards that have lower values (Orthopaedics). * In contrast, the PMV profiles sometimes fail to correlate with the reported thermal comfort. For example, staff thermal comfort associated with Internal Medicine in in-patient rooms is higher compared to Orthopaedics; however, the values of PMV are closer to zero than Internal Medicine. * In the in-patient room, the mean values of indoor temperature were around 26-27 °C, while the maximum values exceeded 29 °C. * The variance in the recorded indoor temperatures exhibited a deficit in the system building, design, and maintenance; therefore, the building envelope should be given specific attention, particularly the corner rooms in a building renovation optic. * Ultimately, the structure of in-patient rooms should be restructured to increase per capita room space, reduce the number of beds, and allow a more relaxed stay and better privacy considered as fundamental in such buildings | <https://www.sciencedirect.com/science/article/pii/S0360132312002235?via%3Dihub> | De Giuli, V., Zecchin, R., Salmaso, L., Corain, L., & De Carli, M. (2013). Measured and perceived indoor environmental quality: Padua Hospital case study. Building and Environment, 59, 211–226. <https://doi.org/10.1016/j.buildenv.2012.08.021> |
| 8 | 2008 | Research | Design flexibility | 6 | * ﻿The capabilities of thermal storage intrinsic in building structure mass may have a crucial impact on the temperature within the space or operation and performance of the HVAC system. * The efficient structural mass application for the thermal storage minimises the consumption of building energy as well as delaying and reducing the cooling loads and peak heating. * Conceivably, the most appropriate application of thermal mass in minimising the consumption of energy involves buildings that consist of passive solar techniques. | <https://meridian.allenpress.com/jgb/article/3/1/44/116316/Energy-Efficient-Systems-and-Strategies-for> | Krarti, M. (2008). Energy Efficient Systems and Strategies for Heating, Ventilating, and Air Conditioning (HVAC) of Buildings. *Journal of Green Building*, *3*(1), 44–55. <https://doi.org/10.3992/jgb.3.1.44> |
| 9 | 2017 | Research | Design flexibility | 1 | * We conducted a literature review in an attempt to decide if the radiant systems enhance better, lower, or equal thermal comfort compared to all the other systems * We did not include the studies whose focus was only on all air or radiant systems as they did not provide data on our comparison * Five studies were identified from the literature review that failed to demonstrate a thermal comfort preference between the radiant and all-air systems. Only three researches showed a radiant system preference. | <https://www.sciencedirect.com/science/article/abs/pii/S0360132316304218?via%3Dihub> | Karmann, C., Schiavon, S., & Bauman, F. (2017). Thermal comfort in buildings using radiant vs. all-air systems: A critical literature review. Building and Environment, 111, 123–131. <https://doi.org/10.1016/j.buildenv.2016.10.020> |
| 10 | 2018 | Research | Coordination | 5 | * ﻿A total of 63 design checklist items were developed for mechanical, electrical and plumbing (MEP) systems’ coordination to enhance overall quality and productivity beside minimising waste in resources. * The design checklist was classified into important categories;   a) Careful consideration and communication between the mechanical, structural and architectural design teams.  b) Constant communication between the electrical and the other design teams.  c) Fire safety consideration.   * This checklist is vital to ensure proper mechanical coordination and to avoid electrical design conflicts. | <https://www.emerald.com/insight/content/doi/10.1108/BEPAM-01-2018-0009/full/html> | Hassanain, M. A., Aljuhani, M., Sanni-Anibire, M. O., & Abdallah, A. (2019). Interdisciplinary design checklists for mechanical, electrical and plumbing coordination in building projects. *Built Environment Project and Asset Management*, *9*(1), 29–43. <https://doi.org/10.1108/BEPAM-01-2018-0009> |
| 11 | 2014 | Code | Coordination | 7 | * The examples of the design’s main components for the healthcare building include passive thermal comfort, whereby the building design’s fabric should assist in establishing thermal comfort conditions. * Issues to consider are reducing solar gain, controlling the infiltration, high thermal insulation, and passive summer cooling. | <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/316247/HBN_00-01-2.pdf> | Health Building Note 00-01 (2014). General design guidance for healthcare buildings. *Department of health*. |
| 12 | 2019 | Research | Coordination | 1 | * ﻿A review paper on effects of indoor environmental parameters related to building heating, ventilation, and air conditioning systems on patients' medical outcomes * Minimal research was found on the suitable ranges of indoor environmental parameters: temperature, humidity and air change per hour. * Evidence come from simulation based-research is more than patient-oriented evidence to inform hospital guidelines. * For simulations and experiments, validation is required by physical measurements to ensure the results are similar. * More multidisciplinary research is required to cover different user groups such as, researchers, patients, building owners, facility managers, and maintenance staff studies are needed, in order to enrich evidence‐based decisions regarding the optimum ranges to improve patient‐oriented outcomes. * To identify optimal ranges for humidity, temperature, ACH besides suitable ventilation design strategies, evidence from multidisciplinary research covering molecular biology testing, advanced computer modelling, experimental testing, and on‐site experimental designs is necessary. * These variables vary from each hospital zone to another due to different unique occupants and different functionality. | <https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12531> | Shajahan, A., Culp, C. H., & Williamson, B. (2019). Effects of indoor environmental parameters related to building heating, ventilation, and air conditioning systems on patients’ medical outcomes: A review of scientific research on hospital buildings. *Indoor Air*, *29*(2), 161–176. <https://doi.org/10.1111/ina.12531> |
| 13 | 2013 | Code | Coordination | 7 | * The design process of HVAC must be coordinated in-depth with the other design fields to succeed. * The involvement of HVAC engineers should not begin later than the pre-concept design, as well as continue until the completion of the design. * This chapter consists of a discussion involving the design features fundamental in hygienic design, comfort conditioning, and good air quality. To obtain these features, the early influence of the HVAC designer on floor plan features affecting space availability and equipment location or the building arrangement is required. * Controllers in a microprocessor-based system can be integrated into BMS through a computer to allow additional control functions and monitoring. Features of microprocessor-based system are: provide precise control, enable energy management control, allow self-tuning, incorporate proportional-plus-integral (and when needed, derivative) control loops, can easily perform complex sequences of control, support global control (e.g., can share outdoor air temperature or air-side economizer status), allow remote setpoint adjustment and display, can use pneumatic actuators, provide extensive and easy-to-use trending and alarming functions and are usually proprietary (to some extent). | <https://www.ashrae.org/technical-resources/bookstore/hvac-design-manual-for-hospitals-and-clinics> | Koenigshofer, D. (2013). *HVAC Design Manual for Hospitals and Clinics*. ASHRAE. |
| 14 | 2016 | Research | Coordination | 3 | * This paper consists of a formal schema that can be applied to seize clash features and its associate solutions during the coordination of MEP. * The main purpose of representation schema involves capturing the experiential knowledge to support the future decision; others include the provision of formal structure for documenting the clash to support coordination management. * The presented schema combines the discoveries from a laboratory experiment, previous research, and surveillance from field studies. Project data was used to validate the results. | <https://www.sciencedirect.com/science/article/pii/S092658051500268X?via%3Dihub> | Wang, L., & Leite, F. (2016). Formalized knowledge representation for spatial conflict coordination of mechanical, electrical and plumbing (MEP) systems in new building projects. Automation in Construction, 64, 20–26. <https://doi.org/10.1016/j.autcon.2015.12.020> |
| 15 | 2013 | Code | Adaptive opportunities | 7 | **Code requirements (refer to section 2)**   * Specific technical requirements suggested by HBN 00-10 Part D as follow: * Restrictor – mechanical device that limits the movement of an opening light so that an opening of not more than 100 mm is achieved at any point even with the application of a significant additional opening force. It can either be fixed (that is, cannot be overridden) or can only be overridden by means of a removable key or other device. They should only be fitted using tamper-proof fixings. * Secondary window – a glazed unit added to an existing glazed window to improve the thermal and acoustic performance. * Thermal barrier – a spacer of insulating material incorporated in a frame to separate the outer surface from the inner surface to improve its thermal performance. * The use of tinted, solar-reflective or other specialised or coloured glass should only be used after the clinical effect has been considered (see also paragraphs 3.7–3.9). * Orientation of the building and the different elevations also need to be taken into consideration. | <https://www.gov.uk/government/publications/guidance-on-flooring-walls-and-ceilings-and-sanitary-assemblies-in-healthcare-facilities> | Department of Health. (2013). Health Building Note 00-10 Part D: Windows and associated hardware. |
| 16 | 2010 | Research | Coordination | 8 | * ﻿If the good standards of operation, commissioning, maintenance, and design are followed, a healthy solution will be achieved. * To prevent indoor-air pollution, the following steps should be observed: (1) the design and building operation correlate with the art’s state about conducted activities and building operation; (2) the performance of the building is in line with the specifications about operating parameters and pollutant concentrations; (3) effective monitoring of step 1 and 2. * Indoor-air problems might still occur even if the preventive steps are observed due to several reasons discussed in this paper. * In such instances, it is essential for hospital facility managers, hospital infection control officers, and HVAC engineers to be aware that there might not be an indication of problems. However, they could still occur, they should not ignore warnings especially if they are associated with human ill health, and they should be innovative and open to novel investigation methods. * To sustain the acceptable indoor air quality (IAQ), it is essential to maintain the ventilation, clean heating, and air-conditioning (HVAC) systems. | <https://core.ac.uk/download/pdf/79627196.pdf> | Ramaswamy, M., Al-Jahwari, F., & Al-Rajhi, S. M. M. (2010). IAQ in Hospitals–Better Health through Indoor Air Quality Awareness. In Proceedings of the Tenth International Conference Enhanced Building Operations, Kuwait. |
| 17 | 2018 | Research | Adaptive opportunities | 2 | **n= 389 occupants including 305 patients, confidence interval (C.l) = 95%**   * The measured thermal environment results were not in line with the DOSH 2010 and MS 1525-2014 guidelines (Malaysian standards) by 54% and 73% indicating non-compliance with local guidelines similar to evidence. * TSVs for patients were ‘slightly cold’ associated with ‘no change’ preference needed in thermal preference scale. * Patients tend to be ‘slightly dry’ in their choice in humidity sensation and prefer ‘a bit more humid’ conditions. * Patients medical conditions significantly had influence on overall comfort, thermal preference and air quality while age, gender and length of stay show no noticeable effect on thermal comfort parameters. * The study recommended a need for revised standards for thermal environments in patient rooms to a warmer temperature range. | <https://www.sciencedirect.com/science/article/abs/pii/S0378778818319443?via%3Dihub> | Khalid, W., Zaki, S. A., Rijal, H. B., & Yakub, F. (2018). Investigation of comfort temperature and thermal adaptation for patients and visitors in Malaysian hospitals. *Energy and Buildings*, *183*, 484–499. <https://doi.org/10.1016/j.enbuild.2018.11.019> |
| 18 | 2005 | Research | Adaptive opportunities | 3 | **n= 75 occupants including 35 patients, C.l = 95%**   * Patients and staff perceptions were differed during winter than summer despite the measured temperatures were similar in both seasons. * Patients were not satisfied with their indoor air temperatures in summer and winter. * Patients were experienced very low humidity in the winter. * Limited thermal adaptation methods such as, blanket used to control level of clothing for patients due to their light pull-gown. | <https://www.sciencedirect.com/science/article/abs/pii/S0378778804003470?via%3Dihub> | Skoog, J., Fransson, N., & Jagemar, L. (2005). Thermal environment in Swedish hospitals: Summer and winter measurements. Energy and Buildings, 37(8), 872–877. <https://doi.org/10.1016/j.enbuild.2004.11.003> |
| 19 | 2012 | Research | Adaptive opportunities | 2 | **n= 10 partitions of the hospital (﻿building was partitioned based on application type, usage of the rooms and the level of the activity)**   * In winter, PMV model was tended to a warm side in the radiology, urgency wards and surgery rooms. * The surgery section reported the highest PPD percentage (Predicted Percentage Dissatisfied) based on the survey in summer and winter. * The surgery rooms may cause thermal stress due to its insulation and lack of air exchange even if the PMV reached the acceptable limits. * Leakage in energy proved due to installed heating system is not sufficient as thermal discomfort to cold side is perceived in winter, it can be seen that no significant difference detected between PMV and TSV inside and outside the hospital. * ﻿Thermal discomfort conditions in sick buildings were frequently reported in summer more than winter. * The study proposed several design solutions to improve thermal comfort conditions and to reduce high energy demands; insulation of all doors and windows, installing curtains for windows to prevent entering solar radiation into the rooms in summer and leaking heat to outside in winter, training the personnel not to use miscellaneous systems independent from the central heating system. | <https://www.sciencedirect.com/science/article/pii/S0003687012000385?via%3Dihub> | Pourshaghaghy, A., & Omidvari, M. (2012). Examination of thermal comfort in a hospital using PMV-PPD model. *Applied Ergonomics*, *43*(6), 1089–1095. <https://doi.org/10.1016/j.apergo.2012.03.010> |
| 20 | 2011 | Research | Adaptive opportunities | 2 | **n= 99 patients, confidence interval (C.l) = 95%**   * No statistical significance difference was found between PMV and TSV for all wards except neurology. * TSVs for patients were higher than PMV that predicted by objective measurements meaning that neutral (comfort) temperatures predicted by PMV are lower than those estimated by TSV for normal occupants and young population. * PMV and PPD are not suitable to predict thermal responses in neurology ward. | <https://www.sciencedirect.com/science/article/pii/S0360132310003665?via%3Dihub> | Verheyen, J., Theys, N., Allonsius, L., & Descamps, F. (2011). Thermal comfort of patients: Objective and subjective measurements in patient rooms of a Belgian healthcare facility. *Building and Environment*, *46*(5), 1195–1204. <https://doi.org/10.1016/j.buildenv.2010.12.014> |
| 21 | 2011 | Research | Adaptive opportunities | 1 | * ﻿A review paper of ventilation of multi-bed hospital wards in the tropics * The indoor temperature for patient rooms should be aligned to their thermal comfort requirements and taken into account the discrepancy of patient body temperature regulatory functions due to severity of medical conditions. * A desirable temperature and satisfactory comfort conditions aid patients in healing process and enhance their moods. * The issue of applicability of standards in tropics is obvious as they only have been published with consideration on temperate climates. | <https://www.sciencedirect.com/science/article/abs/pii/S0360132310003446?via%3Dihub> | Yau, Y. H., Chandrasegaran, D., & Badarudin, A. (2011). The ventilation of multiple-bed hospital wards in the tropics: A review. *Building and Environment*, *46*(5), 1125–1132. <https://doi.org/10.1016/j.buildenv.2010.11.013> |
| 22 | 2013 | Research | Adaptive opportunities | 2 | * The paper’s subject involves the evolution of a simple model to roughly calculate PMV in various medium environments that measures only the relative humidity and air temperature. * The work references to Rohles model [3,4], which was established in the seventies and appropriate for low clothing thermal insulation values (Icl= 0.6 clo). * The objective of this research involved updating the Rohles model and extending it to a wider Icl range (0.25–1.65 clo). * The University of Pavia and Perugia provided the data which was collected during a wide exploratory campaign in divergent seasons (over 1100 questionnaire and over 450 instrumental surveys) in open space offices and classrooms (sedentary conditions) considered to have HVAC systems. | <https://www.sciencedirect.com/science/article/abs/pii/S0306261912008082?via%3Dihub> | Buratti, C., Ricciardi, P., & Vergoni, M. (2013). HVAC systems testing and check: A simplified model to predict thermal comfort conditions in moderate environments. Applied Energy, 104, 117–127. <https://doi.org/10.1016/j.apenergy.2012.11.015> |
| 23 | 2011 | Research | Adaptive opportunities | 1 | * ﻿An adaptive approach has been recommended considering the above (PMV) approach of evaluating thermal conditions based on the exchange of heat between the surrounding environment and the human body. * It presumes that people have the ability to adapt to the thermal environment through expectations’ relaxation and acclimatisation to the conditions they are exposed to or through behavioural adjustments such as modifying the insulation clothing value. * Consequently, the building users can feel comfortable in various conditions compared to the conditions prescribed by using the PMV index. | <https://www.sciencedirect.com/science/article/pii/S0360132310003136?via%3Dihub> | Frontczak, M., & Wargocki, P. (2011). Literature survey on how different factors influence human comfort in indoor environments. Building and Environment, 46(4), 922–937. <https://doi.org/10.1016/j.buildenv.2010.10.021> |
| 24 | 2000 | Research | Temperature range | 2 | * The paper has discussed research concerning ventilation system performance in a typical patient room using calculations of several ventilation indices as well as CFD modelling. * The findings exhibit that the application of baseboard heating is essential in uttermost weather conditions. In specific, it is impossible to attain good occupant conditions due to the baseboard heating. * Generally, a ventilation rate of 4 ACH in the weather conditions provides adequate conditions; however, a rise to 5 or 6 AHC is considered as optimum. | <https://www.orf.od.nih.gov/TechnicalResources/Bioenvironmental/Documents/ASHRAE_transactiondoc509.pdf> | Memarzadeh, F., & Manning, A. (2000). Thermal comfort, uniformity, and ventilation effectiveness in patient rooms: performance assessment using ventilation indices. Transactions-American Society of Heating Refrigerating and Air Conditioning Engineers, 106(2), 748–761. |
| 25 | 2020 | Research | Temperature range | 2 | * n= 522 patients, a longitudinal study of 18 patient rooms in 4 inpatient wards * ﻿Over 28% and 33% of patients were uncomfortable with their thermal environment at IMC and KAMC as indicated by TSV scale. * 71% and 70% of patients sought comfortable conditions according to thermal preference scale (TPV) at IMC and KAMC, respectively. * Relative humidity ranges were complied with ASHRAE-170 which requires 60 % max. * Unneeded cooling loads were shown in both hospitals. * Internal temperature range of oncology ward is 25.3–26.8 °C. * Internal temperature range of cardiology ward is 20.1–21.8 °C. * Internal temperature range of surgical ward is 22.2–23.9 °C. * Internal temperature range of medical ward is 24.8–25.3 °C. | <https://www.mdpi.com/2075-5309/10/8/136> | Alotaibi, B. S., & Lo, S. (2020). Thermal Environment Perceptions from a Longitudinal Study of Indoor Temperature Profiles in Inpatient Wards. *Buildings*, *10*(8), 136. <https://doi.org/10.3390/buildings10080136> |
| 26 | 2019 | Research | Temperature range | 2 | * ﻿The outcomes of the study indicate that there exists an impact on the welfare between air quality and temperature as the in-patient ward’s air quality is affected when the temperature surpasses the standard value. This corresponds to the results of the research concerning Fang state showing the significant links of moisture and temperature on air quality; the air is received by humidity and temperature to ensure it has a negative impact [10]. * The findings of this study show that approximately 79% of temperature does not satisfy the standard and there is a significant part of the room that has been surpassing 24°C of the in-patient rooms. Consequently, the high temperature can be a challenge in controlling the metabolic reaction for the organism. * Also, the patient’s condition might be frustrated by the high cold temperature, hence causing inconveniences. | <https://spiroski.migration.publicknowledgeproject.org/index.php/mjms/article/view/oamjms.2019.605> | Rahayu, E. P., Saam, Z., Sukendi, S., & Afandi, D. (2019). The Factors of Affect Indoor Air Quality Inpatient at Private Hospital, Pekanbaru, Indonesia. Open Access Macedonian Journal of Medical Sciences, 7(13), 2208–2212. <https://doi.org/10.3889/oamjms.2019.605> |
| 27 | 2019 | Research | Temperature range | 1 | Healing environments consist of ventilation systems that aim to achieve conditions of thermo-hygrometric and air quality to guarantee the prevention of users from indoor and contaminants pollution, hence attaining a comfortable and adequate indoor space. Besides, this will allow the management of the processes that control the operational activities for therapeutic and diagnostic therapies. | <https://www.hindawi.com/journals/jhe/2019/8358306/> | Gola, M., Settimo, G., & Capolongo, S. (2019). Indoor Air Quality in Inpatient Environments: A Systematic Review on Factors that Influence Chemical Pollution in Inpatient Wards. Journal of Healthcare Engineering, 2019, 1–20. <https://doi.org/10.1155/2019/8358306> |
| 28 | 2016 | Research | Temperature range | 5 | **n= 236 patients, qualitative study of design features of hospital rooms**   * Perceived control was selected by 22.4% of patients to be prioritised as a second priority of valued design features of patient rooms, while 33.2% and 6% of patients were selected for positive distraction and social support, respectively. | <https://journals.sagepub.com/doi/10.1177/1937586715607052> | Devlin, A. S., Andrade, C. C., & Carvalho, D. (2016). Qualities of Inpatient Hospital Rooms. *HERD: Health Environments Research & Design Journal*, *9*(3), 190–211. <https://doi.org/10.1177/1937586715607052> |
| 29 | 2017 | Research | Temperature range | 2 | **n= 928 occupants including 451 patients, C.l = 95%**   * ﻿Patients preferred warmer temperatures, acceptable range (21.8—27.9 °C) than other occupants; visitors and medical staff * Also, the temperature range of all occupants is warmer than design norms provided by the Thai standard. * PMV is an unsuitable metric for examining thermal comfort for hospital occupants. * The study recommended that different demands of thermal comfort for hospital occupants in tropical region must be incorporated into the current use thermal comfort standards. | <https://www.sciencedirect.com/science/article/abs/pii/S0378778816320096?via%3Dihub> | Sattayakorn, S., Ichinose, M., & Sasaki, R. (2017). Clarifying thermal comfort of healthcare occupants in tropical region: A case of indoor environment in Thai hospitals. *Energy and Buildings*, *149*, 45–57. <https://doi.org/10.1016/j.enbuild.2017.05.025> |
| 30 | 2015 | Research | Temperature range | 2 | **n= 10 patient rooms (the study focused on indoor environmental conditions with no subjective data)**   * Average indoor air temperature ranged weekly from 19.6°C to 30.1°C. * ﻿Average indoor air temperature varied hourly between 19°C and 26°C and median was between 22°C and 25°C. * The indoor temperature variations caused by different patient comfort preferences as a result of their ability to adjust the room temperature. * Strong correlations were found between relative humidity and humidity ratios in patient rooms explained by the capability of fitted HVAC system and rarely effect from other patients’ activities. | <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0118207> | Ramos, T., Dedesko, S., Siegel, J. A., Gilbert, J. A., & Stephens, B. (2015). Spatial and temporal variations in indoor environmental conditions, human occupancy, and operational characteristics in a new hospital building. *PLoS One*, *10*(3). <https://doi.org/10.1371/journal.pone.0118207> |
| 31 | 2020 | Research | Activity level | 2 | **n= 120 patients, confidence interval (C.l) = 95%**   * Wide ranges of neutral (comfort) temperatures (16.2—28.8 °C, mean= 22.7; SD= 2.51), predicted by Griffith’s method, were experienced by inpatients. * Statistical significance differences were found between TSV (0.32) and PMV (-0.5) (C.l= 99%). * The idea of identifying a comfort temperature for whole patients was unsuccessful. * Very low metabolic rates (0.7 met) due to patients lean on beds most of the time. | <https://www.sciencedirect.com/science/article/abs/pii/S0360132319307735?via%3Dihub> | Alotaibi, B. S., Lo, S., Southwood, E., & Coley, D. (2020). Evaluating the suitability of standard thermal comfort approaches for hospital patients in air-conditioned environments in hot climates. *Building and Environment*, *169*, 106561. <https://doi.org/10.1016/j.buildenv.2019.106561> |
| 32 | 2018 | Research | Activity level | 5 | **n= 16 patients (semi-structured individual interviews at stroke units)**   * Suggested architectural improvements focused on the design of communal areas and meeting spaces. * Obtaining patients feedback about their physical environment as a measure for improving the provided care. * Enabling patients to walk to communal areas enhances their experience of social interactions to reduce loneliness. * The design should focus on allowing patients to communicate with outside world and improve elements for stimulate environments. * Patient experience is essential and should be integrated into the design process especially in stroke units. | <https://journals.sagepub.com/doi/10.1177/1937586718806696> | Anåker, A., von Koch, L., Heylighen, A., & Elf, M. (2018). “It’s Lonely”: Patients’ Experiences of the Physical Environment at a Newly Built Stroke Unit. *HERD: Health Environments Research & Design Journal*, *12*(3), 141–152. <https://doi.org/10.1177/1937586718806696> |
| 33 | 2013 | Research | Activity level | 2 | * ﻿Notably, it is essential to recognise the different user groups in HCFs within the same environment who may prefer diverse temperatures concerning comfort due to different acuity and activity levels, clothing, age and duration in the ward; therefore, satisfying everyone in a given space becomes difficult (Legg 1971; ASHRAE 2010; Wu 2011). * Consequently, a compromise must be made to satisfy the majority when designing and operating the thermal environments in HCFs. | <https://www.tandfonline.com/doi/abs/10.1080/17508975.2013.764839> | Salonen, H., Lahtinen, M., Lappalainen, S., Nevala, N., Knibbs, L. D., Morawska, L., & Reijula, K. (2013). Design approaches for promoting beneficial indoor environments in healthcare facilities: a review. Intelligent Buildings International, 5(1), 26–50. <https://doi.org/10.1080/17508975.2013.764839> |
| 34 | 2010 | Research | Activity level | 1 | * The paper has highlighted both the adaptive and rational approaches as well as literature reviews concerning thermal comfort. Notably, each approach is associated with various limits and potentialities. * The rational approach produces precise predictions concerning occupant thermal sensation easily and reasonably as it involves people in steady-state conditions and near sedentary activity. * However, it cannot always be relied on to give a good prediction on actual thermal sensation, especially in settings of a field study. | <https://www.sciencedirect.com/science/article/pii/S1364032110002200?via%3Dihub> | Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. Renewable and Sustainable Energy Reviews, 14(9), 2626–2640. <https://doi.org/10.1016/j.rser.2010.07.040> |
| 35 | 2018 | Research | Activity level | 2 | * ﻿The study exhibit that the occupants are sensitive to local discomfort and temperature fluctuations when their overall thermal sensation is directed towards the cold thermal neutrality side, as a result of combining light clothing with a cooler environment associated with lower activity level. * The average room airspeed must not surpass 0.15 m/s (30 fpm) to reduce the risk from cold air draft discomfort if the operative temperature (Top) is below 22.5°C (72.5°F). | <https://commons.bcit.ca/besys/files/2018/08/Thermal-Comfort-Design-for-People.pdf> | Mora, R., & Bean, R. (2018). Thermal comfort: Designing for people. ASHRAE Journal, 60(2), 40–46. |
| 36 | 2016 | Research | External shading | 2 | * This research consists of an examination of the hospital construction refurbishment in Abu Dhabi, United Arab Emirates, stressing more on the renovation of the building envelope. Also, the research examines a building portion and the month of August as it has the most cooling demand. * ASHRAE measures for the hospital buildings provided these strategies. The new findings were described as the ‘effective case.’ * Some of the future suggestions from the study include a proposal that a green roof is the most appropriate approach to accomplish a notable minimisation in the consumption of energy. * This was exhibited by a gain of the external conduction that shifted to 21 kW that has a green roof from the base case with 29 kW.   The designers and architects will be informed by the results concerning the savings potential from various strategies. | <https://www.sciencedirect.com/science/article/pii/S235271021630081X?via%3Dihub> | Taleb, H. M. (2016). Enhancing the skin performance of hospital buildings in the UAE. Journal of Building Engineering, 7, 300–311. <https://doi.org/10.1016/j.jobe.2016.07.006> |
| 37 | 2014 | Research | External shading | 2 | * ﻿﻿The recorded internal temperatures and hourly weather data in 11 spaces on two sites of the UK National Health Service (NHS) hospital have been used to develop the distributed lag models (DLMs) to predict the future internal temperatures. * The ward spaces were located at five different buildings of diverse ages and types. The best prediction of internal temperature among all the DLMs was attained through three exogenous drivers, including solar radiation, external temperature, and previous internal temperature. * The inherent unknown and known human and thermo-physical influences on space temperatures have been captured by the DLMs. * This revealed the significant effect of site shading and orientation on internal temperatures hence disclosing the shading effects that the previous researchers had failed to notice, including tress and temporary buildings. | <https://www.sciencedirect.com/science/article/pii/S0378778814007919?via%3Dihub> | Iddon, C. R., Mills, T. C., Giridharan, R., & Lomas, K. J. (2015). The influence of hospital ward design on resilience to heat waves: An exploration using distributed lag models. Energy and Buildings, 86, 573–588. <https://doi.org/10.1016/j.enbuild.2014.09.053> |
| 38 | 2014 | Code | External shading | 7 | **Code requirements (refer to section 4)**   * Computer modelling of summer temperatures should be undertaken to ensure that the ventilation system and the control of solar gain are able to manage air temperatures within an acceptable range. * It is important to achieve a balance between economy in capital and energy costs while creating appropriate levels of comfort through mechanical ventilation/comfort cooling (see CIBSE Guide A – ‘Environmental design’). | <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/299276/HTM_00.pdf> | Department of Health. (2014). Health Technical Memorandum 00: Policies and princples of healthcare engineering 2014 edition |
| 39 | 2018 | Research | External shading | 3 | * The paper has also assessed the impact that a solar protection film has in southern Spain on the outer surface of the hospital building window, particularly in the Mediterranean climate. * The room understudy was subjected to real use conditions and observed in three different periods, including mid-season, summer, and winter. * The analysis consisted of two phases: first, the room was monitored when the glazed surface did not have solar film; and the room was observed in after the addition of solar protection film. * The combination of shading shutters with the application of solar control film on the window’s exterior results in a reduction of the consumption of electric artificial lighting systems by 12.2% compared to a room that lacks solar film. | <https://www.mdpi.com/1996-1073/12/3/489> | Calama-González, C., León-Rodríguez, Á., & Suárez, R. (2019). Daylighting Performance of Solar Control Films for Hospital Buildings in a Mediterranean Climate. Energies, 12(3), 489. <https://doi.org/10.3390/en12030489> |
| 40 | 2009 | Research | External shading | 7 | **Report**   * If DV system performance is to be maintained, the gains and losses of the room thermal must be regulated. * This signifies that the design of the facades should reduce the thermal losses and gains to prevent cold and warm surfaces, particularly concerning glazing. The airflow of the DV may be affected by the warm surfaces. Automatic or manual solar shading devices should be installed to eliminate or minimise direct solar gains.   Tests conducted in the field indicated that the floor surfaces warmed via solar gains can act as a thermal hotspot resulting in the displacement of the supply air to short circuit the level of breathing and creation of localised thermal chimneys. Besides, medical and lighting equipment should be reduced. | <https://noharm-uscanada.org/sites/default/files/documents-files/44/Healthcare_Ventilation.pdf> | Guity, A., Nash, M., Burch, L., & Marmion, P. (2009). Healthcare Ventilation Research Collaborative : Displacement Ventilation – Phase II Summary Report. |
| 41 | 2009 | Research | External shading | 3 | **n= 2 monitored case study hospitals, building simulation model**   * Optimising building fabric through dynamic simulations helped to reduce the heating loads and to maintain the indoor temperature in the required range by 9% (different types of external walls, insulation layers, glazed and shaded windows and roofs were tested to generate the optimised model). * Regarding cooling loads, about 73% can be reduced in both simulated hospitals * Investment in building fabric can offer significant energy saving and can keep optimally the indoor environment conditions for patients and staff. * Trade-off designs were identified in term of cost and achieving low carbon buildings in Iran. | <https://www.sciencedirect.com/science/article/abs/pii/S0960148108002632?via%3Dihub> | Khodakarami, J., Knight, I., & Nasrollahi, N. (2009). Reducing the demands of heating and cooling in Iranian hospitals. *Renewable Energy*, *34*(4), 1162–1168. <https://doi.org/10.1016/j.renene.2008.06.023> |
| 42 | 2006 | Code | External shading | 7 | * In summer, the design of good low energy will try to reduce the impact of excessive solar gains through the selection and massing of the building façade as well as appropriate orientation. * Nevertheless, there may be a need to implement additional measures to enhance solar shading to the building to minimise overheating risk and solar gains. | <https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7elAAC> | CIBSE, T. (2006). Design for improved shading control. *London, Chartered Institution of Building Services Engineers*. |
| 43 | 2014 | Research | External shading | 5 | **n= 3 case studies, comparative analysis**   * This report suggests that several architectural and building mechanical strategies are employed to reduce massive energy loads: * In order to reduce solar heat gain, the Scandinavian hospitals applied a combination of both fixed and dynamic exterior shading were installed with consideration of the sun movement. Also, cooling loads can be linked with water-based system. * Electric lighting reductions can be achieved by proper daylighting. * Allowing natural ventilation when operable windows are installed. * Enhancing thermal envelope. * Effective building thermal mass helps to create greater exterior connection. | <https://journals.sagepub.com/doi/10.1177/193758671400800104> | Burpee, H., & McDade, E. (2014). Comparative Analysis of Hospital Energy Use: Pacific Northwest and Scandinavia. *HERD: Health Environments Research & Design Journal*, *8*(1), 20–44. <https://doi.org/10.1177/193758671400800104> |
| 44 | 2003 | Research | External shading | 1 | * ﻿This paper consists of a research overview associated with building a thermal mass application in minimising and shifting the cooling loads in the commercial buildings. * The paper also provides an overview of the problem and optimisation of the zone temperature set-points. It has also provided specific results obtained via field studies, controlled laboratory testing, and simulations. * The simulation studies and tests conducted in the laboratory showed the crucial savings potential for controlling the building’s thermal mass. Nonetheless, they exhibited a sensitivity of the cost savings to the operating conditions, control method, and the application hence making it difficult to establish the suitable strategies for controlling a particular field application. | <https://asmedigitalcollection.asme.org/solarenergyengineering/article-abstract/125/3/292/463427/Load-Control-Using-Building-Thermal-Mass?redirectedFrom=fulltext> | Braun, J. E. (2003). Load Control Using Building Thermal Mass. *Journal of Solar Energy Engineering*, *125*(3), 292–301. <https://doi.org/10.1115/1.1592184> |
| 45 | 2018 | Research | Building monitoring | 5 | **n= 2 LEED and non-LEED healthcare facilities, questionnaire and semi-structured interview for facility managers**   * This study used to capture facility managers perceptions to examine the effectiveness of IEQ in two healthcare facilities. * Facility managers selected temperature comfort, use of space, control over noise, building design, image presented to visitors and ability to meet occupants’ needs as significant predictors for IEQ and had strong relationship with increased productivity. | <https://journals.sagepub.com/doi/10.1177/1420326X16684007> | Xuan, X. (2018). Study of indoor environmental quality and occupant overall comfort and productivity in LEED- and non-LEED–certified healthcare settings. *Indoor and Built Environment*, *27*(4), 544–560. <https://doi.org/10.1177/1420326X16684007> |
| 46 | 2007 | Code | Building monitoring | 7 | **Standard**   * Thermal modelling and calculations should be recorded to make sure the internal temperatures around the patient areas do not surpass 28 °C (dry bulb) during the summer for more than 50 hours per annum. * The operation of mechanical ventilation is expensive; therefore, it should be used in circumstances where it is needed by the served space. Rarely, the loads on the air-conditioning plant are continuous owing to the adjustments in occupancy, the use of heat-generating equipment, lights, and solar gain. Consequently, it is critical to control the supply-air temperature. * The methods of minimising temperature increase should be enforced where the calculations show that the internal temperatures will surpass the chosen design for a duration that transcends the building design risk. * A building management system (BMS) will be used to control most of the systems. This will allow the control tolerances and operating conditions to be set and monitored. At the design stage, it is often not possible to precisely anticipate the building load variation. Monitoring the plant operation through BMS will provide information that will enable the establishment of optimum set-points and reduction of energy consumption. Also, the BMS may be set to record the energy recovered by the energy-recovery device and the actual energy utilised by the system. As a result, the evidence proving energy targets are being accomplished will be provided as well as a useful check on the overall operating efficiency. * Also, if the ventilation system is not modifying the air or providing the cooling and/or the heating requirements, there will be a need to consider the following factors: reducing solar gains and loads, applying chilled beams or ceilings, increasing ventilation rates and providing mechanical cooling system. * During winter, it is essential to retain the humidity of the supply-air below 70% if the humidifier is fitted to minimise the condensation risk on cold surfaces. * The cooling coil, humidifier in sequence, and heater-battery and are controlled by the room humidity and temperature sensors. * It is essential to take temperature precedence over humidity while making sure that the room humidity and temperature are maintained at an acceptable range. * To ensure the humidifier and cooling coil are not together, it is normal to interlock them. * There is a possibility of forming stagnant zones if the supply and extract terminals are too far apart or short-circuiting if they are too close. The individual velocities must not exceed 0.25 m/s where the two opposing air streams meet. * Control items and sensors including control valves should be located close to the plant item being controlled or the element being sensed to reduce time lags within the system associated with creating condition overshoot beyond the design envelope leading to consumption of energy (thermostat location). | <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/144029/HTM_03-01_Part_A.pdf> | Department of Health. (2007). Heating and Ventilation Systems Health Technical Memorandum 03-01: Specialised Ventilation for Healthcare Premises Part A: Design and Validation. |
| 47 | 2013 | Research | Building monitoring | 1 | * ﻿The role of sensors involves providing a controller with data regarding changing conditions in a precise and repeatable manner as well as measuring the controlled medium. * The common variables of HVAC include pressure, relative humidity, flow rate, and temperature. There is a need for high performing sensors as part of smart control strategies to ensure that the energy efficiency is enhanced in an attempt to determine the optimal performance of HVAC equipment. * The most prominent environmental sensors are the ones used to measure carbon dioxide (CO2), relative humidity (RH), carbon monoxide (CO), and temperature. Fig.12 is an illustration of a simplified conceptual schematic showing how the sensors have a significant role in monitoring and generic HVAC system. * Currently, there is a need to develop novel control strategies integrating actuators and smarter sensors to maintain good thermal comfort and IAQ during the reduction of energy use. | <https://www.sciencedirect.com/science/article/abs/pii/S030626191200743X?via%3Dihub> | Chua, K. J., Chou, S. K., Yang, W. M., & Yan, J. (2013). Achieving better energy-efficient air conditioning - A review of technologies and strategies. Applied Energy, 104, 87–104. <https://doi.org/10.1016/j.apenergy.2012.10.037> |
| 48 | 2012 | Research | Building monitoring | 8 | * We came up with a temperature control system, Thermovote, which employs participatory sensing to activate a change in temperature. * We also developed Android and iPhone software together with a webpage where users can send feedback on their experience with the thermal comfort and exhibit a real-time mechanism for controlling room temperature using the user data. * This is accomplished by implementing a method involving the collection of PMV estimates through APV to assess the change in temperature. Our test for the real-time system was conducted in more than five months. Furthermore, three studies were carried out in more than five weeks, whereby the test for real-time and learned procedures was done. * We exhibited 100% contentment for the real-time approach, and only 25% were contented with the baseline strategy. * Moreover, we illustrated that efficiency could be increased by adjustment of the thermal comfort. In the deployment, we illustrated 10.1% saving energy compared to the baseline strategy. | <https://dl.acm.org/doi/10.1145/2422531.2422534> | Erickson, V. L., & Cerpa, A. E. (2012). Thermovote : Participatory Sensing for Efficient Building HVAC Conditioning. In Proceedings of the Fourth ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings - BuildSys ’12 (p. 9). New York, New York, USA: ACM Press. <https://doi.org/10.1145/2422531.2422534> |
| 49 | 2019 | Research | Building monitoring | 1 | * This chapter highlights the general overview of various real-time monitoring systems that the authors have developed and published. * The authors have presented various new cost-effective, and open-source systems developed to monitor the environmental parameters to enhance the indoor air quality for a better health building. | <https://www.intechopen.com/books/indoor-environmental-quality/indoor-air-quality-monitoring-for-enhanced-healthy-buildings> | Marques, G., & Pitarma, R. (2019). Indoor Air Quality Monitoring for Enhanced Healthy Buildings. In Indoor Environmental Quality. IntechOpen. <https://doi.org/10.5772/intechopen.81478> |
| 50 | 2017 | Code | Airstream | 7 | **Standard**   * It is recommended that outlets that have low velocity to provide thermal comfort and proper ventilation and IAQ for occupants. Several types are shown in this standard either isothermal or non-isothermal. | <https://www.ashrae.org/technical-resources/ashrae-handbook> | Handbook, A. S. H. R. A. E. (2017). Fundamentals, ASHRAE–American Society of Heating. *Ventilating and Air-Conditioning Engineers*. |
| 51 | 2017 | Code | Airstream | 7 | **Standard**   * Types of outlets and diffusers: Group A, Group D, Group E * Non-aspirating diffuser: a diffuser that has unidirectional downward airflow from the ceiling with minimum entrainment of room air. Classified as ASHRAE Group E, these diffusers generally have very low average velocity. For the purposes of this standard, the performance of these diffusers is to be measured in terms of average velocity. * Recommended range of Ta (21-24 °C), Rh (max. 60% and lower limit defined for regular patient room), ACH (min. 6 for single-bed patient rooms). | <https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20errata/standards/170_2017_a_20200901.pdf> | ASHRAE, A. (2013). Standard 170-2013. Ventilation of Health Care Facilities. *American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta*. |
| 52 | 2010 | Research | Airstream | 1 | * ﻿A critical analysis was done involving the guidelines that govern the ventilation system design for the hospital wards as well as other multi-bed rooms in the United States and the United Kingdom. * To remove the airborne infections from the ward spaces, a study on computational fluid dynamics (CFD) was undertaken to assess the efficacy of several ventilation approaches. * The simulation of CFD exhibited that the concertation of bioaerosol in the research room was lower (2467 cfu/m3) during the air supply and extraction via the ceiling than the other ventilation approaches that were simulated, resulting in bioaerosol concentration of 12487 and 10601 cfu/m3. | <https://www.sciencedirect.com/science/article/abs/pii/S0196655307008000> | Beggs, C. B., Kerr, K. G., Noakes, C. J., Hathway, E. A., & Sleigh, P. A. (2008). The ventilation of multiple-bed hospital wards: Review and analysis. American Journal of Infection Control, 36(4), 250–259. <https://doi.org/10.1016/j.ajic.2007.07.012> |