26. The influence of climate change in extant dwellings through adaptive comfort approach

Sánchez-García, Daniel [1,*], Rubio-Bellido, Carlos [1]; Guevara-García, Fco. Javier[1]; Canivell, Jacinto[1]

(*) University of Seville, Department of Building Construction II; sangardaniel@gmail.com

(1) University of Seville, Department of Building Construction II

Abstract   Bearing in mind the adaptability of the user to the built environment, the comfort analysis of existing naturally ventilated dwellings is crucial to reduce the current and future energy consumption. In the case of Europe, the existing building stock was mainly built before any energy standard and without considering global warming. This research presents a study of the adaptive comfort model EN 15251:2007, to provide guidance for comfort in existing buildings in the context of climate change. The case study is a residential block built in 1978 in Seville, Spain. The analyses consider the currently used patterns, as well as their spatial and construction characteristics. The data measured onsite are calibrated with dynamic simulation for current and future scenarios. The potential application of adaptive comfort model EN 15251:2007 is shown in this study for today, 2020, 2050 and 2080. The results show a progressive decrease of applicable and comfortable hours as the applicable and not applicable hot hours increase and the applicable and not applicable cold hours decrease respectively. This approach can be useful as a first step to consider in decision-making energy refurbishments as well as in energy policies.

Keywords   Adaptive comfort, Natural ventilation, dynamic simulation, Climate change

1 Introduction

Currently, the depletion of energy resources and the risk of global warming demand sustainable development based on renewable energies and energy efficiency. It is commonly acknowledged that the construction sector represents approximately one third of the total energy consumption in the world (Pérez-Lombard et al, 2008). The International Energy Agency indicates that its absolute consumption can reach 38.4 PWh in 2040 (IEA, 2013), being responsible for 38% of the greenhouse gas emissions (UNEP, 2012). Considering this fact, energy efficiency

in buildings is a crucial factor in the European technical and political agenda for new and existing buildings. This, together with the predictions about future climatic scenarios and about how cities and architecture will adapt (Roaf et al, 2009), albeit with diverse uncertainties (Schiermeier, 2010), stand out as one of the main focal points for research and development in the scientific world. Since the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, which has recently published its Fifth Assessment Report (AR5) (IPCC, 2014), there have been countless studies that deal with global warming, the increase in emissions and the lack of resources. Several studies about future climate scenarios are based on prediction models, which outputs morph the current climate files (Guan, 2009; Jentsch, et al, 2008; Jentsch et al, 2013) and are valid for a large part of the world, although there are already some models that work on a country scale (Chan, 2011).

The climatic adaption of existing buildings and their occupants plays an important role, above all in the European residential sector, where most dwellings are still naturally ventilated. In the countries in the South of Europe, where a temperature increase has been foreseen, the implementation of active air-conditioning systems in homes has been subject to discussion (Barbosa et al, 2015) due to the need for further resources to meet the energy demand, in a scenario where the increase in energy prices and energy poverty, is becoming a reality (Thomson & Snell, 2013). As such, a large part of current studies in the field of residential climatic adaptation are focused on the comfort study of their occupants, trying to reduce the use of active means, and intensifying passive strategies (Van Hooff et al, 2015).

In this sense, in the last few years, comfort models have been developed for the occupants of naturally ventilated buildings. The most widespread ones are the adaptive comfort models (Rupp et al, 2015; Taleghani et al, 2013), the ASHRAE 55-2013 (ASHRAE, 2013) standard and the European EN 15251 CEN (European Committee for Standardization) standard (CEN, 2007) with its respective reviews or studies in specific climates (Dear & G.S. Brager, 2002; Manu et al, 2016), which are based on field studies in diverse locations throughout the world. The potential use of these models for static comfort (ISO, 2005) responds to the fact that occupants of naturally ventilated buildings may have a larger comfort range (Feriadi & Wong, 2004) than those who are used to centralized HVAC systems. In addition, in current adaptive standards, which are derived from the studies carried out by the RP-884 and SCATs projects, naturally ventilated spaces have a close relationship with the external temperature. Diverse studies have applied adaptive comfort models to vernacular architecture, where traditionally there has been a relationship between the environment (Singh et al, 2010) and the construction with the materials available in the area (Desogus et al, 2015), even considering zero energy residential buildings (Attia & Carlucci, 2015).

However, in the current context of global warming, the study of the potential application of adaptive comfort models could have implications in the reduction of energy consumption, bearing in mind that an increase in these is foreseen for the

coming years (Pérez-Lombard et al., 2008). In this sense, dwellings in the south and east of Europe provide a representative case study, since naturally ventilated buildings with energy poverty potential are predominant. One has to consider that these studies must be specifically focusing on each building and climate typology. Because of this, diverse investigations have been made to perform specific case studies (Barbosa et al., 2015; Lomas & Giridharan, 2012).

In the case of Spain by 2020, the Spanish National Energy Plan predicts there will be a 15.6% general reduction from energy savings in the construction sector (Idae, 2011). Standards have been implemented with this in mind for new buildings. However, the existing buildings, above all those in the residential sector, are characterized by being a sufficient sector, and generally, one that is not well maintained (Gangolells & Casals, 2012), with most of the park built before any energy regulation standard was set and without a real focus on global warming. Most of the constructions done before the 80's were developed in cities, as housing blocks. Thus, this building type has been studied in the main cities in Spain from an energy point of view, but specific studies have not been done from the potentiality and adaptation to climate change under adaptive comfort levels. In the case of Seville, in the south of Spain, where the case study of this project is, energy studies have also been conducted in the current context (Domínguez et al, 2012; León et al, 2010).

This research intends on shedding light on the applicability of adaptive comfort model EN 15251:2007 through the study of the residential units of a housing block, for the current and future context. This research is also intended to analyse possible changes in indoor conditions in order to point out suitable passive and mechanical climate adaptation design strategies. Hence, the capacity these dwellings have when facing climate change and how these will have an impact on the comfort of their inhabitants are analysed.

2 Methodology

In order to consider all the factors that have an impact on the study's results, a methodology has been implemented based on stages.

In a first stage; data collection consisted on gathering parameters inherent to the dwelling subject of study:

-        Constructive systems data was collected, including statistical data of similar dwellings built in Seville; definition of the distribution, dwelling measurements and modelling in CAD software.

-        Operation hypotheses were defined based on the different occupation profiles observed in the dwelling (always occupied and unoccupied 8:00 to 15:00) and when the windows are allowed to be opened. Further, it was taken into account the real time that blinds are rolled up and down and the ventilation control of the dwelling.

- External environmental conditions data were collected through the current weather data file from EnergyPlus and the standard temperature values from the National Agency of Meteorology (AEMet) Future scenarios data were obtained through morphing processes for 2020, 2050 and 2080. These forecasts weather data files are use in the simulations.

In a second stage, fieldwork and simulations were carried out, comprising three sections:

- The dwelling was monitored throughout three periods in winter, spring and summer. A process of deployment of cells, data collection and data mining was carried out. Indoor temperatures were measured with sensors placed in the northwest and southeast rooms.

- A numerical simulation of the building was modelled, considering the real building's constructive characteristics, occupation profiles, window operations, projected shadows and solar protections.

- With the measured and simulated indoor temperatures, a calibration process was made in order to make sure the validity and accuracy of the simulation results.

A third stage comprised the application of the adaptive comfort model, which is established in the following sections:

- The applicability potential of the adaptive comfort model was determined considering the external conditions and the standard limitations for present and future scenarios. To accomplish this issue the average dwelling simulation results were use in order to obtain the applicable and not applicable hours of the adaptive comfort model, with different operation hypothesis per each climate scenario.

- Adaptive comfort levels were obtained considering the hourly operative temperatures resulted from the simulation and identifying the comfort zone in a representative room by means of scatter plots and the comfort evolution throughout the year for present and 2080.
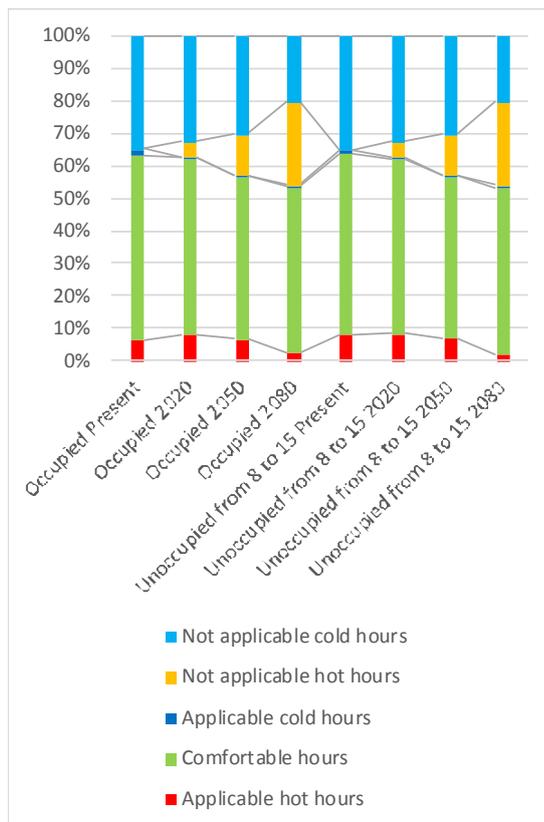
3. Results and discussion

3.1 Applicability potential of the adaptive comfort model

The predictions of future scenarios show an increment on the average annual temperature from the current 18.36°C to 22.74°C, estimated for 2080. The most adverse tendency can be seen in the temperature during summer months, which are currently high. For instance, in June, high average monthly temperature will increase from the current 36.42°C to 43.83°C in 2080. These trends represent a variability in the applicability potential in the comfort model which are applied to average values of the dwelling in order to stablish a general vision of the comfort percentages. In addition, the deviation of the two calibrated rooms is also commented.

The adaptive comfort model present limitations in the applicability of weighted mean outdoor temperatures, being the applicability range from 10-15°C to 30°C. For the clarity of the results hereinafter are called applicable hours to the hours within these limits. The applicability results (Fig. 1) show a progressive reduction of applicable hours produced as the climatic scenarios advance. This is to say, with the increase of temperature, the hottest hours exceed the 30°C limit (from here on, not applicable hot hours). At the same time, the cold hours that were under the 10-15°C limit (from here on, not applicable cold hours) come into the applicability range when the temperature is higher than the one established for the limit, and became applicable hours. In conclusion, not applicable cold hours progressively fall and the not applicable hot hours increase, but the applicable hours decrease because always the increase of not applicable hot hours is greater than the decrease of not applicable cold hours.

Fig. 1 Applicability of EN 15251 under climate change conditions, permanent occupation.

In the winter period, the decrease of not applicable cold hours is estimated from a 34.79% in the current scenario to 20.27% in the 2080 scenario. It can be seen that, in the current scenario, all the unapplied hours in the comfort model are not applicable cold hours, in a way that the winter period prevails over the summer period in terms of applicability. In that way, the increase of temperatures makes the hottest applicable hour exceed the 30°C limit and so become not applicable hot hours. However, the increase of temperatures is not enough to make the not applicable cold hours reach the 10-15°C limit, and so keep out of the applicability range. Hence, the reduction of applicable hours responds to the hours that exceeded the 30°C limit.

In the case of the hypothesis of unoccupied from 8am to 3pm, the applicable hours, not applicable hot hours and not applicable cold hours percentages are close

to those of the profile with permanent occupation in the comfort model, with a variance of 0.20%. In the case of the current scenario, these are slightly lower, but in the rest these are slightly higher. Said lack of variation is due to the internal loads which are compensated to a certain extent by the windows being closed during the unoccupied period of 7 hours, also considering that the outside conditions are not as favourable in this climate. Therefore, the permanent occupation hypothesis is selected for the following analyses.

The variation of the comfort deviation in the southeast and northwest room represents an average value of 2% of comfortable hours. There are more comfortable hours on the northwest room than on the southeast, as the changes in temperature at night are gentler than in the day as they do not receive direct radiation. Hence, southeast room is selected for the next chapters considering the most adverse conditions although scarcity deviations were perceived.

3.2 Adaptive comfort levels

For this analysis, comfortable hours are considered as well as applicable cold and hot hours, that is, above or below the upper or lower limits. In Table 1, the percentages of hours above, within and below the comfort zone are shown with permanent occupation profile in the southeast room.

Table 1 Applicable percentages of EN 15251, southeast room, permanent occupation

| Scenario	Hours above, within or below comfort zone	EN15251
Current	Above	6.53%
	Within	56.66%
	Below	2.01%
2020	Above	8.06%
	Within	54.30%
	Below	0.38%
2050	Above	6.64%
	Within	50.09%
	Below	0.26%
2080	Above	2.59%
	Within	50.84%
	Below	0.55%

The results show a progressive decrease of the comfortable hours, similar to the decrease in the applicable cold hours. The applicable hot hours experience an increase through to 2020, from where these descend as the temperatures are so high that the model is not applicable.

A priori, an increment in temperature could mean that the percentage of hot applicable hours in the 2080 scenario would be the highest of all the scenarios. However, it is the lowest of all. This is because the increase of hours outside the comfort zone due to the temperature increase is accumulated in the not applicable hot hours. This can be seen in Fig. 3, in the 2080 scenario, where the highest temperature area of the upper comfort limit is made horizontally, which means that the weighted mean outdoor temperature has exceeded the upper application limit. In this way, the temperature increase leads to an increase of not applicable hot hours, instead of applicable hot hours just as can be seen in Fig. 1.

Fig. 2 Scatter plot. Comfort zone of EN15251:2007. Southeast room, permanent occupation in the present scenario.
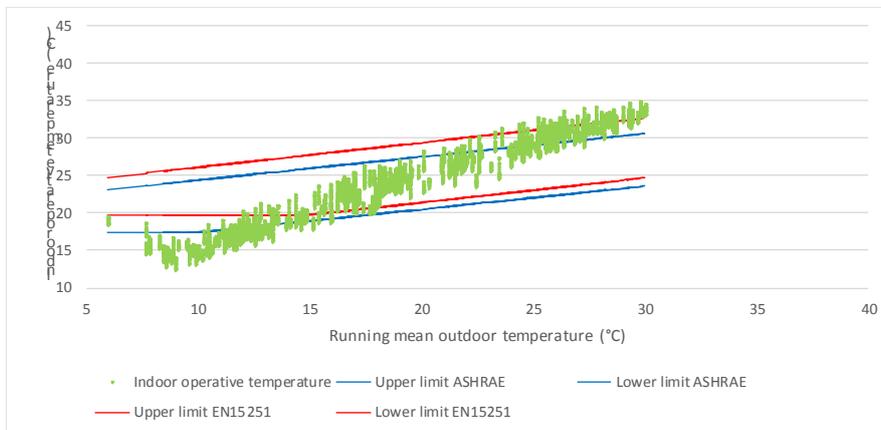

Fig. 3 Scatter plot. Comfort zone of EN15251:2007. Southeast room, permanent occupation in the 2080 scenario.
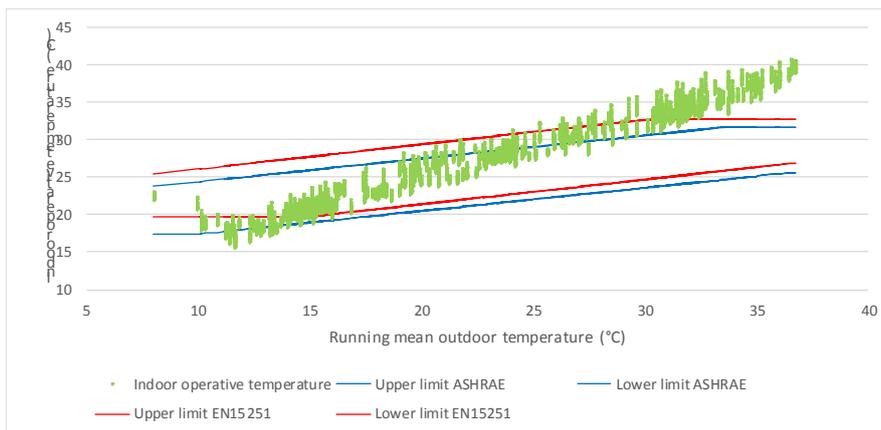
Considering the differences in the evolution of the climate change scenarios (Fig. 2-3), it can be seen that the pattern is displaced and moved to the right of the x axis by increasing the weighted mean outdoor temperature, and is displaced and moved along the y axis by increasing the indoor operative temperature, with the cause lying on the increase of the outside temperature. Said movement along the y axis can be quantified on observing the increase of the indoor operative temperature, with the following minimum and maximum values: 12.52°C and 35.02°C for the current scenario; 13.46°C and 36.24°C for the 2020 scenario; 14.66°C and 38.54°C for 2050; and 15.66°C and 40.82°C for 2080. The displacement along the x axis is quantified on observing the maximum and minimum values which the weighted mean outdoor temperature reaches: 5.92°C and 29.98°C in the current scenario; 6.24°C and 31.69°C in 2020; 7.20°C and 34.35°C in 2050; 7.98°C and 36.75°C in 2080.

Fig. 4 Indoor operative temperature evolution vs. weighted mean out-door temperature throughout the year of EN15251:2007. Southeast room, permanent occupation in the present and 2080 scenario.
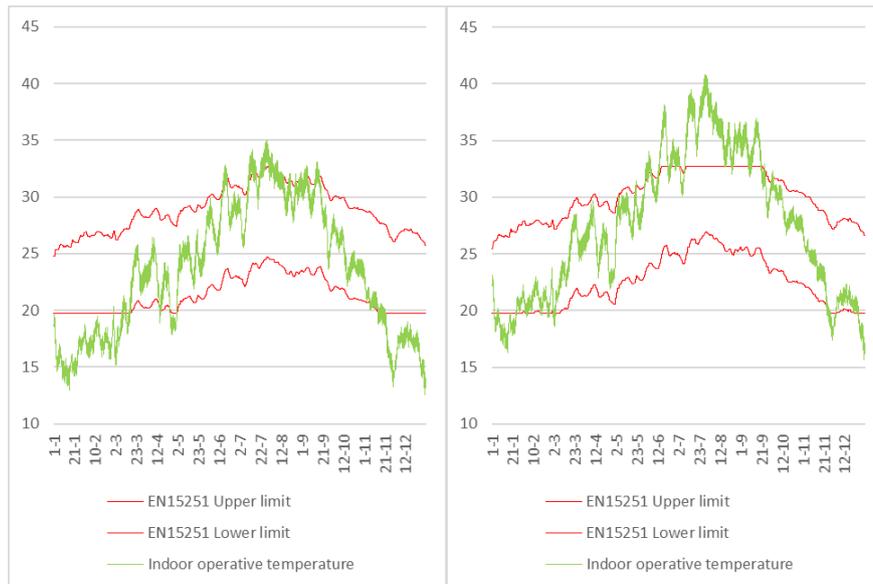
The analysis of the evolution throughout the year (Fig. 4), for both indoor operative temperature and weighted mean outdoor temperature clarified the difference between the current scenario and 2080 scenario. Despite the fact that in cold months (November to February) the indoor operative temperature is generally within the comfortable limits, during hot months (June-September) overheating occurs. Overheating periods can be observed in summer months, when indoor operative temperature rises above comfort limits in the current scenario. However,

2080 is especially adverse, because weighted mean outdoor temperature exceeds applicability upper limit and therefore upper comfort limit is flatten, at the same time that indoor temperature keeps rising. Due to the extremely hot temperatures, overheating periods need a specific study in order to ease discomfort by means of ventilation strategies.

4. Conclusions

This study has focused on evaluating the potential of the adaptive comfort model EN 15251:2007 in the current climate, aggravated by the thoughtful situation of energy shortage, as well as in future climates, where a significant increase in temperature caused by climate change is foreseen. The dwelling studied, subject of field studies to calibrate and check the validity of the data from the simulations, is the most common type of housing in the current residential stock in Spain, built without considering climate change, and drastically increasing its obsolescence as time goes by.

The results show that the temperatures have increased so much that they have exceeded, in a greater proportion, the upper comfort and applicability limits. These results can be explained by showing that natural ventilation is not enough to reach the thermal comfort. Therefore, the current applicability, as well as the potentiality of the adaptive comfort model EN 15251:2007, is limited. To achieve comfort, it would be necessary to recur to other passive design strategies or those that could comprise mechanical or mix mode means.

This research may mean a valuable tool for the first stages of refurbishments plans in the city of Seville and similar climates in the south of Europe.

5. Citation and references

ASHRAE. (2013). ANSI/ASHRAE Standard 55-2013.Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (Vol. ASHRAE Sta). http://doi.org/ISSN 1041-2336

Attia, S., & Carlucci, S. (2015). Impact of Different Thermal Comfort Models on Zero Energy Residential Buildings in Hot Climate. Energy and Buildings, 102, 117–128. http://doi.org/10.1016/j.enbuild.2015.05.017

Barbosa, R., Vicente, R., & Santos, R. (2015). Climate change and thermal comfort in Southern Europe housing: A case study from Lisbon. Building and Environment, 92, 440–451. http://doi.org/10.1016/j.buildenv.2015.05.019

CEN. (2007). EN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality,

thermal environment, lighting and acoustics. European Committee for Standardization, 3, 1–52. http://doi.org/10.1520/E2019-03R13.Copyright

Chan, A. L. S. (2011). Developing future hourly weather files for studying the impact of climate change on building energy performance in Hong Kong. Energy and Buildings, 43(10), 2860–2868. http://doi.org/10.1016/j.enbuild.2011.07.003

Dear, R. J. De, & G.S. Brager. (2002). Thermal comfort in naturally ventilated buildings: revision to ASHRAE standards 55,. Journal of Energy and Buildings, 34, 549–561.

Desogus, G., Di Benedetto, S., & Ricciu, R. (2015). The use of adaptive thermal comfort models to evaluate the summer performance of a Mediterranean earth building. Energy and Buildings, 104, 350–359. http://doi.org/10.1016/j.enbuild.2015.07.020

Domínguez, S., Sendra, J. J., León, A. L., & Esquivias, P. M. (2012). Towards energy demand reduction in social housing buildings: Envelope system optimization strategies. Energies, 5(7), 2263–2287. http://doi.org/10.3390/en5072263

EU. (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, 13–35. http://doi.org/10.3000/17252555.L_2010.153.eng

Feriadi, H., & Wong, N. H. (2004). Thermal comfort for naturally ventilated houses in Indonesia. In Energy and Buildings (Vol. 36, pp. 614–626). http://doi.org/10.1016/j.enbuild.2004.01.011

Gangolells, M., & Casals, M. (2012). Resilience to increasing temperatures: residential building stock adaptation through codes and standards. Building Research & Information, 40(June), 1–20. http://doi.org/10.1080/09613218.2012.698069

Guan, L. (2009). Preparation of future weather data to study the impact of climate change on buildings. Building and Environment, 44(4), 793–800. http://doi.org/10.1016/j.buildenv.2008.05.021

Idae. (2011). Plan de ahorro y eficiencia energética 2011-20 (Spanish National Renewable Energy Plan (NREP) 2011-2020). IDAE, 268. Retrieved from http://www.idae.es/uploads/documentos/documentos_11905_PAEE_2011_2020._A2011_A_a1e6383b.pdf

IEA. (2013). World Energy Outlook 2013.

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Ipcc.

ISO. (2005). ISO 7730: Ergonomics of the thermal environment Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Management, 3, 605–615. http://doi.org/10.1016/j.soildyn.2004.11.005

Jentsch, M. F., Bahaj, A. S., & James, P. A. B. (2008). Climate change future proofing of buildings—Generation and assessment of building simulation weather files. Energy and Buildings, 40(12), 2148–2168. http://doi.org/10.1016/j.enbuild.2008.06.005

Jentsch, M. F., James, P. A. B., Bourikas, L., & Bahaj, A. S. (2013). Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates. Renewable Energy, 55, 514–524. http://doi.org/10.1016/j.renene.2012.12.049

León, a. L., Muñoz, S., León, J., & Bustamante, P. (2010). Monitorización de variables medioambientales y energéticas en la construcción de viviendas protegidas: Edificio Cros-Pirotecnia en Sevilla. Informes de La Construcción, 62, 67–82. http://doi.org/10.3989/ic.09.045

Lomas, K. J., & Giridharan, R. (2012). Thermal comfort standards, measured internal temperatures and thermal resilience to climate change of free-running buildings: A case-study of hospital wards. Building and Environment, 55, 57–72. http://doi.org/10.1016/j.buildenv.2011.12.006

Manu, S., Shukla, Y., Rawal, R., Thomas, L. E., & de Dear, R. (2016). Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). Building and Environment, 98, 55–70. http://doi.org/10.1016/j.buildenv.2015.12.019

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and Buildings, 40(3), 394–398. http://doi.org/10.1016/j.enbuild.2007.03.007

Roaf, S., Crichton, D., & Nicol, F. (2009). Adapting Buildings and Cities for Climate Change - A 21st Century Survival Guide Second Edition. Retrieved from http://library.uniteddiversity.coop/Ecological_Building/Adapting_Buildings_and_Cities_for_Climate_Change.pdf

Rupp, R. F., Vásquez, N. G., & Lamberts, R. (2015). A review of human thermal comfort in the built environment. Energy and Buildings, 105, 178–205. http://doi.org/10.1016/j.enbuild.2015.07.047

Schiermeier, Q. (2010). The real holes in climate science. Nature, 463(7279), 284–287. http://doi.org/10.1038/463284a

Singh, M. K., Mahapatra, S., & Atreya, S. K. (2010). Thermal performance study and evaluation of comfort temperatures in vernacular buildings of North-East India.
Building and Environment, 45(2), 320–329. http://doi.org/10.1016/j.buildenv.2009.06.009

Taleghani, M., Tenpierik, M., Kurvers, S., & Van Den Dobbelsteen, A. (2013). A review into thermal comfort in buildings. Renewable and Sustainable Energy Reviews, 26, 201–215. http://doi.org/10.1016/j.rser.2013.05.050

Thomson, H., & Snell, C. (2013). Quantifying the prevalence of fuel poverty across the European Union. Energy Policy, 52, 563–572. http://doi.org/10.1016/j.enpol.2012.10.009

UNEP. (2012). Building Design and Construction: Forging Resource Efficiency and Sustainable Development.

Van Hooff, T., Blocken, B., Hensen, J. L. M., & Timmermans, H. J. P. (2015). Reprint of: On the predicted effectiveness of climate adaptation measures for residential buildings. Building and Environment, 83, 142–158. http://doi.org/10.1016/j.buildenv.2014.10.006