On the relation of thermal comfort practice and the energy performance gap

Hellwig, Runa T.

Published in:
IOP Conference Series: Earth and Environmental Science

DOI (link to publication from Publisher):
10.1088/1755-1315/352/1/012049

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Hellwig, R. T. (2019). On the relation of thermal comfort practice and the energy performance gap. *IOP Conference Series: Earth and Environmental Science*, *352*(1), Article 012049. https://doi.org/10.1088/1755-1315/352/1/012049

IOP Conference Series: Earth and Environmental Science

On the relation of thermal comfort practice and the energy performance gap

To cite this article: Runa T Hellwig 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **352** 012049

On the relation of thermal comfort practice and the energy performance gap

Runa T Hellwig

Department Architecture, Design and Media Technology, Aalborg University,
Rendsburggade 14, 9000 Aalborg, Denmark

rthe@create.aau.dk, ORCID: 0000-0002-5882-8033

Abstract. Recent research results from different countries show that although energy efficiency measures in buildings indeed led to lower energy use in buildings, there is a performance gap between the calculated energy use and the actual measured energy use in energy-efficient houses, leading to a higher energy use than predicted. Thermal comfort related behaviour is one out of manifold reasons contributing to this performance gap. Thermal comfort requirements are based on objectively measurable parameters. A number of contextual factors impact an individual's thermal comfort perception and preference. Technological opportunities and material arrangements offer several ways to conditioning indoor environments. Research shows that they shape the occupants' thermal comfort attitudes. Over time, technology as conditioning practice and insulation has led to different thermal comfort practice in buildings contributing to this performance gap. As humans show an excellent adaptation potential towards a wide range of temperature, enabling them to adapt to diverse climates but also seasonally, it follows also the adaptation process can work in the opposite direction. Hence, that with reduced exposure to outdoor weather and more narrow temperature ranges inside building humans might also adapt to indoor thermal conditions and get more sensitive to small indoor temperature changes, leading probably to higher indoor temperature over time ("indoor exposure rebound"). As our energy conservation efforts of the recent years show less effects than expected, it seems that the two mainly applied sustainability strategies efficiency and consistency have limited effects as they are affected by rebound phenomena. Sufficiency, as the third sustainability strategy, is not yet a generally accepted strategy. It refers to what has been described as "the right measure". The question of what would be "the right measure" of indoor thermal comfort, meaning what thermal conditions would be sufficient, can be raised. Based on a discussion of findings from literature, it will be concluded that there is a need for a new thermal comfort thinking in climates which have the need for seasonal or all year round active conditioning leading to a more sufficient conditioning practice.

1. Introduction

The need to adapting our built environment and the way we design and use it is a consequence of the progressing climate change. It demands us to rethinking our accustomed routines, behaviours and expectations. It is commonly agreed upon that we need sustainable ways to shape and use our built environment. Sustainability is defined via ecological, economical and socio-cultural quality criteria. In recent years, we have been rather successful in developing energy conservation strategies for new buildings as well as for energy renovation of the building stock. Quality management procedures and measurements have been developed and applied in the building process in order to make sure that the planned energetical performance of a building comprising its envelope and building service systems can be realised in the expected way. Starting with the first low-energy houses in the 80ties and 90ties, we have been able to continuously lowering the energy demand for heating so that we now talk about nearly Zero Energy Buildings (Energy Performance of Buildings Directive EPBD 2010), Zero Energy Buildings or even Plus Energy Buildings – not on research project level or demonstration project level solely - but already on the market with pilot first users. Calculation procedures have become more sophisticated and the system boundaries have been extended from energy use to end energy, primary energy and the generation and use of energy on-site. The technological knowledge on how to design buildings for energy efficiency and the use of renewables gained in research and demonstration projects over a period of 30 years has also shaped our legislation (e.g. in Europe Energy Performance of Buildings Directive EPBD 2010, e.g. on national level in Germany "Wärmeschutzverordnung" WSVO 1995, "Energieeinsparverordnung" EnEV 2002 et seqq.) leading to an improved energy efficiency practice. With the first implementation of the EPBD ranges for comfortable indoor environments (thermal, air quality, acoustical and visual) have been defined in standards (EN 15251 [14] and its successor EN 16798 [15]) in order to ensure that energy conservation does not lead to unacceptable indoor environmental conditions. In recent studies, using data-sets on energy labelled residential buildings (e.g. [18]) it could be shown that there is an energy performance gap between the calculated energy demand and the actual energy used in the real building.

Besides the limitations and assumptions incorporated in energy demand prediction models, reasons for this performance gap are seen in the way buildings are used and users behave in these buildings (e.g. [21]). Thermal comfort practice is one important contributor as it seems to be subject to rebound effects[1]. The aim of this paper is to discuss the relation of thermal comfort and the energy performance gap; how the understanding of what thermal comfort means shapes the way buildings are planned and operated. It will be discussed how other sustainability strategies than energy efficiency can be used to unlock further saving potential. Sufficiency as a sustainability strategy addressing the relation between humans and their environment will be discussed as a key strategy leading, firstly, to a broader understanding of this relationship and, secondly, to developing more sufficient ways of how to design and operate indoor spaces comfortably. In this paper conditioning for thermal comfort in winter is the main focus.

2. Indoor temperature yesterday and today

Over the years, we have been observing an increase in room temperature in winter leading to increased energy use in buildings. Borsch-Laaks [6, p.27] describes the development of the room temperatures depending on the technologies available during certain periods, starting in the 17. and 18. Century, leading to *mean* room temperatures of about 10°C in kitchens or what today would be called the living room. In the early 20ies century all rooms had a heating device (stove) but bedrooms and side rooms normally were not heated. Grytli and Støa [20] point out the impact a central heating systems and electrical heating systems had on the development of more freely arranged layouts of the floor plans of residential buildings in Norway.

In 1858, Pettenkofer [28, p78] recorded an air temperature of 15°C in a classroom in January. Markham's (1947) findings (quoted in [1], p17) give us an impression of the increasing winter comfort temperatures in the UK: around 1900 it was 60°F (15.5°C) and in 1920 it was 64°F (17.8°C). The 1946 British Standards Code of Practice of Warmth in Houses gives a range of 60 to 68°F (15.5 to 20°C) for living rooms (from [1], Tab 2.1). According to a survey of Welch (1960, referenced in [1]), in new buildings with thermostats occupants opted for temperatures of 68 to 70°F (20 to 21.1°C).

---

[1] A gain in efficiency (here: energy efficiency) which does not lead to the same magnitude of reduction in use of a good (here: energy) is subject to a rebound effect.

In 1925, an instruction on how to operate a heating system in a German Ministry's building said that with permanent heating 18°C should not be exceeded as 19°C would be too warm for many persons (quoted in [7], p84/85). In 1935, the German Health Authority recommended winter temperatures between 17.5 and 18.5°C for decentralised or centralised heating and stated that a room with a temperature above 21°C is regarded as being "overheated" [7]. Rothfeld [29] stated 1916 that *more* than 20°C in classrooms would impair the children's learning performance. In East-German indoor climatic guidance values for residential indoor environments in the heating period were 18-23°C [2]. Today a minimum of 20°C is required in winter (Category II according to EN 15251 [14] and its successor [15]) most often far higher temperatures are measured.

From the UK we know about systematic analysis whether indoor temperatures have risen over the years [31] with the result that temperature in rented homes may have increased over time but not owner-occupied houses of the building stock. In the mid 80ies, temperature measurements in first German demonstration projects on energy efficient buildings ("Solarhäuser Landstuhl") showed a temperature practice between 17 to 23°C in the living rooms and 16°C to 21°C in the bedrooms [19]. Already back then, three types of users were defined: the energy saving user having a mean day-time temperature of 18°C and a night set-back temperature of 15°C, the normal user having a mean day-time temperature of 20°C and the energy wasting user with 22°C without having any night set-back. Eight years later, another low-energy house demonstration project ("Niedrigenergiehäuser Heidenheim") showed mean temperatures during the heating period between 17 and 21 °C [16]. In a Danish study it was found that users in houses with better energy labelling tend to have higher indoor temperatures compared with users of houses in buildings with less energy-efficient building label [21].

3. Energy performance gap

Based on 3400 German homes of the building stock, presumably not energy efficient homes, Sunikka-Blank and Galvin [33] found that the actual measured energy consumption is on average 30 percent points lower than the calculated energy demand. They call this the pre-bound effect.

Gram-Hanssen and Hansen [18] analysed data of actual measured energy consumption data of energy labelled detached houses from Denmark showing that for energy-*inefficient* houses the actual energy use is much *lower* than the calculated energy demand (Figure 1). Contrary, the energy-*efficient* houses show an actual energy use which is *higher* than the calculated energy use. They conclude that users adjust their behaviour in energy-*inefficient* houses, leading the lower energy use than expected.

4. Thermal comfort practice

Thermal comfort practice involves several parties, mainly the users, the building professionals (planners, operators) but also companies selling and advertising indoor climate conditioning equipment. In the following possible sources for thermal comfort related rebound effects are discussed.

4.1. Rebound effects related to thermal comfort practice

The performance gap between the calculated and the actual energy use of buildings can partly be explained with changed conditioning practice for thermal comfort. These are:

- extended availability of conditioning systems to more rooms, e.g. through the implementation of central heating systems (spatial rebound: entire unit vs selected spaces of a unit as described in section 2),
- changed conditioning schedules (temporal rebound: intermittent/night set-back or shut-off vs permanent, e.g. [19]),
- changed occupant behaviours (behavioural rebound, e.g. clothing habits, [21]), and
- changed temperature regime (extent rebound: e.g.[21]).

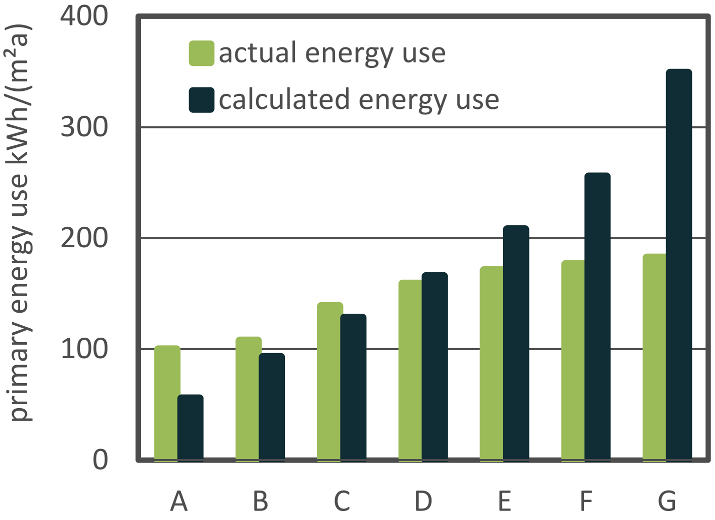

Figure 1: Energy performance gap – Example Danish data, N=135,311 homes, based on data from [18], mean values, variance not shown, A to G are energy efficiency labels.

4.2. *Attitudes towards thermal comfort*

In the 70ies thermal comfort was implemented as a product which can be sold. This leads to the expression of "providing thermal comfort". Building professional can provide a certain temperature range. But an occupant's comfort perception depends on a variety of other factors, which are often factors that cannot be measured or influenced e.g. by the facility manager. That these contextual factors (e.g. outdoor climate, behavioural factors, psychological factors as personal control) play a major role has been shown in numerous research results (e.g. [27], [3]; [10], [23]). De Dear et al. [10, p.3] asked whether building professionals can be seen as providers of comfort and occupants as passive recipients of comfort? Bordass and Leaman [7, p.192] suppose that the focus on comfort provision as a service of building professionals "…may deny occupants simple facilities for discomfort alleviation…" in the design process. Could it also add to an occupant's impression that the locus of indoor climate control was an external one [24]?[2] The often expressed opinion among building professionals that occupants exert unsuitable behaviour would also be supported by using the term "comfort provision". Could this attitude lead to occupants, e.g. in office buildings who would demand changes from the "comfort provider" instead of taking actions themselves, leading to a higher complaint rate? A facility manager or planner saying: ‚Occupants always open the windows which has a negative impact on the energy consumption; they better shouldn't have access to windows!' can cause occupants thinking they would not have the capability to open the window at a suitable time (negative social verbally persuasion[3]). From this argumentation it might follow that occupants may not feel responsible to *seek comfort* because comfort would be *provided* [24]. On the contrary, other research has shown, that occupants who are concerned about environmental issues react more relaxed

---

[2] The concept of locus of control has been used to describe generalised expectancies towards the belief of being in a position (internal locus) or not (external locus) to cause a change [30]. This concept was applied as one impact factor on the individual's level of control in a *conceptual approach of personal control in indoor environments* by [23].

[3] The concept of self-efficacy developed by Bandura [4] was applied as one impact factor on the individual's level of control in a conceptual approach of personal control in indoor environments by [23].

when in a green[4] building the thermal comfort conditions are somewhat outside the normally experienced ranges [26, 12, 13].

4.3. Comparable comfort conditions

The basis for energy efficiency comparison is the approach of "*equivalence of service*". The principle of *equivalence of service* (here thermal comfort) is what the European Energy Performance of Buildings Directive sets as precondition for energy efficiency comparison of different solutions. The energy performance can only be compared within the same building usage (e.g. residential) and with the same thermal comfort. Thermal comfort is expressed in this cas by the operative temperature the building is designed for and has the capability to deliver these conditions on demand. Shove [32] argues that this approach is one driver stabilising "…contemporary, but often recently established ideas, for instance about the meaning of comfort…", "…reinforcing the idea that such interpretations [here: thermal comfort requirements] are non-negotiable…". A planner might perceive a high pressure if he could not meet this *basic need*, followed by e.g. litigation issues. This is what actually happens in planning practice, that the planning does follow the explicit requirements laid down in a standard but seldom adopts the opportunity to fulfil the *goal* or *intention* of a standard in a *different way* than laid down in the standard.

4.4. Indoor exposure rebound

Thermal comfort has been described as a self-regulating system [27]. Based on the principles of human thermoregulation and the physical principles of heat exchange between humans and their environment, numerous studies have shown that there is more factors than pure thermoregulation that affect thermal comfort perception. The theory of adaptive thermal comfort mentions among others physiological adaptation, which stands for acclimatisation processes when exposed to different seasons or when moving from one climatic zone to another (e.g. [3], [34]). Also, psychological adaptation comprising expectations, learnt attitudes or individual concepts of what thermal comfort means play a role (e.g. [8]). These adaptive principles result into an excellent human adaptability to a wide range of temperatures. Thus if humans do rarely spent time outdoors they might adapt to *prevailing indoor temperatures*[5] instead. As we observing higher temperatures in energy-efficient homes (see section 2) this could also be seen as an effect of *indoor exposure adaptation*, hence it could be called an "*indoor exposure rebound"*. It might be explained by the fact that exposure to more stable and narrow temperature ranges changes the expectations towards indoor temperatures and at the same time the human thermoregulatory system might not be "experienced" anymore with temperatures outside this narrow temperature range the body has adapted to. The human body may also get more sensitive to small temperature changes. Therefore the body might get more alert and therefore probably leading to discomfort perception followed by the user adjusting the thermostat to a new set-point.

5. Sustainability goals and strategies to get there

Sustainability rating systems aim at balancing the ecological, economical and socio-cultural aspects of our built environment. Thermal comfort is part of the socio-cultural set of sustainability criteria.

---

[4] Green stands here for all kind of buildings which's performance is described to be more sustainable than standard buildings.

[5] Prevailing indoor temperatures in the heating period are designed following the classic heat balance approach according to [14, 25]. The adaptive model [14] can be applied for periods of the year in which no active conditioning system is operating.

The assessment criteria are set according to a societies concepts about what sustainability means. To the authors individual perception, the definition of thermal comfort criteria in the frame of sustainability rating systems has lead to the above described reinforced attitude that comfort is not negotiable. Besides *criteria* for the assessment of the degree of sustainability of a building, there is also *strategies* to reach sustainability: efficiency, consistency and sufficiency. Efficiency (less resource use per unit of service) and consistency (recycling, renewable energy) have been widely accepted and have been already implemented in design, planning or operation procedures. They are known to be connected to rebound effects as descried earlier. The third strategy, sufficiency is less known and not yet common sense [17]. Sufficiency refers to the right measure. And is often associated to behavioural changes. Sufficiency can be influenced through – amongst other factors which have been described already [5] - changes in the socio-cultural column; here: *Thermal comfort*.

6. Towards sufficient thermal comfort - conclusions

Not getting disturbed thermally, hence reaching thermal comfort is what we are seeking for. However, since we have numerous technological means to make indoors spaces comfortable it seems that we got adapted to the indoor conditions we have created ourselves, still seeking to increase comfort which seems to lead to higher heating set-points, hereby not contributing to less energy use. At the same time we have learnt that a *maximised* comfort would be a *basic need.* While we are using all these technological means to *maximise* our comfort we seem to become more sensitive to temperature changes and seem to have forgotten about the excellent human adaptability to temperatures.

From the above discussed facts and perspectives we can conclude that the energy performance gap we have been observing cannot be overcome without addressing the user’s role in thermal comfort perception. Furthermore, the focus in thermal comfort should be more on contextual indoor environmental factors than purely on temperature (and related factors as air velocity etc.). Instead, we should expect the user’s to play an active role in this process, and support them in doing so by planning for e.g. an appropriate degree of personal control of the indoor environment or inform them about the intended functioning of a building as part of behavioural adaptation processes.

What is needed is a new understanding and thinking approach which addresses the question for the *right measure of thermal comfort* in climates which have the need for seasonal or all year round active conditioning leading to a more sufficient conditioning practice. The physical principles of heat exchange between humans and their environment and human thermoregulation are *one basis* of thermal comfort. However, the often neglected contextual factors should get more attention and become part of the planning practice.

There is already research results [e.g. 26, 12, 13] showing, that, provided the users are conscious about the “green” performance of their building and understand its importance, the controls are usable and they got factual information on how to make use of certain technological means to adapt [23], they will be able to use their building in the intended way. Shove [32, p.8] concludes that a solution would be to design buildings “…that do not meet present needs, and that do not deliver equivalent level of service, but that do enable and sustain much lower-carbon ways of life”, hence with regard to the topic discussed here: more sufficient thermal comfort practice.

Acknowledgement

The author would like to thank the Obelske Familiefond, Denmark for supporting this work.
This work has been performed within the framework of the International Energy Agency - Energy in Buildings and Communities Program (IEA-EBC) Annex69 “Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings”. www.iea-ebc.org, www.annex69.org

This paper is based on previous talks/lectures of the author of this paper at the following events:
1. “Some thoughts …On thermal comfort and sustainability strategies in the built environment” Seminar at the Indoor Environmental Quality Laboratory, Sydney School of Architecture, Design and Planning, The University of Sydney, Australia 15. August 2018,
2. “On the relation of thermal comfort and sustainability strategies in the built environment” held at the “Thermal Comfort and Low Energy Cooling” Symposium organised by CEPT University, Ahmedabad, India on 31. October 2018.
3. “From energy efficiency towards sufficiency strategies for indoor environmental design” held as inauguration lecture at Department of Architecture, Design and Media Technology, Aalborg University, Denmark on 2. May 2019.

References

[1] Angus, T.C. (1968): The control of indoor climate. Pergamon Press, Oxford, London, Edinburgh, New York, Toronto, Sydney, Paris, Braunschweig.
[2] ARK Arbeitsgemeinschaft Raumklimatologie (1972): Empfehlung über raumklimatische Richtwerte für Wohnbauten vom 21. Januar 1972, Stadt- und Gebäudetechnik, 5, 121-126
[3] Auliciems, A. (1981) ‘Towards a psychophysiological model of thermal perception’, International Journal of Biometeorology, 25, pp. 109–122.
[4] Bandura, A. (1977): Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84, 2, 191-215.
[5] Bierwirth, A.; Thomas, S. (2019): Energy sufficiency in buildings. A concept paper. European Council for an energy efficient economy, 48 pp. www.energysufficiency.org, last accessed 15. May 2019.
[6] Borsch-Laaks, R. (2000): Wohnen ohne Feuchteschäden. Schwachstellen und ihre Vermeidung, Hinweise für Eigentümer und Mieter. Heidelberg, frankfurt, VWEE Energieverlag, 2nd Ed. ISBN: 3-87200-655-X
[7] Bradke, F.; Liese, W. (1952): Hilfsbuch für raum- und außenklimatische Messungen (Guidance to indoor and outdoor climate measurements). In German. 2nd ed., Springer. Berlin, Göttingen, Heidelberg
[8] Brager, G. S. and de Dear, R. J. (2003) ‘Historical and cultural influences on comfort expectations’, Buildings, culture and environment: Informing local and global practices. Blackwell Publishing Ltd, pp. 177–201.
[9] Bordass, W.; Leaman, A. (1997): Future buildings and their services. Strategic considerations for designers and clients. Buildings Research and Information, 25, 4, 190-195.
[10] de Dear, R. J., Brager, G. S. and Cooper, D. (1997) ‘Developing an Adaptive Model of Thermal Comfort and Preference’, in Final Report on ASHRAE Research Project 884. Macquarie University Sydney.
[11] de Wilde, P. (2014): The gap between predicted and measured energy performance of buildings: A framework for investigation. Automation in Construction, 41, pp 40-49 http://dx.doi.org/10.1016/j.autcon.2014.02.009
[12] Deuble, M. P., & de Dear, R. J. (2012). Green occupants for green buildings: The missing link? Building and Environment, 56, 21–27. https://doi.org/http://dx.doi.org/10.1016/j.buildenv.2012.02.029
[13] Deumling, R.; Poskanzer, D.; Meier, A. (2017): Who are the low energy users: Lessons for climate policy. Proceedings: eceee 2017 Summer Study on energy efficiency: Consumption, efficiency and limits paper 9-432-17 https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/9-consumption-and-behaviour/who-are-the-low-energy-users-lessons-for-climate-policy/, last accessed 22.01.2019
[14] EN 15251:2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Brussels: CEN (European Committee for Standardization)

[15] EN 16798:2019: Energy performance of buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. (preliminary)
[16] Erhorn, H.; Reiß, J. (Ed.) (1994): Niedrigenergiehäuser: Zielsetzung, Konzepte, Entwicklung, Realisierung, Erkenntnisse. Fraunhofer-Institut für Bauphysik, Stuttgart. 1. Ed, 10/1994
[17] Fischer, C.; Grießhammer, R. (2013): When less is more. Sufficiency: Terminology, rationale and potentials. Oeko-Institute's Working paper 2/2013. Oeko-Institue e.V., Freiburg, Darmstadt, Berlin, October, 2013, www.oeko.de/oekodoc/1879/2013-007-en.pdf, last accessed 29.12.2017
[18] Gram Hanssen, K.; Hansen, A.R. (2016): Forskellen mellem målt og beregnet energiforbrug til opvarming af parcelhuse. SBI forlag. https://sbi.dk/Assets/Forskellen-mellem-maalt-og-beregnet-energiforbrug-til-opvarmning-af-parcelhuse/sbi-2016-09-1.pdf
[19] Gruber, E.; Erhorn, H.; Reichert, J. (1989): Cancen und Risiken der Solarchitekture: Solarhäuser Landstuhl. Köln, Verlag TÜV Rheinland. ISBN: 3-88585-676-X
[20] Grytli, E.; Støa, E. (Ed.) (1998): Fra Årestue til smarthus. Teknologien omformer boligen. Oslo, Norsk Arkitekturforlag, ISBN 82-7532-010-0
[21] Hansen A.R.; Gram-Hanssen, K.; Knudsen, H.N. (2018): How building design and technologies influence heat-related habits Building Research & Information, 46:1, 83-98, DOI: 10.1080/09613218.2017.1335477
[22] Hellwig R.T.; Teli, D.; Schweiker, M., Choi, J.-H.; Lee, J.M.C.; Mora, R.; Rawal, R.; Wang, Z, Al-Atrash, F. (2018): Applying adaptive principles – Developing guidance for planning practice. Proceedings Comfort at the Extremes Conference CATE 19, Heriot Watt University Campus Dubai, 10-12 April 2019
[23] Hellwig, R. T. (2015) 'Perceived control in indoor environments: a conceptual approach', Building Research & Information, 43(3), pp. 302–315. doi: 10.1080/09613218.2015.1004150.
[24] Hellwig, R.T. (2018). Revisiting overheating indoors. Proceedings of 10th Windsor Conference: Rethinking Comfort Cumberland Lodge, Windsor, UK, 12-15 April 2018. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk, paper 0116, www.windsorconference.
[25] ISO 7730 (2006): 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 (ISO 7730:2005); German version , May, 2006.
[26] Leaman, A., & Bordass, B. (2007). Are users more tolerant of 'green' buildings? Building Research and Information, 35(6), 662–673. doi:10.1080/09613210701529518
[27] Nicol, F. and Humphreys, M. A. (1973) 'Thermal comfort as part of a self-regulating system', Building Research and Practice, 1 (3), pp. 174–179.
[28] Pettenkofer, M. (1858): Über den Luftwechsel in Wohngebäuden. Münchem, Cotta'sche Buchhandlung
[29] Rothfeld M. (1916): Lüftung und Heizung im Schulgebäude (Ventilation and Heating in School Buildings) In German. Berlin, Julius Springer
[30] Rotter, J.B. (1966): Generalized expectancies for internal versus external control of reinforcement. Psychological Monographs, 80, 1, 1-28
[31] Shipworth, M. (2011): Thermostat settings in English houses: No evidence of change between 1984 and 2007, Building and Environment, 46, 3, 635-642 https://doi.org/10.1016/j.buildenv.2010.09.009
[32] Shove, E. (2017): What is wrong with energy efficiency? Building Research and Information. DOI: 10.1080/09613218.2017.1361746
[33] Sunikka-Blank, M.; Galvin, R. (2012) Introducing the prebound effect: the gap between performance and actual energy consumption, Building Research & Information, 40:3, 260-273, DOI: 10.1080/09613218.2012.690952
[34] Taylor, N.A.S. (2014): Human heat adaptation. Comprehensive Physiology. 4, 325-365. DOI: 10.1002/cphy.c130022