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Hellwig, Runa Tabea

Published in:
Proceedings of 10th Windsor Conference: Rethinking Comfort Cumberland Lodge, Windsor, UK, 12-15 April 2018. London

Publication date:
2018

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

WINDSOR CONFERENCE
Rethinking comfort
12th - 15th April 2018

Revisiting overheating indoors

Runa T. Hellwig

E2D Energy Efficiency Design, Augsburg University of Applied Sciences, Augsburg, Germany
runa.hellwig@hs-augsburg.de

Abstract: In recent years, an increasing amount of overheating issues in buildings has been reported. Despite available knowledge and recognition of the problem by research, in practice little attention has been paid to the problem. The aim of the paper is to identify contradictions, missing interconnections, communication deficits or barriers. Terminologies used, and time and dynamics in the context of overheating and heatwaves will be discussed. Planning pathways and their consequences on preparedness for overheating or heatwaves will be discussed subsequently. In the context of overheating as well for heatwaves, informing people about the human ability to acclimatise to seasonal changes and addressing acceptable healthy temperature ranges instead of comfort ranges could be supportive in relaxing people's expectations towards indoor climate. Three areas should become a focus of future activities: a) enhancing adaptability in humans b) managing human expectation towards the indoor environment and c) enhancing adaptability of buildings. Time and dynamics in building performance, adaptation processes and mortality predictions are interrelated and will require more attention in future studies.

Keywords: heatwave, adaptability, adaptive, expectations, air-conditioning

1. Introduction

Climate change causes us to adapt our built environment and to rethink our accustomed routines towards our built environment. While in Europe optimising buildings for heating energy performance was the focus in the past, warm season free-running performance was not. What is being reported from practice is an increasing amount of overheating issues in buildings (e.g BRI Special issue 2017, Lomas & Porritt 2017). Although post-war buildings already tended to be overheated due to large transparent areas in the facades and a lack of thermal inertia (e.g. Grandjean 1969, Roaf et al. 2009), overheating has become a severe problem since the implementation of highly energy efficient strategies for winter.

As cooling technologies are available and have become affordable; and a warming world is the outlook, planners are concerned about litigation issues they could face (e.g. Hausladen et al. 2004; Roaf & Boerstra, 2015) and go for the 'safe' choice: active cooling (as a building's design might not be challenged by an engineer). In Germany for instance, compared to 15 years ago, considering active cooling has become almost a matter of course. Area-wide adoption seems only to be a matter of time.

A literature search identified areas of research in the context of overheating: heatwave mortality projections, health impacts, prevalence of elevated temperature indoors, heatwave warning systems, comfort models and standards/assessment methods, deterministic and stochastic studies on design impact, surveys on prevalent behaviours during warm periods, and human heat adaptation (for recent studies see e.g. BRI 2017). This is rather comprehensive knowledge and the question arises why besides the recognition of the problem of overheating by research, "…the matter is paid little attention in practice" (Lomas & Porritt (2017, p2).

Hellwig, R. T. (2018). Revisiting overheating indoors. I Proceedings of 10th Windsor Conference: Rethinking Comfort Cumberland Lodge, Windsor, UK, 12-15 April 2018. London [paper 0116] Network for Comfort and Energy Use in Buildings, http://nceub.org.uk. http://windsorconference.com/ proceedings/

The aim of the paper is to identify contradictions, missing interconnections, communication deficits or barriers towards successfully applying available knowledge on overheating avoidance in practice. The author would like to summarise important pieces of knowledge and research first, on which the discussion of selected points will be based on later. Finally, implications for future actions will be drawn.

2. Overview on selected research

2.1. Sustainability strategies

There is a trinity strategy for reaching sustainability: efficiency (less resource use per unit of service), consistency (ecologically sound technologies) and sufficiency (right measure). The first two have already been implemented in design, planning or operation procedures. Sufficiency is not yet a generally accepted strategy. Efficiency and consistency alone will not lead to sustainability because of rebound effects diminishing the effectiveness of the implemented measures. While efficiency and consistency are seen to be linked to technology application, sufficiency refers more to changes in consumption patterns. Although sufficiency has often been misunderstood as a lack of comfort or even backwardness it could also be seen as a simplification of life or liberation from overabundance; it is often associated with behavioural change, or as a modification of consumption patterns (Fischer et al. 2013).

Sustainability rating systems (e.g. LEED, BREEAM, BNB/DGNB, CASBEE, Green Star, Green Mark) are aimed at balancing the ecological, economical and socio-cultural aspects of our built environment. Sufficiency can be influenced through changes in the socio-cultural column (here: thermal comfort). A building's passive design determines the overall potential for the magnitude of energy demand, and hence is also linked to sufficiency.

2.2. Overheating and Heatwaves

The term *overheating* has been used for temperatures exceeding defined acceptable temperatures ('comfort', see 2.4&2.3) in a warm or cold season. In the context of heatwaves *excessive heat* or *excess heat* are the terms used. The World Meteorological Organisation (WMO, 2015) recommends developing heatwave characteristics for individual regions considering the magnitude, the duration and their combined effect (severity) as well as the heatwave's geographical extent. Heatwaves are often defined as two or three consecutive days with the daily outdoor mean temperature exceeding a threshold value (WMO, 2015).

According to the Intergovernmental Panel on Climate Change heatwaves will cause: a higher mortality, especially when occurring earlier in the warm season, and an increased temperature related morbidity (cardiovascular, respiratory, kidney diseases) (Smith et al. 2014). Hereby, "*Variability in temperatures is a risk factor in its own right, over and above the influence of average temperatures on heat-related deaths.*" (ibid., p713).

Earlier mortality projections are based on static temperature approaches leading to increased projected mortality in the future. Studies (e.g. Armstrong et al. 2011) found different health relevant threshold temperatures for different local climates. Therefore, Gosling et al. (2017) compared six different modelling adaptation methods for 14 European cities in order to compare their impact on the resulting mortality rates (period 2070-2099). Across all of the cities investigated and irrespective of climate/emission modelling, they found that the difference between including and excluding adaptation ranges was between 28% with one and 103% with another method. They concluded that adaptation should not be neglected in future mortality projections.

In future mortality/morbidity projections the quickening of the mean outdoor temperature change from one day to another, both increase >95% percentile and decrease <5% percentile, was considered (equalling +3.5 and -3.6 K resp. in current German climate; Zacharias & Koppe 2015). Diurnal temperature ranges in a heatwave, >95% percentile of the location's range, are also regarded as a stress factor (equalling 12.9 K in current German climate, ibid.).

The German Guideline on heatwave plan development on a regional level identified the following vulnerable groups of people requiring special consideration: elderly, socially isolated including the homeless, obese, people in need of care or with chronical diseases, dementia, special medication, sensitivity to heat, babies and small children (BMUB, 2017). Although sensitivity to heat or high temperatures has been reported to be decreasing (Boeckmann & Rohn, 2014), a higher impact is expected for non-acclimatised people compared to acclimatised (Maloney & Forbes 2011).

2.3. Adaptation to heat

When thermal stress disturbs homeostasis, the immediate response of the human body is thermoregulation (accommodation after Taylor 2014, see comprehensive review); repeated exposure to the stress leads to thermal adaptation, which can be classified into acclimation (artificially induced) or acclimatisation (seasonal or after changed residency). In active acclimation training or experiments two general approaches exist, the classical constant stress approach and the progressive overload or constant strain approach. The latter will lead to a higher degree of adaptation (ibid.). In heat, short-term adaptation goes along with a stabilisation of the cardiovascular system, decreased heart rate, increased sweat rate, lowering of the temperature threshold for sweating and vasodilatation, and lower resting core temperature (e.g. Wendt et al. 2007). After long-term adaptation a habituation of the body's responses (reduced sweat rate,) can be observed; they go along with a decrease in perceived strain as well as a modification in temperature perception (Taylor, 2014). Acclimatisation will not occur if a certain behaviour removes the stress. These could be air-conditioning, buildings sealed from the outdoor climate or rarely spending time outdoors and determine the extent to which acclimatisation will occur. Heat adaptation, once acquired by the body can be re-established in a shorter time than it took to establish adaptation at first (ibid.).

Office work of seasonal acclimatised subjects in an overheated realistic office environment during 4.3 h at temperatures 1 to 6 K above adaptive comfort Cat II (equalling 4 to 24 Kh exceedance per day, EN15251) goes along with gradually reduced willingness to exert (work) effort and less relaxed subjects (Hellwig et al. 2012).

2.4. Adaptive thermal comfort

The classic adaptive thermal comfort model is based on the human ability to adapt to thermal stimuli in three ways: behavioural adjustment, psychological adaptation and physiological adaptation (Nicol&Humphreys 1973, Auliciems 1981, de Dear&Brager 1998).

The current adaptive models of thermal comfort (ASHRAE St 55 2017, EN 15251 2007) determine the range of acceptable operative temperature (often referred to as comfort range) as a function of the prevailing outdoor temperature. The prevailing outdoor temperature has been defined as an exponentially-weighted running value with α being a constant found to best correlate with the indoor comfort temperature at a value of 0.8 (e.g. McCartney&Nicol 2001). ASHRAE St 55 (2017) recommends values of α between 0.9 and 0.6 with 0.9 more suitable for climates having a small day-to-day temperature dynamics and 0.6

for larger day-to-day temperature changes. It serves as a measure of the thermal experiences people collect from the recent outdoor weather and on which they develop parts of their actual expectations.

Alliesthesia is a concept[1] useful to describe phenomena in dynamic thermal environments or for locally varying stimuli on the body (intended or not) (e.g. latest paper Parkinson&de Dear 2017) and to understand the construct of perceived control (Hellwig, 2015).

2.5. Building design and planning

Overheating assessment is based on parameters of excess over upper acceptable temperatures (e.g. Nicol et.al 2009, Lomas&Porritt 2017), targeting time of exceedance, severity and/ or upper limit, e.g. CIBSE TM52 (2013 based on EN 15251 2007) applies three criteria of which at least two have to be complied with: 1: exceedance hours of Tmax (≤3%, occupied hours, non-heating season); 2: daily degree hours ≤ 6 Kh; 3: all temperatures in occupied hours < Tmax+4.

Wilson (2017) proposes a habitability test for buildings in the U.S.: a resilient design module to be implemented in the LEED assessment procedure aiming on maintaining thermal habitability of buildings, hence 'liveable temperatures' over a period of seven days during a power outage allowing for 5 or 10 Kd SET above 30°C SET for residential/ non-residential buildings.

Passive design theory of buildings, design recommendations for warm seasons, or simulation tools were established many years ago (e.g. Koenigsberger et al, 1973, Krause 1974, Hauser 1978). The positive impact of both, limited window-to-wall-ratios and effective solar shading, is nothing new but led to tightened mandatory requirements in Germany (DIN 4108-2 2013) which can be bypassed if compliance based on dynamic thermal simulation is shown. While today's buildings tend to be light-weight buildings the impact of thermal inertia is well-known and has been confirmed in simulation studies (e.g. Schlitzberger et al. 2017) and on the basis of occupant survey data (Gauthier et al. 2017). In this regard, both approaches also demonstrated the importance of heat dissipation by means of night ventilation as also implemented in assessment standards (DIN 4108-2 2013). The difficulty in implementing these strategies into designs has been repeatedly expressed by planners as well as reservations to use future TRY for simulation (e.g. Fischer 2013).

3. Discussion

Although the knowledge on overheating is already rather comprehensive the knowledge transfer has not been overly successful as planning practice shows. First some points regarding terminologies will be discussed. Then, time and dynamics will be discussed as they are important in both, overheating and heatwaves. The planning pathways and their consequences on preparedness for overheating/ heatwaves will be discussed subsequently.

3.1. Terminology

Terminologies often carry certain connotations which reflect attitudes or conventions of everyday life. Connotations or laypersons' understanding of selected terminology in the

[1] How a subject perceives a certain stimulus depends on whether the stimulus contributes to improve the internal state of the subject (positive, pleasant) or impairs the internal state of the subject (negative, unpleasant) (Cabanac 1971). Pleasure serves to reward behaviour and to provide motivation to exercise behaviour beneficial for physiological processes (Cabanac 1996).

context of overheating or heatwaves and the consequences arising from this are discussed as follows.

Comfort

When communicating issues of indoor temperature (here: overheating) normally the term *'comfort'* has been used. At least in the German language meaning, *comfort - Behaglichkeit*, has a strong connotation of cosiness and well-being; and this meaning is shared with English. In most German publications, in every day planning, in sustainability rating systems *Behaglichkeit* has been replaced by *Komfort* (nothing else than the English *comfort* was meant) but has a strong connotation of convenience for most lay persons. Furthermore, *comfort* is something that is seen as being *provided.* Can building professionals be seen as providers of comfort and can occupants be seen as passive recipients of comfort (de Dear et al. 1997, p3)? Could it be that the pronunciation on *comfort provision* as a service of building professionals not only "…may deny occupants simple facilities for discomfort alleviation…" (Bordass&Leaman 1997, p192) in the design process but may add to an occupant's impression that the locus of indoor climate control is was an external one?[2] And doesn't it support the widespread opinion among professionals that occupants exert 'unsuitable' behaviour? On this basis, isn't it logical that occupants would demand changes from the *comfort provider* (e.g. complaint rate)? If this was the case, would there be ways to shift this learnt attitude back towards occupants taking on responsibility for their comfort and actively *seeking* comfort? Further, would building professionals accept not being providers and would it change their ways of designing buildings?

The origin of *providing comfort* probably comes from the promotion of new technological achievements which are about to be brought onto the market, carrying a marketing promise which is *providing comfort.* Such a pattern can be observed repeatedly in practice, e.g. *smart buildings.* Although this marketing promise results in high user expectations which later may not be (fully) satisfied, it may help to further establish *comfort provision* rather than rejecting it.

Stress and adaptation

Even though there is broad evidence from field studies for acceptability or satisfaction in free-running buildings (here: in a warm season), stakeholders in the building process frequently express reservations about the adaptive comfort approach because of the necessary *adaptation* which they assume to cause *stress* (own experience from discussions with professionals, see also de Dear et al. 1997, p30). *Stress* in colloquial language carries an unhealthy connotation. Seasonal acclimatisation to heat is a slow process which physiologists regard as a "…fine-grained adaptation strategy,… [producing]...generalists." (Taylor 2014, Tab1). Although a slowly increasing temperature is seen as mild strain by physiologists, in colloquial language this would probably mean that the 'strain' is not recognisable.

Healthy temperature

[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 (Rotter 1966). This concept was applied as one impact factor on the individual's level in a conceptual approach of perceived control by Hellwig (2015).

Whereas *comfort* and *adaptation* in an overheating context have been discussed controversially, e.g. the extension of the tolerable temperature range in a warm period from an occupational health and safety perspective (at outside temperatures above 26°C) saw a smooth implementation in Germany, even though the indoor temperature was allowed to increase from 26°C, 30°C up to 35°C provided certain supportive measures (adaptive opportunities) are applied (Hellwig&Bux 2013). Discussions in the working group comprising stakeholders from various fields including representatives of unions and employers (as experienced by the author personally) as well as the implementation into practice (as reported from the Federal Institute for Occupational Health and Safety) took place in an objective and factual way, very different from discussions on whether it would be OK to have just a few hours of slight exceedance in an office in a warm period.

From the brief discussion above it may be concluded that comfort could be seen as a highly emotionally loaded term, adaptation may be too much associated with stress whereas healthy temperature appears as a rather neutral to positive term.

3.2. Time and dynamics

Time and dynamics are important factors in overheating and heatwaves, in human adaptation and building performance.

Heatwave mortality projections

Gosling et al. (2017) found that with a static temperature assessment approach mortality rate was overestimated by 30 to 100% compared to approaches considering an adaptation effect. Their study gives cause to seriously considering the modelling of human adaptation in mortality predictions as it is "…a source of uncertainty that can be greater than the uncertainty in … climate modelling…". However, the concept of the running or prevailing mean outdoor temperature (EN 15251 2007, ASHRAE St 55 2017) is currently only applied to comfort questions. It would be interesting to see whether this concept could also serve as a suitable approach to mortality predictions allowing its use to consider dynamics in mortality prediction as well.

Heatwave severity, on- and offset

In dependence on the variability of the prevailing climate in a certain location, there can be different resulting sensitivities in the perception of the severity or on- and offset of heatwaves. Therefore, Nairn & Fawcett (2015) developed the excess heat factor (EHF) which is the product of two indices, one indicating the presence of an unusually warm period (3-day-mean minus annual 95% outdoor temperature percentile) and the second representing the level of acclimatisation at a certain time of a year (3-day-mean minus running monthly mean outdoor temperature). Again, the already developed concept of an outdoor running mean (with α varying according to location) as described earlier in this paper could also serve as one indicator as part of such an index.

What is the gradient in increase or decrease of temperatures, outdoors and indoors that would be still tolerable in the context of health protection? Zacharias and Koppe (2015) used the 5% (-3.6 K) and 95% (+3.5K) percentile of day-to-day mean differences (German weather) and the latter approach was also applied to diurnal temperature ranges (12.9 K). In the 2003 heatwave in Munich a decrease of the mean daily temperature of 6 K and 5 days with diurnal temperature ranges of 13 to 15 K were recorded (own data). No systematic data are available on the prevalence of diurnal temperature ranges or day-to-day mean differences indoors (although many monitoring projects have collected temperatures continuously and innumerable dynamic simulations have been carried out). Own data from the 2003 heatwave show a 4 K diurnal variability always above the adaptive Cat II upper temperature value in a light-to-medium-weight E-W-oriented setting with insufficient shading, a fairly high window-to-wall-ratio and no night ventilation but not air-tight as well as non-insulated.

Buildings

As there is a time lag in adaptation and harsh changes can be indeed stressful to cope with buildings should serve as a buffer. Early acclimatisation responses of the body take 3 to 6 days; the later responses require 7-14 days to develop (Wendt. et al. 2007). In dependence on the magnitude of outdoor temperature increase, solar loads and building design and airing, the full development of the maximum indoor temperature can take up to 10 days (Krause, 1974). For a building, in order to be supportive in the acclimatisation process there should be a delay of about one week, this being beneficial for avoiding standard warm period overheating as well. The before-mentioned light-weight building in the 2003 heatwave in Munich showed *no lag* - the indoor-outdoor temperature difference was almost the same over consecutive days during the rising temperatures of the heatwave.

The classification of buildings according to their effective thermal mass (DIN EN ISO 13790), calculation methods for a building's time constant as well as for heat source-to-sink relation are available. But these are abstract values which cannot be easily related to diurnal temperature ranges or time lags in maximum temperature development. So far, dynamic thermal simulation is carried out in order to determine excess temperatures or to show compliance with acceptable temperature ranges. Characteristic dynamic values as mentioned above are not yet part of typical analyses of results nor do benchmark values or recommendations exist.

The predictability and reliability of a building's thermal behaviour is an important building property for occupants (Bordass&Leaman 1997). A building that reacts 'even-tempered' and 'calm' to changes in outdoor weather would lead to a higher conformity of a user's expectation and actual building performance, hence a higher user satisfaction. This building property is highly linked to a time lag in the outdoor temperature to be mirrored attenuated indoors.

Field surveys

Field survey results reflect prevalent conventions, attitudes, expectations or behaviours at the survey's point of time. Field surveys have been used to develop adaptive comfort models. A changed attitude towards acceptable temperature ranges, overheating, or active cooling should then be reflected in such a result as well. On the one hand a changed attitude or expectation would be interesting to note. On the other hand, if we noted a changed *demand* towards lower temperatures in the warm season or a *demand* for active cooling where cooling was not common, would this give us reason to support this changed *demand* on the basis of the survey, developing an adjusted comfort model? Thus, would we end up with models reflecting the heat balance approach[3]? Nicol and Wilson (2013) asked: "Can it be written with natural ventilation as 'normal'?" Isn't there a need to find out what temperature range would be *sufficient* and *healthy* and then communicate this (certainly not neglecting special needs for groups of people)?

The influence of time or dynamics appears to have been somewhat underrepresented in the discussion of overheating and heatwaves. It seems to be apparent that the time

[3] ..as suggested by Fanger's expectancy factor.

factors or dynamics in the different areas discussed are somehow interlinked and have a direct impact on the planning of buildings. If in heatwave predictions, heatwave severity assessment and building planning practice a similar or even the same variable would be used, this could enhance the understanding of the interrelation of outdoor weather impact on indoor temperature courses in addition to a better interdisciplinary exchange and transfer of new research results into practice.

3.3. Planning pathways and preparedness

Excellent human adaptability to temperatures can not only induce seasonal adaptation. If humans rarely spent time outdoors they would adapt to prevailing indoor temperatures. In the case of adaptation to actively cooled environments the temperature difference to cope with e.g. in a heatwave would be much higher compared to acclimatised persons. Although there is a lack of data from the field, the impact of cooling penetration on mortality/morbidity in heatwaves can be supposed.

Just as other countries and regions in Europe, Germany used to operate their buildings in a free-running mode in the warm season, in all residential, almost all school and the majority of office buildings. Classic air-conditioning systems were not well-accepted.

In 2007 EN 15251 introduced two comfort models in one standard: the heat balance and as a new approach the adaptive model. Since then two models have been existing in parallel. In 2008, a sustainability rating system BNB/DGNB for office buildings was launched in Germany comprising the two comfort models, hence two planning pathways. Hereby, the same magnitude of credits is given to categories I, II or III of comfort independent of which comfort model was used. The separation into two models allows for one planning pathway that may lead to building designs not suitable to meet future resilience requirements. Furthermore, a heat balance pathway tolerates designs with additional energy use and is likely to be a barrier for optimising the passive building design *before* adding active measures. Regarding the two planning pathways, de Dear et al. (1997, p26) believe that the differentiation between the two comfort models is not "irreconcilable".

The next point refers more to the technology side and arguments explaining intensified cooling penetration. A finding by Cabanac emphasised by Nicol&Humphreys (1973) is that humans tend to favour behavioural thermoregulation more than other forms of thermoregulation. Humans receive an immediate rewarding confirmation of their behaviour in causing a useful thermal stimulus contributing to improve the internal state (alliesthesia as interpreted by Hellwig, 2015). Decentralised air-conditioning units controlled by the occupants can provide such an immediate positive feedback as this technology provides an immediate perceptible cold stream of air, explaining at least partly why this technology is so successful. Since the late nineties a new technology, thermo-activated slab cooling/heating systems has been adopted quite fast. If operated in the originally intended way heat sinks in the environment are used (ground or indirect evaporation) and energy is only used for pumping the water. Operated in such a way the cooling capacity is rather limited and can help to replace intense night ventilation or the missing thermal mass in an otherwise light-weight building. More recently and frequently the system has also started to be used in combination with heat pumps for heating *and cooling*, the latter followed by an increase in cooling capacity. Despite the usefulness of the original approach, it seems that this technology is serving as a low threshold cooling service opening doors to implementing cooling in residential buildings and schools. There is unfortunately doubt that this trend will be reversed: Because of the coincidence of cooling demand and highest electricity generation from PV in the day, the use of daytime cooling with heat pumps is now also promoted by industry and consultants as an appropriate measure, hereby increasing the proportion of self-consumed renewable energy from PV systems, appearing to be even more sustainable. Also the fast penetration of activated concrete slabs for cooling (often pronounced cooling capacity from the ceiling) could be explained by alliesthesia, (here: spatial, as defined by Parkinson&de Dear 2015). If this technology is then to be thought of *energy-efficient* active cooling, then it would be the first measure of choice.

It is maybe for the above-mentioned two reasons, that seen against the scenario of increasing future temperatures, engineers, building operators and companies find that cooling has become what Walker, Shove & Brown (2014) call a 'need', even in regions where cooling has not been established widely so far. Shove (2017) argues that the approach of the equivalence of service as the basis for comparison of energy efficiency is one driver stabilising "…contemporary, but often recently established ideas, for instance about the meaning of comfort…". The principle of equivalence of indoor environment service is what the European Energy Performance of Buildings Directive sets as precondition for energy efficiency comparison of different solutions "…reinforcing the idea that such interpretations [here: thermal comfort requirements] are non-negotiable…" (ibid.). If comfort was a 'non-negotiable need', a planner could perceive a high pressure if he could not satisfy this 'basic need', followed by other issues, i.e. litigation issues. Before the background of these two arguments (attractiveness and need) a further spread of cooling appears to be almost unavoidable leading probably to more non-acclimatised people.

Earlier in this paper it was argued that occupants may not feel responsible to seek comfort and to exert behaviour because *comfort* would be *provided*. If this was the case it might be extremely difficult to initiate changes in behaviour. People with a (learnt) attitude of external locus of control (here: regarding comfort) tend to not benefit from information on e.g. appropriate behaviour in an overheated building or from explanations on how the building works because they don't believe they have the power to cause a change and they would probably tend to resist acquiring changes.[4]

Besides the already mentioned vulnerable groups, school children are often regarded as vulnerable because of their dependency on a person in charge, i.e. the teacher (BMUB 2017). Special guidance of teachers on how to support the children in warm periods could be a good solution, organising a changed schedule of lessons, encouraging the children to drink more, shifting more exhausting activities to cooler periods etc.. Non-exposure to warmth could mean to remove any stimulus to acclimatise to warm weather which would diminish the vulnerables' adaptability in the long term. Buildings should also therefore offer reasonable time lags in indoor temperatures rise compared to the outdoor temperature as already discussed above. van Marken Lichtenbelt et al. ("healthy excursions" 2017) propose using (temperature) fitness programs to enhance individual health in general or maybe even adaptability to heatwaves. Such programs could be customised for vulnerable groups as well. They might also be suitable carriers of the message that seasonal acclimatisation occurs as the year progresses and that seasonal acclimatisation is supportive in coping with heatwaves.

[4] According to Bandura (1977) negative (social) verbal persuasion by others, e.g. by facility manager or planner saying: ‚Occupants always open the windows which has a negative impact on the energy consumption; it would be better if they didn't have access to windows!' This could cause occupants to think that they really would not have the *capability* to open the window at the right time. However this principle could also be used in a positive way.

There seems to be a mismatch between planning practice/attitude towards overheating avoidance on the one hand and the clear intention by health authorities that active cooling should be the last choice (for the non-vulnerable population). A broad consensus in society that active cooling measures will increase the vulnerability of humans in the long term seems to be necessary. How building occupants can be involved more intensively compared to current practice and how a shift of the current attitudes of all stakeholders in the planning process (Shove, 2003) could be achieved offers room for future research approaches. Shove (2017, p8) 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." For the planning practice, and in addition to the before mentioned more detailed consideration of building dynamics, it seems to be a necessary future step to develop an integrated model for acceptable temperatures. A first useful step would be of course if all buildings had to comply with minimum passive design requirements as suggested by Wilson (2017). Health-related fitness programs could help to increase the adaptability in the population.

4. Conclusion

In future discussions about temperatures in warm periods, both normal and during heatwaves, it might be useful to address targeted temperature ranges consequently as *acceptable temperature ranges* instead of *comfort ranges.* Addressing *healthy indoor temperature ranges* when it comes to exceptionally warm periods or even heatwaves seems to be appropriate for communicating the topic in a factual way. In order to address both, overheating in today's buildings and the projected higher frequencies of heatwaves two areas should become a focus of future activities: a) enhancing adaptability in humans, and b) managing human expectation towards the indoor environment (all stakeholders in the building process). A third area has already been in the focus of research: c) enhancing the adaptability of buildings, with some questions still remaining to be answered. The following points result from the discussion chapter:

Enhancing adaptability in humans

- relaxing expectations towards indoor climates
- information on the ability of humans to acclimatise to seasonal climate changes and that a good seasonal acclimatisation also helps in heatwaves
- developing suitable health programmes promoting e.g. staying outdoors
- developing fitness programs or special programs for vulnerable groups

Managing expectations

- relaxing all stakeholder's expectations towards indoor climates
- informing about the natural ability of humans to acclimatise to seasonal climate changes and that a good seasonal acclimatisation also helps in heatwaves
- providing information on healthy and sufficient temperatures and behaviour (continue to provide guidance on appropriate overheating mitigation and behavioural mitigation measures as part of heat-wave plans)
- managing occupants expectations on what free-running buildings can offer (sustainable occupancy) and what is *not* in the range of expectation (active cooling, constant temperature)
- informing about low energy use adaptive opportunities in free-running buildings, e.g. campaigns on how to best operate fans

Enhancing building adaptability

- informing stakeholders in the building process that good passive design can offer acceptable and healthy temperature for acclimatised occupants and that an acclimatised population can cope with heatwaves
- establishing adaptability planning (passive design compliance during heatwave scenarios)
- identifying ways to make passive design more appealing to stakeholders taking design decisions
- designing for acceptability which includes predictable thermal building behaviour and personal control
- designing for two design goals: cold *and* warm periods (variable solutions)
- developing and establishing interlinked information on required time lags in indoor temperature rise during warm periods and heatwaves in a certain region

The above list does not aim to be comprehensive and requires further discussion. From the list the great importance expectation plays for indoor climate perception can be noticed immediately. Developing an integrated model for acceptable temperatures (instead of formerly two comfort models) would be more than supportive in communicating indoor temperatures in planning practice. Transdisciplinary approaches and inter-disciplinary collaboration could help managing the change towards sustainable building design and operation.

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