A study of running set-points and user IEQ satisfaction perspectives in the Norwegian commercial building stock

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ABSTRACT

Norwegian building regulations refer to the NS-EN 15251 and the NS-ISO 7730 to define indoor climate criteria in new buildings. For example, the standards prescribe a temperature band of 20-26°C for a normal office situation. Any HVAC engineer or facility manager would however willingly state that office buildings in practice are run with a much smaller temperature dead-band, and that building occupants would complain if temperatures were as high as 26°C. Studies of the North American building stock have found that temperature dead-bands in practice are as small as 1-2 °C, and over-heating and over-cooling occurs frequently (Brager, Zhang, and Arens 2015). There is, however, no published evidence stating the actual temperature dead-bands set points used in the operation of Norwegian office buildings. Nor is there any published material describing how facility managers view the indoor climate preferences of their occupants, or which perceptions and procedures they have for user interaction. This kind of knowledge about the Norwegian building stock and facility management practice is considered to be an important reference for the development of new technologies and business models for reducing energy demand and improving occupant comfort. An interview of 10 facility management coordinators or supervisors was conducted. The answers revealed that the mean temperature dead-band is about 2 °C in Norwegian office buildings. Further, the results indicate that this dead-band could be widened without increasing the number of complaints from occupants. The respondents' perceptions of users IEQ preferences were shown to be partly divergent from those of researchers and building designers, although for some aspects they are convergent. The respondents also reveal a relatively low focus on systems, solutions or technology which could improve user interaction, but at the same time show a high focus on being able to provide quick, personal and local help to the occupants when a problem or complaint of importance arises. In general, the knowledge and focus of the respondents reflect that they are highly tuned to the voice of their users, tenants, customers, operation managers and the individual building. They seem to a lesser extent tuned towards indoor climate research and theory, although this varies among the respondents. The results are systemized, presented and discussed in the paper and may provide a reference for use in the future development and understanding of the industry.

KEYWORDS

Indoor climate, thermal comfort, air quality, set points, facility management

0 INTRODUCTION

The ASHRAE and ISO Standards specify fairly wide ranges of operative temperatures as being comfortable, depending on humidity and occupants' clothing and activity levels. Norwegian building regulations refer to the EN 15251 and ISO 7730 standards, and specify a temperature range of 20-26°C based on assumptions of occupant activity and clothing level. EN 15251 also allows the use of the adaptive model for summer thermal comfort in naturally ventilated or hybrid buildings, typically allowing indoor temperatures close to 27-28 °C oin a hot Norwegian summer day. While regulations have a maximum allowable temperature ranges of 20-26°C for the whole year, the standards NS-EN 15251 and ISO 7730 recommend a seasonal band in offices of 2°C for class I/A, 3-4°C for class II/B, 5-6°C for class III/C. The standards recommend that winter temperatures are lower than summer temperatures in order to make up for the assumed lower clothing level of occupants in summer (0,5 clo) than winter (1,0 clo) (Standard Norge AS 2014, Standard Norge AS 2005). Despite this, it is a known fact that commercial buildings with central HVAC in practice tend to run with smaller temperature dead-bands than this. Several international indoor climate studies have documented the temperature dead-bands which are used in practice. One study reports a dead-band of 1-1.5°C with a seasonal shift of 0.5-1°C, centered around 23°C (Fountain, Brager, and De Dear 1996). Another study reports that for mean building temperature, the median was 23.2°C and the (total) range among the 94 buildings measured was 21.6-24.8°C. Temperature ranges observed in summer and winter were similar, but with median and maximum indoor temperatures 0.5 degrees cooler in summer than in winter (Mendell 2009). Another study of temperature set point ranges states that thermostat set point ranges often are around 2 K, but leaves no reference and claims there is little scientific evidence supporting this (Hoyt, Arens, and Zhang 2014). The same study investigated energy use associated with temperature dead-bands, and (through simulations) found that increasing a cooling set point of 22.2 °C to 25 °C, would save an average of 29% cooling energy. Reducing the heating set point of 21.1 °C to 20 °C saved an average of 34% of terminal heating energy. (Zhang, Arens, and Zhai 2015). It is clear that temperature dead-bands have a large impact on energy use, and the energy saving potential of widening the band is large.

Classic thermal comfort theory is understood to be the theoretical tools to predict thermal comfort stated in ISO 7730 – the PMV-PPD comfort equation based on the research of Fanger in the 1970's. In 1998 Brager and De Dear publicized the Adaptive comfort model, based on field studies of thermal comfort in a large number of buildings world wide (de Dear, R.J., and G.S. Brager 1998). The research shows a large gap between the conditions of which real occupants experience thermal comfort and those predicted by the comfort equation. It also suggests that the occupant's experience of comfort is closely linked to the amount of perceived control the individual feels over personal thermal environment. Where classic theory views thermal comfort to be a direct result of the heat balance between the person and environment in a steady state system, the adaptive comfort model views the occupant as an active part of a dynamic thermo-regulative system, where psychology and expectations also play an important role. The research community has however not fully succeeded in identifying which factors are the most important. In the article "Are 'class A' temperature requirements realistic or desirable?" (Arens et al. 2010), the authors compare occupant acceptability with indoor temperatures in the identified class A, B and C temperature ranges from international standards, where class A has specifies a temperature deadband of 2°C, class B of 4°C and class C of 6°C. In an analysis of high-quality field studies, the three classes did not show different comfort/acceptability outcomes. In other words, the tightly temperature-controlled space (class A) did not provide higher acceptability for occupants than the less tightly controlled spaces (class B and C). The authors argue that this is due to the fact that the occupant's clothing level, activity level and other factors defining their preferred temperature change from day to day causing changes in the ideal temperature changes which are wider than the class temperature dead-band. The authors therefore do not recommend the use of narrow band (class A or B) temperature set points.

In the article "Productivity in buildings: the `killer' variables", Leaman & Bordass claim that losses or gains of up to 15% of turnover in a typical office organization might be attributable to the design, management and use of the indoor environment. They identify *opportunities for personal control* and a *rapid response environment with access to information and feedback regarding complaints etc.* as two of the "killer variables". A study of a large, predominantly North American Post-Occupancy Evaluation (POE) database found temperature and air quality to be the second and fifth largest sources of dissatisfaction among building occupants (Kim et al. 2013). A study on the occupant survey database from Center for the Built Environment (CBE) to estimate individual impacts of 15 Indoor Environmental Quality (IEQ) factors on occupants' overall satisfaction, found *temperature, noise level, amount of space, visual privacy, adjustability of furniture, colours & textures and workspace cleanliness* to be factors that had a nonlinear negative relationship to overall satisfaction. This meaning that their negative impact outweighs their positive effects on overall satisfaction, so it is important that these factors are maintained at satisfactory levels (Kim and de Dear 2012). Based on the theories of adaptive thermal comfort, psychology and environmental psychology, Hellwig proposes two new definitions for the key concepts of *satisfaction* and *perceived control*. Hellwig defines satisfaction with the words *"... satisfaction is caused by either comfort or pleasure, i.e. not exclusively by comfort. Comfort results from homeostasis. Pleasure is caused by a successful control behaviour. Satisfaction can be caused by either comfort or pleasure."* In classic IE theory, focus has been only on comfort as a goal for IE control (i.e. the term "Thermal Comfort"). As described by Cabanac in his definition of the phenomenon "Alliesthesia", comfort describes a situation where everything is right, whereas pleasure indicates a change or stimulus that is for the better. In recent IEQ research, the concept of alliesthesia has been proposed as a framework which can link both classic comfort theory and adaptive comfort theory which also involves psychological aspects. Hellwig defines *perceived control* to be influenced by the persons experiences, personality, expectations to IE factors, preferences for IE factors and the constraints felt by the person. Among these, the following can be influenced through the design and operation of a building: *expectations, constraints and current feedback experiences*. All of these factors can be, and are, influenced by facility management (FM).

Although there exist a vast amount of research and theory within the field of indoor climate, thermal comfort and air quality, building design and facility management professionals only partly seem to have incorporated this knowledge into practice. While Norwegian building designers are well educated in the school of classic indoor climate theory and lean on this theory in the design of buildings, facility managers seem to lean more on experience and feedback from occupants in the day to day operation of the same buildings. Or in some cases a combination of the two. The this may lead to both lower occupant satisfaction and higher energy consumption than necessary. Prior to this study several central IEQ professionals in the Norwegian building industry were asked about existing knowledge/statistics on how IEQ is treated in FM practice and whether the temperature dead-band of 1-2°C found in the studies of the North American building stock is representative for Norwegian office buildings. It was revealed that there is no known published information on these topics, and there exists a knowledge gap.

It is therefore interesting to investigate operating temperature set points further, as well as understand which perceptions of user preferences and practices for interaction with users which are dominant among facility management professionals. The objective of this study is to use interviews of facility management coordinators to gain indicative answers to these three questions. We start with a hypothesis that operative temperature set points in Norwegian office buildings are *not* in the range of 1-2 °C as found in the American studies. Further we attempt to determine whether FM coordinators' view of user IEQ preferences and their practices for user interaction reflect the ISO standards or IEQ theory presented in the introduction.

1 METHODS

1.1 Method of research

Due to limitations in time and resources, and the lack of access to a database of field studies for thermal conditions in Norwegian office buildings, the study was conducted as short interviews with selected FM coordinators or key personnel in the largest FM operators in Norwegian office buildings. Thirteen FM operators were identified and a key IEQ professional/ FM coordinator in each company was asked to take part in a 15 minute telephone interview. All of the respondents were supervisors attending to the whole of the FM operator's portfolio and had some kind of strategic responsibility. None of them were building-level operation managers, but all had good practical knowledge about the topics asked. The topics covered were; building portfolio size and share of office buildings, temperature set points, air quality set points (CO_2), conditions who lead to occupant complaints, practices and systems for user interaction. In the questions involving numerical answers, the respondents were asked whether the information was based on their personal opinion/assessment or was based on empirical sources.

1.2 Research questions

The following research questions were sought answered through the study:

RQ1: "What are the running set-points for temperature in Norwegian office buildings and are they comparable to those reported in other studies? What is the air quality set-point (CO_2) (if any)?"

RQ2: "Which systems, tools and focus do the FM's have to determine, assess and analyze the set-points of several buildings in a portfolio?"

RQ3: "Which views and experience do the FMs have on occupant IEQ preferences, comfort and satisfaction?"

RQ3: "Which systems, preferences and practices for interaction with users do the FMs have to collect and act on occupant feedback?"

2 RESULTS

2.1 General

Among the 13 FM operators invited to the study, interviews were completed with 10. The last 3 who were contacted id not have time to take part in an interview. The selected companies together manage the indoor climate in 14 mill. m² of building mass, where 11.8 mill. m² were office buildings. The respondents were asked to only answer for the office buildings. According to 2012 numbers from the Norwegian National Bureau of Statistics, the study covers approximately 30% of the national office building stock. The FM operators can be divided into two categories; building owners who manage their own buildings and professional FM operators who perform building management on behalf of others (hard FM as well as other FM services). The 6 building owners who answered in the study manage smaller portfolios (300'-1,300' m²), while the 4 professional operators who answered operate larger portfolios (1,400'-4,000' m²). Interviews were performed in Norwegian. One operator answered partly via email.

2.2 Running set-points

When asked for mean heating and cooling set points the respondents typically answered with a temperature range for each, as set points vary among buildings and season. Ranges and calculated average are displayed in Table 1.

Table 1: Temperature set points

	Value	**Comment**
Average heating set point	21.1 °C	Range among answers 19-22 °C
Average cooling set point	23.0 °C	Range among answers 21-25 °C
Calculated average dead-band	1.95 °C	
Range in dead-band between respondents	1.0-4.0 °C	4 respondents with DB=1.0 °C, 1 respondent with DB=4.0 °C

Only one of the operators referred to statistics for their answers. The rest did not have a central register of set point temperatures. Two of the respondents had a system or strategy for determining the set points. In the rest of the cases, set points were determined and adjusted by the individual building operations manager responsible for each building. In these cases the respondent answered based on experience. All respondents reported that set points vary quite a lot between buildings due to difference in users preferences (both official preferences specified in the lease and gender differences are mentioned), building state (old/new, insulation level, solar gains, internal gains) and knowledge level of the building operations manager at the site.

Although the question was not part of the interview, two of the respondents reported that they have lower temperature set points in summer than winter. One of the respondents reported to have higher set point temperatures in summer.

Table 2: CO_2 set-points

	Value	**Comment**
Average set-point	745 ppm	Range among answers 600-900 ppm

Only one of the operators referred to statistics for their answers for CO_2 set points. The rest did not have a central register of CO_2 set points. Two of the respondents had a system or strategy for determining the set points. All respondents reported that CO_2 set points hardly ever were reached or used, and that they seldom pay attention to them.

2.3 Experience with user IEQ preferences

The respondents were asked for threshold temperature and CO_2 conditions where users "start complaining" to them. One FM operator had statistical evidence for their answers. The rest of the answers were based on the personal experience of the respondent. All respondents gave the impression to have a clear opinion on the matter. Numerical results are given in Table 3

Table 3: Thresholds for IEQ complaints to FM operator

	Value	**Comment**
Average temperature where users complain about "too cold"	19.9 °C	Range among answers 17.5-21 °C

Average temperature where users complain about "too hot"	23.9 °C	Range among answers 22,5-24,5 °C
Average CO2 where users complain about "bad air"	817 ppm	Range among answers 600-950 ppm Based on only 3 answers.

Without being asked, all the respondents pointed out that complaints about "bad air" seldom were due to high CO_2 or other emissions from humans. Eight of the ten respondents reported that most complaints about "bad air" actually were due to high temperature and/or humidity. Two of the respondents highlighted that "bad air" complaints often were due to other effects such as insufficient cleaning or material emissions. All respondents reported that there was little consistency between CO_2 and number of complaints.

Table 4 contains the factors that the respondents said were most important for the IEQ satisfaction of the occupants. One of the respondents mentioned "stable temperatures and cooling" as an important factor. All the other respondents primarily emphasized factors who fall within the three groups covered in Table 4.

Table 4: Most important factors for IEQ satisfaction

	Taking the users/complaints seriously and show action	**Influencing and meeting the expectations of the users, explaining reasons for why**	**Good communication with the users and for the user to have a real person to speak to**
"Which factors are most important for keeping building occupants happy with IEQ conditions?"	6/10	5/10	7/10

Two respondents emphasized that complaints on IEQ measures often were connected to other factors for well-being, and that they experience more complaints from tenants where there are organizational problems etc. One respondent expressed: "We become like mini-psychologists".

On the question "What portion of your total complaints are related to IEQ?", 7 of the respondents gave a qualified-guess percentage. The answers ranged between 10% and 60% of the complaints, with a mean of 40%. The respondents were somewhat divided in their view on how important IEQ was in the total picture. Several claimed that: "IEQ is something that our tenants/occupants expect to be in order, so they can do their job".

Six of the respondents got an extra question for whether they experience that being able to open windows is important for user satisfaction. On this question, one answered "not as far as I know", while four emphasized that operable windows were a problem, and that they do not let users open windows. Two expressed that opening windows may give a positive psychological effect for the user, as they were able to perform personal control and could feel a closer connection to the outside. Two also emphasized that manual control of solar shading devices was more appreciated among users than automatic control. It was however clear that the general opinion was that operable windows match poorly with modern ventilation systems, as open windows disturb the "finely tuned" systems. They largely attributed this fact to poor design of buildings and systems. Focus on energy use was also mentioned as a reason to restrict the opening of windows.

2.4 User interaction procedures

The respondents were asked a set of questions to gain knowledge about their perceptions and procedures related to interaction with the end user.

One of the professional FM operators manages HVAC systems only on behalf of others, and is not responsible for the direct communication with users. The questions were therefore not applicable and answers from this respondent are removed from the total in Figure 1.

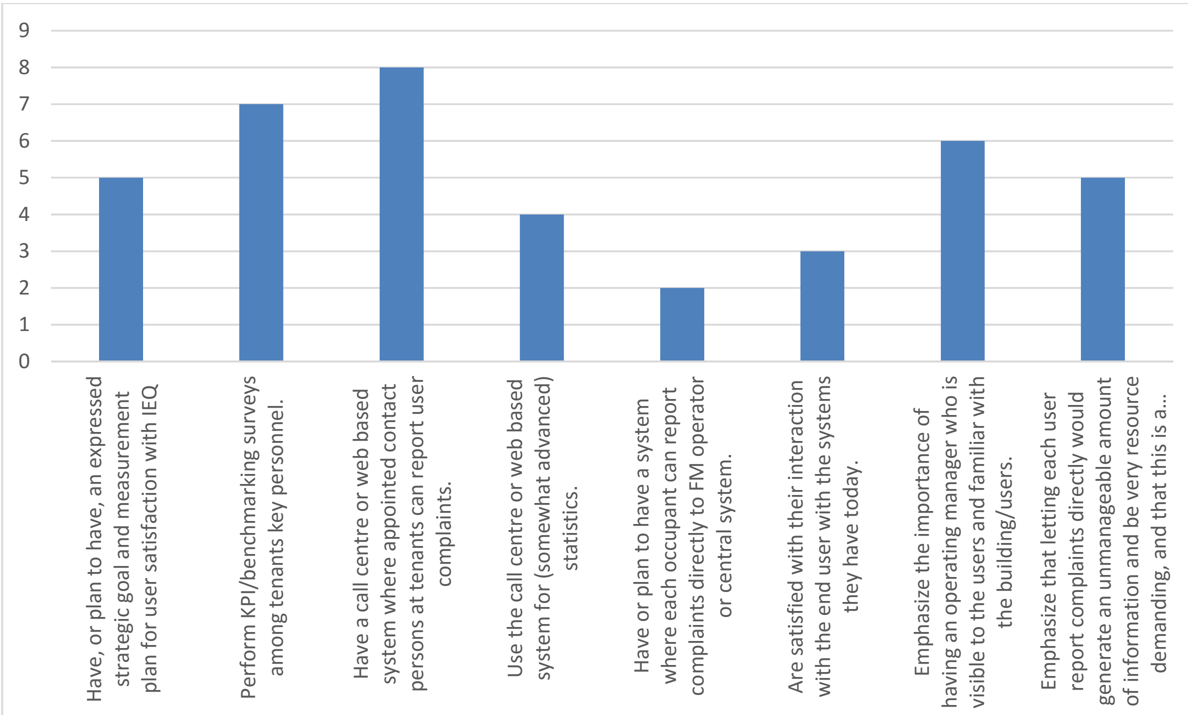

Figure 1: Perceptions and procedures for user interaction

3 DISCUSSION

3.1 General

In general, the answers from the FM operators reflect that they are highly tuned to the voice of their users, tenants, customers, operation managers and the individual building. They seem to a lesser degree tuned towards indoor climate research and theory, although this varies. In general, the majority of the respondents were not utilizing modern technology beyond the building management systems delivered with the buildings and simple facility management software. Few of the respondents utilize available data for learning purposes beyond what is done at site by the operating manager.

3.2 Running set points

Since only one of the respondents had statistical evidence of the data, and the rest answered based on personal experience or opinion, the method for determining the running set points and dead-band is unprecise. The respondents did however have clear opinions and much experience on the matter, and there is reason to believe that the answers obtained are close to reality. Set points were mostly determined and adjusted by the individual building operations manager responsible for each building. It is perhaps somewhat surprising that the process behind selecting set points is so simple, when there exists so much theory on the field. Again, most of the FM operators seem to rely on their operating managers experience and the response from users as guidance, rather than relying on research and theory. Two of the respondents reported that they have lower temperature set points in summer than winter. This is also somewhat surprising as it is opposite of the majority of thermal comfort research, but it is consistent with other research (as mentioned in the introduction). All respondents reported that CO_2 set points hardly ever were reached or used, and that they seldom pay attention to them. This is also interesting, as a great deal of effort and money is put into equipping buildings with such sensors in design and construction.

3.3 Perspective on user preferences

The reported threshold temperature and CO_2 conditions where users "start complaining" to the FM operators were also based on the respondents personal experience and opinion, and may not be accurate. Also here, the respondents did have clear opinions and much experience on the matter, and there is reason to believe that the answers obtained are close to reality. Interestingly, the calculated mean dead-band between "complaint" temperatures is 4 °C, while the set point dead-band is only 2°C. One would then think that there is considerable room for expanding the set point temperatures. Only one of the respondents used a dead-band of 4 °C. Without being asked, all the respondents pointed out that complaints about "bad air" seldom were due to high CO_2 or other emissions from humans, and that most complaints about "bad air" actually were due to high temperature and/or humidity. This is in line with IEQ theory, and could perhaps even seem to be less highlighted in theory than it is among the practitioners. On the question about factors most important for user IEQ satisfaction, the respondents gave surprisingly well-aligned answers without guidance. All the three most given answers are not connected to the indoor climate itself, but to "psychological" factors in the interaction with users. Three somewhat related factors stood out among the answers:

- Have good communication with the users and preferably give personal help
- Take the complaints seriously and show action quickly.
- Give information, explain "why" and avoid unrealistic expectations

These factors are comprised by *rapid response environment with access to information and feedback regarding complaints,* one of the "killer variables" of Leaman & Bordass (Leaman and Bordass 1999), and both *expectations, constraints* and *response time* is mentioned as central to perceived control by (Hellwig 2015). Responses are therefore well in line with theory, although they most likely originate from practical experience. A few of the respondents mentioned personal control over temperature and solar shading as something "preferred" by users, which is comprised by *opportunities for personal control,* another of the "killer variables". Most of the he respondents did however not mention personal control as an important factor. Several emphasized that complaints on IEQ measures often were connected to other factors for well-being, and that they experience more complaints from tenants where there are organizational problems etc. This is also in line with some theory, such as (Brager and De Dear ' 1998) and (Kim et al. 2013). The question regarding portion of total complaints related to IEQ is very unscientific, as this depends on the total number of complaints. The answers showed that respondents were somewhat divided in their view on how important IEQ was in the total picture. This could perhaps be explained by the non-linear negative relationship between IEQ factors and total satisfaction found by (Kim and de Dear 2012).

Six of the respondents got an extra question for whether they experience that being able to open windows is important for user satisfaction. This revealed a somewhat surprising perception among most of the respondents, as they viewed operable windows to be very problematic for modern office buildings and most of the respondents prohibited occupants to open windows. Two of the respondents did however acknowledge that there may be a positive effect for the user to be able to open a window, but it seemed that this effect in most cases was heavily outweighed by the problems opening windows would lead to for other occupants and the system in general. They largely attributed this fact to poor design of buildings and systems. It is not known whether this problem was larger in open office spaces than in single offices, but we can expect that this is especially a problem in open office plans.This finding should become a key guidance in the design of new buildings, as operable windows are heavily encouraged by both researchers and buildings design experts.

3.4 Perceptions and procedures for user interaction

The findings in this section revealed that the respondents in general, with a few exceptions, are conservative in their views and ambitions for using technology and systems for user interaction. Most respondents seem to base their operation on yearly KPI's, a call centre or web based system for interaction with selected user representatives, and a operation manager on site for tending to problems and complaints personally. Although user interaction is highlighted as important in research literature, and also was mentioned as the most important aspect by the respondents in the previous paragraph, most of the respondents seem to prefer a "human approach" for handling user interaction. At the same time, many emphasize that it is important to maintain a certain filter or some necessary constraints for limiting the ability for each individual occupant to complain about every little thing. This is due to the fear of using too much resources on complaints. One could think that modern data handling technology could take care of the amounts of data that could come if every user could complain with the touch of a button. But seen in connection with the argument that most respondents highlight the importance of taking each complaint seriously and showing that action is taken quickly, this means that each complaint would have to be processed and followed up toward the user immediately for ensure satisfaction. In this case, it may be better to limit the number of complaints and maintain the quick response to complaints that matter.

4 CONCLUSIONS

The results of the study show that the hypothesis is falsified, as the temperature dead-band of 2 °C in Norwegian buildings fall within the band reported in other studies. Further, the results indicate that this band most likely could be widened without increasing the number of complaints. The respondent's perceptions of users IEQ preferences were shown to be partly divergent from IEQ theory for the topics of personal control and adaptive comfort, although for the topics of rapid response environment, influence of psycho-social aspects and air quality they seem aligned. The respondents also reveal a relatively low focus on systems, solutions or technology for user interaction, but at the same time show a high focus on being able to provide quick, personal and local help to the occupants when a problem of sufficient importance arises.

Further research recommended on the following topics:

- All numbers who are obtained qualitatively in this study should be re-investigated with quantitative methods to achieve sufficient accuracy
- All findings in this study who point at a discrepancy between established theory should be investigated more closely.

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6 REFERENCES

Arens, Edward, Michael A. Humphreys, Richard de Dear, and Hui Zhang. 2010. "Are 'class A' Temperature Requirements Realistic or Desirable?" *Building and Environment.*

Brager, Gail S. and Richard J. De Dear '. 1998. "Thermal Adaptation in the Built Environment: A Literature Review." *Energy and Building* 17.

Brager, Gail, Hui Zhang, and Edward Arens. 2015. "Evolving Opportunities for Providing Thermal Comfort." *Building Research and Information*.

de Dear, R.J., and G.S. Brager, 1998. 1998. "Title: Developing an Adaptive Model of Thermal Comfort and Preference." *ASHRAE Transactions* 104(1):145–67. Retrieved (http://escholarship.org/uc/item/4qq2p9c6).

Fountain, Marc, Gail Brager, and Richard De Dear. 1996. "Expectations of Indoor Climate Control." *Energy and Buildings*.

Hellwig, Runa Tabea. 2015. "Perceived Control in Indoor Environments: A Conceptual Approach." *Building Research and Information* 43(3):302–15.

Hoyt, Tyler, Edward Arens, and Hui Zhang. 2014. "Extending Air Temperature Setpoints: Simulated Energy Savings and Design Considerations for New and Retrofit Buildings." *Building and Environment* 88:89–96. Retrieved (http://dx.doi.org/10.1016/j.buildenv.2014.09.010).

Kim, Jungsoo and Richard de Dear. 2012. "Nonlinear Relationships between Individual IEQ Factors and Overall Workspace Satisfaction." *Building and Environment*.

Kim, Jungsoo, Richard de Dear, Christhina Cândido, Hui Zhang, and Edward Arens. 2013. "Gender Differences in Office Occupant Perception of Indoor Environmental Quality (IEQ)." *Building and Environment*.

Leaman, Adrian and Bill Bordass. 1999. "Productivity in Buildings: The 'killer' Variables." *Building Research and Information* 27(1):4–19.

Mendell, Mark. 2009. "Indoor Thermal Factors and Symptoms in Office Workers : Findings from the Indoor Thermal Factors and Symptoms in Office Workers : Findings from The." (December):1–26.

Zhang, Hui, Edward Arens, and Yongchao Zhai. 2015. "A Review of the Corrective Power of Personal Comfort Systems in Non-Neutral Ambient Environments." *Building and Environment*.

Standard Norge AS (2014) 'NS-EN 15251:2007+NA:2014', *European Committee for Standardization*

Standard Norge AS (2005) 'NS-ISO 7730:2005', *European Committee for Standardization*