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Comfort models as applied to buildings

Mark B. Luther and Peter Horan
Deakin University, Geelong, Australia
luther@deakin.edu.au, peter.horan@deakin.edu.au

Abstract: This investigation is about applying the ISO-7730 Fanger (static) Comfort model to two fully air-conditioned, yet, differently performing buildings, based on research into on-site comfort performance measurements using comfort carts. The results challenge the common perception that the ISO-7730 model is concerned with a narrow temperature band. Regardless of the environmental variations encountered temporally and spatially throughout real office environments, occupants appear to achieve comfort with reasonable success. The paper explores this flexibility within the 'static' model, more than perhaps is commonly realised. We consider the possibilities that many of Australian office buildings can operate under much greater temperature variation than expected and that there are mechanisms for occupants to adapt to varying conditions.

Keywords: Comfort; climate; offices; buildings.

1. Introduction

Thermal comfort is an essential component of occupants' perceptions of a building. Comfort is formed in part as a function of human physiology, behavioural and psychological encounters (deDear et al., 1997). However, the results of thermal comfort also have many aspects involving the environment and composition of the building spaces themselves, their construction, materials and technologies as well as their social and cultural expectations. Thermal comfort also extends to the individual's social position and how they pursue it (Nicol and Stevenson, 2013). Therefore, the present investigation and research into comfort in our buildings is complex, yet relevant.

There are several reasons why comfort models (calculations) may not provide the outcome expected at a specific location in a building. One reason rests in the development of the comfort model itself; other reasons are because the building composition and operation are ignored (Nicol and Stevenson, 2013). Other biases of comfort calculation may rest in the parameters selected and applied in the well-known ISO-7730 equation ignoring occupant behaviour or the external environment (Humphreys and Nicol, 2002).

The authors of this paper suggest that more research is required to understand the occupant environment in real buildings and how the level of comfort is achieved. It is also suggested that perhaps the present PMV model is still appropriate but requires modification according to specific field conditions. A change of the existing ISO-7730 "PMV" comfort model was strongly proposed by reputable comfort scientists who made revisions to the PMV model to include a bias according to actual occupant votes (Humphreys and Nicol, 2002). With the exception of this paper it took over ten years to reinvestigate the application of the PMV model parameters as applied to field measurements of HVAC and naturally ventilated buildings In addition to this, several authors believe that occupants do not want 'thermal boredom' and endorse temporal variation in comfort within a set location (deDear, 2006; Corgnati et al., 2007 (Langevin, J. et. al., 2013).

This paper develops a previous paper (Reference removed to preserve anonymity) into observing the variability of comfort, temporally and spatially, throughout a building level. It explores the variations of comfort experienced in two very different office buildings at different locations and different daytime periods. It challenges our understanding of how our buildings provide for or fail to provide for comfort. What building contributions might be required to ensure comfort?

To better grasp the changing comfort levels experienced by an occupant, throughout the day and at various specific locations, we present this information in a time-series chart. This gives an overall picture of the thermal comfort performance of the building throughout a day in relation to its orientation, ambient temperature, and façade exposure or lack of it. It displays graphically where comfort changes occur. This information consists of measured on-site data (both internal and external) from which comfort indices of PPD (percent predicted dissatisfied) from the ISO-7730 model are calculated. Since the buildings we are investigating are fully air-conditioned and primarily consist of fixed glazed windows we use the ISO-7730 (Fanger) comfort model. However, we consider the flexibility available to the occupants to manage their own comfort in such environments. Indeed, occupants do have some control in fully air-conditioned buildings.

2. The investigation

In an earlier investigation, we measured the climate and comfort of 15 fully air-conditioned office buildings between Brisbane and Melbourne, Australia during brief seasonal periods. Only two of these buildings comply with the narrow comfort band required by the ISO-7730 comfort model. All the others show a more direct relationship with external air temperature, which challenges the omission of this parameter in the ISO-7730 model for HVAC buildings.

In the present investigation, we compare the core (central) building comfort level with comfort levels at other locations on the same floor level on the same day at different time intervals. This investigation allows us to select two very differently performing offices in our discussion of comfort variability and expectations. Both buildings are located in the CBD of Melbourne and are multi-story government office buildings. The first building is typical among office buildings in Australia. It is poorly sealed with air leakage and exhibits a variable air temperature difference across a daily cycle. The second building is one where the temperature variation is tightly controlled. The temperature and comfort measurements are taken at a central 'core' of the building to determine the comfort uniformity.

The measurements of both buildings utilise two comfort carts constructed according to the ASHRAE Standard-55 (ASHRAE, 2013), to measure air temperature, globe temperature, and air velocity at 0.1m, 0.6m, 1.1m and 1.7m heights. Air humidity is also measures at 0.6m. One cart is programmed to measure continuously at 15 minute averaged intervals while the second cart is set in a 'survey' mode to be relocated for 10 minute sampling at designated locations. Figure 1 is a picture of the comfort carts used in the measurements. The survey comfort cart is positioned and allowed to settle for 5 minutes to equilibrium with its environment before the actual measurements are taken in the final 5 minutes.

Figure 1 Comfort Carts as used in the measurements of the project.

2.1. Central Building Core Comfort

First, measurements from the building ‘core’, in a central part of a floor level, are investigated. This procedure and its instrumentation are described in (Reference removed to preserve anonymity). Figures 2 and 3 illustrate the comfort levels in the two selected buildings according to a PMV/PPD ISO-7730 (Fanger) comfort model. Measurements from the comfort carts presented in Figure 1 are used in an EXCEL spreadsheet routine to calculate the ISO-7730 (PPD) comfort result.

Both these figures show a ‘clothing comfort band’ according to CLO values from surveying occupants. It was discovered that a ±0.2 CLO difference was the norm, regardless of season, on any given day, across many of the surveyed buildings (reference omitted to preserve anonymity). It is evident that allowing for this ‘CLO range’ shows that the buildings can be comfortable if the standard prescriptions are relaxed.

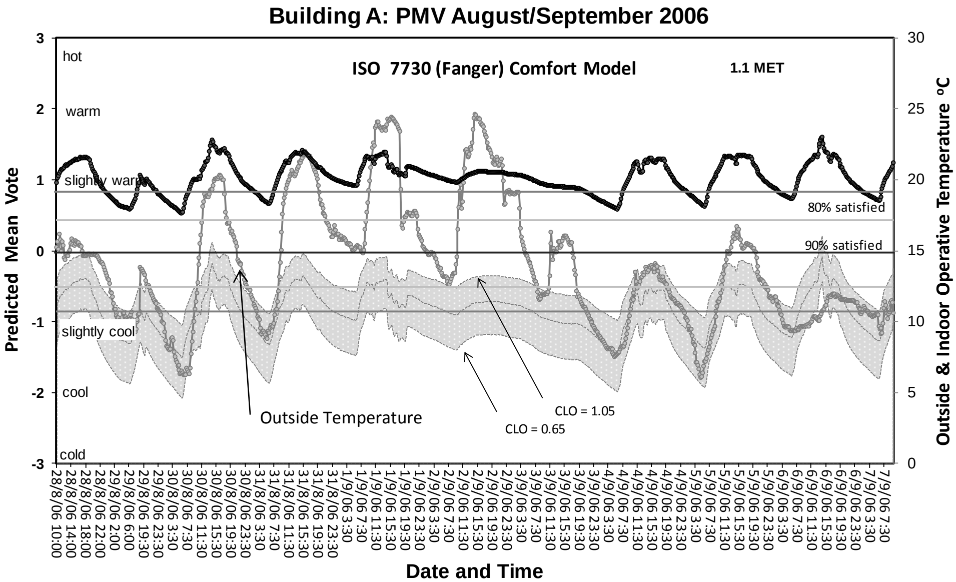

Figure 2: PMV Comfort Band (shaded) with External & Internal Air Temperatures

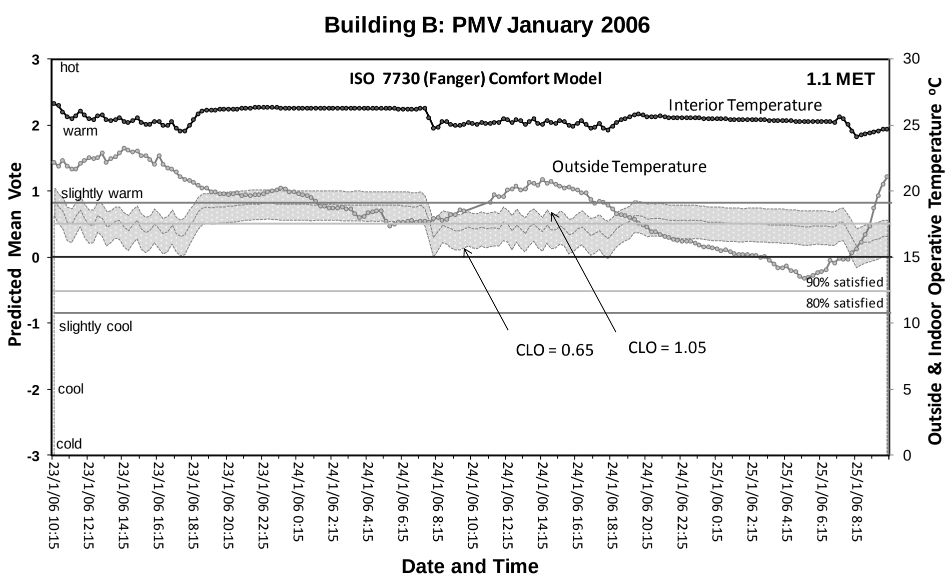

Figure 3: PMV Comfort Band (shaded) with External & Internal Air Temperatures

Throughout a day, the behaviour of the comfort in Building A (Figure 1) is noticeably different from that of Building B (Figure 2). Unfortunately the dataset for Building B was not as large. Regardless of outdoor temperature changes there is a much larger swing in comfort in Building A. It has also been confirmed, by results not shown here, that this behaviour is independent of whether the assessment is made in winter or summer.

The conclusion is that Building B is more stable in its comfort band because of its operation and construction. Note that this building does exhibit a slight change in its comfort band when it is unoccupied and comfort is irrelevant. However, it appears that Building B possesses an all-round 'comfortable' environment. But this conclusion rests on the assumption that the 'core' behaviour applies throughout the building. So, an important question is whether the comfort within each of these buildings, at various locations, is uniform and in accordance with the 'core comfort' band shown here. In fact, there is a surprising deviation in comfort at various locations throughout the day for each of these buildings.

2.1. Surveyed Locations Compared to Building Core

Figures 4 and 5 illustrate the differences in comfort measured at several surveyed locations. Each such location is measured with the survey comfort cart as described above for a duration of 10 minutes three times a day clustered at mid-morning, midday and mid-afternoon. (The figures indicate the 'PPD comfort vote' (right heading) calculated for a specific location on the plan shown within the chart. The external air temperature scale is provided on the left hand side of the graph).

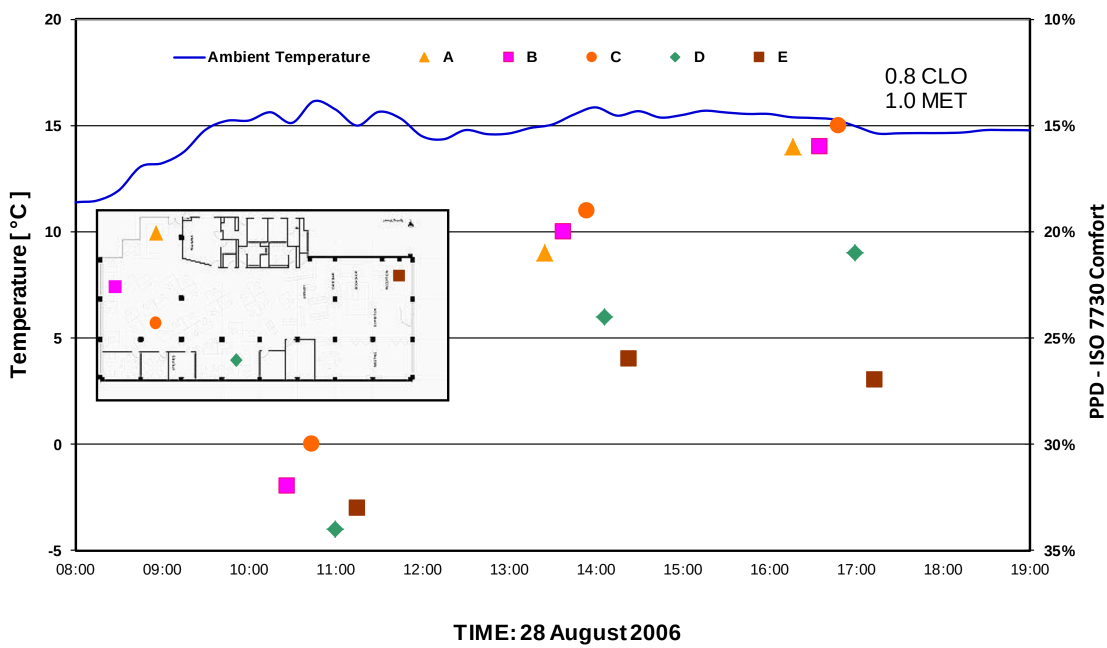

Figure 4: Comfort at Various Locations in Building A

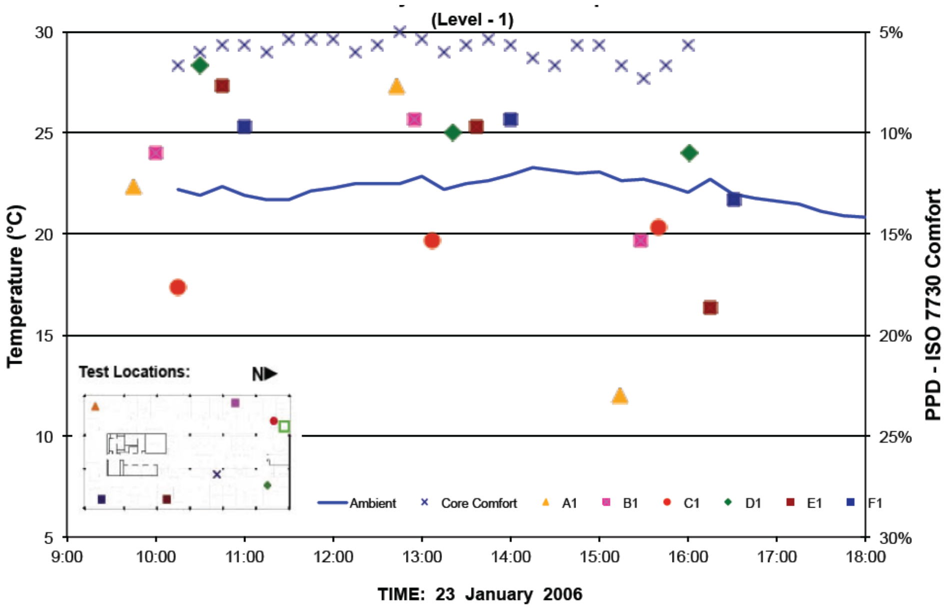

Figure 5: Comfort at various locations of Building B

These two figures show, in two different air-conditioned buildings, how the predicted percent dissatisfied (PPD) at each time period is scattered rather than clustered closely together. In Building A the PPD ranges from 10% at best to 42% (i.e. off the graph) at worst. Throughout the day, the PPD changes for points on the west of the building. Note the 'square point' next to the east wall which is fully glazed from floor to ceiling which is never less than 25% PPD. Such points are characteristic of the building composition (a glazed facade) significantly determining their comfort result. The parameter of mean radiant temperature would heavily influence comfort at this location. For the point on the south the PPD also decreases, but is never less than 20%. For this case, there is a cold pocket with poor air temperature distribution, since this location actually faces an internal corridor.

Figure 5 shows the 'more stable' Building B as well as data for a central point in the building monitored continuously throughout the day. This is labelled the "core" PPD, which is always close to 5%. However, the comfort is not as uniform as may be expected, because the PPD away from the core ranges from 7% at best to 23% at worst. However, the three points on the east of the building form a cluster which has a PPD better than 10% at mid-morning and noon, but which is scattered between 10 and 20% in the afternoon. Again, the orientation and location of the measurement at specific times during the day has an impact on comfort.

Do the occupants in such variable environments remain in comfort or not? If adjustments to clothing are accounted for, the `clothing comfort band' allows a PPD less than 10% to be achieved. Table 1 shows the effect on PPD for the mid-morning in Building A as CLO is increased in steps of 0.2 – the effect of adding a light sweater, for example. Wearing a jacket increases CLO by 0.35, and an outdoor coat (or a woollen dressing gown) by 0.6. If occupants are not restricted by dress codes, they have the freedom to control their personal comfort significantly. Japan has had success with the "Cool Biz" policy introduced in 2005 by Prime Minister Junichiro Koizumi, in which the dress code was relaxed so as to save energy from summer air-conditioning (Cool Biz, 2005).

Table 1: The effect of clothing on PPD

Point	CLO = 0.8	CLO = 1.0	CLO = 1.2	CLO = 1.4
A	42	21	11	6
B	32	16	8	5
C	30	14	7	5
D	33	16	8	5
E	32	16	8	5

3. Discussion

The presented information raises the question as to whether occupants are actually comfortable under variable conditions throughout a day. Unfortunately, other than having clothing surveys filled out, no other comfort questionnaire was taken during these measurements. Nevertheless, there are quite some observations to be made which could provide useful in future research.

The first of these observations is related to the variability of comfort around the same floor level at various locations within a space. This variability indicates that it is in fact erroneous to accept and rely on a single 'core' comfort result for an entire floor level. There can be and are huge differences according to the zones (north, east, west or south) of a building and at various times of the day. In fact we can identify the influence of orientation and its exposure (or lack of it) to solar radiation. Factors such as mean radiant temperature and air velocity differences can definitely influence comfort changes at a particular location. However, most of these changes to comfort could be rectified by varying CLO (clothing).

It is useful to investigate more on the façade thermal behaviour in relation to occupant comfort for perimeter building zones. It is indicated that when occupants sitting next to a glazed façade with some control of its shading, can participate to regulate it back into comfort (Anderson and Luther, 2012). Such opportunities constitute a change in occupant behaviour, which removes the stigma of a non-controllable HVAC building.

Interestingly, Figure 6 shows only the air temperature for Building A (Figure 4), which seems to indicate that there is little difference among the various locations measured. Based on this information, one may conclude that other comfort parameters are irrelevant and do not influence the final comfort result. Indeed, Figure 4 shows this is not true. Note that this is a current flaw in NABERS IEQ Comfort assessment where a single wall thermostatic temperature reading determines whether comfort is achieved or not.

Furthermore, it should not be forgotten that there are social, behavioural and psychological parameters informing thermal comfort. These, of course, seem to be absent from any comfort model; static or adaptive. However, adaptive models appear to inherently account for and give reason for an occupant's freedom to adjust their environment for comfort. The two buildings investigated here do not satisfy the requirements to qualify for an 'adaptive model' assessment. This is in fact a further issue or problem in the applications of various comfort models where evidently many researchers are applying adaptive models to 'static' model buildings. Is it possible that some 'static' buildings could be adjusted to allow them to qualify for 'adaptive model' assessment? The research of Humphreys and Nicol (2002) and of Langevin et.al. (2013) suggest that it is.

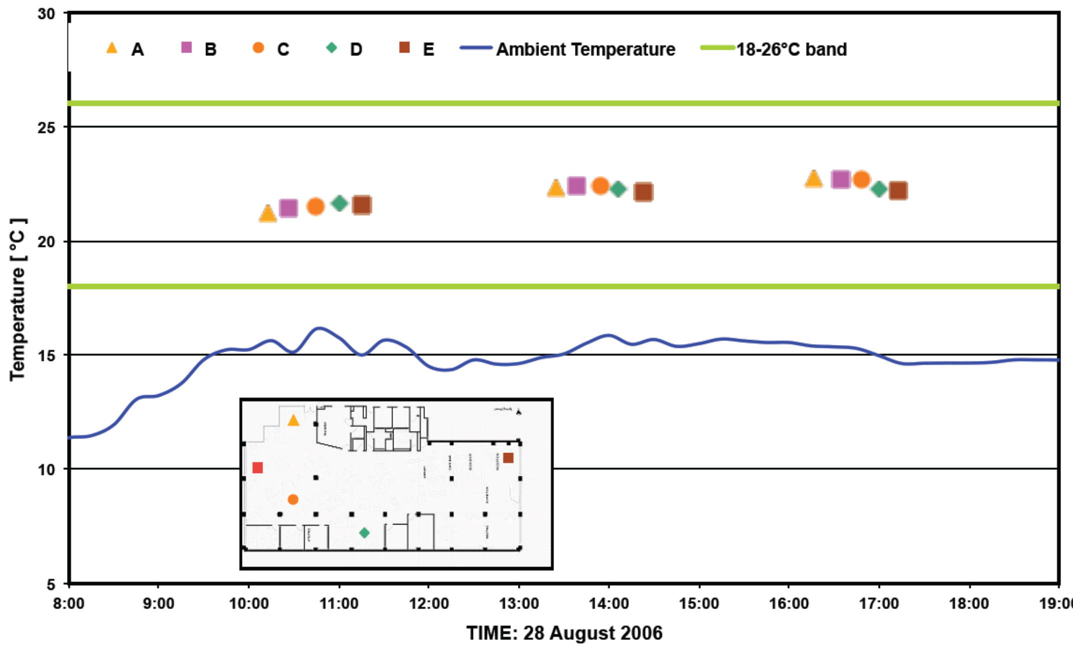

Figure 6: Building A - Dry-Bulb (air) Temperature of the Various Locations

Almost all of our measured buildings had a prime open office space connected with the façade boundary. Back in the day when the ISO-7730 comfort model was developed, (1970's to 1980's) many of the buildings consisted of enclosed offices. Although there were 'open offices' very few open offices had façade exposure and the office layout was very restricted. In contrast to this, many of our buildings had controllable, manually or automatic blind systems and some had ceiling fans. Several occupants also had their own task lighting at their desks.

The design layout and the behavioural working conditions have changed significantly over the last 30 or more years. Occupants in 'static' buildings are gaining some control of their environment and are often permitted to dress accordingly to the weather conditions. HVAC building control strategies are evermore increasing in the application of economizer cycles, night time purges and mixed-mode operation. Controlled daylighting or artificial lighting is increasingly becoming the norm in most office spaces. The entire office design layout itself is changing, allowing occupants to go elsewhere in the building to do their work. The 'breakout' or meeting space is included in most office designs. All of these building features would certainly influence the comfort of an occupant and need to be considered in today's evaluation of an office space.

4. Conclusion

New and endorsing other existing research contribution of our research includes but is not limited to the following:

- While air temperature alone might be uniform throughout a floor level the actual comfort results can vary significantly. This indicates the importance and necessary inclusion of other parameters that determine comfort. The charting of measured and calculated ISO-7730-PPD (Figure 4) is quite different from Figure 6 showing air temperature alone. This indicates the danger of using air temperature alone to determine occupant comfort, which is so often performed.

- Clothing level (CLO) is a major 'game changer' in an occupant's comfort. Therefore, it is unreasonable to consider a singular CLO value in the use of the ISO-7730 model. Occupants vary their clothing ±0.2 CLO on any given day during any given season.
- Too often single parameters are applied, restricting any provision of a 'comfort band' or 'range' which appears to exist realistically within buildings.
- Furthermore, our investigation shows that it is unreasonable to consider a single comfort value for an entire floor level.
- In the investigation, the comfort data has been plotted both temporally and spatially. The graphical representation is a good way of showing how we perceive and understand daily comfort variations within a building.

In addition to the above, several authors believe that occupants do not want 'thermal boredom' and endorse temporal variation in comfort within a set location (deDear, 2011; Cognati et al. 2007; Humphreys and Hancock, 2007). This study introduces the concept of a 'comfort band' to evaluate comfort for HVAC conditioned buildings. Therefore, in rating system calculations, such as NABERS and Green Star, the use of a 'comfort band' would be more realistic. Our results indicate that a 'comfort band' would provide for a more reasonable assessment in the allowance and planning of comfort.

What is evidently missing from our study are the occupant comfort surveys in relation to the actual measurements. This is unfortunate; however it highlights the importance of a comfort survey in future work. Nevertheless, our rating systems rely on 'established' calculations without surveys. It would be interesting to know what is calculated where and when in such evaluations since location and time of day have been shown by this research study to make a significant difference. It should also be recognized that the construction (materials) and design of office buildings vary and have significantly changed from what they used to be. Also, HVAC control systems themselves and their operation have changed since the development of the ISO-7730 static model.

Given the above research, as well as previous research into changes to the ISO-7730 PMV model for field applications, it is crucial to commence and continue with real measurement studies on thermal comfort. We need to understand whether the models are in fact relevant or require adjustment in the near future. It is indicated by others that in fact the ISO-7730 model offers quite some flexibility and allowable variation and can be used for both HVAC and naturally ventilated buildings.

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