

A Survey of the Adaptive Comfort Approach and its Impact on Alternates - to - Air Conditioning Part 1 of 2

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A typical classroom in India with students dressed in light cottons and short sleeves. With high outdoor temperatures, it does not require a room temperature of 24°C for comfort. Using the approach discussed in this article, a much higher temperature with no cooling, apart from fans, can be found comfortable.

Abstract

The article introduces the concepts of the Adaptive Approach/Model for comfort, in which the comfort temperature selected for the built-in space will vary over a relatively large range. They are discussed extensively with particular reference to the familiar Fixed Temperature concepts, that are covered elaborately in the Fundamental Volumes of ASHRAE Handbooks and in ASHRAE Standard 55 over the last few editions. The Adaptive Comfort Standard (ACS), which is presented briefly in several editions of ASHRAE Standard 55, is covered in much greater detail in this article. The coverage includes reference to a recently published article, in which a worked example illustrates the selection of the comfort temperature range and also, the design of selected systems for which the Adaptive Approach can be applied. Due notice has been taken of the inclusion of natural cooling methods, viz., Evaporative Cooling, Radiant Panel Cooling, Radiant Night Sky Cooling and such Passive Cooling methods - also called

"Alternatives-to-Air Conditioning" systems - which are especially suitable for meeting the requirements of Adaptive Cooling Approach and the Adaptive Comfort Standard. While a member of the family of Passive Cooling Systems can be a stand-alone option for a whole building, it can also participate in a MMS (Mixed Mode System), in significant ways. Attention has been drawn to a recent development of significance in this context - articles have been appearing in ASHRAE Journals, which elaborate on the rising significance of the Adaptive Comfort Approach and on the relaxation of the current restrictions to the limits of its application. This development helps to give a great fillip and boost for the acceptance and growth of Passive Cooling (Alternate-to-Air Conditioning) Systems.

Comfort Conditions

ASHRAE Standard 55 has ruled the roost for a long time now in HVAC. Recently, there has been some talk about the Adaptive Comfort Standard too. This article will concentrate on the latter but we

will introduce it (Adaptive Approach) here keeping the familiar Fixed Temperature Approach as the benchmark, to help achieve a better and faster understanding of the Adaptive Approach.

The Fixed Temperature Approach (FTA)/ Standard - The 23°C Paradigm

For over several decades now, mainstream air conditioning has been standing for 23°C DB (and 55% RH) for comfort. Ranges and tolerances for DB, RH and air movement have been stipulated, but they are narrow, like $\pm 1^\circ\text{C}$ and $\pm 5\%$ RH with the range of air movement, if referred to, being 0.2 to 0.3 m/s, representing

About the Author

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still air. Notwithstanding such usual tolerances, this standard is also called the Fixed Temperature Standard – because the tolerances are narrow. The 23°C paradigm has been a well-known goal that mainstream HVAC has been seeking all the time. These observations are based on ASHRAE Standard 55-2004.

ASHRAE Standard 55 specifies conditions or comfort zones where 80% of sedentary or slightly active persons find the environment thermally acceptable. Because people wear different levels of clothing depending on the situation and seasonal weather, ASHRAE Standard 55-2004 defines comfort zones for 0.5 and 1.0 clothing levels. For reference, a winter business suit has about 1 clo of insulation, and a short-sleeved shirt and pair of trousers has about 0.5 clo. The warmer and cooler temperature borders of the comfort zones are affected by humidity and coincide with lines of constant Mean Effective Temperature. In the middle of a zone, a typical person wearing the prescribed clothing would have a thermal sensation at or very near neutral zone. Near the boundary of the warmer zone, a person would feel about +0.5 warmer on the ASHRAE thermal sensation scale; near the boundary of the cooler zone, that person may have a thermal sensation of -0.5.

PMV and PPD

PMV-index (Predicted Mean Vote) predicts the subjective ratings of the environment in a group of people, recording their assessment of the category of thermal sensation they are experiencing on the ASHRAE Thermal Sensation Scale.

PPD-index (Percentage People Dissatisfied) is derived from PMV value and predicts the number of dissatisfied people for a given PMV value. A PPD of 10% corresponds to the PMV range of ± 0.5 and even with PMV equal to 0, about 5% of the people are dissatisfied. The PMV range of ± 0.5 represents the Neutral Zone. The location of the ASHRAE comfort point is in the middle of the Neutral Zone.

PMV Based Approach is predicated on study of Comfort:

- Study of sensations under laboratory conditions (Climate Chamber*)
- Steady state
- Known and uniform activity level (metabolic state)
- Known clothing – tables of ensembles of clothing vs. insulation values derived from experiments using heated mannequins being the sources of values.

* Climate Chamber is a very particular environment, where conditions

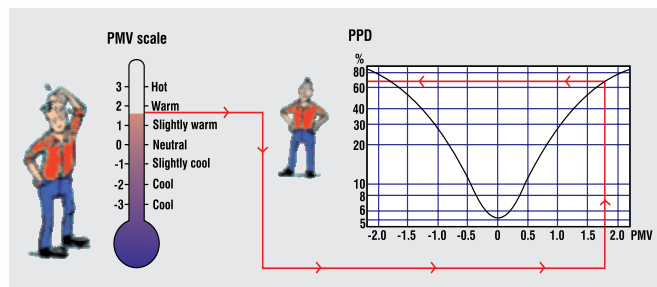


Figure 2: PMV and PPD explained

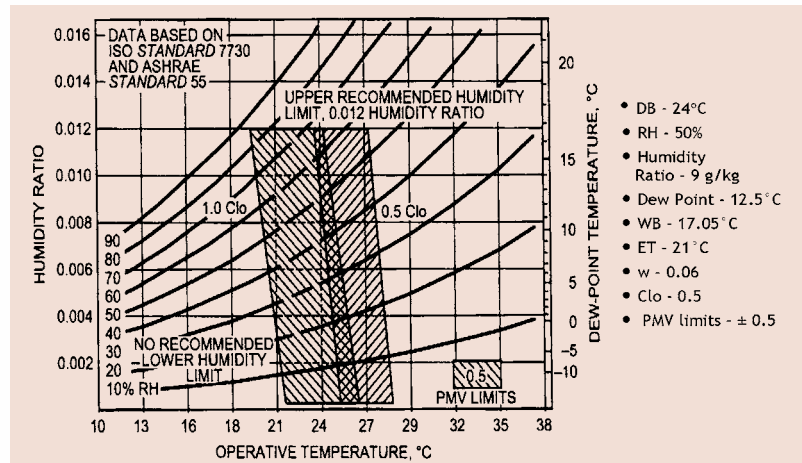


Figure 1: ASHRAE Comfort Chart (from ASHRAE Fundamentals Handbook – 2009)

and occupant action are closely controlled by the researcher for the period of an experiment.

Standard 55 duly takes environmental factors (DB, RH and air movement) and physiological factors (skin temperature and metabolism) into consideration. However, adaptive capabilities inherent in people are not factored in adequately.

Buildings built to Fixed Temperature Standard have often given rise to buildings, which are too cold in the summer or too warm in the winter, with the result that energy consumption due to HVAC is seen to be high. Above all, it does not allow any significant increase in summer comfort temperature for non-ventilated buildings.

The need to exercise the option of going for higher comfort temperature during summer for Non-Ventilated (NV) buildings and semi-air conditioned buildings, especially in tropical regions, has led to an earnest search for a variable temperature model or guidelines or standard. Achieving success in such an undertaking will go a long way to legitimize the exercise of option for higher comfort temperature.

Problems with Fixed Temperature Approach

- Fixed Temperature Approach does not consider impacts of
 - Climate and weather (is based on Climate Chamber Studies and not Field Studies)
 - The fact that it is based on steady state
 - That there are different kinds of built environment
 - Different clothing patterns
 - Different kinds of activities and differing activity levels
 - Differing comfort requirements/preferences
 - Lack of freedom for occupants to move to differing thermal environments - in the same building
 - Absence of individual controlling devices – operable windows, facility to draw blinds open and close, adjustable speed desk fans, ceiling fans, etc.
 - Larger range of air movement variation offered by desk fans/ wall mounted fans, ceiling fans, etc. compared to 0.03 m/s maximum factored in the model
 - Narrow range of comfort zone on energy consumption and sustainability of build environment
- The Adaptive Approach takes care of all these factors.

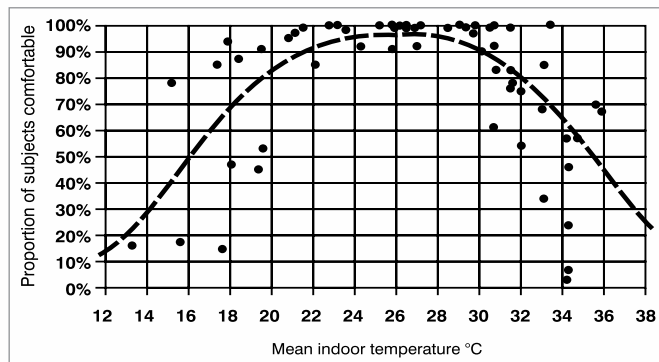


Figure 3: Proportion of office workers comfortable at different indoor temperatures. It will be noticed that on many occasions the subjects recorded no discomfort.

Principles of Adaptive Approach

- The Adaptive Principle is: if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort.
- By linking the subject's perception of comfort to the change and reaction, the Adaptive Principle introduces context as a factor in comfort.
- The comfort temperature is thus, a result of interaction between the subjects and the building or the other environment they are occupying.

Figure 3 shows, in a study conducted in Pakistan, the proportion of subjects comfortable at various mean indoor temperatures. The latter in turn depends mainly on the ambient conditions (climate and weather) and building construction. The comfort temperature is influenced by season, clothing, and activity level (amongst other factors). With a continually changing indoor temperature and comfort temperature, Pakistani buildings were found comfortable at temperatures ranging between 20 and 30°C with no cooling apart from fans (from Nicol et al, 1999).

Amongst all these factors, the ambient temperature is the most important. Note that the comfort temperature in this case is 20°C to 32°C. Compare this with the Fixed Temperature Approach of 23°C±1. Even though one can say that the Fixed Temperature Approach allows temperatures up to 26°C in summer and 20°C in winter, these are absolute limits and the Fixed Temperature Approach tag sticks.

In Adaptive Approach, on the other hand, controls available like air movement, postures, position changes, operable windows and such other factors are controllable by the individual occupant to manipulate and keep raising/lowering to suit his/her sensation of comfort. Please see Figures 4 and 5 also. In the Fixed Temperature Approach, the subjects are not aware of either the climate or the building and therefore they have no opportunity to adapt themselves and arrive at a comfort temperature in a larger range.

The months June and August refer (Figure 4) to, say, New Delhi – typically in the composite zone. Figure 4 helps to correlate indoor temperatures in NV buildings (offices in this case) with the time of the year/season. Please also see Figure 5.

- People have a natural tendency to adapt to changing conditions in their environment. This natural tendency is factored in the Adaptive Approach.

- It has been demonstrated that there is more *forgiveness* of buildings in which occupants have more access to building controls. By forgiveness, it is meant that the attitude of the occupants to the building is affected so that they will overlook shortcomings in the thermal environment more readily.
- In the Adaptive Approach, comfort vote by occupants is not based on voting in a climate chamber, but in actual built environment (often called Field Surveys). Field Surveys concentrate on gathering data about the thermal environment and the simultaneous thermal response of subjects in real situations, interventions by the researcher being kept to a minimum. The basis is voting in actual built environment. This will naturally comprise varieties of buildings, differing mix of people and varieties of location.

ACS in Standard 55-2004 and ASHRAE RP-884

The foregoing discussions lead us to the ACS stipulations in Standard 55-2004. The acceptable indoor conditions are furnished therein against mean monthly ambient temperatures (Figure 6). The coverage offered for ACS is rather brief, but Figure 7 is based on the application of Adaptive Approach, and ASHRAE RP-884, a Research Program.

The Adaptive Comfort Approach leading to ACS has been covered and described elaborately and in a fascinating way in *Climate, Comfort, & Natural Ventilation: A new adaptive comfort standard for ASHRAE Standard 55*, UC Berkeley, Center for the Built Environment - April 2001 by Brager, G. S., de Dear, R. (2011).

The raw data for the project - enormous, as it is – was collected in Field Surveys. Collection of data started in the year 1995. It is particularly important to note that it includes polling of comfort votes, which in contrast, is carried out in laboratories in the Fixed Temperature Approach.

Features of the work done under RP-884 are listed below:

- 21,000 sets of raw data compiled from field surveys in 160 buildings
- Buildings located in 4 continents in a variety of climatic zones
- Buildings include both (centralized) HVAC buildings and NV (Naturally Ventilated) buildings

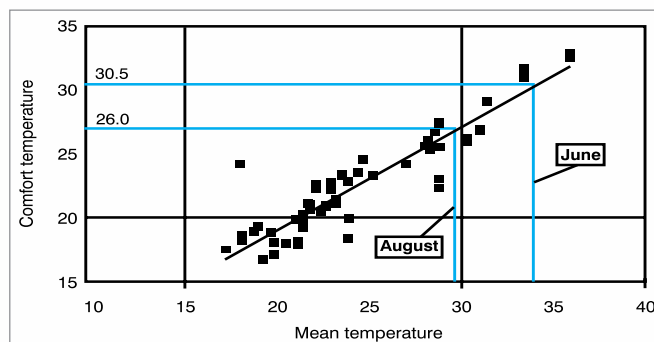


Figure 4: Mean interior temperature vs. comfort temperature

Figures 3, 4 and 5 are taken from *Adaptive Thermal Comfort and Sustainable Thermal Standards for Building* – J. Fergus Nicol and Michael A Humphreys – Oxford Centre for Sustainable Development, School of Architecture, Oxford Brookes University, Gipsy Lane, Oxford OX3 0BP, UK.

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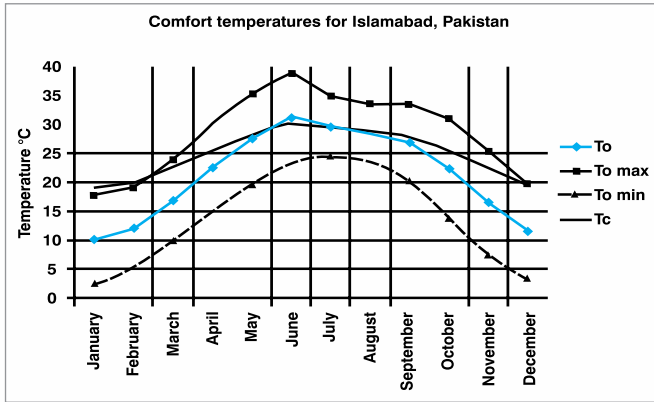


Figure 5: Comfort temperature of Islamabad, Pakistan
Note that $T_c=30^\circ\text{C}$ for $To\ max = 38^\circ\text{C}$ (in June – peak summer)

Operative Temperature (OT) - the temperature of a uniform, isothermal “black” enclosure in which man would exchange heat by radiation and convection at the same rate as in the given non-uniform environment **or** as the average of MRT and DBT weighted by their respective transfer coefficients.

$$OT = \frac{h_r MRT + h_c DBT}{h_r + h_c}$$

When the building in which the aspect of heat gain through envelope is specifically addressed, $MRT \approx DB$.

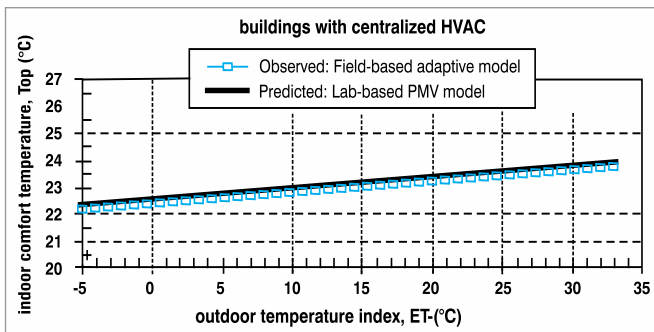


Figure 6a: Observed and predicted indoor comfort temperatures from RP-884 database, for HVAC buildings.

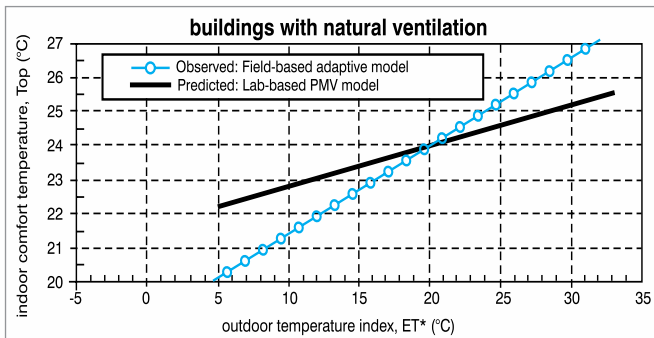


Figure 6b: Observed and predicted indoor comfort temperatures from RP-884 database, for NV buildings

Figure 6a and 6b are taken from Brager, G. S., de Dear, R. (2011), *Climate, Comfort, & Natural Ventilation: A new adaptive comfort standard for ASHRAE Standard 55*, UC Berkeley: Center for the Built Environment - April 2001.

Observations on RP-884 Results

Figures 6a and 6b present a regression of indoor comfort temperature for each building against Mean Effective Temperature as the outdoor temperature index.

Two strong patterns emerge from these graphs. First, the steeper gradient of observed responses (dotted line) in NV buildings (Figure 6b) compared to HVAC buildings (Figure 6a) suggests that occupants of HVAC buildings become more finely adapted to the narrow, constant conditions typically provided by mechanical conditioning, while occupants of NV buildings prefer a wider range of conditions that more closely reflect outdoor climate patterns.

Secondly, a comparison of the observed and predicted lines within each graph illustrates the role of adaptation in these two building types. In the HVAC buildings Fixed Temperature Approach, PMV was remarkably successful at predicting comfort temperatures, demonstrating that behavioral adjustments of clothing and room air speeds (both of which are inputs to the PMV model) fully explained the relationship between indoor comfort temperature and outdoor climate variation. In contrast, the difference between these two lines in the NV buildings shows that such behavioral adjustments accounted for only half of the climatic dependence of comfort temperatures. The rest must come from influences not accounted for by the PMV model, and our analysis suggests that *Psychological Adaptation* is the most likely explanation. In particular, the authors inferred that indoor comfort temperatures in NV buildings are strongly influenced by shifting thermal expectations resulting from a combination of higher levels of perceived control, and a greater diversity of thermal experiences in the building.

These two patterns emerging from Figures 6a and 6b and the resulting inferences there from lead to Figure 7, which is the trademark graphic for the ACS in Standard 55.

Proposed ACS In ASHRAE Standard 55 NV Buildings

Recognizing that climate, especially the ambient temperature, is a major influence on the sensation of comfort, Figure 7 shows the indoor operative temperature against mean monthly outdoor temperature. Note that the operative temperature is determined from the temperature of Thermal Neutrality. The PMV and PPD procedures have been applied to arrive at 90% and 80% acceptability.

Energy Savings Due to Application of Adaptive Model

Figure 8 represents energy savings possible due to the use of ACS. It begins with July climate data for the U.S., and then compares the upper 80% acceptability limit of the ACS to the upper limit of the ASHRAE Standard 55 comfort zone (based on 0.5 clo and 50% RH), which is 26°C.

ASHRAE Standard 55. Darker areas indicate larger differences between set point temperatures and therefore, larger energy savings.

Note that near maximum savings corresponding to a difference (5°C) between ACS and fixed temperature standards and savings when the difference declines to 4°C, are in areas like Texas, Arizona and New Mexico. They correspond to warm areas. Large areas in our country would fit into these categories. Application of ACS to such areas would therefore result in huge energy savings.

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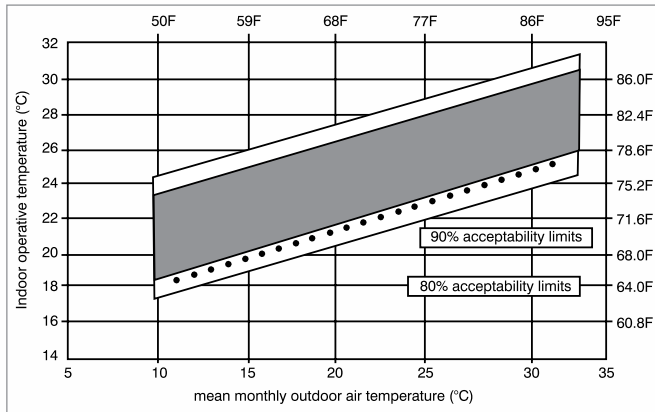


Figure 7: Acceptable operative temperature ranges for naturally conditioned spaces

Figure 7 is taken from ASHRAE Standard 55–2004 – “Thermal Environmental Conditions for Human Occupancy”

The map shows the regions of the country where the difference in comfort temperatures using these two methods ranges from 0 to 5°C. Energy savings would be proportional to the difference in these set points. This is actually a conservative estimate, and savings are likely to be much higher than indicated since it is more common to operate buildings at the center of the ASHRAE Standard 55 comfort zone (approximately 23°C), rather than at the upper end of 26°C.

It should be emphasized that this is a preliminary application of GIS technology to thermal comfort analysis and is based on coarse data. However, the picture is still indicative of the large potential for saving energy by using natural ventilation instead of air conditioning (assuming that people have direct control of the operable windows, and are also free to adapt their clothing). This is also an example of combining thermal comfort prediction methods with GIS technology to expand our analysis to a regional scale.

A look at Figure 8 serves to illustrate the kind of energy savings that can be achieved by application of ACS and Passive Cooling technologies to comfort cooling including air conditioning - and eventually, to other HVAC work also. No doubt, this applies only to the United States. Considering, however, that a large part of our country falls under the composite climatic zone, the relevance of this observation to our country becomes obvious. It is recommended that a study on the above lines (represented by Figure 8) be initiated in our country by professional bodies in the HVAC sector and/or governmental bodies.

Constraints to ACS

Applicability of Clause 5.3 of ASHRAE Standard 55

- Spaces where occupants regulate thermal conditions through opening and closing of windows; they must be easy to access and operate.
- If heating is provided, the method (Adaptive Control) does not apply when it is in operation.
- There should be no mechanical cooling system; examples: refrigerated air conditioning, radiating cooling, desiccant cooling.
- Mechanical ventilation (unconditioned air) is acceptable, but control will primarily be through operable windows.

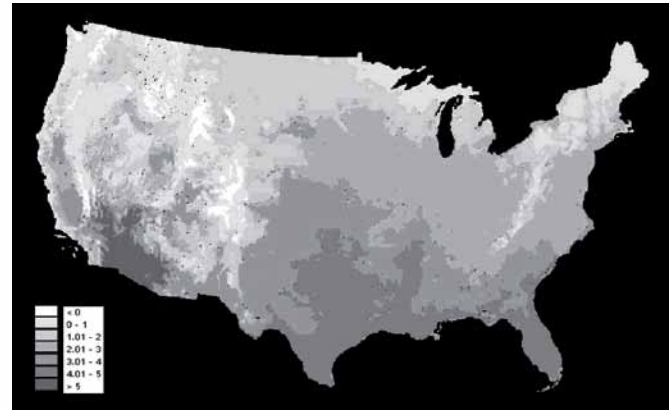


Figure 8: Comparison of recommended indoor comfort temperatures, upper limits of ACS vs. ASHRAE Standard 55. Darker areas indicate larger differences between set point temperatures and therefore larger energy savings.

Figure 8 is taken from Brager, G. S., de Dear, R. (2011). *Climate, Comfort, & Natural Ventilation: A new adaptive comfort standard for ASHRAE Standard 55*, UC Berkeley: Center for the Built Environment - April 2001.

- Activity levels to be within 1 to 1.3 met. Occupants must be able to freely adapt their clothing to indoor outdoor thermal conditions.

Range of acceptability

- 80% acceptability for typical application
- 90% for higher comfort levels

ACS is an optional standard

- Only recommendations
- No code enforceable requirements
- ACS cannot be met at all geographical locations

Note: Some of the constraints listed above look too harsh today, but they are now under a process of significant dilution and even withdrawal.

Uses of ACS

- As an optional design standard with 80% to 90% acceptability.
- Use simulation tool and check with ACS whether thermal conditions achievable are acceptable. If no, make design modifications and try. Repeat process.
- Application to Mixed Mode buildings: apply ACS as an operating guideline. Benefits could be downsizing the plant, first cost reduction, energy saving, etc.
- Apply ACS to Task/Ambient Conditioning (TAC) systems. Building ambient can be allowed to float within border limits of ACS with individual controls to elevate local comfort levels.
- Use for regional climate analysis to identify feasibility of using natural ventilation.

Part 2 of this article, to be published in the next issue, gives a worked example for better understanding of the Adaptive Approach. It then gives an insight into the available Alternatives-to-Air Conditioning Systems, and their impact on mainstream HVAC.