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

Part 2 of 2

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 comforable.

By R. V. Simha
Airtron Consulting Engineers Pvt. Ltd.
Bangalore

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.

Worked Example

We shall study the worked example below to get a better understanding of how the Adaptive Approach works.

A. Preliminary Considerations and Equations

We shall begin by determining the comfort temperature. It is applicable to all systems where the removal of total sensible heat gain is effected by supplying cool air, the requirement being that the product of the air flow rate and the difference between the built space temperature and the supply air temperature equal the total sensible heat removed.

Total sensible heat gain is removed

About the Author

R. V. Simha is a graduate in both electrical and mechanical engineering with over 40 years experience in HVAC. He is a past president of ISHRAE (1991-'92), founder president of ASHRAE South India chapter (1999-2000) and an ASHRAE Fellow. Recently, he served as a corresponding member of several ASHRAE technical committees and his current interests are climate, comfort, room air movement, natural cooling and related topics. He can be contacted at *simha@airtron.in*

from the occupied space by convection; this is also the way it is absorbed by air in the room (and expelled to the ambient). The equation governing the heat transfer is familiar:

RSH = air flow rate x temperature pick-up

i.e. $q = Q \times 1.23 \times (t_r - t_{sa})$

where q = total sensible heat gain (watts), Q = air flow rate (l/s), t_r = room DB temperature (°C), and t_{sa} = supply air temperature (°C)

The starting point for t_r may be regarded as t_n, which is the temperature corresponding to Thermal Neutrality, i.e. the temperature of minimum stress reported on verbal scales of mean levels of air or globe temperatures (t_i) experienced by respondents (indoor or outdoor). It is recorded over a period of approximately a month. t_n is obtained from *Figure 5 (Air Conditioning and Refrigeration Journal, October-December 2011, page 68) or from the equation:*

$$t_n = 17.8 + 0.31 \cdot t_m$$

where t_m = outdoor mean temperature

It is thus seen that the starting point for t_r is based on the outdoor air temperature or, in other words, climate. (This is in line with the adaptive principle that comfort temperature should reflect dependence on ambient temperature.)

Starting from t_r, calculations of acceptable comfort temperature eventually lead to t_{comf}, which represents the desired comfort level that serves as the target for calculation and achievement.

For working convenience, (t_r-t_{sa}) may be called temperature pick-up or even more simply pick-up. It may also be noted that room is synonymous with built space or built environment.

As we have already seen, t_r also stands for comfort temperature. The pick-up by itself and t_r & t_{sa} as individual parameters, are both of crucial importance. t_r depends on the climate and on the desired comfort. t_{sa} depends on the system chosen and equipment employed. If t_r is too high, occupant comfort will not be achieved; if it is too low, the air conditioning plant will be expensive. It is by optimization of (t_r-t_{sa}), t_r and t_{sa} as well as economic considerations that system choice and equipment selection are made.

B. Methodology for Calculation and Selection of Comfort Temperature and the System

The methodology presented below offers a step-by-step approach for arriving at the acceptable comfort temperature and temperature range for the project.

- The first step is to arrive at t_r. The choice of value for t_r depends on the climate and desired / acceptable / feasible comfort level.
- Next, arrive at band-widths of t_{comf} (calculated from the above equation) for 90% and 80% acceptability. These turn out to be 5°C and 7°C respectively.
- Monthly t_{max} and t_{min} are required. They are usually available in published climatic data.
- The following exercise should then be carried out for (at least) 2 months – the hottest month(s) and the worst month(s) during monsoon / rainy season / period – the period of highest wet bulb temperatures. The hottest months usually occur from February to July, while the highest WB could occur between May and September. The overlap between the two seasons depends on the latitude and is noticeable because of the size of the country. Calculations may have to be made for more than two months because of the overlap. This must be checked by the engineer. In the given example, the months of June and July/August have been selected. For both months, implement the following steps:
  - For a mean temperature of 34.3°C in the month of June, comfort temperature for the month is found to be 28.34°C from the equation

    $$t_n = 17.8 + 0.31 \cdot t_m$$
  - By applying the same equation for a mean temperature of 29.9°C in the month of August, the comfort temperature for the month is found to be 27°C.
  - Locate t_n on 50% RH line on the psychrometric chart with Standard Effective Temperature (SET) line superimposed on the chart.
  - The comfort zone can then be taken as t_n-2.5 to t_n+2.5°C (i.e. 5°C wide) for *90% acceptability*. This yields a comfort temperature range of 30.84°C to 25.84°C. It is the upper limit (30.84°C) that should be in focus in the hot months. Nevertheless, both the upper and lower limits are marked in *Figure 9*. The SET lines through the upper and lower limits yield the side boundaries of the comfort zone.
  - The humidity limits are taken as 12 and 4 g/kg for the upper and lower limits of dew points of the comfort zone.
  - The system selected should be able to maintain t_n+2.5 = 27+2.5 = 29.5°C.
  - The temperature range can be extended to t_n = ±3.5 (i.e. 7°C wide as compared to 5°C) if *80% acceptability* is adequate in lieu of *90% acceptability*.
  - Normally, *80% acceptability* is adequate; *90% acceptability* may be designed for only where expectations are sophisticated.
  - The summer upper comfort limit for subjects wearing 0.5 clo is set as 26°C Effective Temperature (ET) with 0.2m/s air movement. This can be extended by 1°C for each 0.275 m/s increase in air velocity, up to 28°C ET with 0.8 m/s air velocity.

    Note the due importance accorded to air movement as a crucial factor in comfort.
  - The horizontal scale of *Figure 7 (Air Conditioning and Refrigeration Journal, October-December 2011, page 70)* is Operative Temperature (OT). If Mean Radiant Temperature (MRT) = DBT and average wind velocity is negligible, DBT can be used for OT; otherwise adjustments must be made.

C. Design Calculations

Table 1: Ambient temperatures, cooling systems and leaving air temperatures

Sl. No.	Description	Evaporative cooling	IDEC
1	**Outside air temperature**		
	a. Entering db, °C	41.5	41.5
	b. Entering wb, °C	23.5	23.5
2	**Leaving db temperature, °C**	25.09	20.37
Air washer efficiency assumed as 0.9 and indirect-direct evaporative cooling (IDEC) efficiency as 1.15			

Table 2: Arriving at comfort temperature required

Sl. No.	(All temperatures in °C)	Summer		Monsoon	
		IDEC+DEC	DEC	IDEC+DEC	DEC
I. Comfort requirement					
1	Thermal neutrality (t_n) @ V_r = 0.2 m/s	28.34	28.34	27	27
2	SET from psychrometric chart @ t_n and 50% RH (see Figure 9)	28.34	28.34	27	27
3	t_{SET-ul} = Upper limit of tcomf = SET @ t_n + 2.5°and V_r = 0.2 m/s	NA	NA	29.5	29.5
II. Equipment and system performance					
1	Equipment leaving air temperature	20.37	25.09	27.75	29
2	Temperature rise	1	1	1	1
3	Supply air temperature	21.37	26.09	28.75	30
4	($t_r = t_{sa}$) + pick-up (3ºC-variable)	24.37	29.09	31.75	33
5	Room SET (from chart - t_r/65% RH, V_r=0.2m/s)	25	30.1	32.1	34.7
Note: *A pick-up value of 3ºC has been used in the calculation. This has been chosen on the basis of air flow rate considerations. Pick-up values of 3ºC and above yield moderate air flow rates (Q).The air flow rates increase sharply as pick-up values drop below 3ºC. The applicable equation for Q = q/(1.23 x pick-up).*					
Observations : *In IDEC & DEC (direct evaporative cooling) systems, the calculated room SET is well below tn. The room SET can be raised if required by reducing the pick-up. This will result in a reduction of plant size. Calculations can be repeated with different values of room pick-up. For DEC system, calculations have been continued by stretching the upper limit of comfort temperature range to values between t_n+2.5 and even to t_n+3.5. At the same time, plant performance can be improved by raising V_r using LAMDs (Local Air Moving Devices). Both the concepts have been applied in the calculations. Alternately, DEC or other systems with higher leaving air temperatures can be applied, if found adequate.*					
III	**Improving plant performance by raising V_r to meet the selected t_{SET-ul}**				
1	SET @ V_r - 0.2m/s	28.34	29.5	29.5	29.5
2	SET @ V_r - 0.3m/s	28.7	29.9	29.9	29.9
3	SET @ V_r - 0.4m/s	29.1	30.3	30.3	30.3
4	SET @ V_r - 0.5m/s	29.5	30.8	30.8	30.8
5	SET @ V_r - 0.6m/s	30	31.1	31.1	31.1
6	SET @ V_r - 0.7m/s	–	31.4	31.4	31.4
7	SET @ V_r - 0.8m/s	–	31.8	31.8	31.8
8	SET @ V_r - 0.9m/s	–	32.1	32.1	32.1
9	SET @ V_r - 0.9m/s	–	32.1	–	–
Legend: *t_r = Room Temperature, t_{sa} = Supply Air Temperature, T_n= Thermal Neutrality, t_{SET}=Standard Effective Temperature, t_{SET-UL}=Upper limit temperature of SET, t_{comf} = Comfort Temperature, t_m = mean monthly ambient temperature, t_{max} = maximum temperature, t_{min} = minimum temperature*					

We may remind ourselves that if 80% acceptability suffices (this is recommended and is a default value for standard applications), t_{comf} (in row 3) will be t_n+3.5 = 30.5 (at V_r = 0.2 m/s); higher values of acceptable t_{comf} can be obtained by enhancing room air movement (V_r).

Use of the Methodology

This methodology involves use of spreadsheets. It is essentially a design tool to help check the feasibility of providing various available systems, size the plant, and make approximate energy calculations; it would not, obviously, be appropriate to use it for submissions as a back-up for applications for certification from regulatory authorities, like LEED for example.

The approach and methodology shown is a suggestion; others may also be developed. The implementation may also be improved. Software can be developed for implementation, depending on acceptability, deliberations and debate.

It is hoped that the proposed methodology will be useful in any case for practicing engineers.

Available Alternatives-to-Air Conditioning Systems (Passive Cooling)

For selection of an appropriate system, it is time to survey the scenario of comfort cooling systems available. Please see *Figure 10.*

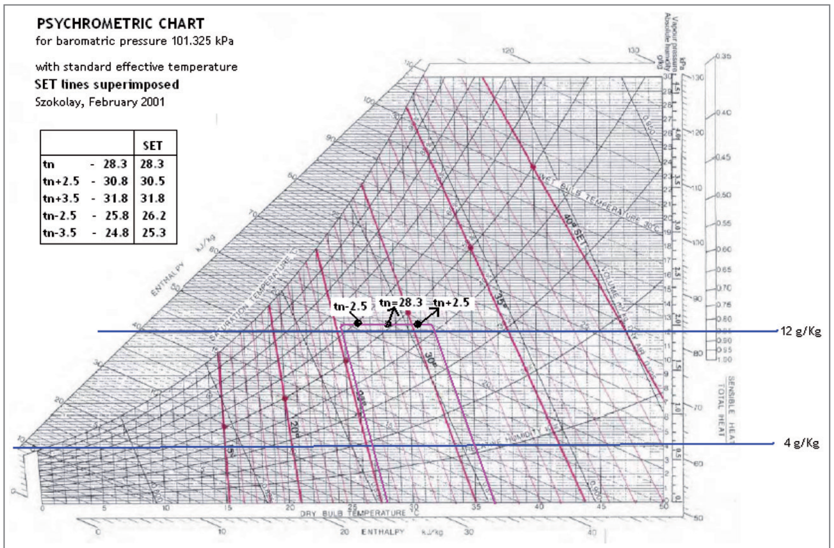
The term Passive Cooling Systems needs some clarification. In this context it applies to various cooling techniques that enable the indoor temperatures of buildings to be lowered through the use of natural energy sources. The term passive does not exclude the use of a fan or a pump when their application might enhance performance. In most cases the cold collection and storage elements of such a system are an integral part of the building itself – the roof, structural materials, or soil under the building, for example.

Even when mechanical devices are used, their coefficient of performance (COP) – the energy input per unit of cooling that is obtained within the building – is much higher than the value common in air conditioning. *Table 3* shows the approximate COPs of some systems for ready comparison.

The values shown are based on examples

continued on page 75

continued from page 72



Standard Effective Temperature (SET): *SET is a sub-set of ET under standardized conditions: clothing standardized for given activities (thus the effective heat transfer coefficients h's and h'es). The process of standardization was continued in terms of metabolic rate and clothing and it was established that an inverse change of clo can compensate for an increase of met. h's is the total heat transfer coefficient of saturated air. he's is the total evaporative heat transfer coefficient of saturated air. Both are at skin temperature, and include conductance of the clothing!*

Figure 9: Comfort temperature on psychrometric chart with SET lines superimposed.
Figure 9 is taken from Thermal Comfort, Andris Auliciems and Steven V. Szokolay, in association with the University of Queensland, Department of Architecture

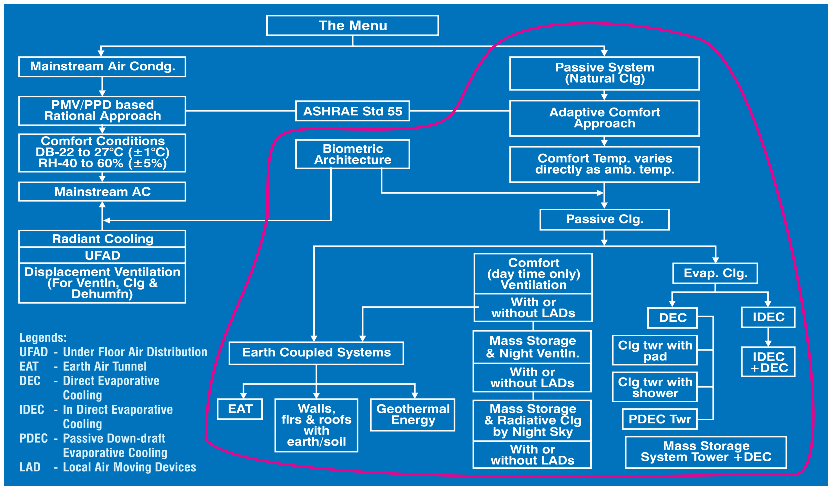


Figure 10: Availability of passive cooling systems

Table 3: COPs of various systems

Sl. No.	Description	DEC	IDEC	AC
1	Connected power, kW	225	252	554.5
2	Consumed power, kW	178.2	240	514
3	Cooling energy, kWhrc	2877501	2890726	4770756
4	Consumed electrical energy, kWhre	248786	311731	1187902
5	Electrical energy/sqm/ year	26.81	33.59	128.01
5.1	DEC/AC	0.203	–	–
5.2	IDEC/AC	–	0.262	–
6	COP	11.57	9.27	4.02
6.1	DEC/AC	2.87	–	–
6.2	IDEC/AC	–	2.3	–

worked out for other studies carried out by the author.

For systems which are directly coupled to earth, COPs can be higher. Even for an Earth Air Tunnel which is air-coupled, COP values of 20 to 25 or higher can be achieved.

Comfort Zones and Applicable Systems

Concepts for projects at preliminary stages can be visualized with the help of bioclimatic charts. In *Figure 11*, some WB lines have been incorporated to help correlate the information in the chart with ASHRAE psychrometric charts. The figure identifies systems applicable for all the conditions that it covers. Conditions above the upper boundary of the systems shown require air conditioning.

Mainstream Air Conditioning and Passive Cooling in Mixed Mode System (MMS)

Figure 12 identifies system(s) required to operate at various ambient conditions and the duration of operation (hrs/year) of such systems during a period of 8760 hrs. This example illustrates how an MMS is applied to a project.

In a sense, Mixed Mode Systems are not brand new. High quality design engineering (particularly abroad) has always been looking at a plethora of evolving concepts, state-of-the-art systems and equipment, to apply them in various ways to minimize the owning cost of HVAC plants. However, in today's scenario of power and energy scarcity, the drive towards improved air quality and the industry's adoption of an Adaptive Comfort model for naturally conditioned spaces, interest is growing among HVAC engineers towards reapplying natural ventilation, low energy comfort cooling and other Alternate-to-Air Conditioning systems. This interest is exemplified by the three projects noted below:

- Kirsch Center for Environmental Studies
- San Francisco Federal Office Building
- Yang and Yamazaki Environment and Energy

All the three projects are situated in San Francisco Bay area in the US. This author has not carried out a systematic survey. One can therefore extrapolate that there must be many such projects elsewhere. The significance of MMS today is that this process of pursuing excellence and implementing sound engineering practices and higher levels of professional performance is not just offered but is essential and demanded. In other words, searching for the right systems to

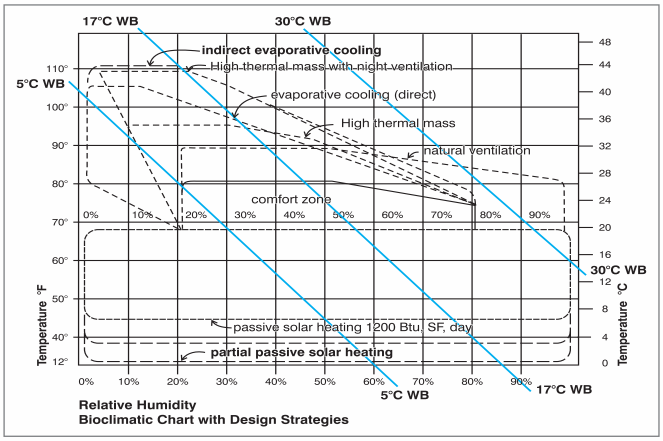


Figure 11: Selection of HVAC and passive systems for different climatic and indoor conditions

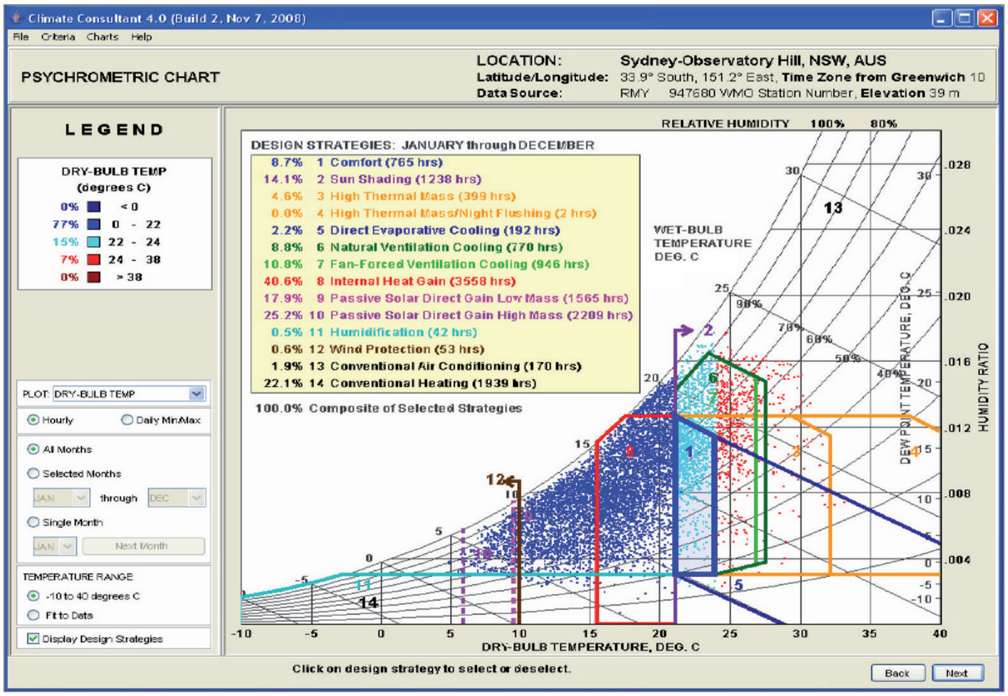


Figure 12: Selection and operation of Mixed Mode System

obtain overall optimization is not an exception but is driven by mandatory requirements. This is what is *new* about MMS.

It is interesting to read, in this context, the following observation in an article about the need to develop knowledge, learning and a mindset captioned Mixed Mode Ventilation – Finding the Right Mix by Erin McConahey, P.E., published in the September 2008 issue of *ASHRAE Journal* (see *Reference 8*):

"However, since the introduction of air-conditioning by Willis Carrier's 1906 patent, half-dozen generations of Americans have become accustomed to mechanical conditioning of indoor spaces, especially for large commercial buildings. Therefore, the "reapplication" of natural ventilation into modern buildings requires care, intentionality, involvement of the client parties, and in particular, a full understanding of the most recent ASHRAE standards: ANSI/ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality and ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy."

This is another way of saying that engineers must recall and brush up the knowledge of pre-Carrier days. Dr. Carrier has made it too easy to practice engineering all these decades by his work and therefore the old knowledge is fading. The author has also used the word reapplication for converting the fading knowledge to new knowledge.

A closer look at the task of reapplication of what is *fading and not new* can begin with some definitions. Here again, the material that follows is taken from Erin McConahey's article.

The potential for natural

Mixed Mode Systems	*"... refers to a hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that include air distribution equipment and refrigeration equipment for cooling."*
Naturally Ventilated Spaces	*"... shall be permanently open to and within 8 m (25 ft) of operable wall or roof openings to the outdoors, the openable area of which is a minimum of 4% of the net occupiable floor area. ..."* *"The means to open required operable openings shall be readily accessible to the building occupants whenever the space is occupied."*
Naturally Conditioned Spaces	*"... are those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows."*
Adaptive Model of Thermal Comfort	*"... Field experiments have shown that occupants' thermal responses in [occupant controlled naturally conditioned spaces] depend in part on outdoor climate and may differ from thermal responses in buildings with centralized HVAC systems primarily because of the different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations.* *"... Allowable indoor operative temperatures for spaces that meet these criteria may be determined from Figure 5.3 [from Standard 55-2004]."*

ventilation as a viable means of comfort conditioning often relies on mixed mode approaches that use natural ventilation for most of the year, but rely on mechanical cooling for peak loading conditions. Commonly, mixed mode systems are categorized as one of the following:

- Concurrent (same space, same time);
- Changeover (same space, different times); or
- Zoned (different spaces, same time)

Who Has Done What?

It is also of interest to know, in this context, who has done what in developing the Adaptive Approach, Adaptive Comfort Systems and Mixed Mode Systems.

Here again, let us cite from Erin MaConahey's article and some paragraphs appearing under the caption *Design Guidance, or Lack Thereof* on pages 37 and 38:

Standard 55-2004 states that "no specific guidance for naturally conditioned spaces is included in this standard." Standard 62.1-2007, Section 5.1, explicitly states that "an engineered natural ventilation system when approved by the authority having jurisdiction need not meet the requirements" of the prescriptive approach, but gives no indication of what an "engineered" system would consist of. The 2005 ASHRAE Handbook — Fundamentals provides only two pages (27.10 – 27.11) to explain the physics of how natural ventilation flows can be calculated and provides qualitative guidance regarding placement of openings.

In looking for further guidance, one would primarily turn to the Chartered Institution of Building Services Engineers (CIBSE) Applications Manual AM10, Natural Ventilation in Non-Domestic Buildings, 2 which is referred to as the basic criteria used by the U.S. Green Building Council's LEED® for New Construction, Version 2.23 to establish minimum proof that the natural ventilation system is likely to give comparable IAQ ventilation as compared to a mechanically ventilated system. Table 3 lists the documentation requirements by associated LEED credit, and it begins to point towards the level of analytical investment that is appropriate for proposing a naturally ventilated or naturally conditioned space at the construction documents phase.

(Clauses and tables referred to are not part of this article.)

ASHRAE was slow to start with and cool towards Passive Cooling. The Adaptive Comfort Approach appeared first in the 2004 issue of *Standard 55*. It was brief and far from the levels of presentation of details for implementation. It is unnecessary to make any further observation on ASHRAE's performance than those in the McConahey article. It is also worth noting at the same time that ASHRAE's well known *RP-884* was taken up long ago in the year 1995.

The article cited in *Reference 4* had appeared in April 2001. And that is nearly 10 years ago. Besides these two workers (Brager, G. S., and de Dear, R.), admirable and exhaustive work has been carried out by J. Fergus Nicol and Michael A. Humphreys also; there would, of course, be many others too.

A significant part of this article is based on *References 4, 5, 6* and *7*, particularly *Reference 4*, which is ASHRAE's research project *RP-884* that forms the basis for much of the work by ASHRAE which has resulted in whatever progress we see in last few years in creating awareness of the Adaptive Approach. It is therefore surprising that till as recently as September 2008, the McConahey article had to make the kind of observations that it made.

It thus appears that ASHRAE's work is patchy. It seems that it has not focused for any length of time on any particular goal, while dealing with the topic of Adaptive Approach. There have been no significant efforts to generate and promote awareness of the concept, no road map for taking up preparation of design guide lines, providing solutions (like worked examples), manuals, standards, literature and documentation. It is heartening to note, however, that currently efforts are being made to tackle this issue. Even so, it appears that ASHRAE's focus could be different from what we need in our country.

This may be contrasted with CIBSE's work; as a matter of fact, ASHRAE has been selling *Natural Ventilation in Non-domestic Buildings – CIBSE Applications Manual AM10:2005* in the US through its bookstore. A look at this manual will make us aware of the kind of work CIBSE has been doing all the time.

Impact of Adaptive Approach on Mainstream HVAC and Alternatives-to-Air Conditioning

The impact of the Adaptive Approach on the Alternative-to-Air Conditioning systems (Passive Cooling Systems) is through the Mixed Mode System. As of now, the A-to-AC systems are not a part of mainstream HVAC systems, but this situation appears set to change. Again, one needs to take a look at *Reference 8* to sense the way the wind is blowing. The title of the article itself gives the clue, which is a good deal about selecting the right mix for a project. HVAC buyers are becoming increasingly aware of trends in technology and they will duly sit up and take notice. The larger the projects, the higher the demands from owners, architects, and HVAC engineers to take a look at the menu of systems individually and evaluate their pros and cons. The industry, as of today, is not in a position to react appropriately and effectively. It should recognize, as it has done abroad, that introduction of passive systems into MMS projects skillfully requires application of new knowledge. This is a challenge that HVAC professionals will need to face. The response of the industry, especially the professionals, must factor in the legitimacy that passive cooling systems are set to acquire because of their mainstreaming in the US (and more generally in North America) through Mixed Mode Systems.

The need to acquire familiarity with passive systems on a new footing does not necessarily disappear if the thrust of Mixed Mode Systems turns out to be weak, because the need to save energy is acute and pressing in all situations.

References

1. *ASHRAE Standard 55-2004* – Thermal Environmental Conditions for Human Occupancy.
2. *ASHRAE Handbook of Fundamentals* – 2009.
3. *ASHRAE Handbook - HVAC Applications (SI)* – 2007, Chapter 51, Evaporative Cooling.
4. *Climate, Comfort, & Natural Ventilation: a new adaptive comfort standard for ASHRAE Standard 55*, UC Berkeley Center for

continued on page 79

continued from page 77

the Built Environment, April 2001, Brager, G. S., de Dear, R.

5. *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.

6. *Thermal Comfort,* J. Fergus Nicol, LEARN, School of Architecture, University of North London, UK.

7. *Thermal Comfort,* Andris Auliciems and Steven V. Szokolay in association with the University of Queensland Department of Architecture, PLEA Notes.

8. *Mixed Mode Ventilation* – Finding the Right Mix, Erin McConahey, P.E., ASHRAE Journal, September 2008.

9. *EAT & Comfort Cooling (and Heating),* R.V. Simha, Air Conditioning and Refrigeration Journal, Oct-Dec 2010 and Jan-Mar 2011.

Bibliography

1. *Sustainability and Air Conditioning,* presentation and paper by R. V. Simha at Green Building Congress organized by CII-Godrej, Hyderabad, May 2007.

2. *Alternative to Air Conditioning Systems - as a response to Challenges to Sustainability*, paper presented by R.V. Simha at Acreconf, New Delhi, 2007.

3. *A Fresh Approach to Evaporative Cooling,* Air Conditioning and Refrigeration Journal (ISHRAE), Oct-Dec 2008. ❖