COMFORT CONDITIONS FOR BUILT ENVIRONMENTS IN SRI LANKA

by

M.T.R. Jayasinghe and R. A. Attalage

Abstract

The neutral temperatures for different locations in Sri Lanka have been established using actual climatic data. Based on these neutral temperatures, standard comfort zone for each of these locations can be identified on the psychrometric chart. Field measurements have been carried out for the validation of comfort zones for Sri Lankan conditions. The effects of physiological cooling at relatively high internal air velocities have been highlighted. In order to check the applicability of standard modification techniques for the comfort zones to take account of elevated internal air velocities, surveys have been carried out at two different velocities. The need for additional boundaries to standard modifications to suit Sri Lankan conditions have been highlighted. This provides a method of extending the boundaries of these comfort zones thereby accommodating higher levels of dry bulb temperatures and humidites in the built environments. This fact can be utilised as the basis of minimising the energy demand in buildings either air conditioned or not, by making use of combined modes at different internal air velocities.

1.0 Introduction

The demand for electricity in Sri Lanka is growing at over 8% per annum. At present, the energy used for air-conditioning and lighting in public and industrial buildings accounts for over 30% of electricity sales. A major contributing factor to these electricity sales is air-conditioning of buildings (Attalage and Wijetunga, 1997).

The energy required for air-conditioning can be considered as a major contributing factor to the running cost of buildings. Thus, any saving in air-conditioning loads can be very profitable to the owners and also may lead to a reduction in the capital and equipment cost if reduction of the energy demand is considered as an objective at the initial planning stage. A high energy demand for air-conditioning could justify the necessity for carrying out studies to minimise this energy usage.

With the increase in oil prices, a lot of countries have reintroduced the well known passive techniques as one of the effective measures of reducing building electricity consumption in their National Energy Conservation Programmes. Those measures could be stated as the use of passive elements (thermal mass, shades, blinds ...), radiative cooling, natural ventilation and evaporative cooling with the objective of reducing the electricity consumption for active based air conditioning of the buildings.

One of the primary objectives of the building designer is to ensure that the "built environment" is thermally comfortable to its occupants throughout the day, around the year. However, this has become an almost impossible task to achieve due to unforeseen heat interactions from occupants, from equipment, through the envelope and due to incorrect or inappropriate design features. Moreover, thermal comfort, which is the sensation of complete physical and mental well being, is a subjective quantity which results from internal environmental variables such as dry bulb temperature, mean radiactive temperature, humidity and air velocity and also personal variables such as activity and clothing levels of the occupants.

The thermal comfort could be achieved for several combinations of the above mentioned environmental and personal parameters. These combinations of parameters form the basis of a "comfort zone" on the standard psychrometric chart. One of the main objectives of air conditioning is to ensure that thermal comfort is achieved within the built environment; this means ensuring that the environmental parameters are within the specified comfort zone.

Establishing the comfort zones and validating them for different parts of Sri Lanka would be of paramount

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importance to determine the conditions required by Sri Lankans inside the buildings. This is because Sri Lanka is a tropical country and it is most likely that Sri Lankans would be able to bear higher temperatures without feeling discomfort and also might feel uncomfortable due to excessive cooling even at $24C^0$.

For a country like Sri Lanka, where the electricity prices are relatively high, it would also be prudent to consider the alternative means of creating thermally comfortable conditions directly or combining some of the alternatives. For example, artificial ventilation can be considered if external temperatures and humidities are close to thermally comfortable conditions; in this case a continuous supply of exterior air can be provided within the building. As a combined alternative, it would be possible to use active based air-conditioners to reduce the temperature and humidity to a certain extent while using fans to provide internal air movement. In order to try these different alternatives and strategies with confidence in existing or proposed buildings, it is necessary to establish various comfort zones under different conditions and to verify whether they are actually considered as comfortable by the occupants; this can be done by conducting a questionnaire survey among a large number of people of different categories at different environments.

In this study, which is still on going, neutral temperatures have been established for various parts of Sri Lanka. These neutral temperatures have been used to establish comfort zones for different areas. These comfort zones have been modified to take into account of internal air velocities corresponding to artificial ventilation provided using fans. The establishment of comfort zones and the modifications have been done using the standard methods given in Szokolay (1991). In order to check whether these standard methods are applicable to Sri Lanka and also to determine the adjustments required for the standard techniques, a questionnaire survey has been carried out. Such adjustments to standard techniques can be justified since some researchers have even tried to analyse the dynamic interaction between the external climate and the building occupants in order to develop comfort conditions as a function of external conditions (Nichol et al. 1997).

The comfort zone established based on the climatic data for Moratuwa (location where the university is situated) has been used to check the validity of the comfort zones established for Moratuwa and Ratmalana area (western coast of Sri Lanka) by Fernando et al. (1996).

Once these comfort zones are established, it will be possible to incorporate them in approximate load evaluations forms or they can be used in precise cooling load calculations. These data also could be used in building envelope and equipment modelling and building energy management systems (BEMS).

2.0 State of the art survey

Due to variance of biological, emotional and physical conditions of individual subjects, it is not possible to build an environment which could be thermally comfortable to all. However, it would be possible to aim at creating an optimum thermal comfort level for a group of a particular unbiased sample; that is creating conditions in which the highest possible percentage of the group is comfortable.

The combination of the two environmental variables, the dry bulb temperature and the humidity of internal air, which form the conditions so that around 70% of the populations finds the whole body thermally comfortable, are considered as the comfort zone. However, the standard comfort zone implicitly considers sedentary activity level (1.2 met = 69.6 W/m2) with light to medium clothing (around 0.8 clo), internal air velocity less than 0.25m/s and without any asym-

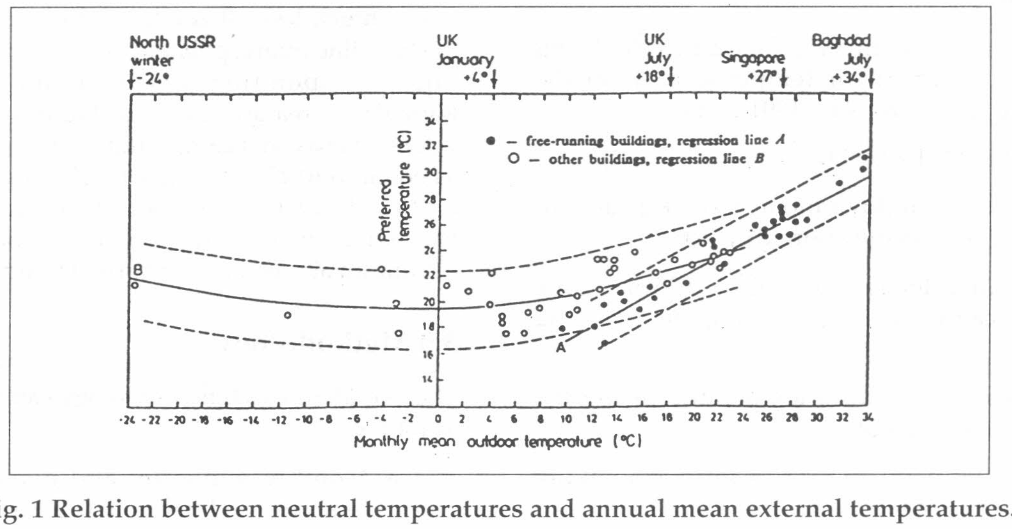

Fig. 1 Relation between neutral temperatures and annual mean external temperatures.

metrical radiation from surrounding surfaces (ANSI/ ASHRAE, 1981).

Nevertheless, local thermal discomfort may be present on one or particular parts of the body caused by unwanted heating or cooling, head to feet temperature gradient, radiation asymmetry and draughts (Achard & Gicquel, 1986).

It is shown by Humphrey (1978) that the annual mean external temperature of a location could be related to its neutral temperature (denoted as the preferred temperature) which is considered as the centre point of the above mentioned comfort zones as shown in **Figure 1.** The curve and the data points show that much more tolerance to both high and low temperatures in non-heated free running buildings than in heated or cooled buildings. This shows that the free running buildings are more acceptable to the occupants over a wide range of conditions than conventionally serviced structures (e.g. air conditioned buildings).

2.1 Standard methods of developing the comfort zone

The comfort zone is established using the neutral temperature which is considered as the centre point of the comfort zone. The neutral temperature is calculated based on the meteorological data obtained over a number of years, for example, about 10 years. The neutral temperature is given be the following equation (Szokolay, 1991):

$$Tn = 17.6 + 0.31\ T0 \qquad (1)$$

where T0 is the annual mean dry bulb temperature at a selected locality.

The boundaries of the comfort zone are determined using a set of lines called Standard Effective Temperatures (SET), which represents the combined effects of temperatures, humidity, radiation and air movement, for an internal space.

SET Line can be approximately found by calculating the base line intercept for temperature T on the pshchrometric chart (Szololay, 1991), where

$$Tintercept = T + 23\ (T - 14)\ HR_T \qquad (2)$$

where HR_T is the humidity ratio in Kgw/Kga at temperature T and 50% relative humidity (RH).

When the wind velocity is less than 0.25 m/s, the comfort zone can be developed using the following steps:

1. Calculate the neutral temperature using the meteorological data.
2. Locate this point on the 50% relative humidity (RH) curve of the chart.
3. The boundaries of the standard comfort zone consist of two SET lines corresponding to $T_1 = T_n - 2^0C$ and $T_2 = T_n + 2^0C$ points on the 50% RH curve.
4. The top and bottom boundaries will be at 0.012 and 0.004 humidity ratio levels.

The comfort zone established for Ratmalana area is shown in **Figure 2,** where a neutral temperature of 26⁰C has been used.

2.2 Modification of comfort zone for different air velocities

When natural or artificial ventilation is available, people will feel comfortable even outside the standard comfort zone. The air movement produces a physiological cooling effect. Thus to take account of this effect, the boundaries of comfort zone should be modified according to the air velocity. It is usual to consider the following limits:

1. Air movement less than 0.25 m/s where the comfort zone is established.
2. Air movement between 0.25 m/s and 1.0 m/s.
3. Air movement greater that 1.0 m/s.

The physiological cooling effect of air movement is taken into account in the psychrometric chart by using the following modifications, where the value of T2 is modified (Szololay, 1991):

$$dT = 6v - V^2\ {}^0C \text{ for air velocities up to 3.0m/s} \qquad (3)$$

$$T_3 = T_2 + dT \qquad (4)$$

The SET line corresponding to T_3 is drawn up to 90% relative humidity and the upper boundary of the comfort zone is now considered as 90% relative humidity line. In very low humidities experienced in hot dry climates, evaporation from skin is not restricted even with still air, so the improvement due to ventilation is much less. It is taken into account by halving the base line intercept below a humidity ratio of 0.012. The corresponding modified comfort zones for Ratmalana area are shown in Figures 3 and 4. For a velocity between 0.25m/s and 1.0m/s, v is considered as equal to (0.25 + 1.0)/2 = 0.625 m/s. For wind velocities above 1.0 m/s, the velocity used for calculation is 1.25 m/s because 1.5 m/s is considered as the maximum air velocity for normal building occupancy.

3.0 Methodology

The overall research methodology can be summarised as follows:

a. Monthly minimum and maximum relative humidity and dry bulb temperature values for

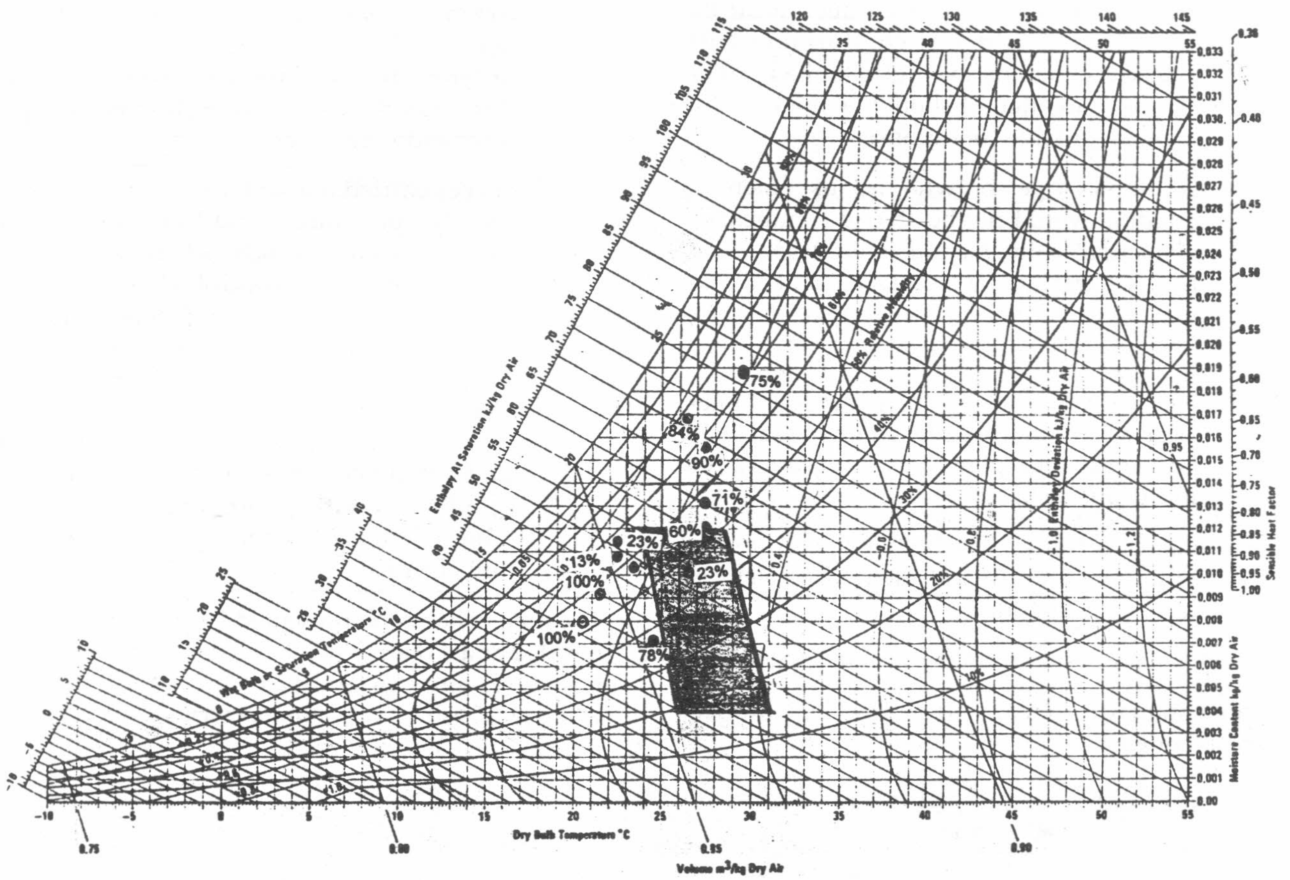

Fig 2: Results of questionnaire survey for internal air velocities less than 0.25 m/s presented together with the standard comfort zone where the neutral temperature is 26.5°C (Applicable to Ratmalana area in the west coast)

different locations in Sri Lanka have been obtained from Meteorological Department of Sri Lanka. This data has been used to determine the neutral temperatures for various parts of Sri Lanka. Since Sri Lanka is a tropical country with little annual variation in climate, data collected over only three years have been used to calculate mean annual dry bulb temperatures.

b. In order to determine whether the standard comfort zones and the modification for increased air movement are applicable to Sri Lanka, a questionnaire survey has been carried out among the staff and students of University of Moratuwa. The items considered have been selected according to the following reasons:

i. Activity level: The metabolic rate of people vary according to the work that they are involved with. The sensation of the people (whether they feel comfort or discomfort) in similar environmental conditions can be compared according to their activity level. Subjects at sedentary activity level have been considered for this study.

ii. Sensation of people: The sensations selected are cold, cool, slightly cool, comfortable, slightly warm, warm and hot. Air-conditioned buildings such as computer rooms, auditoriums, laboratories, etc. have been used to create and maintain various temperature and humidity levels.

iii. Type of air movement: Since the primary objective is to minimise the energy demand, it is very important to consider the type of ventilation supplied to the building. If the occupants would feel comfortable with natural ventilation even to a limited period of a day, an attempt should be made to use these favourable conditions.

iv. Duration: A person who has just entered a building would not be able to comment on his actual feelings about the thermal comfort. Generally, it would take about 15 minutes to realise the actual reactions to the prevailing built environment. Sometimes a person may be able to tolerate a higher or a cooler temperature up to about 30 minutes, after which he would be totally dissatisfied. So the duration plays a very important role in a comfort survey.

v. Gauge readings: Dry bulb temperature, wet bulb temperature and internal air velocity have been obtained.

The questionnaire survey form is given in Appendix A.

The questionnaire survey can be divided into two main categories:

1. Survey carried out with normal conditions: The questionnaire survey has been carried out under normal conditions in lecture rooms, common areas and reading rooms with normal ventilation and increased ventilation at different times of the day over a period of three months to represent different temperatures and humidities.

2. Survey carried out with controlled conditions: Ideally controlled conditions should have been obtained in a room where humidity and temperature can be controlled. However, due to non-availability of such facilities, the questionnaire surveys were carried out in an air conditioned auditorium and in a seminar room in which both fans and air conditioners were available. The main advantage of using undergraduates as 'subjects' was that a large number of data points could be obtained while changing temperatures, humidities and air velocities.

The data collected is presented in tabular form in Tables **1, 2 and 3** (Fernando et al., 1996). These data have been presented in graphical form on the comfort zones established for Ratmalana area as shown in Figures 2, 3 and 4.

Table 1: Results of questionnaire survey (air velocities less than 0.25 m/s) giving number of responses and the corresponding percentages

DB^0C	R. H. %	Comfort		Discomfort	
		Number	Percentage(%)	Number	Percentage(%)
20.0 - 21.0	50 - 55	Nil	-	07	100%
21.0 - 22.0	55 - 60	Nil	-	02	100%
22.0 - 23.0	60 - 65	12	13.1%	80	86.9%
22.0 - 22.0	65 - 70	8	23.5%	26	76.5%
23.0 - 24.0	55 - 60	Nil	-	02	100%
24.0 - 25.0	35 - 40	18	78.0%	05	22.0%
26.0 - 27.0	45 - 50	08	22.9%	27	77.1%
26.0 - 27.0	75 - 80	177	84.7%	32	15.3%
27.0 - 28.0	50 - 55	26	60.0%	14	40.0%
27.0 - 28.0	55 - 60	31	71.1%	14	28.9%
27.0 - 28.0	65 - 70	57	90.5%	06	9.5%
29.0 - 30.0	70 - 75	98	75.3%	32	24.7%

Table 2: Results of questionnaire survey (0.25 m/s <wind speed, 1.0 m/s) giving number of responses and the corresponding percentages

DB °C	R. H. %	Comfort		Discomfort	
		Number	Percentage(%)	Number	Percentage(%)
24.0 - 25.0	70 - 75	13	31.7%	28	68.3%
27.0 - 28.0	70 - 75	34	66.7%	17	33.3%
27.0 - 28.0	90 - 95	19	46.0%	22	54.0%
28.0 - 29.0	40 - 45	06	60.0%	04	40.0%
28.0 - 29.0	65 - 70	31	72.0%	12	28.0%
28.0 - 29.0	75 - 80	41	63.1%	24	36.9%
29.0 - 30.0	30 - 35	09	64.0%	05	36.0%
29.0 - 30.0	45 - 50	74	79.5%	19	20.4%
29.0 - 30.0	65 - 70	04	80.0%	01	20.0%
29.0 - 30.0	70 - 75	41	63.1%	24	36.9%
30.0 - 31.0	70 - 75	09	23.1%	30	76.9%
31.0 - 32.0	65 - 70	19	57.5%	14	42.5%
31.0 - 32.0	70 - 75	51	49.5%	52	50.5%
31.0 - 32.0	75 - 80	134	75.7%	43	24.3%
31.0 - 32.0	90 - 95	01	33.3%	02	67.0%
32.0 - 33.0	45 - 50	61	33.0%	12	16.4%
32.0 - 33.0	50 - 55	30	83.6%	05	14.3%

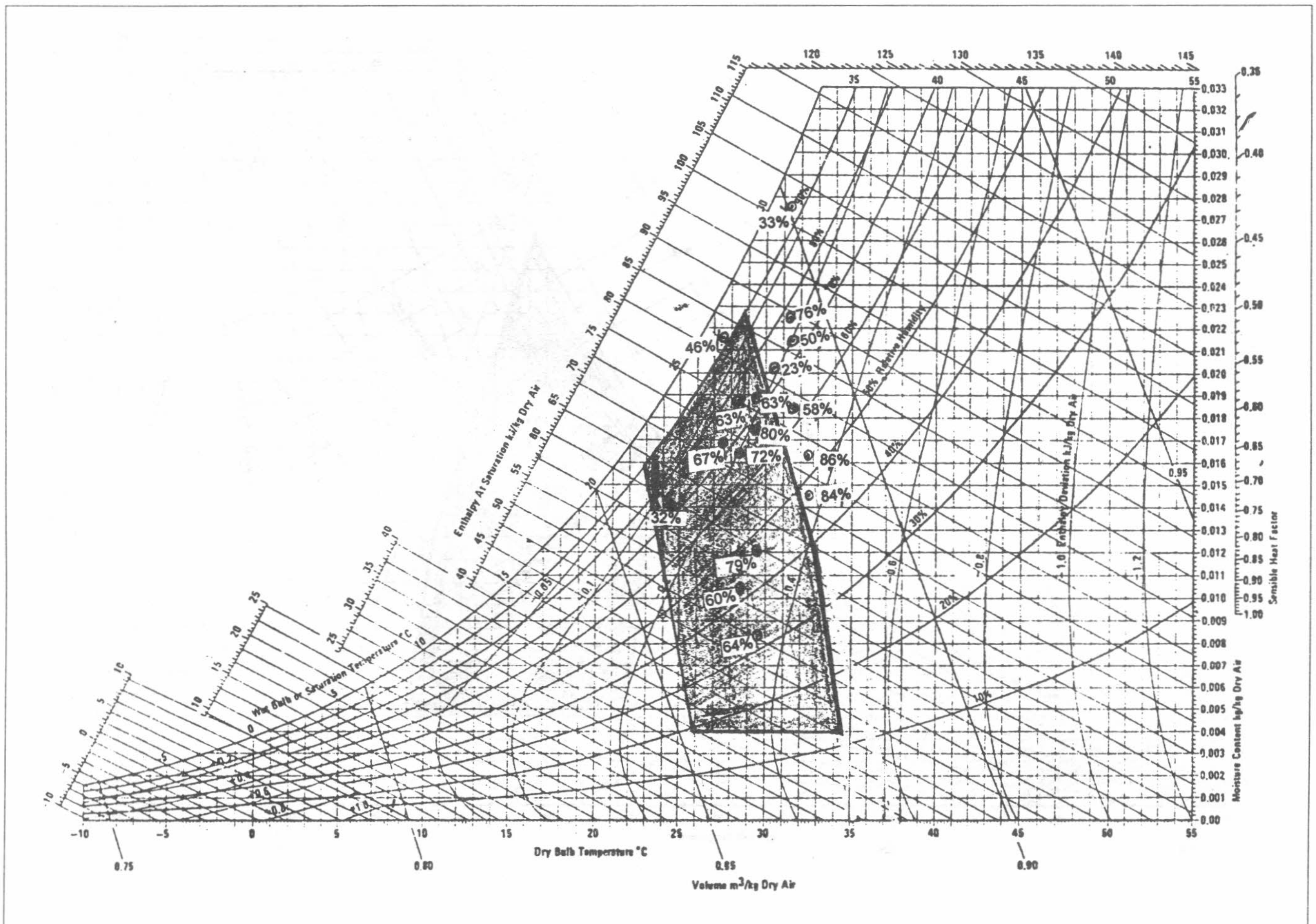

Fig: 3 Results of questionnaire survey for internal air velocities between 0.25 m/s and 1.0 m/s presented together with the modified comfort zone where the neutral temperature is 26.5°C (Applicable to Ratmalana area in the west coast)

Table 3: Results of questionnaire survey (wind speed >1.0 m/s) giving number of responses and the correspondng percentages

DB °C	R. H. %	Comfort		Discomfort	
		Number	Percentage(%)	Number	Percentage(%)
24.0 - 25.0	70 - 75	22	29.7%	52	70.3%
24.0 - 25.0	75 - 80	09	25.7%	27	74.7%
26.0 - 27.0	75 - 80	77	67.5%	37	34.5%
29.0 - 30.0	65 - 70	04	14.8%	23	85.2%

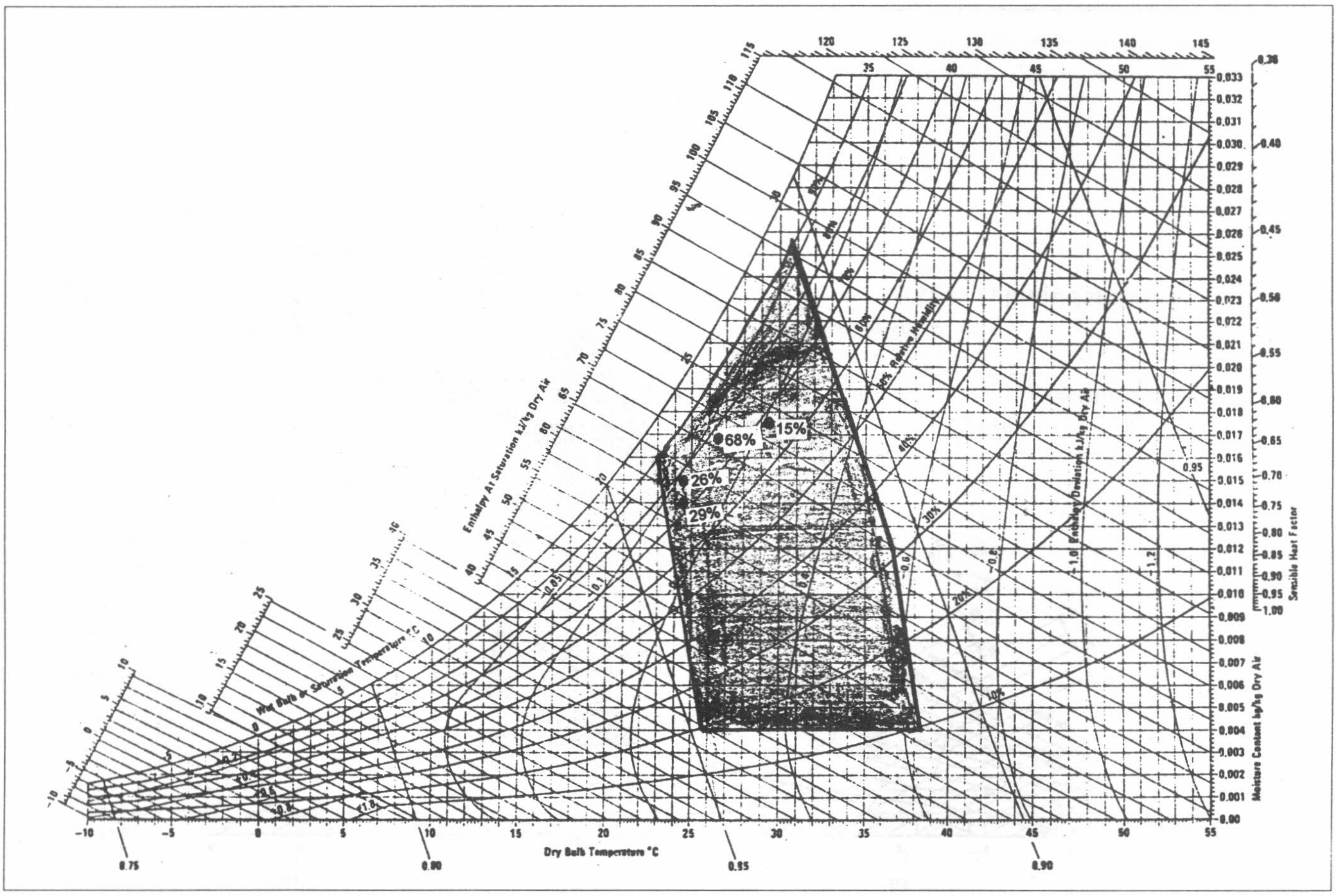

Fig: 4 Results of questionnaire survey for internal air velocities greater than 1.0 m/s presented together with the modified comfort zone where the neutral temperature is 26.5°C (Applicable to Ratmalana area in the west coast)

Table 4: Mean annual temperature and corresponding neutral temperature for different locations in Sri Lanka

Meteorological station	Mean Annual temperature °C	Neutral temperature °C	Altitude (h) above mean sea level (m)
Ratmalana	28.6	26.5	100 < h < 200
Anuradhapura	28.1	26.3	h <100
Bandarawela	20.7	24.0	1600 < h < 1800
Badulla	24.3	25.1	600 < h < 700
Batticalo	28.6	26.5	h < 100
Colombo	27.7	26.2	h < 100
Galle	28.0	26.3	h < 100
Hambantota	27.4	26.1	h < 100
Katunayake	27.4	26.1	h < 100
Katugastota	25.2	25.4	300 < h < 400
Kurunegala	28.0	26.3	h < 100
Nuwaraeliya	16.9	22.8	2000 < h < 2200
Puttlam	28.9	26.6	h < 100
Ratnapura	28.8	26.5	100 < h < 200
Trincomalle	30.0	26.9	h < 100
Vavunia	27.8	26.2	h < 100

4.0 Analysis and results

The data obtained from the Meteorological Department and those obtained with questionnaire surveys have been analysed to determine neutral temperatures for different parts of Sri Lanka and to validate the use of standard comfort zones for Sri Lanka.

4.1 Establishment of neutral temperatures

The neutral temperatures for various parts of Sri Lanka have been established using the climatic data. These are given in **Table 4.** These neutral temperatures can be used to determine the comfort zones as explained in Section 2. It can be seen that in areas with low altitudes in any part of Sri Lanka, it would be reasonable to use a neutral temperature of about 26°C.

4.2 Validation of comfort zones

Figures 2, 3 and 4 show the results of the questionnaire survey. Figure 2 shows that for the comfort zone established for Ratmalana at internal velocities less than 0.25 m/s, the subjects find being comfortable even around its periphery. A similar trend is observed for Figure 3 too. However, Figure 4 suffers from the main deficiency of an inadequate number of points being available.

For velocities less than 0.25 m/s, the low percentages obtained inside the comfort zone were due to people feeling discomfort due to too low temperatures and humidities. It may be possible to capture more points indicating comfort if the upper limit on humidity ratio is raised to 0.015. This will allow maintaining elevated temperatures and humidity in air conditioned environments thus reducing the energy required for air conditioning.

When the air velocities are between 0.25m/s and 1.0 m/s, majority of the people feel comfortable inside the modified comfort zone. There are few responses like 32% where the discomfort was due to feeling too cold thus has been ignored in the analysis. It can be seen that the standard modifications to take account of ventilation effects moves the modified comfort zone into very high humidity ratios when the neutral temperatures are high as for tropical climates. Therefore, it may be appropriate to introduce a new upper boundary given by a humidity ratio of 0.020.

In order to carry out more general analysis, more tests should be carried out covering a wide spectrum of points under test cell facilities with a more controlled environment.

4.3 Computer simulations on energy savings

In this study, the computer simulations have been carried out using the software package CASAMO developed as part of Ademe-AIT RUE Project at Asian Institute of Technology. It is a tool for designing buildings with pleasant thermal conditions or low energy consuming air conditioning or calculating the air-conditioning loads of proposed or existing buildings. In hot humid tropical climates, the main sources of heat gains are generally conduction from the walls and especially roofing, due to high outdoor air temperature and the solar energy absorbed by the facades, especially through glazed areas. In commercial buildings, casual sources of heat from occupants, lighting and appliances are often high and contribute to heat gains in an appreciable manner.

The main functions performed by CASAMO include:

a. evaluating the comfort conditions of a building,

b. calculating cooling loads when air conditioning is desired,

c. calculating the dissipated heat gains in an enclosure, solar radiation input or casual gains, and

d. determining the thermal effects of buildings inertia.

In this research work, CASAMO has been used to determine the air conditioning loads for different indoor temperatures throughout the year at an interval of two months. The annual air conditioning loads are calculated without considering the casual gains due to occupants and usage since the idea is to determine the effects of internal temperatures on the air conditioning load of the building with respect to external thermal gains. The air conditioning loads have been calculated for every two months since the sun path varies throughout the year. A much preferable interval of one month was not considered in order to keep the number of computer simulations at manageable limits.

The air conditioning loads calculated are used to determine the annual air conditioning load per square metre per year. These results has been obtained for different internal temperatures maintained, varying from 22^{0}C to 29^{0}C.

The details of the case study is as follows.

1. Building details: Two building shapes have been considered. One is square with 24 m x 24 m size and the other is rectangular with 20 m x 30 m giving approximately the same area. These two cases are considered to check which shape is thermally more efficient. Both build ings had ten storeys. The floor to floor height is 3.6 m. The square building is denoted as X and rectangular as Y in the charts. These are shown in **Figures 5 & 6.**

2. Facade details: It is quite common to use large glass panels in building facades generally without shading. Two types of glass facades have been considered. Those having a height of 3.0 m per floor (denoted as A) and those having a height of 1.8 m with the sill level at 1.2 m (denoted as B), thus giving a total height of 3.0 m.

3. Glazed facades: For each building, it is considered that glass facades of Types A and B will be provided on sides facing north and south, since it is difficult to control the penetration of solar radiation through the windows facing east and west. When glass is not used, walls of thickness 200 mm have been provided.

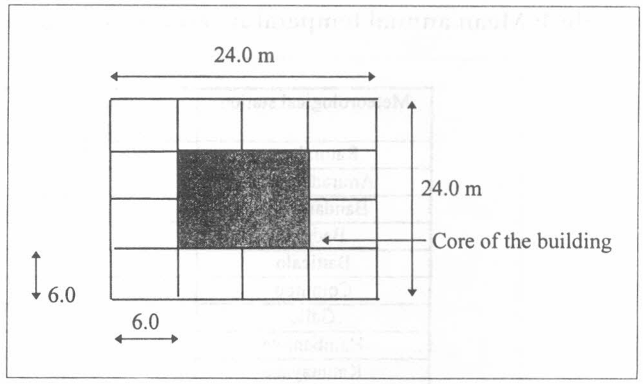

Fig 5: The plan view of the ten storey square building used for the analysis

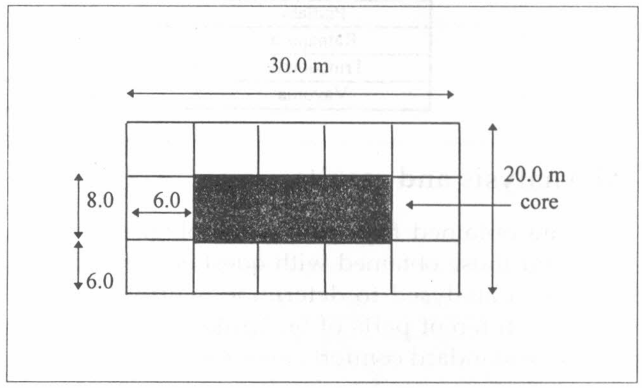

Fig 6: The plan view of the ten storey rectangular building used for the analysis

4. Temperatures and humidities maintained inside: The temperatures maintained inside are 22, 24, 26, 28 and 29. The relative humidity has been maintained at 60%.

5. The outside temperature from March 21st to September 21st is considered to vary between 27^{0}C at 0600 hours to 34^{0}C at 1400 hours. It varies between 25^{0}C at 0600 hours to 32^{0}C at 1400 hours from September 21st to March 21st. The outside humidity varies between 90% at 0600 hours to 60% at 1400 hours. These values have been selected using the temperature and humidity variation charts given for few typical days in Jayasinghe et al (1997) which indicated that the average temperature variation in a typical day is about 7^{0}C and a humidity variation as given above for low altitudes of Sri Lanka.

The air conditioning load calculated at two month intervals have been added up to determine the annual air conditioning load and then this value has been divided by the total area of the building to determine the annual air conditioning load per square metre.

4.4 Analysis of the results of computer simulations

The results of the computer simulations for square and rectangular buildings are given in **Table 5.** It can be seen that the energy consumption of rectangular buildings are less than the energy consumption in square buildings. This stems from the fact that it is easier to control the external energy gains through the facades facing north and south than those facing east and west. Thus, it is advantages to have rectangular buildings with minimum facade areas on east and west.

Internal temperature °C	XA	XB	YA	YB
22	308.75	281.29	311.76	263.16
24	218.16	225.10	214.52	208.80
26	169.63	143.98	165.85	144.52
28	105.56	89.28	99.36	82.10
29	80.29	73.21	73.8	56.29

Table 5: Annual air conditioning load values for square and rectangular buildings - notations as given in Section 4.3.

The inside temperature that is maintained for thermal comfort also has a significant effect on the energy consumption. For example, in the case of a rectangular building, with inside temperature being maintained at 28°C, the annual air conditioning load is about 82.1 kWhours/m^2 whereas when the same building is maintained at 24°C, the air conditioning load is about 208.80 kWhours/m^2. This indicates nearly 2.5 times increase. It should be noted that 28°C with 60% humidity and wind velocity less than 0.25 m/s can just provide thermally comfortable conditions for Sri Lankans if the upper boundary of the comfort zone is extended up to a humidity ratio of 0.015 (see Figure 2).

Thus the annual air conditioning load that can be reduced by maintaining the building at 28°C instead of maintaining 24°C for the 10 storey rectangular building shown in **Figure 6** is 760 MWhours. If the coefficient of performance of the air conditioning system is 4.0, the total electrical energy savings will be 190 MW hours per year.

If an average size house consumes 1000 units of electricity per year (1 MW hour per year), these energy savings of a ten storey building will be sufficient to provide electricity to 190 households. It has been reported by Perera (1997) that the annual energy consumption of rural house holds will be below 350 units per house. These energy savings in a ten storey building will be able to provide electricity to 542 rural households. These figures indicate the need to maintain the interior of the buildings at just the sufficient thermally comfortable conditions for a country like Sri Lanka which has already tapped most of its hydropower potential.

5.0 Discussion and conclusions

It was shown that the standard method of modifying the standard comfort zones at elevated internal air velocities can be used for Sri Lanka with some additional boundaries. The method can be summarised as follows:

1. Modify T_2 by dT where dT is calculated using equation (3), and then obtain T_3.
2. Determine $T_{intercept}$ for T_3 and establish the SET line and extend it up to 90% relative humidity.
3. Below a humidity ratio of 0.012, halve the base line intercept.
4. Establish the upper boundary of the modified comfort zone as 0.020 humidity ratio (HRt).

At elevated internal air velocities, the modified comfort zones show that higher dry bulb temperatures and humidity ratios can be tolerated within the occupies spaces, in terms of thermal comfort. This will enable the designer to have an advantage in the following processes.

a. Establishment of higher operating dry bulb temperatures would result in reducing the capacities of active based air conditioning equipment, thereby lowering the capital expenditure and operating cost. These newly established comfort zones could form a basis for a voluntary building code for the purpose of carrying out complementary tests; this could lead to the development of a mandatory building code to determine the performance indexes with respect to energy usage for thermal comfort.

b. Establishment of more realistic internal thermal conditions as guidelines for the building envelope designers to tune his building envelope design at the modelling phase.

c. Consideration of the possibilities of using building envelopes design strategies such as "ventilation only", "active based air conditioning only" or an combination of both, through a modelling phase, with the aid of modified comfort zones for Sri Lanka.

6.0 References

1. **Achard, P., Gicquel, R.** (1986), European Passive Handbook, Published for the Commission of European Communities by Directorate-General xii for Science, Research and Development, Brussels, p. 2.25.

2. **ANSU/ASHRAE Standard 55-1981,** Thermal Environmental conditions for Human Occupancy, ASHRAE.

3. **CASAMO** - Version 2.0, Ademe-AIT RUE Project, Asian Institute of Technology.

4. **Attalage, R.A., Wijetunga, P.D.C.** (1997), "Energy conservation potential in the Commercial Sector in Sri Lanka", Proceedings of symposium at Open University of Sri Lanka - An Energy Policy for Sri Lanka, OUR Engineering Technology, Vol 3 -#1, March, pp 47-53.

5. **Fernando, M. P., Nanayakkara, L. S., Rajapakse, R. K. I.** (1996), "Energy Efficient Buildings", Undergraduate research report, Department of Civil Engineering, University of Moratuwa, Sri Lanka.

6. **Humphrey, N. A.** (1978), Outdoor temperatures and comfort indoors, BRE, United Kingdom, July.

7. **Jayasinghe, M.T.R., Sujeewa, L.C., Fernando, K.K.J.S., Wijayapriya, R.A.** (1997), "Passive solar techniques for Sri Lanka", Proceedings - Research for Industry - 1997, University of Moratuwa, Sri Lanka, 21st November, pp 11/1 - 11/14.

8. **Nichol, J., Raja, J.** (1997), "Modelling temperature and human behaviours in buildings", ibpsaNEWS, pp 8-11, Number 1, Vol 19, April.

9. **Perera, H.Y.R.**,(1997), "Rural electrification policy in Sri Lanka", Proceedings of symposium at Open University of Sri Lanka - An Energy Policy for Sri Lanka, OUR Engineering Technology, Vol 3 -#1, March, pp 54-57.

10. **Szokolay, S. V.** (1991), "Heating and Cooling of Buildings", Ed. Cowen, H. J., Handbook of Architectural Technology, Van Nostrand Reinhold, New York, 323-365.

Nomenclature

T_o = mean annual temperature (°C)
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HR_T = humidity ratio in kg of moisture in kg of air (kg_w/kg_a)

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