SUMMARY

T.J. Williamson and S. Coldicutt: The Assessment of Thermal Comfort in Dwellings with Evaporative Cooling. Evaporative cooling is commonly used in Australia to provide comfort air conditioning in dwellings. Simple indices of thermal comfort such as environmental temperature or effective temperature cannot be used to assess the thermal performance of such dwellings as evaporative cooling results in significantly high humidity levels and air movement. An alternative approach based on the Predicted Mean Vote concept developed by Fanger is suggested as a suitable index of discomfort. This index accounts for all important environmental factors and in addition allows dynamic modelling of human responses to the thermal environment, such as adjusting clothing levels and metabolic rate. Computer program TEMPAL is used to predict internal environmental conditions within a dwelling. TEMPAL is shown to be sufficiently accurate for this purpose by comparing predictions with monitored conditions. Using this technique the thermal conditions produced by evaporative and refrigerative cooling plant are compared.

RESUME

T.J. Williamson et S. Coldicutt: L'Evaluation du Confort Thermique dans les Maisons equipées du Refroidissement Evaporatif. Le refroidissement par évaporation ou 'évaporatif' s'utilise souvent en Australie pour le conditionnement de l'air dans les habitations. Les indices simples du confort thermique tels que la Temperature Effective ne sont pas efficaces dans l'évaluation de la performance thermique des habitations equipées de tels systèmes, parcequ'ils causent des niveaux élevés d'humidité et de mouvement de l'air. Le présent article propose comme indice approprié de gêne thermique dans ces cas une méthode alternative basée sur le Vote Moyen Prédit développé par Fanger. Cet indice prend en considération touts les facteurs importants de l'environnement thermique, et de plus permet de simuler de manière dynamique les réponses humaines à l'environnement, telles que le changement de l'épaisseur des vêtements et le taux de metabolisme. Selon une comparaison entre ses prédictions et les conditions mesurées sur place, le programme d'ordinateur TEMPAL démontre une précision suffisante pour prédire les conditions d'ambiance dans une maison. L'article présente une comparaison effectuée avec ce programme des conditions thermiques produites par le refroidissement évaporatif et le conditionnement d'air réfrigératif.

KURZFASSUNG

T.J. Williamson und S. Coldicutt: Die Beurteilung des termischen Komforts in Häusern mit Wasserverdunstungskühlungssystemen. In Australien wird hauptsächlich das Verdunstungskühlungssystem (Luftanfeuchtungskühlsystem) zur Luftkühlung in Wohnhäusern benutzt. Einfache Angaben über termischen Komfort, wie z.B. Umgebungstemperatur oder bewirkte Temperatur, können für die Beurteilung der termischen Leistung solcher Wohnhäuser nicht benutzt werden, da Verdunstungskühlsysteme eine wesentliche Erhöhung der Luftfeuchtigkeit und der Luftbewegung bewirken. Als Alternative wird daher das von Fanger entwickelte Konzept der "Predicted Mean Vote" (Vorausgesagte Durchschnittswahl) als wirksamer Indikator des Unbehagens vorgeschlagen. Dieser Indikator beschreibt alle wichtigen Umgebungsfaktoren und ermöglicht darüberhinaus ein flexibles Modellieren von menschlichen Reaktionen zur Temperaturumgebung, wie z.B. die Angleichung der Kleidung und das Tempo des Stoffwechsels. Das Computerprogramm TEMPAL wird zur Vorhersage von internen Umweltbedingungen in Wohnhäusern benutzt, TEMPAL hat sich als genau genug für diesen Zweck bewiesen, indem es Vorhersagen mit gemessenen Bedingungen vergleicht. Mit dieser Methode können die termischen Bedingungen, die durch Verdunstungskühlsysteme und Kompressionskühlsysteme hergestellt werden, verglichen werden.

THE ASSESSMENT OF THERMAL COMFORT IN DWELLINGS WITH EVAPORATIVE COOLING

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Introduction

Evaporative cooling is an adiabatic process capable of providing comfort conditions in hot dry climates at much less cost than refrigerative cooling systems. Direct or wetted-pad type evaporative coolers, figure 1, are used commonly over wide areas of Australia.

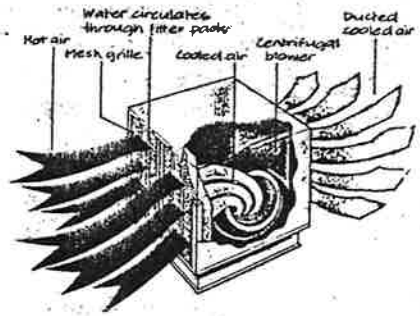

Fig. 1. A typical evaporative cooling unit using the adiabatic saturation principle.

The room air condition produced by evaporative coolers generally has a high humidity level and compared with a refrigerative cooling system, a much higher flow rate of air is used.

A study sponsored by the State Energy Research Advisory Committee of South Australia aimed to compare evaporative and refrigerative air-conditioning in dwellings, for the wide range of climates occurring in the State. Previous work in this area was of limited usefulness: using a steady state analysis Pescod (1) had attempted to compare the performance in dwellings with evaporative and refrigerative cooling systems, but he acknowledged the limitations of the results in that significant variables such as the design of the building, cooling appliance performance characteristics and the variability of the weather could not be taken into account properly.

The present comparison of evaporative and refrigerative cooling systems is able to include these factors and incorporates a method whereby the thermal conditions in the different situations may be compared directly.

Thermal Discomfort

The human perception of thermal environmental conditions depends on a number of factors:

- air dry bulb temperature
- mean radiant temperature
- wet bulb temperature
- relative air movement
- metabolic rate
- clothing level
- posture

Simple indices of thermal discomfort such as environmental temperature or effective temperature fail to account for all these variables. When dealing particularly with evaporative cooling which results in high humidity levels and air movement, an index which considers the full range of variables must be used if realistic results are to be achieved. In addition, simple indices account for variations in clothing level and metabolic rate by establishing a comfort zone of likely acceptable conditions and are therefore not sensitive to these factors. In reality individuals adjust their thermal sensation in response to changes in temperature etc by altering clothing and activity levels. Fanger (2) presents a technique for combining environmental, activity and clothing functions to predict the thermal sensation. The method enables calculation of the predicted mean vote (PMV) related to the seven point psychophysical ASHRAE scale. At a PMV of 5.5, 50% of the population would be voting more than 5.5 and would therefore be too hot.

Providing suitable data on environmental parameters within a dwelling can be estimated the PMV technique may be used to dynamically model the thermal comfort conditions.

Prediction of Environmental Conditions

Computer program TEMPAL (3) was used to estimate environmental conditions within dwellings. TEMPAL was validated for adequate prediction of evaporative and refrigerative cooling operation by monitoring two identical dwellings constructed in Adelaide with these types of appliances installed. Over a twelve week summer period comprehensive data were collected on the external climate, internal conditions, plant characteristics and energy use. Measured and TEMPAL predicted results were compared. Figures 2. and 3. show the comparison of measured and predicted environmental and wet bulb temperatures over a typical six day period using initial input data. Statistical techniques were used to test the correspondence of measured and predicted data. The standard error of predicted environmental temperature was less than 0.3C with a standard deviation of 1.3C. The small discrepencies between measured and calculated temperatures were attributed mainly to the difficulty of simulating thermostat behaviour because the exact thermostat settings could not be determined accurately from the available internal conditions data. A sensitivity analysis showed that these assumptions were critical to achieving a good match between measured and predicted results. Despite this problem the correspondence of measured and predicted conditions including energy consumption shows that TEMPAL is sufficiently accurate to be used in the study of the thermal performance of dwellings.

TEMPAL output consists of hourly values for a living zone and a sleeping zone in a dwelling of:

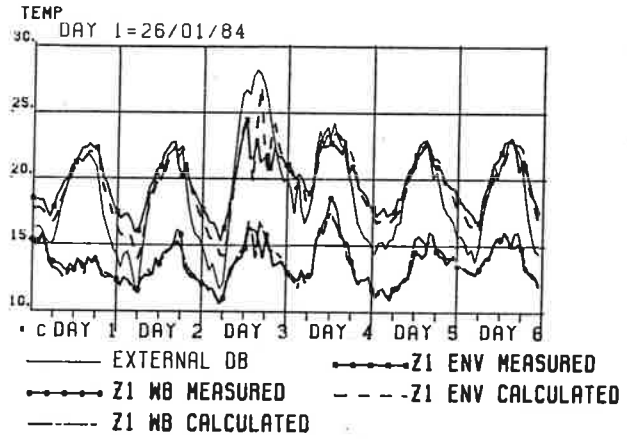

Fig. 2. Comparison of measured and predicted temperatures, for dwelling with evaporative cooling.

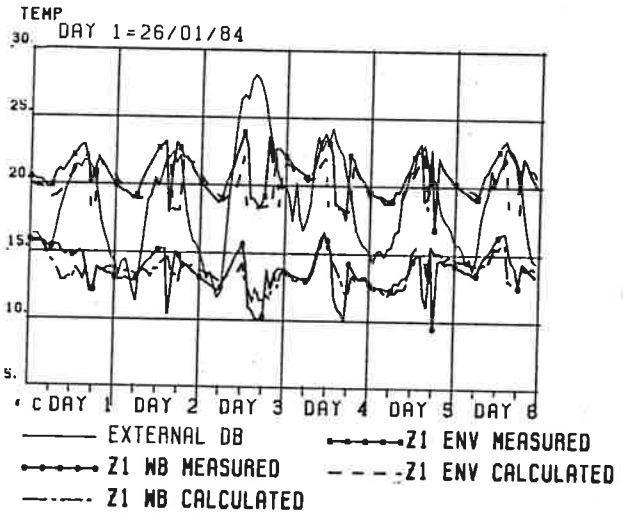

Fig. 3. Comparison of measured and predicted temperatures for dwelling with refrigerative cooling.

- air temperature
- mean radiant temperature
- wet bulb temperature
- ventilation OR air change rate
- the energy required to condition the zone

In addition to these factors a full comfort analysis requires knowledge

of the air movement within the dwelling. Measurements of air speed at a number of locations in the monitored houses, 1.2 m above the floor level, were correlated with measured ventilation and air change rates to derive an empirical relationship (Eq. 1) between average air speed in a zone and the air change rate.

$$S = ACH/C \qquad (1)$$

S - average air speed in zone, m/s
ACH - air change rate per hour
C - a constant in the range 20-30, depending on house layout, zone, type of appliance, etc.

Especially in the house with the evaporative cooler, air speeds were found to vary within the zone by as much as ±100% of the average speed.

Assessment of Comfort Conditons

A computer program was developed which uses TEMPAL output data to calculate hourly values of the PMV.

In this program allowance is made for adjusting clothing levels according to the logic shown in figure 4. A person feeling too hot or too cold alters the thermal sensation towards neutral by adjusting the clothing level a maximum of 0.2 clo in increments of 0.1 clo at each hour, to a minimum value of 0.4 clo for hot conditions. Also, different metabolic rates are set for each zone in the dwelling according to the activities expected in that zone.

In this study the number of hours over a full summer season with a PMV greater than 5.5 was used as a measure of discomfort.

Comfort Conditions Compared

Using the techniques outlined above the comfort conditions produced by ducted whole house evaporative and refrigerative cooling plant were compared for a range of climates, building types, plant capacities and plant operation. The dwellings were assumed to be occupied by a family of four which uses them sensibly; for example, windows are left closed in the house with refrigerative cooling, open in the house with evaporative cooling when the plant is required to operate, and blinds are drawn at night. The dwellings were considered to be divided into two zones, a living zone and a sleeping zone. More details of this study may be found elsewhere in the Conference Proceedings (4).

Conclusion

The general conclusion for the climates tested is that an adequately sized evaporative cooling system will achieve satisfactory comfort conditions. However, over a summer season a properly designed refrigerative plant will

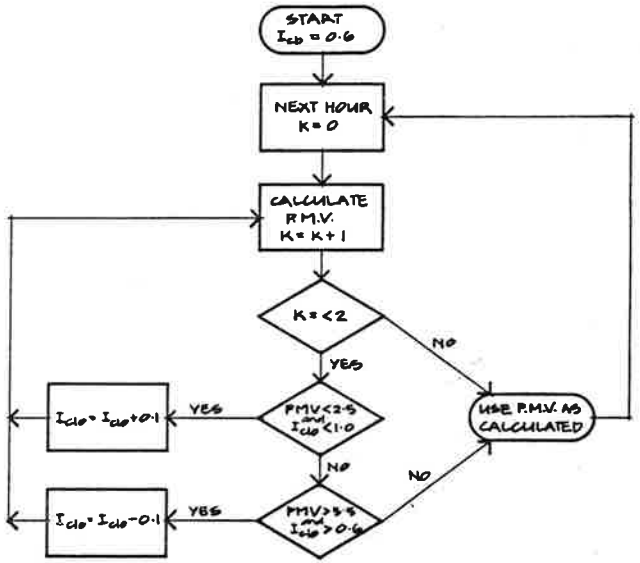

Fig. 4. Logic for alteration of clothing level in calculation of PMV.

produce slightly less discomfort for the daytime hours (07-22) in the living zone when compared with the conditions achieved by an evaporative cooler. The periods of discomfort associated with the evaporative plant correlate with the occurrence of high external air temperature coupled with high humidity. During the night-time hours (23-06) in the sleeping zone both types of coolers produce similar satisfactory conditions.

Evaporative cooling systems compared with refrigerative plant have the advantage of being less expensive to install and operate.

References

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