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Norms to Establish the Most Elementary Environmental Control System Which Ensures Summer Thermal Comfort in Office Buildings

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Various types of environmental control systems (ECS) such as natural ventilation, mechanical ventilation, evaporative cooling and full air-conditioning can be used to cool buildings in hot climates. It is not always clear which of these would be the most elementary ECS that would still ensure thermal comfort in a thermally efficient building for a specific climate. No method to establish norms describing a minimum acceptable ECS was found. This paper proposes a method and gives the norms for South African buildings.

The norms are based on existing thermally efficient reference buildings. The minimum ECS to provide comfort in the reference building for a specific summer climate is established by means of a novel and easy to use thermal simulation procedure. The designer must then ensure thermal comfort in new designs by utilizing this minimum ECS.

Although only norms for buildings in South Africa are given the method can easily be applied to other climates. The method is very comprehensive but requires only a few hours to apply. Savings in building capital and running costs should more than compensate for the extra effort spent on the design.

INTRODUCTION

THE THERMAL environment inside buildings is influenced by the building structure and the environmental control system (ECS). As the fixed structure of a building is inexpensive to maintain, its full potential in creating indoor thermal comfort should be utilized. Unfortunately this is generally not the case. For example, in the moderate South African climate, where cooling is a problem, large air-conditioning systems are often unnecessarily used to cool non-residential buildings, mainly due to bad design. Since these systems are expensive in capital and running costs the Department of Finance initiated a project to establish minimum cooling ECS requirements to provide thermal comfort in new state-funded office buildings in different South African climates. By prescribing comfort and the minimum ECS for a specific climate the problem is reduced to designing a building that is thermally efficient.

Many countries employ thermal standards but do not specify a minimum ECS or account for thermal comfort. This may result in a thermally efficient building which does not provide thermal comfort or a situation where a more elementary and thus less costly ECS could have been used. Furthermore, most countries that employ thermal standards for buildings provide little flexibility for the designer. Many of them [1, 2], for example the United Kingdom, Finland and Denmark place restrictions on individual building elements such as percentage glazing. All of the above-mentioned countries as well as Turkey, West Germany, Canada, Ireland and New Zealand place constraints on thermal transmittance values of walls, windows and in some cases even doors [1, 2]. It is interesting to note that the prescribed thermal resistances [1, 2] in some cases vary with a factor of three for a specific building element!

Although the above-mentioned prescriptive approach may be easy to apply and administer it is not adequately comprehensive. The actual heat flow through the envelope determining the ECS type and size is a function of many more variables of the building design. It is therefore not surprising that existing buildings often perform much better than the standards for new buildings [3, 4].

A more comprehensive strategy is the performance approach where complete energy requirements of a building over a period of at least a year is determined. Building capital and running costs (life cycle cost) are weighed against thermal improvements. In the USSR for example, the optimal thermal resistance of the building envelope is determined by the minimum value of the life cycle cost of a building [2]. The British Standards BS 8207 [5] and BS 8211 [6] also consider life-cycle cost when evaluating a building's thermal performance. The predicted life-cycle cost must conform to a certain target based on energy consumption of real but thermally efficient buildings.

The ASHRAE Standard 90.1 [7, 8] probably has the most comprehensive approach. It comprises three compliance paths namely the prescriptive, performance and energy cost budget paths. The prescriptive path pre-

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scribes minimum thermal resistances for the shell elements while the performance path prescribes maximum permissible annual heating and cooling loads in different climates. The energy cost budget path which is also performance-based, is the most comprehensive path of the three. Designers perform simulations of their own designs and a reference building. The annual energy costs for the new design must be less than that for the reference building. Potential problems of the performance based standards are that much detail and computational effort are usually required to accurately calculate financial implications. This implies that the method is only effectively applied in a later stage of the design process. A thermally efficient building however, originates at the early design stage.

From the reviewed literature it seems that no norms distinguish between different ECS types or prescribe the minimum ECS to provide thermal comfort in a certain climate. This would of course be the most efficient solution. It was furthermore felt that thermal comfort could receive more attention when evaluating thermal efficiency by means of norms.

PHILOSOPHY FOR THE NEW NORMS

The aim of the norms is to determine theoretically in which summer climate which minimum cooling ECS in conjunction with a thermally efficient building will be sufficient to provide thermal comfort. The designer of a new building must then ensure that the new design is thermally efficient to provide comfort with only the minimum ECS.

Before clouding the problem with details the criteria for the norms are stated below:

—Occupant comfort and the minimum ECS for a specific climate must be addressed.
—Norms and the analysis procedure must be adequately comprehensive and based on practical buildings to ensure confidence in it.
—The designer must be able to apply it with ease at the early design stage where a good or bad design originates.
—The designer must not be unduly restricted by the norms.

Providing thermal comfort for building occupants constitutes the essence of the complete building system and can thus not be neglected as is the present case with most standards. A mathematical model of Sherman [9] which is based on the Fanger equations [10] is used to simulate thermal comfort for the purpose of the proposed norms. The model accounts for relative humidity, indoor air movement, human activity level and occupant clothing. It was modified to calculate a comfort range for a given percentage of occupants which are satisfied with the indoor thermal environment [11]. The predicted comfort range is compared to the predicted indoor air temperatures in a thermally efficient building in order to establish the minimum cooling ECS for a certain summer climate. The comfort range is later also used by the building designer to establish whether his new design will provide thermal comfort when equipped with the minimum ECS.

Most other norms apply to the most expensive type of ECS namely full air-conditioning. It was however necessary that the proposed norms also investigate less expensive systems. These are natural ventilation, night cooling using mechanical ventilation and different types of evaporative cooling.

As the climate has an important influence on the choice of ECS it should be adequately addressed. For the proposed norms an hourly analysis of a typical summer design day was deemed sufficient. The proposed norms also account for the time of day a building is in use. Norms for office buildings for example, apply only from 7.00 till 18.00 since this period represents the probable occupation time. Indoor air temperatures are allowed to drop during night-time and unnecessary thermal requirements are thus averted. This concept is unique in comparison with other standards [1, 2, 5–8].

The proposed norms are based on existing thermally efficient reference buildings rather than on purely theoretical considerations. The designer therefore knows that the goals set in the norms are achievable in practice, thereby evoking confidence in the norms. This concept is similar to that of ASHRAE Standard 90.1 [8]. Load calculations for a range of buildings were performed in order to select a reference building. The final choice was one with ample fenestration, a low shell-to-floor area ratio and a good thermal performance. The best thermal performer was not chosen because insulation in all walls, triple glazing, manoeuvrable external shading, etc. may be excellent from a thermal point of view but may lead to a very expensive building. The fact that life-cycle costs are not accounted for in the present norms is perhaps its biggest limitation. However, if life cycle cost is introduced, care should be taken to ensure that the norms are still easy to apply.

The interaction between comfort, ECS, climate and building design is simulated by means of the thermal analysis computer program QUICK [12] which can be used *inter alia* to predict indoor air temperatures. QUICK is not only user-friendly but also comprehensive as it accounts for all the relevant heat flow phenomena. Yet, it runs on any IBM-compatible personal computer.

The exterior thermal driving forces that are simulated are time-varying solar radiation, ambient air temperature and outdoor humidity. Physical properties of the building that are accounted for include thermal transmittance, exterior colour, type of fenestration, a detailed treatment of building mass, shading devices, orientation and ground contact. Thermal comfort and the effect of time-varying heat sources, natural and mechanical ventilation as well as evaporative cooling can be simulated. By utilizing all these features, indoor air temperatures, a comfort range and loads to keep the indoor air temperature within a certain range can be calculated. For more detail of the program see [12].

The comprehensiveness of the analysis method and the fact that the program was verified for more than sixty practical cases ensure confidence in the predictions. As much effort was put into the user-computer interface, designers are able to apply the program with ease at the early sketch design phase. Designers are furthermore not unduly restricted since only indoor air temperatures are evaluated and not individual building elements.

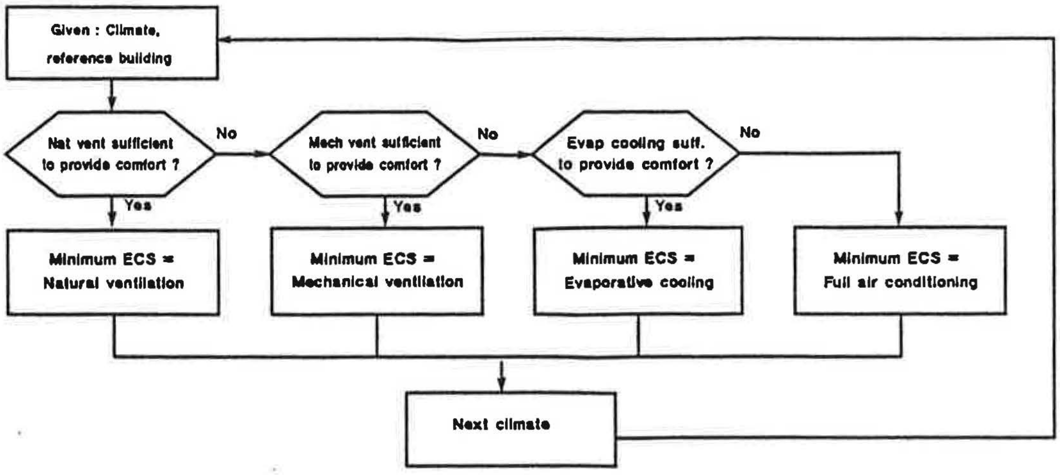

Fig. 1. Procedure to determine the minimum ECS that will provide comfort in a certain climate.

METHOD TO DETERMINE NORMS

A flow diagram of the procedure to associate a minimum cooling ECS with a specific climatic region is given in Fig. 1. The reference building is hypothetically "moved" to a certain summer climate using the computer program QUICK. This is done by entering the building's physical data and climatic data for the design day into the computer program. Comfort criteria associated with a specific building application and internal loads are also simulated. The thermal performance of the reference building is then calculated assuming an air change rate of five ach (air changes per hour) for natural ventilation. Calculated indoor air temperatures under these summer conditions are then compared to the calculated comfort range. If the indoor air temperatures do not fall within the comfort range during the period of occupancy, it means that natural ventilation cannot provide thermal comfort in that specific climate. The reference building is then simulated with night-time mechanical ventilation at certain given practical air flow rates namely ten, fifteen and twenty ach. Calculated temperatures are again compared with the comfort range. If mechanical ventilation is not sufficient different forms of evaporative cooling are investigated. If all these options fail, it is clear that only full-air conditioning will be able to provide indoor thermal comfort in that specific region.

The above-mentioned procedure is repeated for every summer climate of interest. A complete picture of all the important South African climatic regions and associated minimum cooling ECS types was obtained with the procedure and is presented in Table 1. A graphical presentation of the results is given in Fig. 2.

From Table 1 it can be seen that a specified air change rate comprises the norm where the minimum ECS is ventilation. For evaporative cooling the norms prescribe a specific type of evaporative cooler. For the case where full air-conditioning is needed the norm consists of a sensible cooling peak load. In this case only the shell is investigated and the peak load therefore does not include any internal loads.

The results can be best explained by means of an example. Table 1 indicates that a thermally efficient building in East London cannot be designed to ensure comfort utilizing natural ventilation. However, mechanical night ventilation of fifteen ach is sufficient. Durban on the other hand definitely requires full air-conditioning. In this case the maximum cooling load is restricted to 21 W/m^2 shell area. All climatic regions are likewise associated with a minimum ECS.

METHOD OF APPLICATION

The designer now has Table 1 at his disposal from which he knows the minimum cooling ECS associated with the location of his newly designed building. The associated ECS and climatic data are read into the computer program QUICK [12] from data files. The building physical data must be entered by the designer. A com-

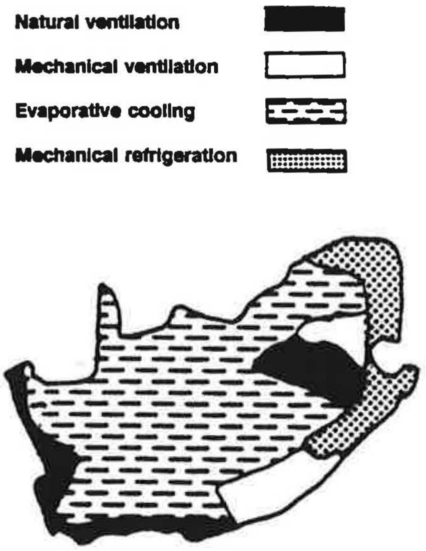

Fig. 2. Minimum cooling ECS types providing thermal comfort in different South African climates.

Table 1. Minimum ECS associated with different climates

	Environmental control system (ECS)									
	Natv	Mec10	Mec15	Mec20	Evap1	Evap2	Evap3	Evap4	Evap5	Airc
Bisho										
Bloemfontein										
Cape Town										
Durban										21
East London										
George										
Jan Smuts										
Kimberley										
Mmabatho										
Phalaborwa										55
Pietersburg										
Port Elizabeth										
Pretoria										
Umtata										
Upington										

NatV - 5 ach natural ventilation
Mec10 - 10 ach mechanical night ventilation
Mec15 - 15 ach mechanical night ventilation
Mec20 - 20 ach mechanical night ventilation
Airc - Full air-cond., peak sensible cooling load (W/m²)
Evap1 - Single stage direct evaporative cooling, 15 ach
Evap2 - Single stage indirect evaporative cooling, 15 ach
Evap3 - Two stage indirect evaporative cooling, 15 ach
Evap4 - Two stage indirect + direct evaporative cooling, 15 ach
Evap5 - Three stage indirect + direct evaporative cooling, 15 ach

ion is carried out to see whether thermal vided with the minimum ECS. If thermal rovided the design must be improved and is process is repeated until the norm is ive computer program QUICK is ideal Orientation, insulation, fenestration in be quickly modified and the effect ..ormance observed. The complete pro- .s schematically displayed in Fig. 3.

The above-mentioned method can again be best explained by means of an example. The designer knows that a mechanical night ventilation rate of 15 ach should provide comfort in a thermally efficient building situated in East London. If the analysis of the new building shows that the indoor air temperatures are higher than the maximum allowed comfort temperature, it is clear that the design is not acceptably thermally efficient. The design must then be modified until comfort is achieved.

As all the new designs are simulated under the same conditions namely climate, internal loads, reference building, comfort etc., they are all treated on the same basis. If necessary however, some of the assumed conditions can be changed for future norms.

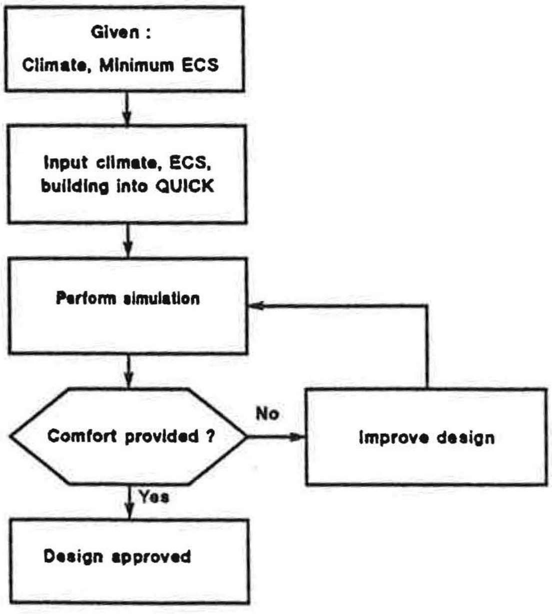

Fig. 3. Procedure for application of norms.

CONCLUSIONS

A thorough approach was presented to establish norms for the most elementary environmental control system (ECS) that will ensure thermal comfort in a specific summer climate. The ECS type and thermal comfort are usually not addressed satisfactorily by present norms. The proposed norms further fill the gap between over-simplified standards prescribing thermal resistance values for elements and complicated methods calculating complete energy demand and life cycle cost.

The proposed method is comprehensive but still easy to use. Design freedom is provided by not restricting the thermal characteristics of individual building elements. Although only norms for buildings in South Africa were established the method can be successfully applied to other ECS types and climates. The extra effort put into the design of a building will be adequately compensated for by savings in life cycle cost.

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