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THERMAL COMFORT IN A HOT CLIMATE DUE TO NATURAL MEANS :

EVALUATION OF THE QUALITY OF SOLAR PROTECTION OF BUILDINGS

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ABSTRACT

In a hot climate, thermal comfort in buildings achieved without using artificial air-conditioning requires excellent protection from the effects of solar radiation. Although traditional buildings have often empirically led to satisfactory solutions, this is not the case for a large number of modern buildings. Ways of providing good solar protection - screens, reflective coatings and insulation - are known but, since their efficiency cannot be evaluated, they are rarely used correctly.

So that effective solutions can be found, we have devised a simple method of evaluating the quality of the solar protection of a building. A solar heat gain coefficient Us is used (on W/m^3) calculated by adding together the heat gains for each of the surface components.

A building is more comfortable if it is protected from the sun, that is, has a lower Us coefficient. Other factors come into play, however, in achieving a specific level of comfort, such as thermal inertia, orientation and, for natural cooling, ventilation. We have used these parameters to determine the value of coefficient Us, i.e. Usc, which ensures thermal comfort in buildings in a wet, tropical climate. By comparing the Us coefficient of a building with the Usc value, we can determine whether its solar protection is sufficient and, where necessary, what effects any improvements will have.

This method was applied to demonstration operations and its validity was confirmed by measuring the inside ambient conditions obtained.

LE CONFORT THERMIQUE EN CLIMAT CHAUD PAR LA CLIMATISATION NATURELLE :

APPRECIATION DE LA QUALITE DE LA PROTECTION SOLAIRE DES BATIMENTS

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RESUME

En climat chaud, l'obtention du confort thermique dans les constructions sans recours à la climatisation artificielle nécessite une bonne protection contre les effets du rayonnement solaire. Si les constructions traditionnelles avaient souvent abouti empiriquement à des solutions satisfaisantes, il n'en va pas de même pour bon nombre de constructions modernes. Les moyens d'assurer une bonne protection solaire : écrans, revêtements réfléchissants, isolation, sont connus mais, faute de pouvoir en apprécier l'efficacité, ils sont rarement utilisés correctement.

Pour permettre le choix de solutions performantes, nous proposons une méthode simple d'évaluation de la qualité de la protection solaire d'un bâtiment. On caractérise celui-ci par un coefficient d'apports solaires Us (en W/m^3), dont le calcul par sommation des apports dus à chaque paroi a été précisé.

Un bâtiment sera d'autant plus confortable qu'il est bien protégé du soleil, c'est-à-dire que son coefficient U_s est faible. D'autres facteurs interviendront cependant dans le niveau de confort obtenu comme l'inertie thermique, l'orientation et, en climatisation naturelle, la ventilation. Nous avons, en fonction de ces paramètres, déterminé la valeur du coefficient Us, Usc, assurant, pour le cas du climat tropical humide, un bon confort dans les constructions. La comparaison du coefficient Us d'un bâtiment à la valeur Usc permet de déterminer si sa protection solaire est suffisante et, si nécessaire, les effets d'une amélioration.

Cette méthode a été appliquée lors d'opérations de démonstration, et sa validité a été confirmé par des mesures de conditions d'ambiance intérieure obtenues.

1 - INTRODUCTION

Achieving satisfactory thermal comfort is an important factor of quality for buildings in hot climates. Traditional buildings have often empirically produced satisfactory solutions, given the building techniques available.

Modern buildings are often less efficient, which leads either to a marked lack of comfort or high artificial air-conditioning costs. However, this does not have to be so, thanks to the development of building techniques, but is rather the result of insufficient attention being paid to the problem.

To change this state of events, decision-makers must be given the tools needed for them to choose the most suitable solutions from the design stage on. The main reason for temperature increases inside a building are heat gains due to solar radiation. Correct design means reducing these heat gains, which must therefore be calculated according to the technical features of the premises.

This is the aim of the work presented below. A building (or part of a building) is characterized by its volume coefficient of solar heat gain Us, described in detail in the following paragraphs. We will then explain how it is used to evaluate the thermal quality of naturally cooled buildings in warm humid tropical zones.

2 - DEFINITION AND CALCULATION OF THE VOLUME COEFFICIENT OF SOLAR HEAT GAIN Us

2.1 - Definition of coefficient Us

The volume coefficient of solar heat gain Us of a building or part of a building is defined as the average heat gain due to insolation over a given period, expressed as a ratio of the volume of the building.

Us is not only a characteristic of the building in itself, but of the building in a specific solar radiation environment. For a given building (characteristics of surface components, orientation, latitude), Us depends on the reference period chosen (time of year and insolation conditions). Its value is as follows :

$$Us = \left(\sum_i A_i \, . \, Fts_i . \, RS_i \right) / V \qquad (1)$$

where V is the volume of the building and where, for each outside surface component of the building i :

A_i (m^2) is the surface area of the surface component,

Fts_i (s.d.) is the solar transmission factor of the surface component i.e. the ratio of the heat flow due to the insolation transmitted by the surface component to the incident solar radiation flow,

RS_i (W/m^2) is the average incident solar radiation on the surface component for the period considered.

2.2 - Notion of equivalent horizontal areas

The coefficient Us has to be recalculated when the insolation conditions of the building change. This involves fastidious calculations if a large number of cases are to be examined (when analyzing recorded temperatures, for example). It therefore seems useful to define a building independently of the insolation conditions. Based on average daily values, solar gains due to the effects of direct solar radiation can be separated from those due to diffuse solar radiation, by the formula :

$$Us = \sum_i A_i \cdot Fts_i \, (CD_i \cdot Dh + CI_i \cdot Ih) \,/V \qquad (2)$$

Where Dh (W/m^2) is the average daily diffuse radiation on a horizontal plane,

Ih (W/m^2) is the average daily direct radiation on a horizontal level,

and where, for each surface component :

CD_i is the orientation coefficient for the diffuse radiation,

CI_i is the orientation coefficient for the direct radiation.

If the diffuse radiation is considered to be isotropic, CD_i will only depend on the orientation (azimuth and inclination) of surface component i and the coefficient of reflex luminous intensity from the ground ; CI_i will also depend on the latitude and the month of the year (its slight variation over the course of a month can generally be ignored).

A building can therefore be defined for a given month m by two equivalent horizontal areas - one for the diffuse radiation ADh and the other for the direct radiation, AIh(m).

For a day in this month characterized by the values of Dh and Ih, Us is simply calculated by the following formula :

$$Us = (ADh \cdot Dh + AIh \cdot I_h)/V \qquad (3)$$

avec $ADh = \sum_i A_i \cdot Fts_i \cdot CD_i \qquad AIh = \sum_i A_i \cdot Fts_i \cdot CI_i$

If the values of Dh and Ih are not known, they can be deduced from the value of Gh by a correlation of the following type :

$Dh/Gh = f\,(Kt)$ (4) where $Kt = Gh/Gh\ ext$

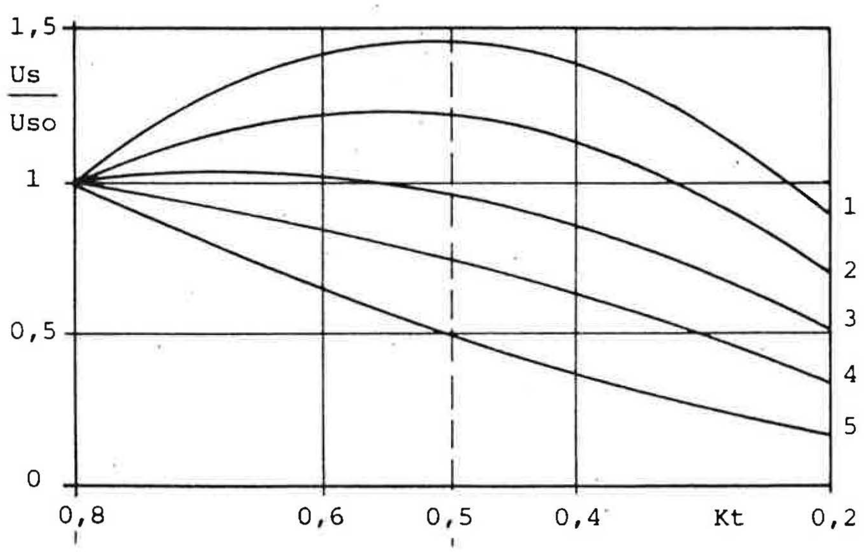
where Gh is the overall average daily horizontal radiation and

Gh ext is the extra-terrestrial average daily overall horizontal radiation.

2.3 - Calculation of Us for standard conditions

It is not always necessary to evaluate the Us coefficient for many cases of insolation. To appreciate the quality of a building with natural cooling for example, what is most important is to define the most uncomfortable conditions, that is, those for which heat gains due to solar radiation are the highest. This maximum value is, at a close estimate, the highest value obtained for a clear sky and an overcast sky with strong diffuse radiation :

Let us take Uso to be the value of Us for a clear sky. Since Dh and Ih are related (4), we can trace the value of the ratio Us/Uso as a function of Kt (Kt diminishes as the sky becomes more overcast). Figure 1 shows that, with very little error, the value Us/Uso is obtained either for a clear sky (Kt = 0.8) or for an overcast sky with strong diffuse radiation (Kt = 0.5). The first case corresponds to buildings for which ADh is close to AIh ; the second case corresponds to buildings which are more sensitive to diffuse radiation than they are to direct radiation (ADh > AIh).



clear sky overcast sky with strong diffuse radiation

Figure 1 : The variation of solar heat gain coefficient Us as a function of the amount of cloud for different types of buildings (from 1 to 5, protection from direct solar radiation decreases).

If the maximum value of Us is required, it is easier to calculate it using the incident solar radiation with a clear sky and with an overcast sky. Tables giving the values for this radiation have been published for inter-tropical zones. As well as the aspect of the surface components, the reduction of radiation due to horizontal sunshades has also been taken into account by share coefficient f. The average global radiation on a surface component is therefore equal to the following :

RSp = RSn x f (5)

where :

RSp (W/m2) : global radiation on the protected surface component,
RSn (W/m2) : global radiation on a bare surface component with the same orientation
f(ad.) : shade factor due to the sunshade (f < 1).

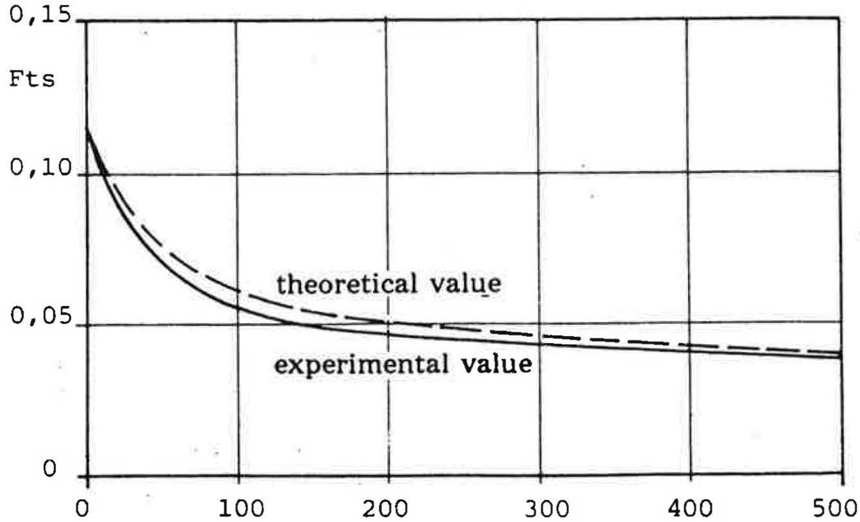
2.4 - Calculation of the Fts values

The notion of a surface component solar factor is currently used for windows. The extension of this notion to all surface components required additional work. For opaque surface components without ventilated cavities, the calculation is based on the usual characteristics of the surface component (coefficient of absorption of the side exposed to the sun, coefficient of heat transmission of the surface component).

For surface components with a ventilated cavity on the outside (ventilated sunshades), a mathematical model was devised, based on an experimental approach (figure 2), in which the value of Fts can be calculated using the following formula :

Fts = Cqs. Ftso + (1 - Cqs) Fts inf (6)

where Ftso is the solar factor of the surface component when the cavity is not ventilated,
Fts inf is the solar factor of the surface component when the air flow in the cavity is very high (towards infinity),
Cqs is a weighting coefficient depending on the degree of ventilation of the cavity (air flow as a ratio of the surface of the surface component)



air flow expressed as a ratio of the roof surface ($m^3/hr/m^2$)

Figure 2 : Solar transmission factor of a dark coloured roof as a function of the air flow in the roof space (where the thermal resistances of the roof and ceiling are very low).

For certain opaque surface components which are difficult to modelize, a test bench was set up at REUNION University to determine the solar factor by directly measuring the cross flow (photo 1).

Photo 1 : Test bench of roof at the REUNION University.

3 - EVALUATION OF QUALITY, APPLICATION TO A WAR HUMID TROPICAL CLIMATE

3.1 - Calculation of Us comfort

In a war humid tropical climate, outside air temperatures rarely exceed 32 °C and are often less than 30°C. Correct comfort would thus be achieved if the temperatures obtained in the buildings were to remain lower than the maximum outside temperature and if, during the hottest part of the day, an air speed of about 1 m/s were created on the occupants, either by a breeze or by fans (an air speed of 1 m/s results in a drop of about 4 °C in the temperature felt by the occupants when compared with still air).

Inside temperatures will be lower if the solar heat gains (and therefore Us) are lower. The results will be better if the building has an eastern orientation (since solar heat gains then occur when the outside temperature is not too high) and the building is well-ventilated and enables solar and internal heat gains to be evacuated. The inertia of the building also comes into play ; all things equal, comfort will be better in the daytime when the inertia is high and better at night when the inertia is low.

Based on these parameters, various simulations and experiments were carried out to calculate a value of coefficient Us called Us comfort (Usc) which enables the temperature target defined above to be achieved by applying the following formula :

$$Usc = (\sum_i Ci \cdot Ai) / V \qquad (7)$$

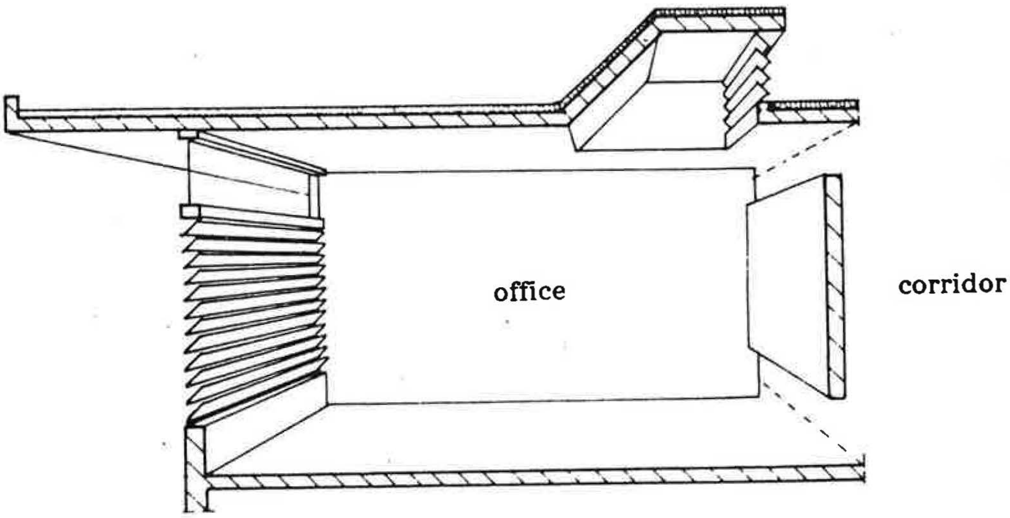
where V (m^3) is the volume of the building or part of the building, and where, for each outside surface component i :
Ai (m^2) is the area of the surface component,
Ci (W/m^2) is a coefficient which depends on the type of surface component (roof, wall, window), its orientation and thermal inertia of the building.

The choice of C coefficients takes technical possibilities into account : a roof is easier to protect than a wall (a roof can be ventilated or insulated fairly easily) and a wall is easier than a window (which must let light and breezes through).

3.2 - Example of application

Demonstration operations were carried out in MARTINIQUE to test the validity of the approach described above. The first operation concerns an office building for the Electricité-de-France local board ; the second involved the construction of three individual homes as part of a competition. It was then checked that the inside temperatures each day remained lower than the maximum outside temperature.

We will analyze the example of the E.D.F. building. Below is a section of one of the offices :



It is a local district building consisting of a public reception hall, a meeting room and offices.

The roof is protected by 4 cm of sprayed polyurethane. The windows, partially protected from direct and indirect solar radiation by the overhanging eaves, have aluminium blinds over the larger part and a fanlight above which provides minimum natural lighting when the blinds are closed.

Since the building consists of a central corridor with rooms on either side, the ventilation of the building, studied in a wind tunnel at the C.S.T.B., was improved by air intakes or outtakes in the roof and openings in the upper and lower parts of the partition walls separating the offices from the central corridor.

Table 1 gives the values of Us for a clear day in June (an overcast sky produces lower values) and the value of Usc. Since Us is lower than Usc, the rule of quality is proved correct, and this was confirmed experimentally (figure 3).

Surface component	A m^2	Fts	RSn W/m^2	f	A.Fts.RSn.f W	C W/m^2	A.C. W
Roof	16	0,026	344	1	134,2	10	150
Glazing	1,8	0,86	173	0,32	85,7	12	21,6
Alu blinds	5,4	0,45	173	0,55	231,2	75	405
Breast wall	1,2	0,102	173	0,74	15,7	12	14,4
					466,8		591
				Us (W/m^3) = 11,1		Usc = 14,1	

Table 1 : Calculation of Us and Usc for an office in the main part of the building presented in the text (the room has a volume of 42 m3).

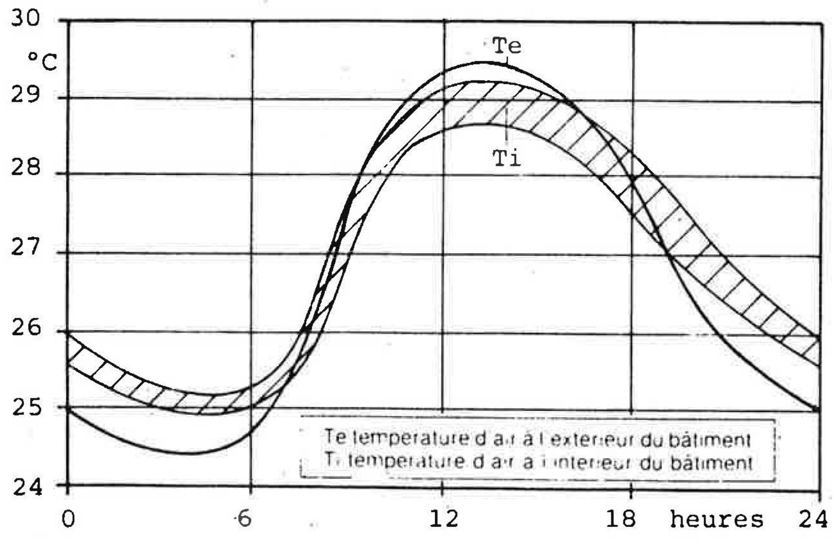


Figure 3 : Range of inside temperatures observed in the different offices (Ti) on a clear June day.

CONCLUSION

We have defined a simple method of evaluating the solar protection of a building using an average solar heat gain coefficient Us. Us can be determined experimentally or by calculation for standard insolation conditions.

We have also defined a value of Us for a wet tropical climate i.e. Usc, which enables natural cooling comfort to be obtained. The solar protection of a building is sufficient if Us is less than or equal to Usc. This rule means that a building project can be assessed during the design stage and the most suitable technical solutions found.

The method has been applied to several buildings and the results obtained have been confirmed by subsequent temperature controls.

Its extension to artificial air-conditioning in wet, tropical climates and other climates is currently being studied.

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