ATLAS OF NATURAL COOLING TECHNIQUES IN SOUTHERN EUROPE: APPLICATION TO EVAPORATIVE COOLING SYSTEMS

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ABSTRACT

This study is a contribution to European projects Pascool/Joule II and Altener/Sink that deal with the usability of passive cooling systems in Europe. The first phase of this work was to define design methodology in order to evaluate natural cooling potential according to the climatic quantification criteria of the site, the cooling needs of the building, the cooling system performances, and comfort criteria defined by the couple of temperature and relative humidity set points. Numerical simulations have been performed in the second step in order to calculate the Theoretical Evaporative Potential Index, the Net Evaporative Potential Index, the Cooling Need Index and the Natural Cooling Saving Factor. These parameters have been evaluated for different types of evaporative cooling systems (direct and indirect), for different sites in southern Europe, and for various temperature and relative humidity set points. A design methodology of the natural cooling potential which was developed in order to build southern European atlas will be presented in this paper. This atlas locates the applicability zone of the passive cooling techniques and would provide, for building designers, decision making tools during the first steps of building design.

Keywords : Passive cooling technique, evaporative system, cooling potential, natural cooling saving factor, climatic atlas, energy conservation.

RESUME

Cette étude s'inscrit dans le cadre de notre contribution aux projets européens Pascool/Joule II et Altener/Sink relative à la faisabilité des techniques de rafraîchissement passif comme alternative à la climatisation conventionnelle dans le sud de l'Europe. La première étape de notre travail a consisté à la définition d'une méthodologie d'évaluation du potentiel de rafraîchissement des systèmes passifs en considérant les critères relatives aux conditions climatiques, les besoins de climatisation d'été du bâtiment, la performance intrinsèque du système et les aspects de conforts, définis par des consignes de températures et d'hygrométries. Des simulations numériques ont été réalisées afin de déterminer les différents indices évaluateurs du potentiel de rafraîchissement des systèmes passifs. Pour chaque consigne en température et hygrométrie, ces indices ont été évalués pour différents sites de l'Europe du sud et pour les systèmes évaporatifs direct et indirect. Nous allons présenter, lors de cet article, une approche d'évaluation du potentiel de rafraîchissement des systèmes passifs. Une application de cette approche aux différents sites européens a permis de bâtir un atlas représentant les zones de l'Europe du sud susceptible d'accueillir favorablement l'utilisation des techniques passives de rafraîchissement. Cette démarche pourrait être utilisée par les concepteurs du bâtiment comme outil d'aide à la décision durant les phases d'avant projet.

Mots Clés : Technique de rafraîchissement passif, système évaporatif, potentiel de rafraîchissement, facteur de couverture, atlas climatique, économie d'énergie.

INTRODUCTION

During the various steps of design and building construction, multiple information, of varied nature, are the necessary criteria for the different actors of the project. Among these informations are to choose a type of building design, to choose a cooling technique that insures a sufficient comfort degree, to size air conditioning systems, and finally to evaluate the energy consumption as well as the energy gain following the use of a passive cooling technique. Concerning the evaluation of buildings equipped with passive cooling systems, several methods mentioned in the literature (Givoni 1976, Szockolay 1986) offer global informations more or less precise about the building thermal behaviour. These approaches based on the use of the psychometric chart provide useful qualitative information to architects and building designers on the feasibility of a passive cooling technique based on comfort aspects.

However they neither allow to quantify the potential of each cooling technique nor to calculate the energy gain realised using a passive cooling system. The solution developed during European projects Pascool/Joule and Altener/Sink consists on two approaches of building thermal evaluation. The first is a detailed method of the building thermal behaviour, obtained by the coupling of passive cooling systems models with a thermal code (Belarbi et al.1997). It can be used during the sizing phases of air conditioning systems.

The second presented in this paper, is a simplified approach based on an analysis of cooling potential evaluation of climates and on the determination of assessment indexes, presented in the form of an atlas for each passive cooling technique. This approach provides helpful information for architects and designers of the building dealing with the interest and the feasibility of each passive cooling technique according to the comfort criteria as well as energy conservation aspects.

I. METHOD OF EVALUATION OF THE COOLING POTENTIAL

The analysis of natural cooling systems behaviour shows that it is possible to establish a common general equation for all natural techniques (Alvarez et al.1997, Belarbi et al. 1994). For each studied passive cooling system, it is possible to define assessment indexes which characterise the climate, the nature of the technique (sink) and the building typology. These factors allow to compare the different passive cooling techniques potential. The knowledge of the used fluid properties and the characterisation of the natural source of cooling, called sink, permit to quantify the theoretical cooling potential index which is obtained assuming an ideal system (system efficiency = 1). During the cooling process and according to heat and mass transfer with the sink, the fluid will have an evolution from an initial state characterised by outlet conditions : $T_{Outlet}(t)$ and $\omega_{Outlet}(t)$ to a final state characterised by the inlet conditions : $T_{Inlet}(t)$ and $\omega_{Inlet}(t)$. In an ideal process, inlet conditions of the system coincide with those of the sink ($T_{Inlet}(t)= T_{Sink}(t)$ and $\omega_{Inlet}(t)= \omega_{Sink}(t)$). The energy theoretically available by the sink can therefore be written :

$$Q_{Theoretical} = \int_{\tau} m'(t)C_p(T_{Outlet}(t) - T_{Sink}(t))dt \qquad (1)$$

For the passive cooling systems which operate with a fixed air massflow rate and the same fluid (air), the value $[T_{Outlet}(t)-T_{Sink}(t)]$ integrated on the period of study τ, constitutes an index of comparison of the theoretical potential that depends only on the system by $T_{Sink}(t)$ and on the climate of the site by $T_{Outlet}(t)$ (see figure 1). This index is particularly interesting to establish a comparative potential cartography of the different passive cooling techniques (Allard et al. 1998).

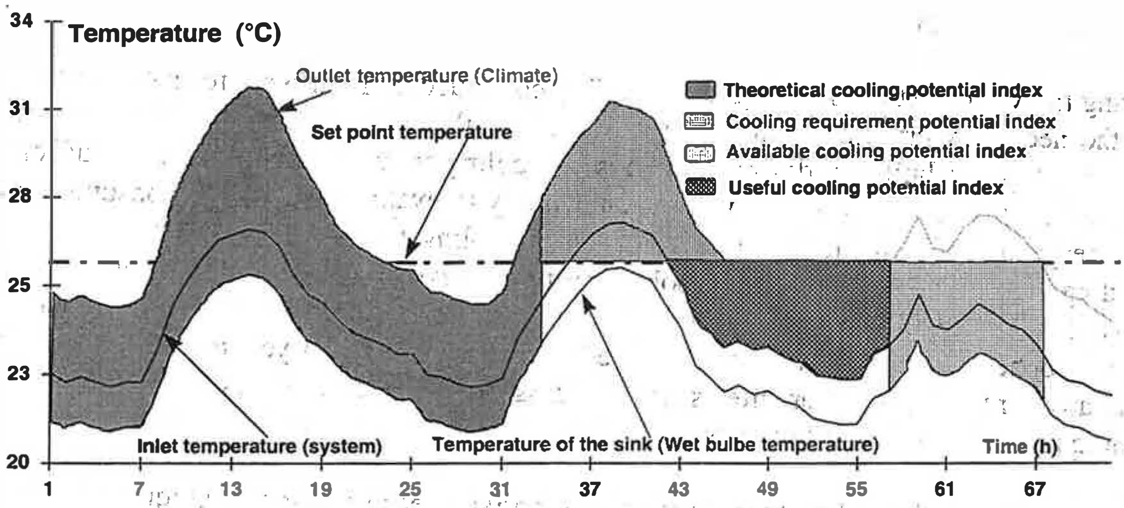

Figure 1 : Representation of the different cooling potential indexes

Unfortunately this notion of theoretical cooling potential index does not take into account the system efficiency and the cooling requirements of the building. For more precise comparisons, we had to define three other factors :

- **The available cooling potential index** which depends on : climatic conditions of the site, the nature of the technique and some comfort criteria of the building defined by a temperature and a relative humidity set points (see figure 1). It is given by :

$$IP_{Available} = \int_{\tau} (T_{Set\,point}(t) - T_{Sink}(t))\delta(t)dt \quad (2)$$

$\delta(t) = 1$ si $T_{Sink} < T_{Set\,point}$ et $\delta(t) = 0$ si $T_{Sink} > T_{Set\,point}$

- **The useful cooling potential index** which depends not only on climatic conditions of the site and the wished comfort degree but also on the performance of the passive cooling system itself. It is given by:

$$IP_{Useful} = \int_{\tau} (T_{consignSet\,point}(t) - T_{Inlet}(t))\delta_1(t).dt \quad (3)$$

with $\delta_1(t) = 1$ si $T_{Inlet} < T_{Set\,point}$ et $\delta_1(t) = 0$ si $T_{Inlet} > T_{Set\,point}$

- **The cooling requirement index** represents cooling needs to be provided by the system to insure the suitable thermal conditions in the building (see figure 1). It is given by:

$$IB_{Requirement} = \int_{\tau} (T_{Outlet}(t) - T_{Set\,point}(t))\delta_2(t).dt \quad (4)$$

$\delta_2(t) = 1$ si $T_{Outlet} < T_{Set\,point}$ $\delta_2(t) = 0$ si $T_{Outlet} > T_{Set\,point}$

II. APPLICATION OF THE COOLING POTENTIAL APPROACH

These indexes have been defined for different climatic conditions of 105 south European sites. For the evaporative cooling technique, and for different levels of temperature and relative humidity set points (providing the wished comfort degree), assessment of air conditioning requirement index have been undertaken. Evaluation of available and useful cooling potentials index as well as the rate of energy provided by the evaporative cooling system (natural cooling saving factor) has been done. This part constitutes a preliminary assistance level for the choice of a natural cooling technique which will provide a suitable comfort in the building. From real meteorological data of studied sites (La Rochelle, Crotone, Carpentras, Roma, Sevilla, Athens, and Lisbon), we have evaluated, during this phase, the climatic potential of each site by considering their respective cooling needs. This study has been realised during the five months of summer (May to September). Figure 2 presents values of the available cooling potential index for these different European sites. We can observe very high value of available potential index for Carpentras and Athens, about 16000 °h, high values of the available index for Sevilla, Lisbon and Crotone, about 7000 °h, average values for Roma, around 6000 °h and finally a small value of the available cooling potential index for La Rochelle (3600 °h). Figure 3 presents the evolution of the useful cooling potential index of the evaporative system according to the levels of temperature set points. This index takes into account the efficiency of the evaporative system. For a system with a constant efficiency, it behaves with a homotetical way compared to the available potential index. Figure 4 presents the evolution of the cooling requirement index according to the temperature set point levels.

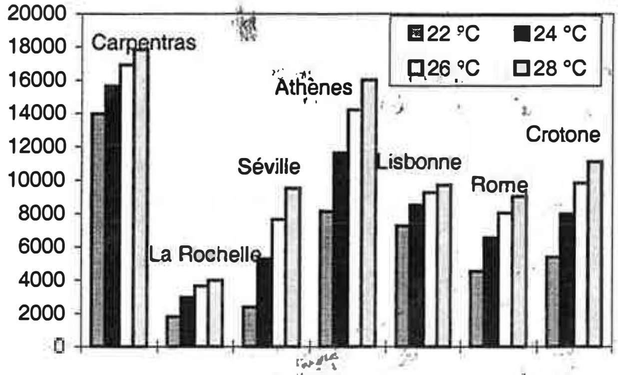

Figure 2 : Available cooling potential Index for evaporative cooling system (°h)

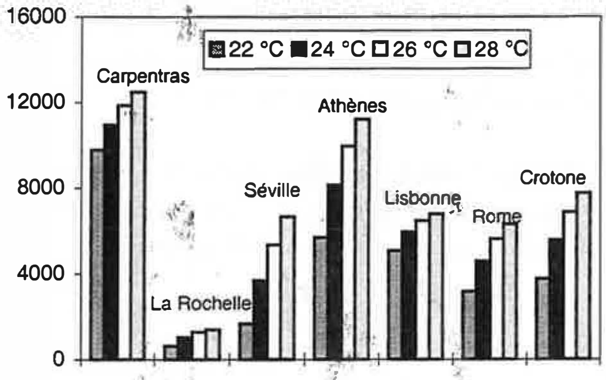

Figure 3 : Useful cooling potential index for evaporative cooling system (°h)

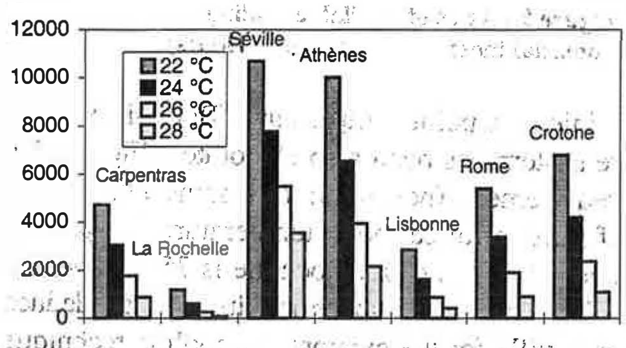

Figure 4 : Cooling requirement index (°h)

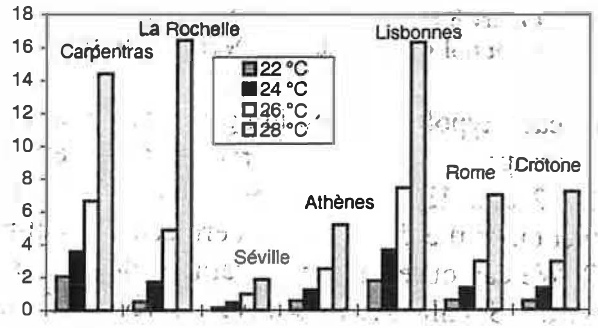

Figure 5 : Natural cooling saving factor for evaporative cooling system

These results show that, taken independently, the theoretical cooling potential index does not represent the aptitude of the system to cover the cooling needs. So it is necessary to couple this theoretical potential to the cooling needs of air conditioning (defined from the building type) considering the system performances. From these considerations we have introduced the natural cooling saving factor (Allard et al.1998) defined as the rate between the useful cooling potential index and the cooling requirement index during a given cooling period τ and for each temperature set point. The representation of the natural cooling saving factor, given by figure 5, shows that we can have an available cooling potential index in one locality (Sevilla) higher than an other locality one (La Rochelle) while the cooling saving factor in the first site is less than for the second site (figures 2 and 5). Consequently, the cooling saving factor appears to be a more relevant index for passive cooling systems evaluation.

III. ATLAS OF EVAPORATIF COOLING SYSTEM POTENTIAL

The generalisation of the study to other sites of southern Europe enabled us to represent, for each country, a cartography of the different cooling potential indexes which were defined previously. An atlas of available cooling potential index of south European country, for evaporative cooling systems, is presented in figures 6 to 10. We can note that the available cooling potential index of La Rochelle is 48 % less than Sevilla' one (respectively 3600 °h and 7000 °h).

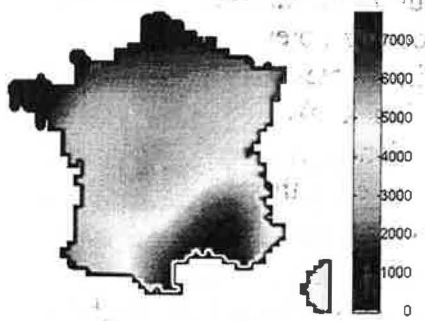

Figure 6 : Atlas of available cooling potential index in France (Degree-Hours)

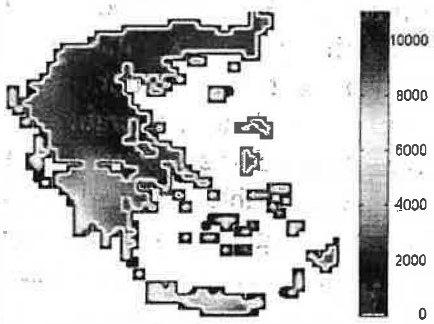

Figure 7 : Atlas of available cooling potential index in Greece (Degree-Hours)

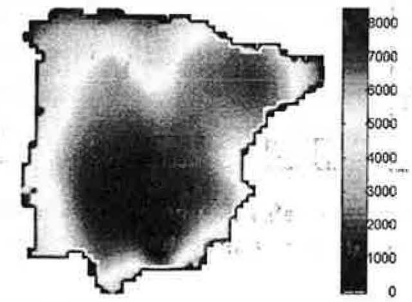

Figure 8 : Atlas of available cooling potential index in Iberia (Degree-Hours)

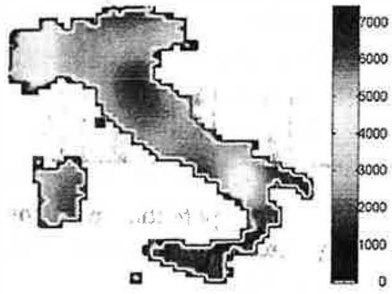

Figure 9 : Atlas of available cooling potential index in Italy (Degree-Hours)

For each typology of building and for each level of inlet set point temperature (Belarbi 1998), a cartography of cooling requirement for an evaporative system has been also elaborated. Figures 10, 11, 12 and 13 represent the variation of cooling requirement (needs) of this same building in function of the different southern countries climate of Europe for set point temperature $T_{Set\ point}$=25 °C. We can observe, for the same building, that the cooling needs of La Rochelle is 75 % less than that the Sevilla one(respectively 6 Kw.h/m² and 25 Kw.h/m²). From these results, we can deduce that the site of La Rochelle is far more propitious that Sevilla for the evaporative cooling technique use. Consequently, comparative studies of the European atlas of the different passive cooling techniques could have been used during the first steps of building project, by architects, as helpful decision making tools for the choice of the most appropriate passive technique.

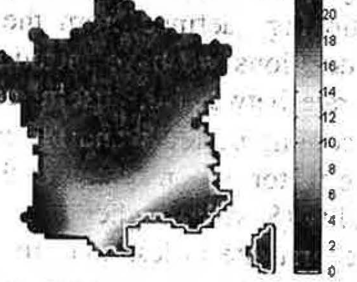

Figure 10 : Cooling needs in France (Kw.h/m²)

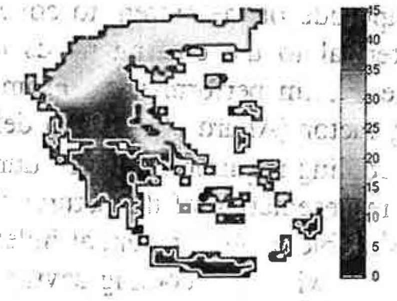

Figure 11 : Cooling needs in Grèce (Kw.h/m²)

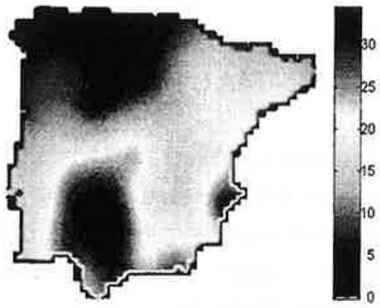

Figure 12 : Cooling needs in Iberia (Kw.h/m²)

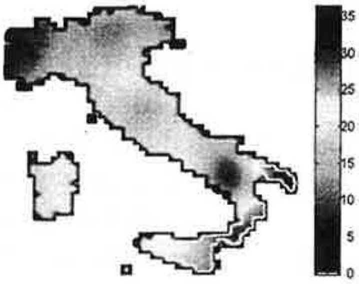

Figure 13 : Cooling needs in Italie (Kw.h/m²)

CONCLUSION

The approach developed in the present paper provides information which could be used to contribute to a bioclimatic analysis of European sites and to study the performances of different cooling systems according to the climate characteristics and comfort criteria. An evaluator, called natural cooling saving factor, was defined in order to make comparison studies of passive cooling system potential. It allows to select, for each locality and for each building type, the adapted passive technique which provides a wished degree of comfort with less energy consumption. Simulation results, obtained for the evaporative system, show that this technique offers a good cooling potential level for the most sites located in the south of Europe. By extending this study to other cooling techniques we will be able to localise southern sites of Europe suitable for each passive cooling technique. The generalisation of this approach on others European sites has allowed to build a decision making tool, in the form of an atlas, that could be used by architects and building offices during the first phases of a project. However, the proposed approach does not consider internal heat gains contributions, the typology of the building and the interaction building/cooling system. In order to get the overall evaluation of a proposal solution, an integrated approach coupling a modeling of the system to a numerical code defining the thermal behaviour of the building is necessary (Belarbi and al.1997).

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