Natural Cooling Techniques

S.A. Dominguez

Dept. de Ingeniería Energética y Mecánica de Fluidos - Escuela Superior de Ingenieros Industriales
Avda. Reina Mercedes s/n - 41012 Seville - Spain

ABSTRACT.

This paper is not intended as an exhaustive account of all the available natural cooling techniques, including an interminable list of references, the advantages and disadvantages of each technique, and their field of application.

Rather, it is intended to present the perspectives of future research and the topics that should be covered within the frame of a European concerted action. Thus, it will concentrate on the main obstacles and faults that we feel exist in the current research, and subsequently on the measures that should be taken to correct this.

1. CLASSIFICATION OF NATURAL COOLING TECHNIQUES.

The opinions of diverse authors don't agree regarding the best way to classify natural cooling techniques. Thus, these classifications can be made according to:

- Nature of the heat sinks (ambient air, sky, etc.)
- Heat and mass transfer phenomena involved (convection, evaporation, etc.)
- Storage period (daily, weekly, seasonal)
- Storage material (water, rock, etc.)
- Type of application (hot/dry climate, hot/humid climate)

The diversity of this classification yields to a certain confusion between the causes and effects, with the result that identical strategies are often considered from very different points of view. For example, the ground in earth-coupled structures, considered a heat sink by some authors, is treated as seasonal storage material by others.

These questions have a conceptual interest, but are irrelevant to the objectives of this presentation. For methodological reasons, natural cooling techniques will be classified depending on how they influence the thermal behavior of the building.

We will distinguish between:

- Direct cooling systems, where the heat sink promotes a direct cooling action on the building structure, and/or the interior air.

- Indirect cooling systems, where the system first cools a specific amount of air, which is then discharged (with or without intermediate storage) to the building.

This classification can be further clarified by the following examples:
- The ground in contact with the building structure is a direct cooling system, but the ground used as a means to cool the air blowing through an underground duct is an indirect cooling system.
- Roof ponds, roof sprays, or roof water films are examples of direct cooling systems, but the water used in mechanical evaporation cooling units, wind towers, or cool-towers (as the one proposed in the Appendix), are considered indirect cooling systems.
- Typologies used to promote cross ventilation to produce comfort and the nocturnal ventilation strategies used to cool the building structure are direct cooling systems.

Obviously, there are cases where certain systems will not exactly fit this classification. These systems can be considered as mixed cooling systems and will not modify the conclusions of this paper.

2. PROBLEMS CONNECTED TO CURRENT RESEARCH ON DIRECT COOLING SYSTEMS.

Independently of the fact that direct cooling systems may be elements inherent to the building structure (roof pond, underground walls, etc.) or not (ventilation, strategies, etc.), a characteristic common to all of them is the strong coupling between their thermal behavior and that of the building.

For instance, in earth-contact structures, the building modifies the ground's temperature field; hence evaluation of their thermal performance requires realistic formulation of the boundary conditions, especially if surface treatments are accomplished to improve the ground cooling potential (shadow on adjacent spaces, irrigation, etc.). This degree of detail implies the use of two-dimensional or three-dimensional transient conduction.

However, in most computer simulation codes used for buildings' energy analyses, thermal conduction is considered one-dimensional. Thus, the only way they treat conduction through the ground is via an "assumed" ground temperature.

Conceptually, this situation is very similar in other direct cooling systems. Evaluation (thermal performance) of a certain component usually require a level of complexity that infers the use of certain modelling technique. If the computer code available to simulate the building uses a different modelling technique, the component cannot be "integrated" into the code, or, at most, this integration will be made based on simplified assumptions that disturb the evaluation results.

With regards to ventilation strategies, the same difficulties are encountered. Many of the existing computer codes are unable to properly manage

166

multizone air flow exchanges, especially if the building includes typologies oriented to promote ventilation (e.g., solar chimneys). The problem here is the impossibility of modelling the thermal and aeraulic couplings.

A demostration of the magnitude of errors that occur when a ventilation strategy is inadequately modelled is show in Figure 1 the results of an inter-program comparison exercise. Cases 100 to 210 represent changes in design parameters of a reference cell - e.g., inertia, absorptivity of the walls, window area, etc.; cases 220 and 230 represent the results for low mass and high mass cells, respectively, when nocturnal ventilation has been included.

As can be seen, the differences between the programs -acceptable for cases 100 to 210 - are considerably increased when considering ventilation.

In sum, the major problem encountered in the evaluation of direct cooling systems is that the strong coupling existent, makes them inviable for realistic treatment in most computer codes. Consequently, we cannot properly analyze the true effect of a component, system, or strategy on the building's performance.
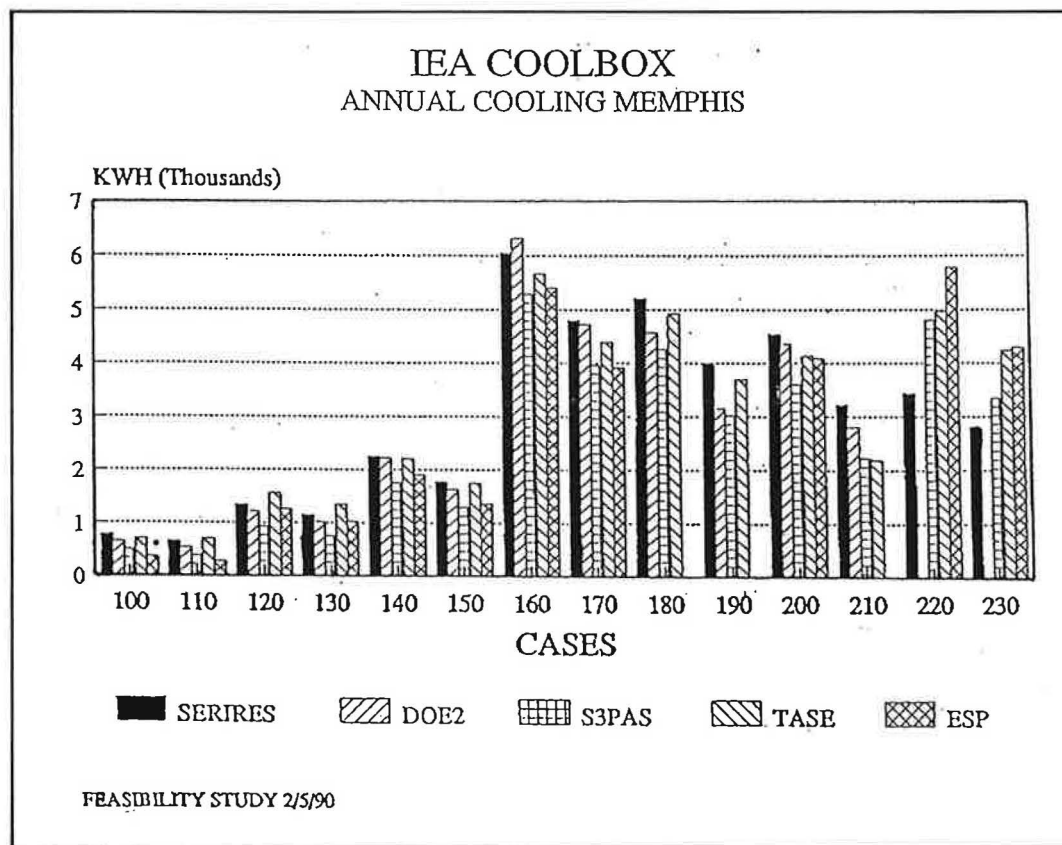

Fig.1 Interprogram comparison exercise

3. PROBLEMS CONNECTED TO CURRENT RESEARCH ON INDIRECT COOLING SYSTEMS.

Scientific literature reports hundreds of different manners to cool the air using natural means.

An inspection of technical papers reveals that most of them deal with research that includes monitoring, superficial analysis of the results usually in terms of efficiency, and in some cases, modelling based on more or less sophisticated correlations.

Apart from a few exceptions, the design of the system has been made based on intuition and without the use of even the most rudimentary calculation methods. After the experiment (usually poorly monitorized), there is a lack of in-depth analysis directed to explain the reasons for the results or the possible design failures.

Finally, there is usually a lack of modelling and validation activities; consequently, a sensitivity analysis is out of the question, and the opportunity to determine the following is lost:
- Which design parameters are relevant?
- How should these design parameters be modified to improve the design?
- What is the optimum range of variation of each design parameter according to different climatic conditions?

Consequently, the results of research are very limited, from which we obtain little more than a demonstration plant.

In light of this situation, and taking into account the large degree of variation that each cooling technique allows, it has not yet been possible to obtain a sound basis for systematic extrapolation of the results, and the elaboration of the subsequent design guidelines.

4. PROPOSALS FOR FUTURE RESEARCH.

4.1. Direct Cooling Techniques

In my opinion, the first action to be taken in research to promote the understanding, enhancement, and use of direct cooling techniques, is to develop general coupling methodologies. These would allow the integration in computer codes of algorithms pertaining to components or strategies, with no restrictions on the modelling technique or the degree of complexity.

In addition, further research must be performed to improve the characterization of some direct cooling techniques and strategies (e.g., ground coupled structures and multizone air flow).

4.2. Indirect Cooling Techniques

To obtain a sound background that enables the elaboration of design guidelines for indirect cooling techniques, it would be useful to promote specific studies which should include:

- Modelling of the heat and mass transfer phenomena involved, explicitly including all the design parameters

- Fully monitorized experiments
- Rigorous validation
- Sensitivity analysis

The Appendix includes an example that illustrates the proposed methodology. An indirect cooling technique is presented, intended to use for climate conditioning of open spaces in the Expo'92 Universal Exhibition.

However, these type of actions are unsuitable for a multinational research program, for the following reasons:

- There are too many systems.
- Different systems are usually based on different physical principles.
- Each country or region would be interested only in a limited number of actions, depending on their own climate peculiarities and natural resources
- The study of each system will not require the conjunction of researchers from different groups.

Consequently, it will be more convenient to perform these studies on a national, or even regional, level.

A European concerted project could link these efforts through common methodology of work and documentation.

Concerning the integration of the indirect cooling techniques used in building performance, we highlight a relevant topic that could be included in a Community concerted project. This topic has been partially mentioned for direct cooling techniques and consists of the development of formulations to characterize the coupling of thermal models, air flow models, and water/vapor transport models.

The inclusion of water/vapor transport models is of great interest from a comfort point of view, to evaluate the effect of indirect cooling systems based on adiabatic saturation processes.

APPENDIX: COOLING-TOWER PERFORMANCE

This Appendix is a short presentation to illustrate the possibilities of research carried out according to the methodology previously cited.

The system (Figure 2) consists of a transparent PVC tower, with nozzles that create an artifical fog by injecting water at high pressure through minute orifices. Since the water droplets are very small, their evaporation is almost instantaneous. This evaporation cools the air blown by a fan placed at the top of the tower.

The research carried out on this tower included the following:

- Modelling of the evaporation of a single water droplet in the air

- Characterization of the droplet size distribution produced by the fog generators (micronizers).

- Modelling the simultaneous heat and mass transfer phenomena occurring when air flow and fog (droplets of different sizes) come into contact in the tower.

- Design of the experiment (select the different variables).

- Experimentation (summer 1989).

- Qualitative analysis of results (Figures 3 and 4).

- Validation (Figure 5).

- Sensitivity analysis, in which the following items were examined:
    - Influence of the air flowrate (m^3/h).
    - Influence of the quality of micronizers in terms of their VMD (Volume Median Diameter): better quality infers lower VMD.
    - Influence of the water flowrate $(l/m^3$ of air).
    - Influence of the micronizers location within the tower.
    - Influence of the tower's height (distance between the base and the micronizers).
    - Influence of exterior conditions (ambient temperature and relative humidity).

Figures 6 and 7 show, respectively, the outlet temperature and the percentage of evaporated water as a function of the tower height and the VMD of the micronizers.

The sensitivity analysis provided us with the knowledge of the influence of the relevant design parameters, through which we were able to establish design guidelines for this kind of systems.

For a new application, we are now able to specify all the design variables and the control strategy to maximize the cooling capacity, while avoiding people from getting wet because of non-evaporated water droplets.
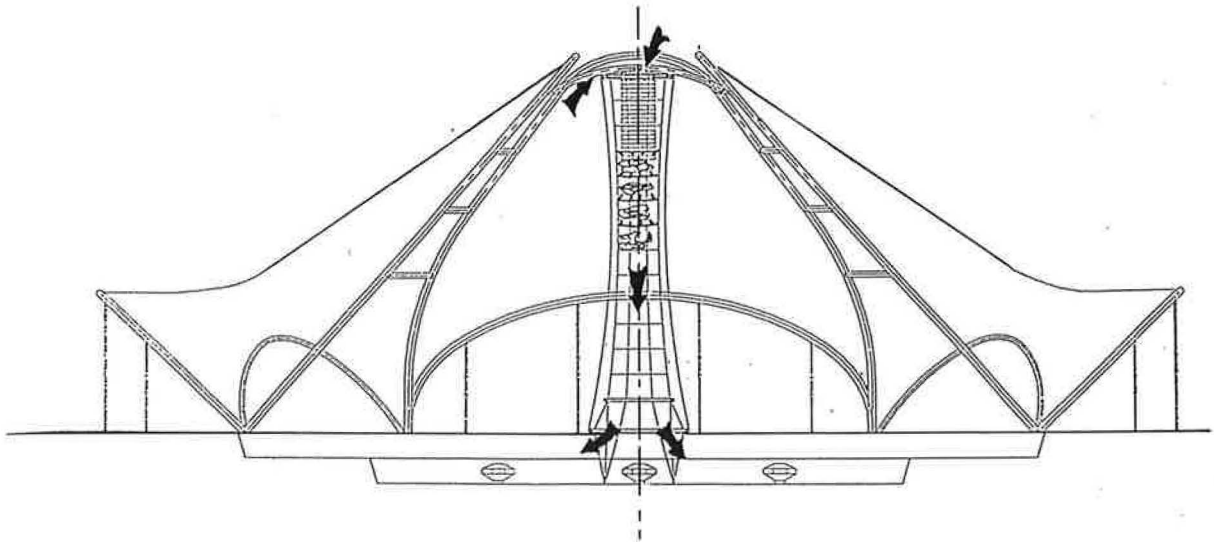
170

Fig.2. The cooling tower

DIA INICIAL: X 16 AGOSTO 89

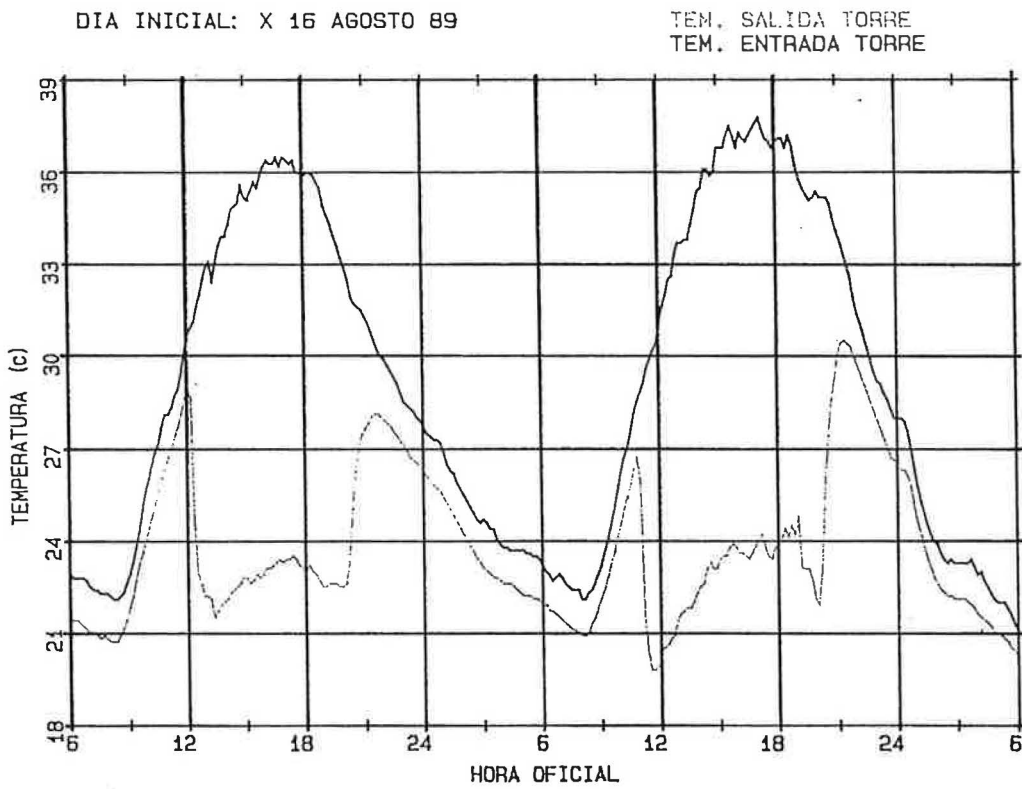TEM. SALIDA TORRE
TEM. ENTRADA TORRE
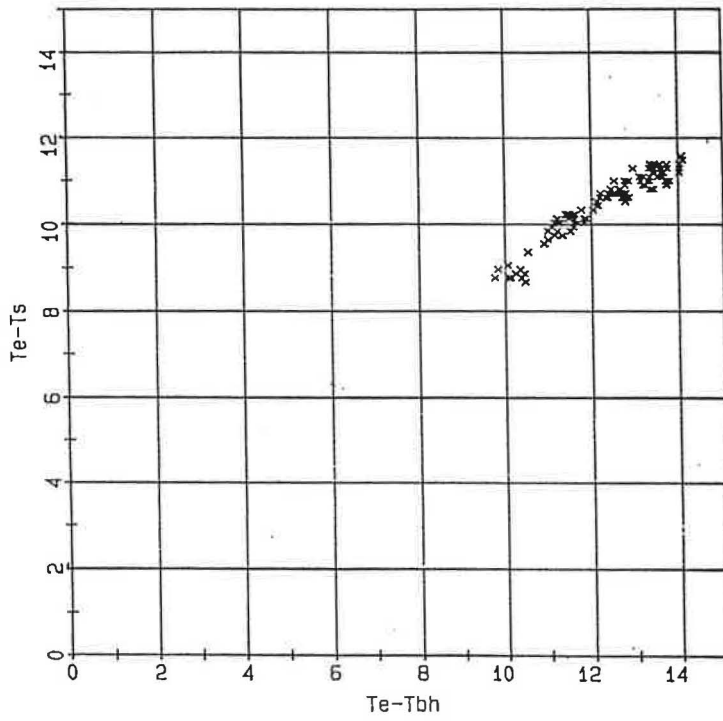
Fig.3. Experimental results
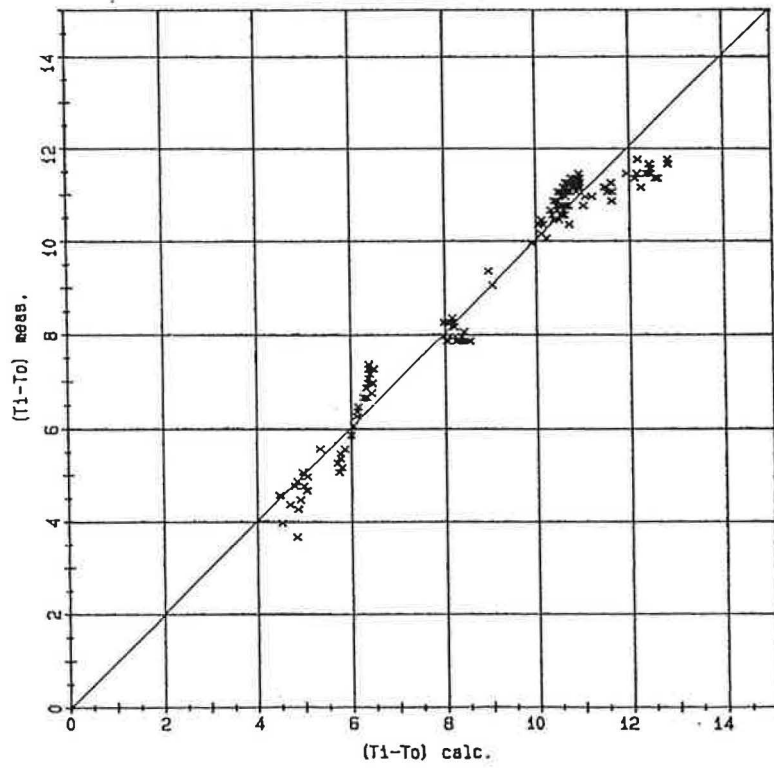
Fig.4. Experimental results
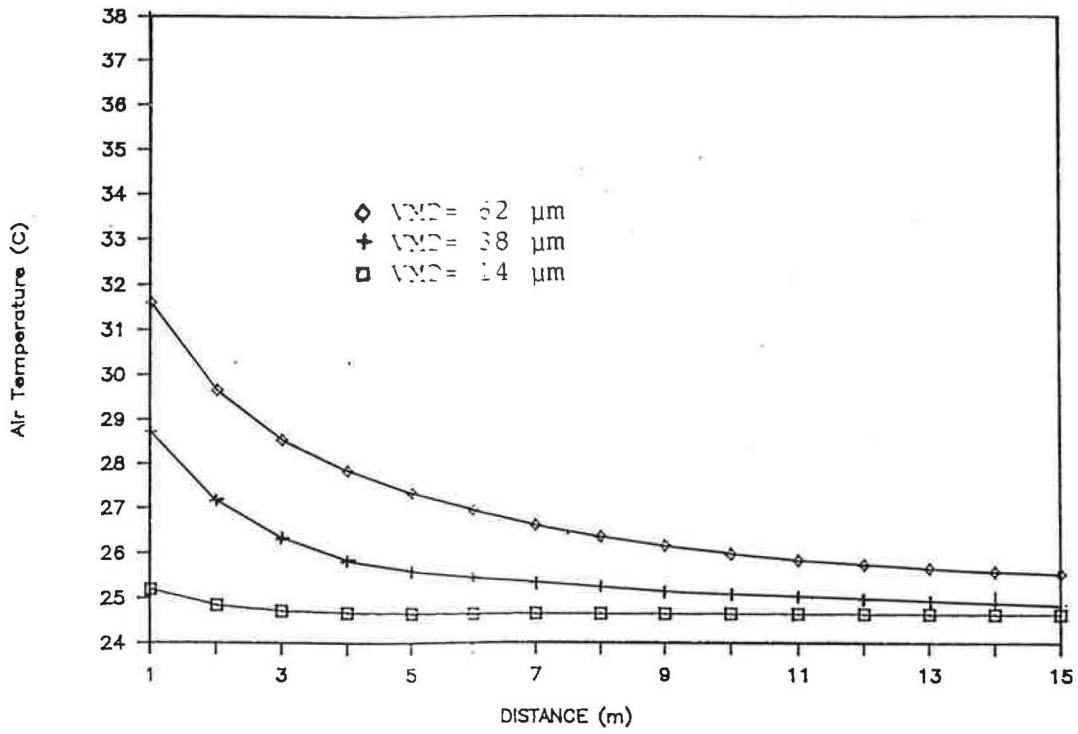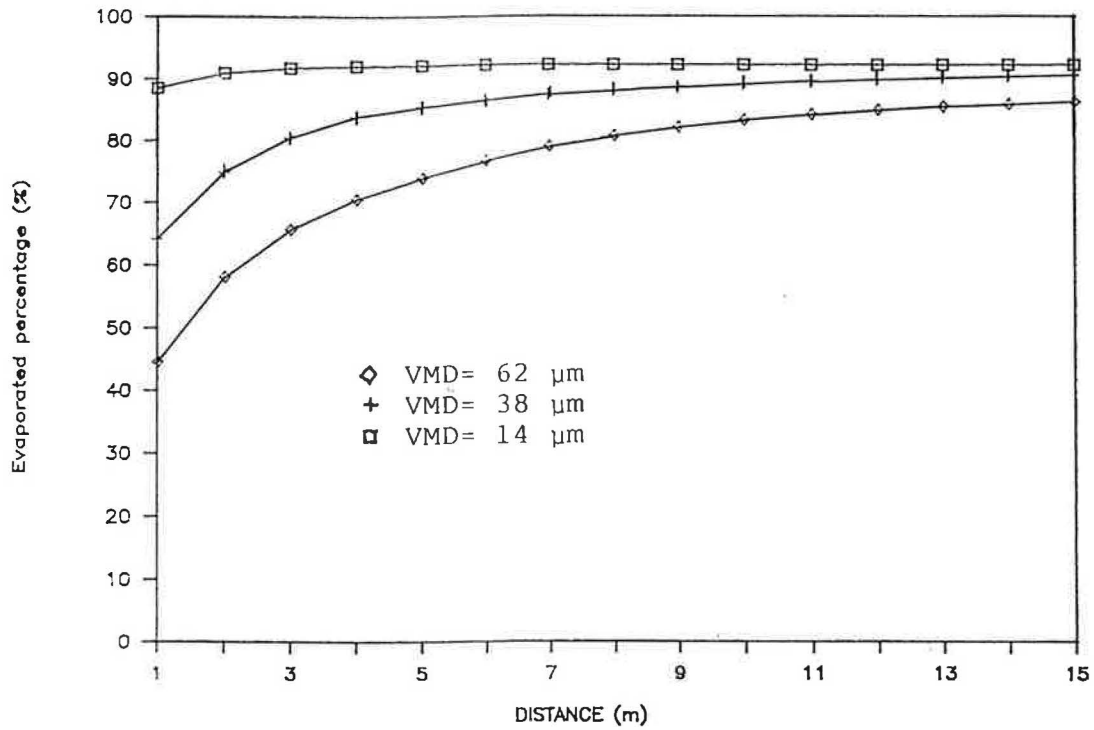

Fig.5. Example of validation

Fig.6. Example of sensitivity analysis

Fig.7. Example of sensitivity analysis