Monitoring in Passive Cooling

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ABSTRACT. The paper describes the possible role of monitoring activities in the study of passive cooling concepts. Special attention goes to monitoring activities for post-implementation performance analysis on real buildings. Various aspects of the monitoring method, the set-up of a monitoring campaign, accuracy aspects of monitoring results as well as their extrapolation are discussed. The essential message of the paper is the idea that the success of a monitoring campaign can only be guaranteed if the various aspects of the monitoring are well prepared and if the people managing the monitoring campaign are well experienced or supported by people with the appropriate experience.

1. INTRODUCTION

Passive cooling strategies can be divided into 2 categories [1] :
- measures which minimize heat gains;
- measures which maximize heat losses by removing heat from the building once it is inside.

Passive cooling concepts can be applied in various situations :
- the improvement of an existing building or the construction of a new building;
- the major objective can be passive cooling as alternative for active cooling or it can be passive cooling as tool for improving thermal comforts.

This paper indicates the potential of monitoring techniques with respect to the implementation of passive cooling strategies and highlights a number of requirements for monitoring campaigns.
The results of IEA-ECBCS Annex 11 "Energy Auditing", focused on the applicability of measures to reduce energy consumption, were of a great help in the preparation of this paper.

2. THE ROLE OF MONITORING IN THE STUDY OF PASSIVE COOLING CONCEPTS

2.1. Passive cooling strategies

Passive cooling strategies are receiving more and more attention in the Mediterranean region.
A systematical study could include the various stages as illustrated in fig. 1.

2.2. Building rating

Building rating involves a simple assessment of the likely passive cooling potential of the building stock. It probably requires to split the building stock into building types.

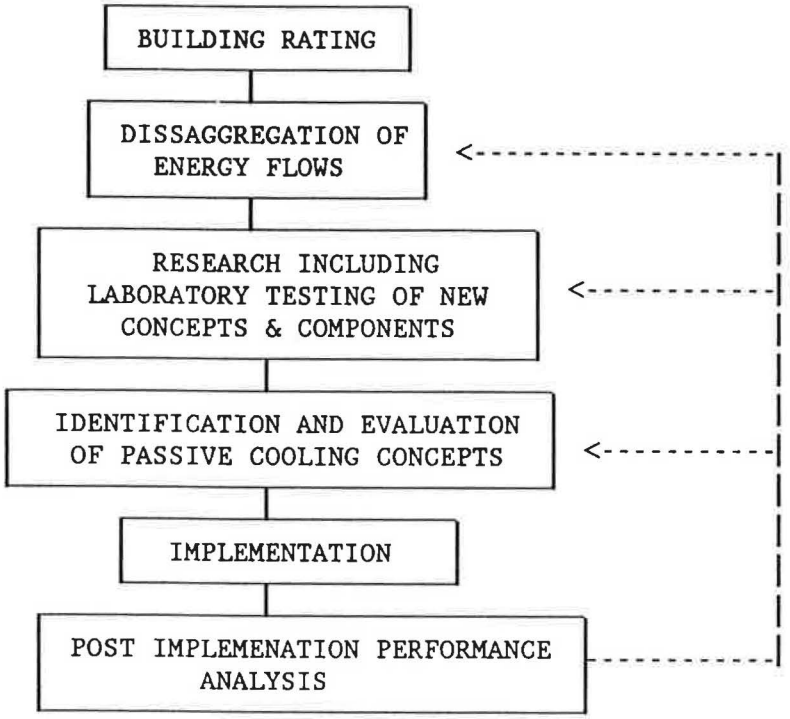

Fig. 1 : Study of passive cooling strategies

In energy conservation studies the rating of buildings often is based on "energy indicators" (e.g. yearly energy consumption per m^2). A "passive cooling potential indicator" could be a useful tool in passive cooling studies for existing buildings.

Such information for the whole building stock could be an important information for decision makers (on CEC-, national or local level) for orientating their programmes and/or financial support. The use of monitoring techniques is of less importance in the stage of building rating.

2.3. The disaggregation of energy flows

The disaggregation of energy flows, consisting in dividing the various energy flows into components allows to identify the relative size of the various energy flows.
The heat gains can be split into the following categories :

. solar gains through fabric
. solar gains through openings
. conductive gains through fabric due to high external air temperature
. ventilation gains due to high external temperatures
. occupants
. lighting
. equipment

Such a splitting-up of heat gains can be applied for existing buildings before renovation and allows to help in the evaluation of the suitability of the various passive solar concepts.

A disaggregation of the heat losses (free cooling, night radiation to the sky, earth cooling,...) can also be done but seems to be somewhat more difficult.

2.4. Research including laboratory testing

The next logical phase in passive cooling studies is the identification

and evaluation of passive cooling concepts. However, research including laboratory testing is in many cases required/appropriate before application in real buildings.

This laboratory research can involve testing of passive cooling concepts in test cells. Various types of test cells exist.
The CEC DGXII has developed in the PASSYS project a network ot test facilities which offer a high quality infrastructure, also for the monitoring of various passive solar concepts. Figure 2 shows the PASSYS test cell concepts. Figure 3 shows the location of the test centers in Europe. A modified version of the test cell allowing to test also roof components is developed especially for the Mediterranean countries and will be installed at the end of 1990. The detailed monitoring of passive cooling concepts under such more or less well controlled conditions can be in many cases a cost effective method for understanding the behaviour and performance of passive cooling concepts.

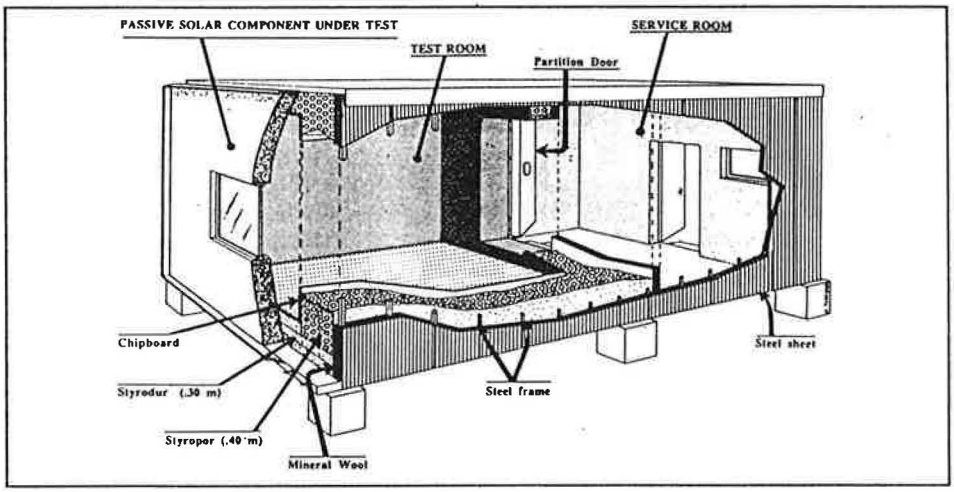

Fig. 2 : PASSYS test cell concept

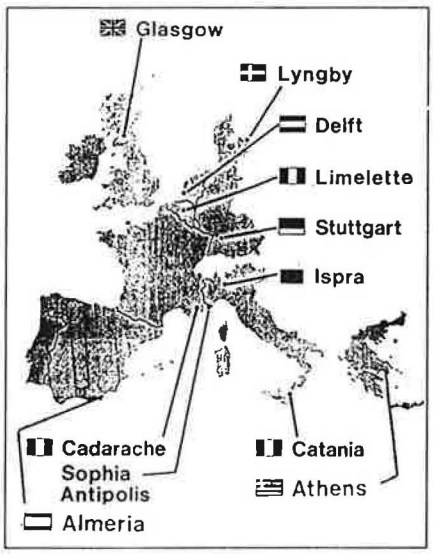

Fig. 3 : PASSYS testcenters in Europe

2.5. The identification and evaluation of passive cooling concepts

The identification and evaluation of passive cooling concepts for a given project should include the knowledge gained from research and laboratory testing.

At this level detailed calculation methods as well as appropriate simplified design or calculation tools can be used. They must help the designer/building physics expert in the selection of the most appropriate technologies. This phase is very important but is outside the scope of this paper.

2.6. The Post Implementation Performance Analysis (PIPA)

The Post Implementation Performance Analysis (PIPA) must allow to evaluate the performance of the implemented concepts after erection or modification of the building. This will require in most cases monitoring activities of which the size depends on the interested parties and the complexity of the study.

The interested parties can be [1] :

. the research team and the supporting organisation(s) studying the passive cooling concept.
  Monitoring can be required for :
  - evaluating the performance of the passive cooling concept in that specific building;
  - the validation of an empirical model developed for such kind of passive cooling concepts;
  - studying the performances including occupant behaviour.
. policy makers who want to know whether the conditions for public financing (subsidies,...) have been met.
. building owners who want to check the effectiveness of the implemented technology (e.g. a hotel chain who has applied passive cooling concepts in one of their hotels as a test case).
. companies specialised in 'third party financement' who finance the investment and who are compensated on the basis of the energy saving and/or comfort improvement.

The Post Implementation Performance Analysis can include a comparison with the conclusions found before implementation. This can result in an improvement of the evaluation procedures to be used in the future. There can also be a coupling with the laboratory testing : improved laboratory testing procedures or interpretation methods can be a results of it. This coupling of the various phases is indicated in figure 1.

Some relevant aspects of monitoring activities with emphasis on post implementation performance analysis are discussed in 3.

3. VARIOUS ASPECTS OF MONITORING

3.1. Monitoring method

According to [1], Fracastero and Lyberg make a distinction between 3 basic methods for evaluating retrofitting activities :

a) before/after expermiment
b) test/reference control experiment
c) on/off experiment

It is clear that method a) is not applicable for new buildings.

All 3 methods have advantages, and disadvantages.

. the before/after experiment requires that a number of conditions are fulfilled.

* the same type of data must be collected both before and after implementation of the passive cooling concept;
* weather corrections must be applied;
* corrections must be made for changes in indoor climate;
* occupant's behaviour must be assumed unchanged;
* it must be realistic to assume that the only significant difference between both periods is the implementation of the passive cooling concept.

It is the only possible monitoring technique for a non-reversible retrofitting activity in an individual building. Satisfying results can probably only be expected if the impact of the passive cooling concept(s) on the thermal comfort and/or energy consumption is significant (at least 10....20 %).

. The test/reference approach requires to monitor also the reference building(s). It allows in principal to eliminate or reduce the effect of non-controllable effects such as changements in fuel prices, modified occupance behaviour (if the samples are large enough). A good example can be 2 existing side by side, identical hotel blocks where in one of the 2 blocks passive cooling techniques are implemented.
. The on/off approach requires passive cooling concepts which are reversible (e.g. evaporative cooling systems, night time ventilation).

3.2. Monitoring set-up

A very important decision in the preparation of a monitoring campaign is the selection of the variables to be measured. Several studies have failed due to the fact that one recognized only after the monitoring that crucial parameters were not measured. This is in the non-reversible before/ after experiments in most cases dramatical.

The on/off approach has the big advantage that it can always be repeated which allowes improvements in the set-up (but of course higher costs). A big challenge in the detailed monitoring of many passive cooling systems can be the collection of the required measurement data within a given budget. Indeed, the measurement of flow rates, thermal comfort, heat storages, ... are not so easy and may require complex and expensive equipment. As an example can be mentioned the use of a photovoltaic element for the measurement of the solar radiation. A reasonable level of accuracy may be obtained if the element is calibrated in the laboratory against a pyranometer.

3.3. Accurate measurements in monitoring campaigns

The level of required accuracy is related to the aim of the monitoring campaign : measurements serving for empirical model validation probably require a much higher accuracy than measurements aiming to inform the owner about the achieved performances.

A number of criteria must be fullfilled for obtaining accurate measurements :

- a representative measurement location and/or enough sensors.
  ex. : - the measurement of the average indoor air temperature of a large room;
  - one assumes for the measurement of the air change rate of a room or building normally perfect mixing. This is often not the case, especially in natural ventilated rooms with high flow rates (ex. night ventilation).
  A reliable measurement will in such cases only be possible if one finds a more or less representative measurement location and/or by taking the average of several measurement points. The alternative is to use much more complex analysis techniques.

- an appropriate measurement frequency.
  ex. : the measurement of the ground temperature requires a very low measurement frequency while the measurement of solar radiators, wind speed, energy consumption often requires a high measurement frequency (up to several measurements per minute).
- a high quality measurement chain including accurate sensors.
  ex. : Pt100 temperature sensors are available in various accuracy levels (a factor of 10 in accuracy)
- the sensor measures the desired variable
  ex. : - an accurate measurement of a surface temperature during sunshine requires a lot of precaution. Figure 4 shows results obtained in the framework of the PASSYS project.
  - the measurement of the air temperature (inside, outside) is not so easy. Figures 5 and 6 show the sensors used in the PASSYS-project.

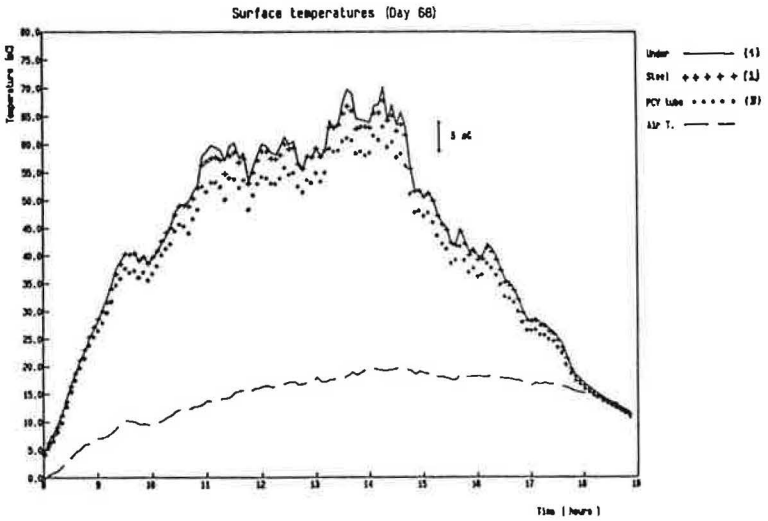

Fig. 4 : Measurement results surface temperature

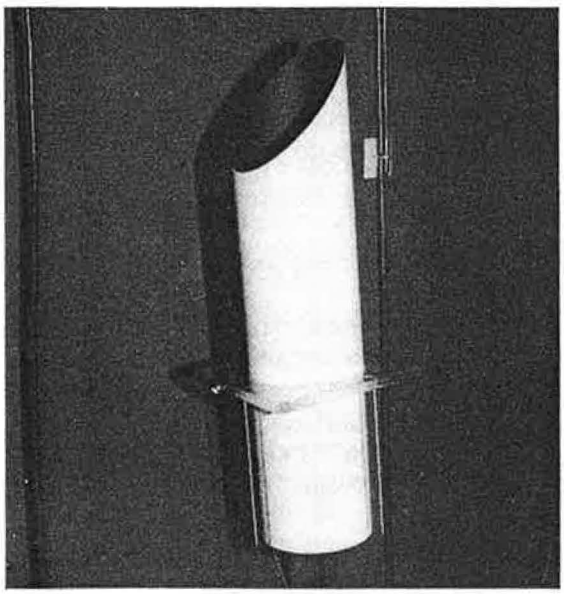

Fig. 5 : θ_i interior

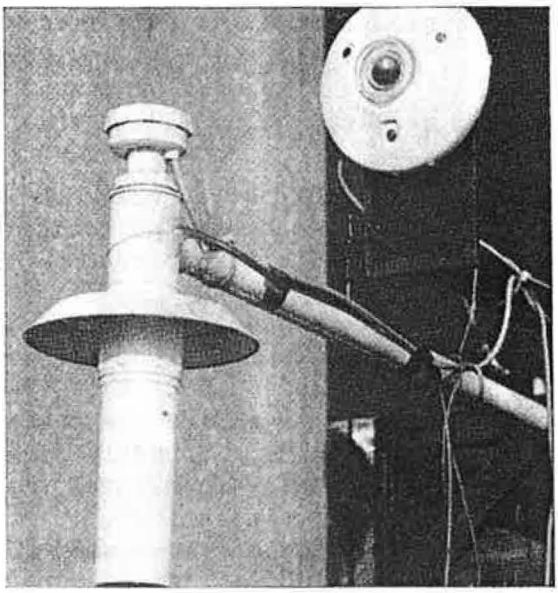

Fig. 6 : θ_e air exterior

It may be useful for measurements of crucial importance in the analysis to check the accuracy with great care.
ex. : the evaluation of burried pipes as earth cooling components [2] (fig. 7) requires the measurement of the air flow rate through the pipes. This flow rate can be measured in various ways :
- by measuring the pressure drop across an orifice (orifice changes the performance !!)
- by using tracer gas
- by ...

A comparison of the obtained flow rates with the flow rates measured by a calibrated fan may allow to estimate the accuracy level and/or to improve the measurement procedure.

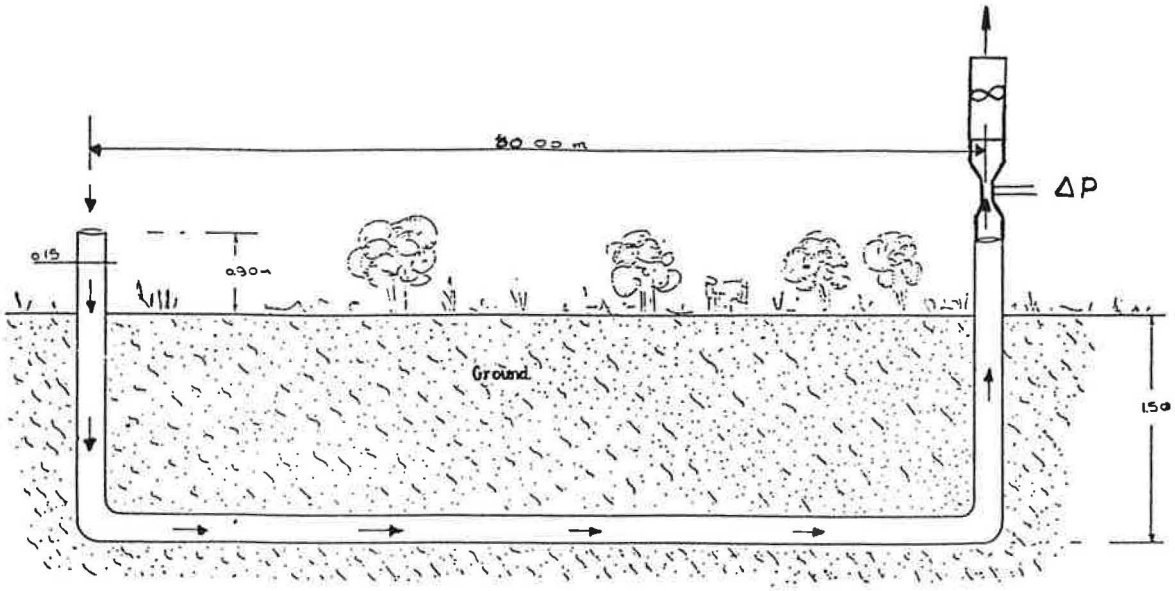

Fig. 7 : burried pipes

3.4. Interpretation of monitoring results

It is difficult to give general rules for the interpretation of monitoring results. Some points of interest are mentioned :
- the complexity of the interpretation depends on the type of monitoring campaign : 'a before-after'-experiment may require more corrections (e.g. for weather occupancy) than a repeated on/off experiment. The application of corrections increases the risk of systematical errors in the conclusions.
- the monitoring can be focused on a whole set of buildings, a specific building or a building component. The interpretation possibilities/ problems can vary significantly.
- the available evaluation tools influence strongly the interpretation possibilities :
  ex. : - an intelligent use of a powerful statistical software package allows refined interpretations of the measured data;
  - the use of appropriate identification methods allow in principle to obtain accurate results.
- the use of regression techniques is a common tool for the interpretation of monitoring results. Statistics have an enourmous potential as interpretation tool, however, it is clear that one can prove almost everything with statistics if it doesn't include a detailed error analysis and/or if the regression methods are badly chosen.

Multiple regression techniques should be used or at least checked by people experienced in statistics.
- The reporting should clearly indicate the assumptions in the analysis : was it assumed that the occupancy was identical, how were results for weather data corrected,..

The development of concepts for the interpretation of measured data should start preferably before the set-up of a monitoring campaign to reduce the risk of missing variables.

The use of enquiries may be useful and/or required if the performances are strongly influenced by occupants' behaviour or if the appreciation by the users of the passive cooling concept is an important element. The preparation of such enquiries may require the support of sociologists or other disciplines.

3.5. Extrapolation of monitoring results

The possibility to extrapolate monitoring results to other building designs or other weather conditions is in most campaigns desirable :
- the extrapolation to other weather conditions can be necessary for several reasons :
  - the weather conditions during the measurement campaign didn't cover all weather conditions for that region;
  - the results of the monitoring campaign should also be useful for other locations.
- the extrapolation to other building designs is in many cases necessary.

Extrapolation of results requires always great care especially when the interpretation techniques aren't based on a well developed theoretical concept. Therefore, one should very well describe the assumptions behind the extrapolation of results.

4. CONCLUSIONS

Monitoring is an essential element in performance assessment. Appropriate applications of passive cooling concepts may require some monitoring activities of the existing building stock, monitoring campaigns in well controlled test conditions as well as monitoring campaigns after implementation in real buildings.

The choice of the monitoring method (before/after, test/reference, on/off) can strongly influence the possibilities/problems with respect to measurements and interpretations. A careful preparation of the monitoring campaign together with an appropriate evaluation of the results are required for obtaining reliable conclusions.

5. REFERENCES

[1] Volume 1, Source Book for Energy Auditors, Edited by M.D. Lyberg, IEA Energy Conservation, April 1987
[2] Santamouris M., Triantis E., The philosophical school of the university of Ioannina, Proceedings Building 2000 Workshops, Dordrecht, Dec. 1988.