alter-CLIM: a decision tool for passive and hybrid thermal control strategies

Geoffrey van Moeseke

Architecture et Climat, Université catholique de Louvain, Louvain-la-Neuve, Belgique

ABSTRACT: A free access internet tool has been designed for architects. The objective is to give them knowledge about passive free cooling and active slab cooling strategies and convince them to study those further in their projects. The software, called “*alter*-CLIM”, is based on a transient simulation database build with Trnsys16. Simulations determine thermal comfort and energy consumption for various architectures and system designs. Investigated parameters are glazing surface, shading devices, lighting control, thermal mass, orientation, hygienic air flow, free cooling management and implementation (without or with complementary mechanical cooling : hybrid solutions). Various room destinations, such as individual or landscape offices, hotel rooms and meeting rooms are studied. New build and renovations cases are taken into account.
The software is easy to handle in order to become an often used tool by architects or engineers. Thanks to the comparison of various strategies’ performances, *alter*-CLIM helps to choose thermal control strategies in early design stages and to modify architecture in order to achieve thermal comfort and energy savings.
The starting point of *alter*-CLIM’s message is that architectural design and design of systems have to be determined simultaneously. The author believes this starting point is a condition to reach sustainable design.

Keywords: energy, comfort, software, free cooling

1. INTRODUCTION

Various studies and monitoring reports show how free cooling techniques are useful when trying to reduce energy consumptions of commercial buildings [1, 2]. Free cooling in this paper describes cooling techniques which do not request mechanical cooling. Literature shows that it is possible to design comfortable commercial buildings relying on those techniques if architectural and management conditions are met [3].

The energy consumption of commercial buildings is a major part of the energy consumption of the Brussels Capital Region. Free cooling techniques then appear to Brussels authorities as promising ones. Nevertheless, some questions had to be respond before promoting them among designers: for example, what are architectural design implications and how to ensure thermal comfort?

So Brussels authorities funded a research program intended to determine technical requirements, feasibility criteria and design guidelines for free cooling techniques. The research program had to result in a user-friendly tool for architects and engineers, introducing those elements.

2. METHOD

2.1 Strategy

Considering that a large number of architectural and management parameters are concerned when talking about the feasibility of the free cooling, it has been concluded that it was difficult to give precise guidelines for all parameters, since they all interfere. In place of textual guidelines, it has then been decided to create an interactive tool witch would give feasibility indications and improvement guidelines adapted to the particular case of the designer’s project.

A database compiling results of more than 250000 simulations has then been created. The simulations are dynamic ones computed for a typical Belgian year and a measured heat wave (July 1976). To exploit this database, stocked by the Brussels administration, a free access internet tool is created. Thanks to it, designers are able to access results of dynamic simulations for typical cases close to their particular concern.

2.2 Parameters

Simulations have been made for different kinds of rooms: a modular office surrounded by similar modules, a modular office placed under the roof or in the corner of the building, a meeting room, a class room, a landscape office with two opposite façades (symmetrical façades or not), a cafeteria, an hotel chamber and an hospital chamber. Those different rooms cover most of the commercial affectations in buildings.

The architectural parameters considered are:

- Orientation: North, East, South and West orientations are modelled, others are interpolated;

- Façade glazing surface: a centred window (40% or 70% façade opening) and a fully glazed façade are modelled;

- Shading device: clear glass, selective glazing (solar factor=0,3, light transmission=0,7), external solar screen, large overhang and neighbouring buildings' mask are modelled;

- Thermal mass: massive ceiling and massive floor or massive floor but false ceiling;

Management parameters are also considered:

- Artificial lighting management: with or without dimming;

- Internal gains: two levels (low and medium), with different values for every kind of room;

- Hygienic air flow rate: Two levels are proposed: 30 or 60 m³/hour/pers.

2.3 Systems

Different free cooling systems have been studied:

- Free cooling with intensive natural day ventilation: 4 ach managed during occupant's presence. This represents a manual opening of the windows by an occupant;

- Free cooling with intensive natural night ventilation: 8 ach managed during night. A limitation to night time represents free cooling strategies a noisy or polluted area;

- Free cooling with intensive natural day and night ventilation: the combination of the two preceding options;

- Free cooling with intensive mechanical day and night ventilation: 8 ach ensure day and night with mechanical pulsing and extracting. Designers may choose mechanical ventilation for architectural design considerations.

Those 4 free cooling strategies are studied in 3 ways:

- Used alone: free cooling is the only one strategy used to create thermal comfort. Nevertheless, thermal comfort is not ensured;

- Hybrid mode: a mechanical cooling is ensured in the rooms, next to the free cooling strategy. The free cooling is used firstly in order to maximise energy savings. This combination of free and mechanical cooling ensures thermal comfort;

- Assisted mode: a limited mechanical cooling is avoided on the hygienic air flow. A small cooling machine is able to ensure 1 ach at 14°C to assist free cooling. Thermal comfort is not ensured but more easily obtained than with the "used alone" mode.

Finally, a slab cooling system is proposed, either with a mechanical cooling of the injected water or with a free chilling (injected water cooled by heat exchange with outside air temperature). Our intention was to determine if those new techniques have to be promoted next to the free cooling techniques.

A reference optimal active cooling is also modelled. In every case, a mechanical pulsing and extracting is assumed for hygienic air flow.

2.4 Outputs

Two kinds of outputs are presented to the user: consummations data and comfort data. Two criterions are used to evaluate a thermal comfort level.

The first comfort criterion is to consider 100 occupied hours above 25.5°C and 20 occupied hours above 28°C as a comfort limit. This is a commonly used criterion, easily understood by architects and based on Fanger's theories [5]. In order to give more precise indications to the user, this criterion has been refined and 4 comfort levels defined: very comfortable (less than 50 hours<25.5°C and less than 10 hours<28°C), comfortable (less than 100 hours<25.5°C and less than 20 hours<28°C), uncomfortable (less than 200 hours<25.5°C and less than 40 hours<28°C) and very uncomfortable (more than 200 hours>25.5°C and more than 40 hours>28°C).

The second comfort criterion is based on adaptive theories developed by professors Brager and De Dear [6]. Comfort zones are defined following the external temperature of previous days. The implementation of this criterion in our tool is inspired from [7]. It is used to give comfort considerations for the modelled heat wave.

3. SOFTWARE DESCRIPTION

The designed software is organised on a two steps procedure. The first step is the identification of a simulation close to the designers concern. The second step is the detailed analysis of simulations results.

3.1 Identification of a simulation

To identify the closest simulation to the user's project, 11 simple questions are asked on 11 successive screens. Examples of questions are: "Which is the orientation of the studied room?", "Which level are internal gains?", etc. For every question, the user has to choose between different answers, corresponding to the various simulated cases.

Those questions allow identifying the parameters' values exposed in section 2. But they also are the occasion to give to the user some advices. A few lines are written for every question explaining which choice is the most efficient in order to reduce energy demand and to improve thermal comfort in case of free cooling.

An illustrated style has been chosen for the screens, in order to make them user-friendly.

Links are provided for every question to html files describing detailed hypothesis. Those files ensure an appropriate interpretation of the results by the users. Nevertheless, it is dubious that users will read all of the hypothesis files. So most important elements are repeated on the selection screen (figure 1). Links are also provided to PDF files (2 to 4 pages long) describing from a theoretical point of view the impact of the parameter on the thermal phenomena and illustrating this impact with results obtained from the database of simulations. Those PDF files also give rational energy use advices.

Once all parameters have been defined and a cooling strategy has been chosen. Three screens guide the user to more appropriate choice:

- The first one shows the energy consumption and comfort level for all modelled systems, applied to the architectural and management choices made (Figure 2). This allows the user to evaluate the pertinence of the chosen system and to switch to another one;

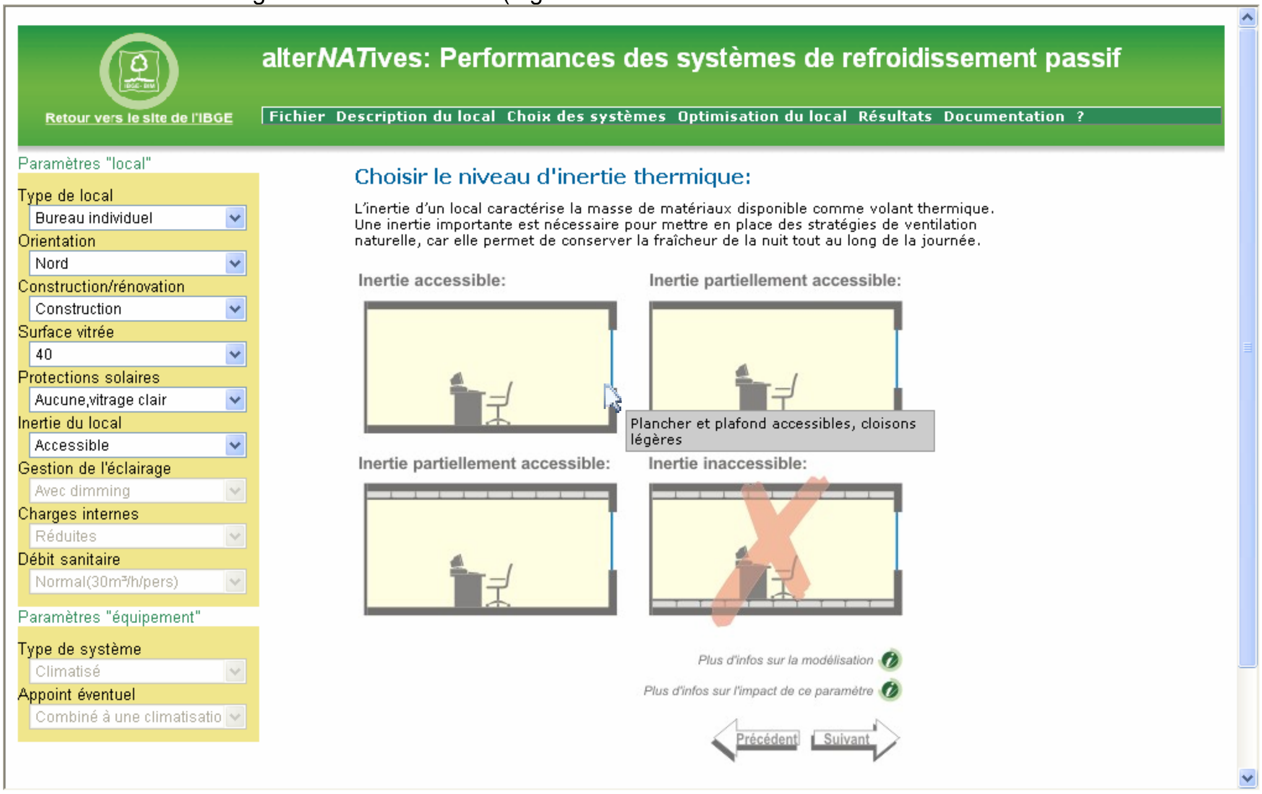

Figure 1: Example of a parameter definition screen (choice of the level of thermal mass). The user has to select one among four choices. Some advices are given on the top of the central part of the screen. Details appear in the grey box following the mouse cursor position. Links to html and PDF files with details are on the bottom right.

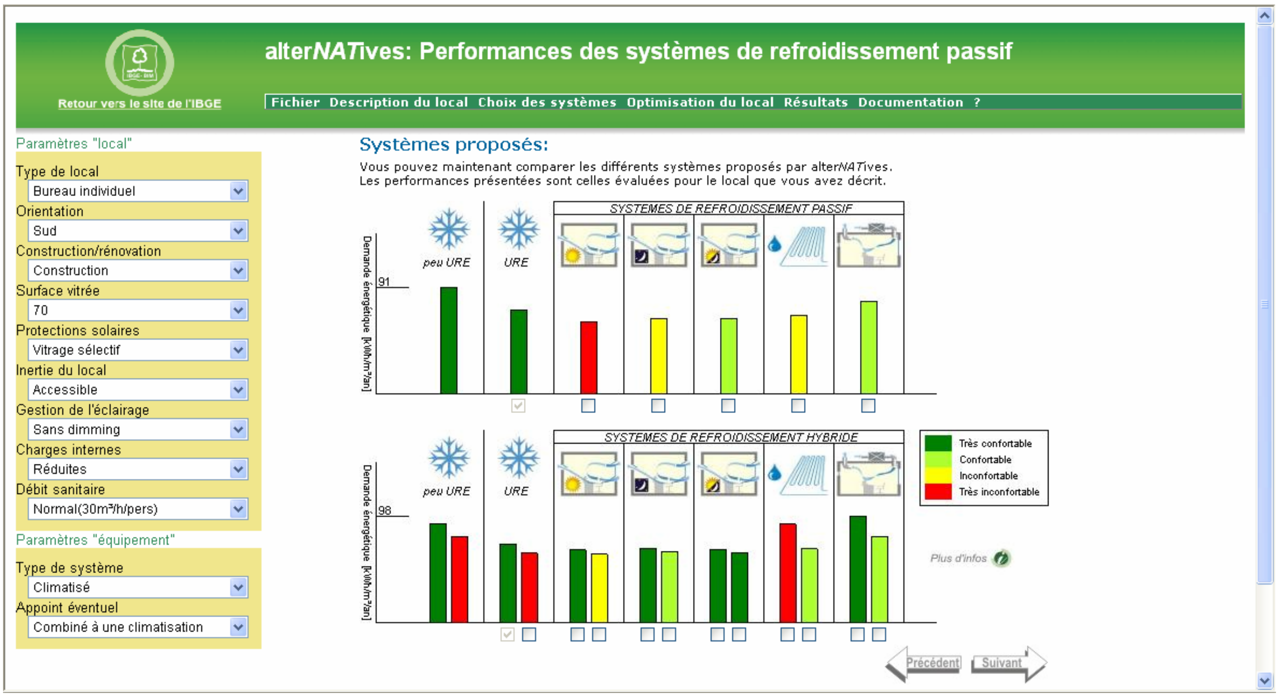

Figure 2: Screen showing energy consumption and comfort level for the chosen room and various cooling strategies.

- The second one shows, for the chosen cooling strategy and architecture, the impact of management and interior design choices on energy consumption and comfort level (thermal mass, lighting dimming,…);

- The third one shows, for the chosen cooling strategy, management and interior design, the impact of architectural choices as glazing ratio and shading device.

The objective of those screens is to remind that the systems and the architecture have to be designed together, influencing one the other: after choosing the architecture and a cooling system, the software proposes to reconsider the cooling strategy following the architecture and the architecture following the cooling strategy.

At every moment, as well when making choices as when reconsidering them, every parameter may be modified by a click on shortcuts on the left margin.

3.2 Detailed results

Once choices are made for the architecture and the cooling strategy, and after calling those choices into question, the user is shown detailed results for the simulation identified. Those results are of 4 kinds, divided in 4 screens:

- Details: this first results' screen shows performances of the combination of selected parameters. Those are expressed as hours exceeding 25.5 or 28°C, internal and operative temperature profiles, energy consumptions for heating, cooling, humidification, dehumidification, lighting, office automation, fans, pumps, etc. These consumptions are given in terms of building energy consumption (kWh/m²/year), primary energy need (kWh/m²/year), yearly costs (€/m²/year) and CO2 production (Tons/m²/year). Some advices are also given in order to improve the energy efficiency, for example the impact of an air exchanger on the hygienic air flow network;

- Alternative: this second results' screen allows the user to consider simultaneously two different choices' combinations. The outputs described for the "details" screen are shown for both cases. It allows determining the most interesting one of two strategies;

- Sensitivity: a dynamic tool allows the user to drawn histograms illustrating the impact of one or two parameters, all other parameters being kept constant;

- Investment cost: cost of architectural choices and free cooling techniques have been studied for a theoretical building considered as a reference one. The cost of various elements is shows to the user. He may select some of them and calculate the difference in investment for 2 cases: a free cooling strategy or an active cooling one. Default values for different elements may be changed by the user. Objective of this tool is only to give comparative estimations. Thanks to this, the user knows if the passively cooled building design is cheaper, more expensive or comparable to a standard design.

3.3 Documentation

Two kinds of documents have already been presented: html files describing hypothesis and PDF files describing impact of various parameters on building's thermal behaviour.

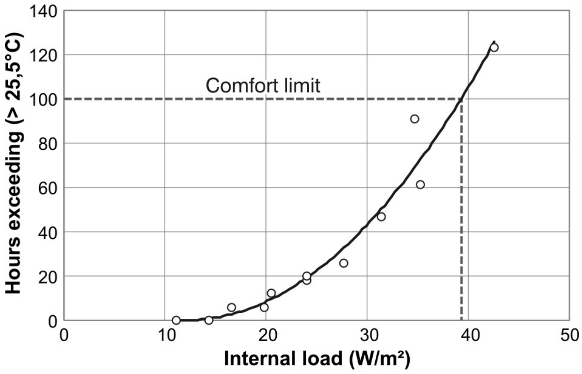

Figure 3: Internal gains impact on comfort for a South oriented office module with optimal choices in a free cooling strategy context.

Two other kinds of documents are provided on a PDF format:

- Some describing the technical implementation of free cooling techniques: architectural impact, physical principles, dimensioning rules, examples of existing buildings, various questions like air quality, noise problems, etc. Those documents try to vulgarise the architectural and technical consequences of free cooling techniques;

- Some describing the performances of free cooling assisted free cooling and hybrid cooling strategies. These documents show energy savings and conditions to ensure thermal comfort for the chosen strategy. Results are based on the simulations realised and on existing monitoring.

By printing and collecting all these PDF files, the user disposes of an exhaustive handbook about free cooling design.

4. RESULTS

The implementation of the software described in section 3 was only a part of the research program. The other part was to determine feasibility criteria and design guidelines. As explained above, the software itself plays this role, but some other generic rules have been pointed.

This section resumes findings for some parameters. More extensive results may be found in former papers [8, 9].

4.1 Internal gains

An upper limit for measured internal gains is found. Its value is 40W/m² (Figure 3). For internal gains above this limit, free cooling strategies will not be able to create thermal comfort conditions.

To determine this value, all parameters except internal gains are set to the optimal value: glazing surface is set to 40%, shading is ensured with external screens, orientation is set to south (but the external screens make this parameter of lower impact), false-floor and false-ceiling are removed, day and night intensive ventilation in ensure.

A mechanical cooling assistance may upraise this limit by 10%.

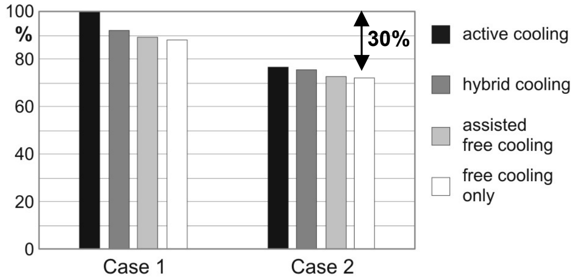

Figure 4: Total energy consumption for 2 office modules. Case 1= 100% south oriented selective glazing, mechanical cooling, 28 W/m² internal gains. Case 2= 70% South oriented glazing, external blinds, massive floor and ceiling, day and night intensive ventilation, 20 W/m² internal gains.

4.2 Energy savings

Large energy savings are possible thanks to the free cooling strategies. Those are maximal if architectural and management interventions limit external and internal loads. Figure 4 compares a common design (case 1) with a most efficient one from an energy point of view (case 2).

Figure 4 also shows energy savings for an office module when only the cooling strategy is changed. These may exceed 10%. Mechanically assisted free cooling leads to lower savings (10%). Hybrid cooling allows 7-8% energy savings.

4.3 Thermal comfort

Free cooling techniques may be insufficient to ensure thermal comfort conditions. Figure 5 show the comfort levels for a typical year with various cooling strategies. Glazing surface is of major impact: fully glazed ones leads to discomfort in most cases. Even for limited glazing surfaces, interventions on shading devices, internal gains or thermal mass may be necessary to reach thermal comfort.

A limited mechanical cooling may be efficient to upraise comfort levels. But it will not ensure comfort for every situation.

During a heat wave, unpublished results show that free cooling will seldom ensure the thermal comfort. All parameters have to be set on the most favourable values to maintain desirable internal temperature.

Thanks to a limited mechanical cooling supply, heat waves may more easily be supported, while most of the energy savings remains possible.

4.4 Free cooling with mechanical intensive ventilation

Designers may think that intensive ventilation with a mechanical pulsing and extracting is an interesting way to manage free cooling, for example when fresh air needs to be taken in a distant courtyard or when an earth-air heat exchanger is foreseen.

Unfortunately, simulation results show that energy savings permitted with the free cooling strategy are compensated and sometimes overruled by the increase in fan consumption (Figure 6). Our assumption for the fan consumption was of 0.85 Wh/m³ which represents a typical mechanical ventilation network.

4.5 Slab cooling

This technique shows some interest since the noise and security problems inherent to intensive ventilation are avoided. But the energy savings are smaller because of control difficulties, leading to an increased heating demand (Figure 6).

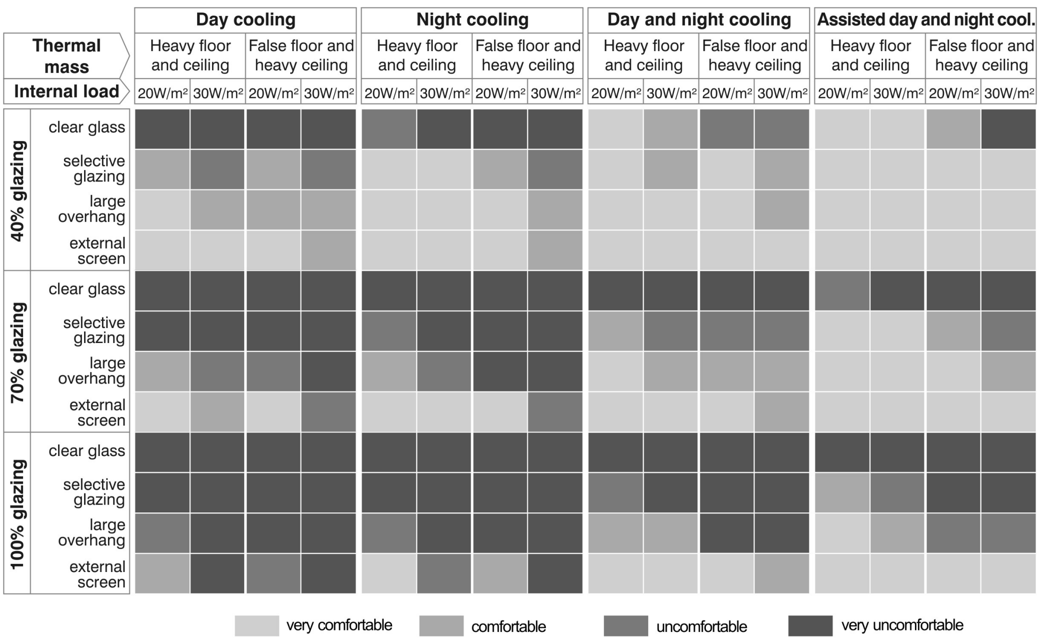

Figure 5: Comfort conditions for three free cooling strategies (day only, night only, day and night) and one assisted free cooling strategy (day and night intensive ventilation + limited mechanical cooling).

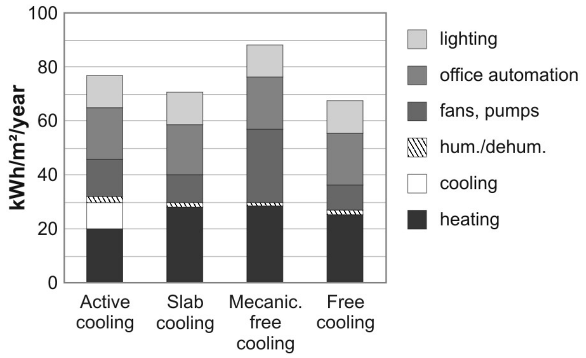

Figure 6: Energy consumption for an office module with 70% South oriented selective glazing, 28 W/m² internal gains and high thermal mass.

5. CONCLUSIONS

5.1 Internet tool

A user-friendly internet tool has been developed to promote free cooling techniques among architects and building designers. It is based on thousands of dynamic simulations.

This software compares the impact of various architectural and management parameters, as well as various cooling strategies. Studied outputs are the energy consumption and the thermal comfort. The structure of this software is made to guide the user to the most efficient choices from the energy point of view. The idea that the designs of a building and of cooling systems have to be thought as interacting elements is the basis of this tool.

This tool will accessible be online in autumn 2006 from IBGE website: www.ibgebim.be.

5.2 Feasibility criteria and design rules

Next to this tool, feasibility of free cooling techniques is examined. Thermal comfort for a typical year is found behind reach is some design rules are followed. Most important are:

- To reduce solar gains by reducing glazing surface and using efficient solar shadings;
- To reduce internal gains by limiting electrical power in the rooms and support natural lighting;
- If night cooling is used, to manage a large thermal mass.

Nevertheless, considering a heat wave, all parameters will have to be optimized in order to ensure thermal comfort. Unfortunately some parameters may be beyond control of designers, like rooms orientations in urban context, or specifically high internal gains due to a particular activity. Those unfavourable conditions will make the free cooling strategies difficult to spread among promoters. They nevertheless merit to be sustained.

5.3 Assisted and hybrid cooling

Mechanically assisted free cooling strategies appear to be particularly interesting. Energy savings remains large if the free cooling is used firstly, and thermal comfort is more easily reached. Those assisted free cooling strategies may be generalized in new and retrofitted buildings since major arguments against free cooling are answered: comfort is more easily ensured, investments are limited if considering that a mechanical hygienic flow network is always provided and energy savings are large.

Hybrid cooling, with a priority in use for free cooling, also allows energy savings. This solution is of interest when architectural choices are so that free cooling is strictly forbidden: a fully glazed surface for example. Nevertheless, alternative solutions such as different architectural choices should be encouraged in place of the hybrid strategies. Indeed, a reduction of the cooling demand will save more energy and is a more sustainable solution than maintaining a high energy need, partly filled with natural methods.

5.4 Slab cooling and mechanical intensive ventilation

Those two techniques have been studied. Their interest appears to be limited compared to natural intensive ventilation.

6. AKNOWLEDGEMENT

This research was made possible by contribution from the Institut Bruxellois pour la Gestion de l'Environnement. The authors gratefully acknowledge their support of this project.

7. REFERENCES

[1] BRE, Natvent project monitoring reports, available at http://projects.bre.co.uk/natvent/

[2] A.Delsante, T.A.Vik, Hybrid ventilation: State of the art review, 2002, IEA Annex 35

[3] H.Bresch, A.Bossaer, A.Janssens, Passive cooling in a low-energy office building, Solar Energy 79 (2005), 682-696

[5] ISSO. Energie-efficiënte kantoorgebouwen: binnenklimaat en energiegebruik. 1994, SBR publicatie 300, Rotterdam

[6] G.S.Brager, R.J.De Dear, Thermal adaptation in the built environment: a literature review. Energy and Buildings 27 (2002),. 83-96

[7] A.C.van der Linden, A.C.Boestra, A.K.Raue, S.R.Kuvers, R.J.de Dear, Adaptive temperature limits: A new guideline in The Nerderlands, Energy and Building 38 (2006), 8-17

[8] G.van Moeseke, I.Bruyère, A.De Herde, Development of design guidelines for tertiary sector buildings equipped with natural ventilation systems, proc. 26th AIVC Conference, Brussels, Belgium (2005), 191-196

[9] G.van Moeseke, I.Bruyère, A.De Herde, Design guidelines for natural ventilation systems in tertiary sector buildings, proc. CISBAT 2005 Conference, Lausanne, Switzerland (2005), 305-309