Approach to classification and evaluation of naturally cooled buildings and analysis of what impact passive cooling systems have on architectural design

Gianluca Cadoni

ENSA-Marseille, Laboratoire ABC, 184 av. de Luminy - case 924 13288 Marseille, France

Abstract:

Passive cooling systems are the combined technical solutions and design strategies used to promote low carbon cooling. The aim of our research is to evaluate the performance and efficiency of these systems, why and when they do not function correctly, and to assess what impact they have on architectural design. This methodological approach allows us to compare passive cooling systems in contemporary architecture in different parts of the world and to analyse the posture regarding the integration of passive cooling systems.

Keywords: Passive cooling system, low carbon cooling, building-system, an architect's posture

1. Introductıon

1.1. Article plan

The aim of the present research is to estimate the efficiency of passive cooling systems, the reason for their success or failure and what impact they have on architecture. Thus, an analysis and evaluation methodology was set up to verify the viability of passive cooling systems in contemporary architecture. Two *tools* were set up to evaluate the buildings: firstly, a data matrix, which we shall call a *critical database* that allows for comparisons to be made between qualitative and quantitative data, and secondly, *files* on each building that contain both quantitative data and a critical analysis of their architecture. The *files* serve as instruments of communication. Moreover, the architectural appraisal they contain aims at understanding the architect's posture[1] regarding the integration of passive cooling systems. To explain the methodological approach, we will use the French Lyceum of Damascus, Syria, designed by the architect Yves LION, as an example.

1.2. Why is it important to do a research on the passive cooling systems?

Some data about Air Conditioning are essential to explain the necessity of this type of research: in 2007 the global market for AC increased by approximately 14%. Even more worrying is the fact that in 2008 China became the world's largest market for air-conditioning (1). We can easily imagine the consequences on energy demand.

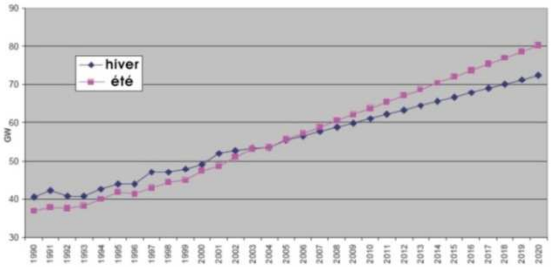

Figure1. Previsions of electrical consumption in Italy MAP (2)

Other important confirmations can be obtained from this graph, diffused by the Italian Ministry of Productive Activities. We can see that in 2004 summer energy consumption exceeded the winter energy consumption. In the Mediterranean area the necessity of cooling are more important than the necessity of cooling (3).

1.3. The issue of research

Few architects have employed passive cooling systems in recent years. The problem is that the scientific literature and technical solutions are rare or in experimental phases. It is difficult for an architect to propose solutions that haven't been tested. Passive cooling systems were common in vernacular architecture, but architects have stopped using this knowledge. In hot climatic regions, vernacular architecture has often been studied to guarantee summer comfort. In the past, physical activity in houses was more important. In winter, users covered themselves or Lit fires. In summer, they could only reduce physical activity. The comfort temperature in houses was about 16°C in winter. Today the comfort temperatures are different and vary from 21/22°C in winter to 26/27°C in summer (4 p. 18). Contemporary architects, to respond to contemporary comfort demands, have preferred to abandon vernacular construction rules in favour of AC systems. The reason is that it is not easy to adapt vernacular constructive solutions to contemporary comfort demands without research and experimentation.

We consider that the number of contemporary buildings that adopt passive cooling as a design strategy to promote low carbon cooling is very limited (3). The PHDC[2] research group, for example, estimates that no more than 50

[1] Dictionary definition. Posture: a mental or spiritual attitude, from: http://dictionary.reference.com/browse/posture [20/05/2011]

[2] Passive and Hybrid Downdraught Cooling (http://www.phdc.eu/)

buildings cooled by evaporative cooling systems have been built worldwide over the past 15 years (5 p. 47). The problem, was that we had to analyse buildings that are localized in different parts of the world. Our methodological approach aims at comparing and evaluating summer bioclimatic buildings performances, as well as understanding the integration of passive cooling systems in architecture. The adopted method has led us to compare buildings with different functions in different parts of the world. We have put into place a number of indicators that will enable us to make critical analyses and comparisons of different buildings. These indicators will also help us to analyse both summer and winter bioclimatic performances.

2. Methodology adopted for building analysis

To resolve our problem, we have developed a methodology that permits us to evaluate the buildings as systems, the objective of which was to guarantee the thermal comfort of users. Our *systemic* approach (6) permits us to study buildings and their architectural devices[3] and to interpret them as an engine that guarantees the thermal comfort of users. We consider "*that a dynamic and responsible interaction between inhabitants and architecture can lead to important energy and carbon reductions, and consequently that buildings do not consume energy, inhabitants do through the medium of architecture*" (7). Therefore, evaluation must take into consideration not only technical solutions, but also the comportment of users and social aspects. E. RECHTING et M. MAIER (8) define the complex systems as models composed by linked devices that aim to obtain a result. We analyse buildings as complex systems composed by different devices: technical, usage, social, and so forth.

2.1. Methodology-based research

The analysis was carried out by dividing the building into progressively smaller architectural devices, starting with territorial implantation and concluding with design details. The functions within the building system were also analysed, based on J.L. LE MOIGNE's systemic approach, by adapting the method's four precepts to our problem. The aim of this division into individual elements was to analyse each element following its function within the whole system. In order to evaluate and divide the building up we followed the method used by S. HANROT (9). The vertical break-down of buildings gave rise to a matrix of both quantitative and qualitative data, which we designated as the *critical database*. The evaluation of the architectural devices followed S. HANROT's method (10), with critical appreciation for them ranging from 1 to 6: 1=very poor, 2= poor, 3= sufficient, 4=good, 5=very good, 6=excellent. Hence, by using these grades, the bioclimatic performances of buildings could be evaluated. A satisfactory mark (3) corresponds to a well-designed device that was congruent with the building system. The lowest grade means that the device has reached a *critical point* – the point at which a single factor causes the non-functioning of the building system - where the building was unable to guarantee user thermal comfort.

2.2. The critical database

The critical database is a data matrix analysed at different definition levels. It contains technical and quality data as well as critical analysis data and the grades that enable us to evaluate the bioclimatic buildings performances. The critical database is broken down into the following definition levels: <u>Territory</u> => latitude, longitude, the climate, etc. <u>Group of buildings</u> => orientation, etc. <u>Entities</u>=> morphology, volume, etc. <u>Systems to improve user comfort</u> => cooling, control strategy etc. <u>Divisions</u> => outward vertical divisions, etc. <u>Constituent parts</u> => inert materials, types of glass, etc. One of the aims of the critical database is to compare different passively cooled buildings.
Given that over 60 architectural devices have been analysed, the amount of data is too large for easy comparisons to be made between any two buildings. To resolve this problem we chose the most significant indicators - those which are badly designed or built can jeopardize the bioclimatic functioning of a building - and created a radar chart that had 12 indicators and the average mark attributed to each element. The most important indicators are:
<u>*Morphology of the group*</u>: defines the shape and the layout of the buildings in the global operation. <u>*Usage*</u>: defines the use of the building at the time of researching. <u>*Functional plan*</u>: defines the organizational structure of the building. <u>*Shape coefficient*</u>: defines the ratio (adimensional (11 pp. 52-74)) between the outside surface and the volume of a building. <u>*Rate of active glazing*</u>: defines the ratio between the glazed surfaces and the peripheral floor shape. <u>*Relationship between the passive cooling system and the climate*</u>: defines whether the passive cooling system used is appropriate to the site's climate. <u>*Natural lighting*</u>: defines what percentage of daylight penetrates the building. <u>*Thermal inertia*</u>: defines the capacity of keeping a stable temperature. <u>*Functioning of the passive cooling system*</u>: defines how passive cooling systems function and how they are adapted to the building. <u>*Control strategy of building services, both automatic and human*</u>: defines the control mode of passive cooling systems and how they relate to the whole building. <u>*Partitioning*</u>: defines the internal barriers preventing air flowing through buildings. <u>*Solar protection of vertical surfaces*</u>: defines the presence and quality of sunscreens.
If one or more of these indicators is badly conceived or implemented, then the entire building system cannot guarantee the thermal comfort of its users. The image that this radar chart provides concerning the French Lyceum in Damascus is easily interpreted.

[3] Dictionary definition of "device" : a machine or tool used for a specific task, from: http://dictionary.reference.com/browse/device+ [20/05/2011]

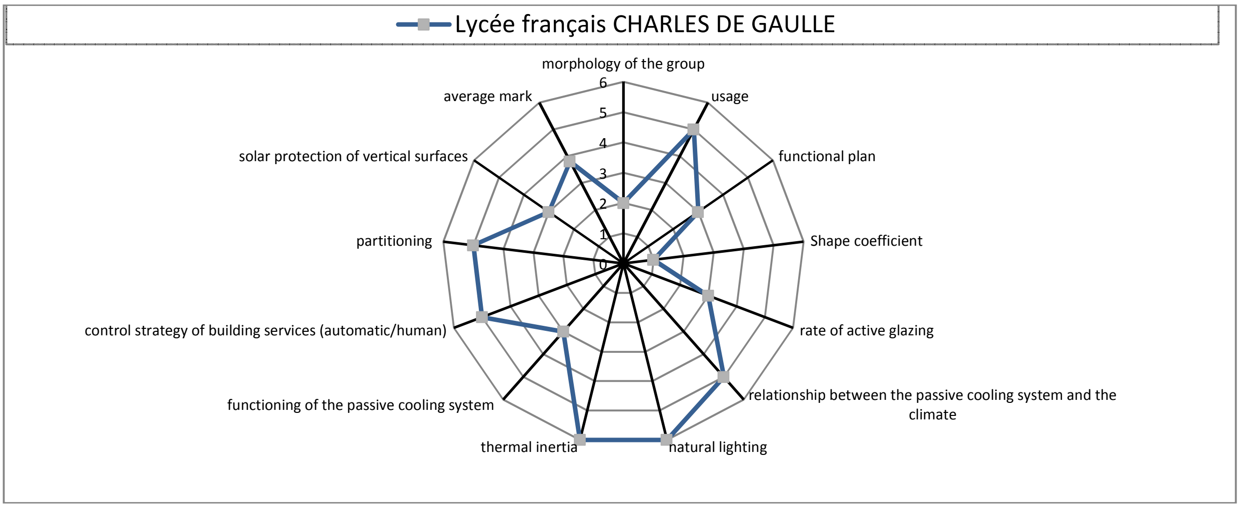

Figure2. The radar chart of Lycée Français Charles de Gaulle, Damascus.

The building is well conceived and built, although one badly-ranked indicator underlines certain weak points. The critical indicator is: Shape coefficient. The building is composed of little pavilions that are connected by exterior corridors. The problem is that the external surface of the building is very large. Moreover, the absence of thermal insulation, linked to the shape coefficient can jeopardise the thermal comportment of the whole building. One of the most unusual devices of this building is the control strategy. The architect has decided to adopt the human control strategy as an educational instrument. The users open and close the solar chimneys following instructions displayed in every classroom. If the users do not make correct use of the openings that are studied to guarantee natural ventilation at night time, the passive cooling system does not work, and the classroom is too hot the next morning. In other places, this system of functioning is not highly regarded, but considering the educational purpose of this building we have decided to give it a good grade for this device.

2.3. Comparison of two different buildings

This methodological approach has enabled us to compare different buildings in different parts of the world. In this article, we are comparing the French Lyceum in Damascus with the CII Institute of Quality, Bangalore, India; the building contains offices of the Indian industry institute.

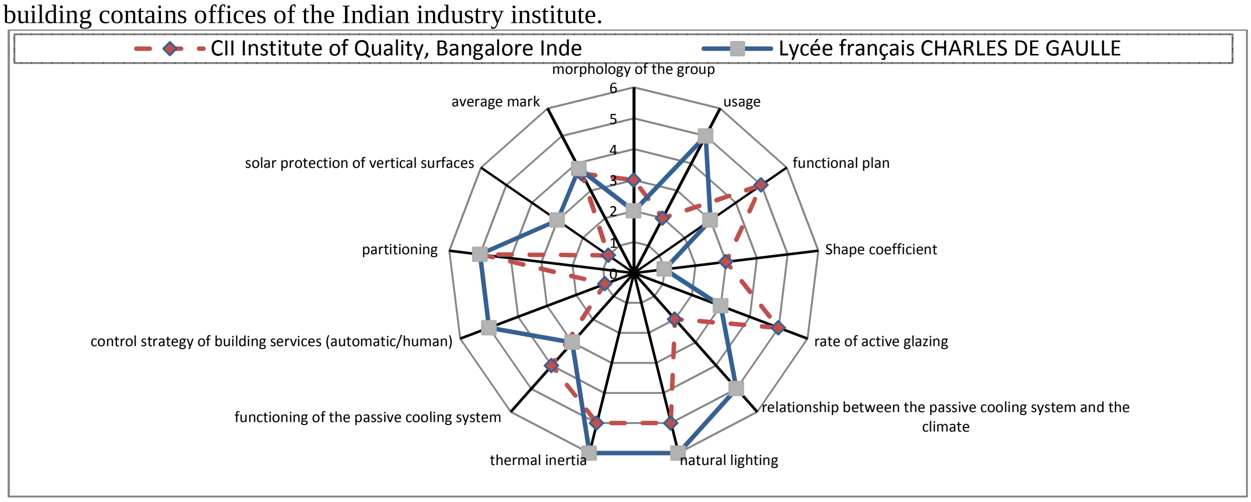

Figure3. The radar chart of comparison between the French Lyceum and the CII Institute of Quality

The graph shows us that the two buildings have a similar average grade, but the Bangalore building has different problems, in particular the control strategy and the solar protections. The solar protections are insufficient, because the building faces west, a problem that can jeopardize the working of the system. The most important problem is that the passive cooling system has a human control strategy. This is a problem because users start the evaporative cooling system only when they are in thermal discomfort. The passive downdraught evaporative cooling system can maintain the comfort temperatures, but cannot lower the temperature, in the extreme climatic conditions of Bangalore. However, if the control system were automatic, it could start functioning before discomfort temperature levels were reached. Thus we can see, in this case, how control strategy can jeopardize a building's entire system, depending on the analysis of the usage linked to the type of building and the type of passive cooling system.

2.4. Methodology adopted to analyse the posture of architects in relation to the integration of passive cooling systems

We use the same classification that G. BAIRD uses in the book *The Architectural Expression of Environmental Control Systems* to analyse the posture of architects in relation to the integration of technical systems "*…'building system integration can also be used as a means of visual expression'… Level 1: Not visible, no change. The system or subsystem in question is not in view to the building user, and therefore modifications of its physical form are esthetically irrelevant. Level 2: Visible, no change. The system is exposed to public view but not altered or improved in any way from what the purely functional application requires. Level 3: Visible, surface change. The system is visible to the building's occupants and has had only surface alterations made to it, with its other physical aspects remaining unchanged. Level 4: Visible, with size or shape change. The system is visible to the user of the building and has been given a size and/or shape other than what is simplest and most economical. The surface treatment and position may remain unchanged. Level 5: Visible, with location or orientation change. The system is exposed to the view of the occupants of the building, but its position has been altered from what is functionally optimal. The shape or surface, however, may remain unchanged.*" (12 p. 12). By applying Baird's system, the Damascus lycée obtains a level 3 and the Bangalore IIC Building a level 5.

2.5. The impact of passive cooling systems on buildings typology

We try to analyse what is the impact of passive cooling systems on architectural design. Y. MANSOURI in his research works (13), has linked the typology and the topology of natural ventilation systems to the typology of buildings. Starting from his works we have modified his typo/topological grid to adapt it to all the passive cooling systems. This image permits us to better understand the architectural constraints generated by passive cooling systems.

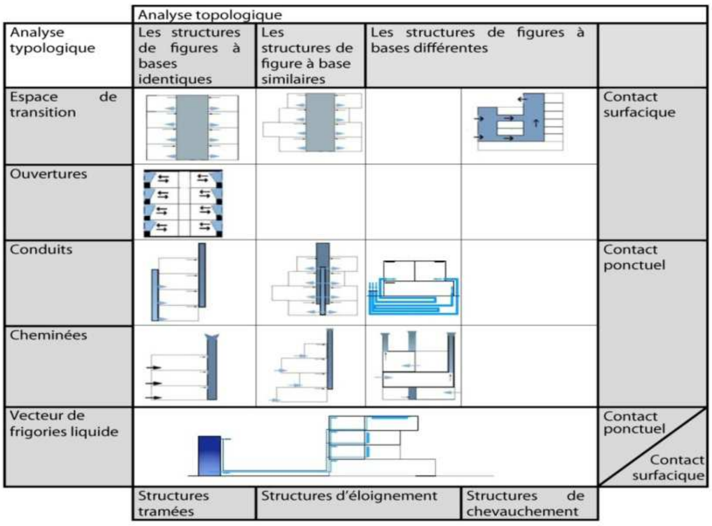

Figure3. Grid of typo/topological analysis of passive cooling systems

3. Files of buildings

To improve the knowledge of buildings and to communicate the analytical results, we used the second *tool* that we created. While the data matrix enables us to understand the way passive cooling systems function, files on buildings allow us to focus on their architectural aspects and communicate the results of the research.

3.1. Content of files

The building files layout derives directly from the critical database, and is divided into four parts: A synthetic, analytical description of the building appears on the first page, along with the file index, the building's geographical and climatic positions and a *synthetic logo* of the building that facilitates understanding of how the building functions, the typo/topology of passive cooling systems and the level of integration of passive cooling systems.
The second and third pages contain the radar chart and the psychometric analysis of the climate of the site. The third part details the devices based on the critical database analysis, with some images helping us to understand better the synthetic analysis. The fourth part is devoted to architectural reviews that aim to investigate the architect's posture in relation to the integration of passive cooling systems. Previous analyses have allowed us to understand the bioclimatic functioning of the building. The methodological approach that we used has enabled us to assess the different architectural devices. The architectural reviews aim at replying to another question: what is the impact of passive cooling systems on architecture? The files contain the images and graphs, which illustrate and explain the analyses more clearly and coherently. Moreover, when data is accessible, the results of pre-construction simulations and the real performances of the buildings, as well as post-occupancy assessments, are presented and analysed.
These supplementary analysis have added to our knowledge of the building and to the design orientations taken by architects to obtain the final results.

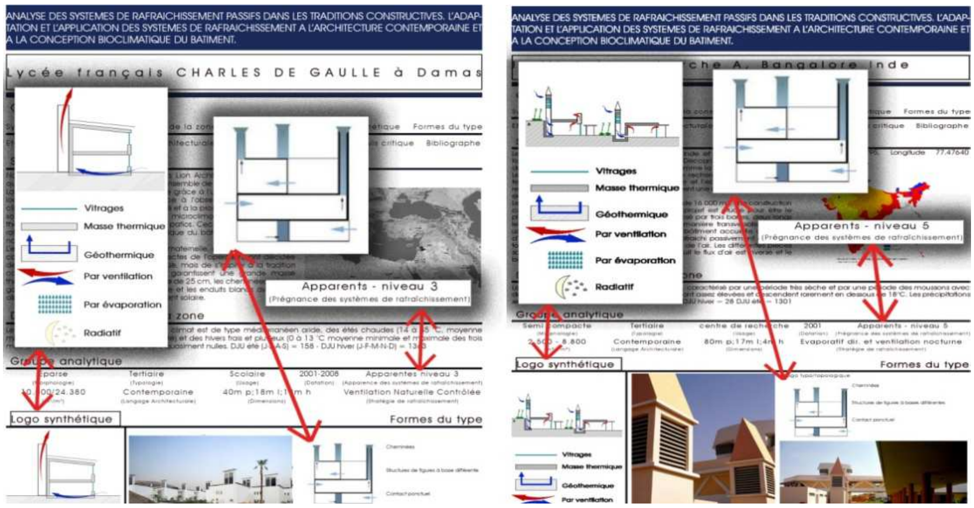

Figure4: The first page of Damascus and Bangalore files, emphasis on synthetic and typo/topological logo.

4. Conclusions

It was possible to compare two different buildings thanks to the critical database. The architectural appraisal has enabled us to understand the decisions made by the architects. The data matrix has allowed us to understand better the functioning of passive cooling systems in the same way as the files have allowed us to give prominence to the architectural aspects and the architect's position regarding the integration of cooling systems in his project. Although only two buildings have been compared in this article, our methodological approach will enable us to compare many buildings and to know when, how and whether passive cooling systems work well or not. We aim to create a database of rules that will allow the architect to reduce errors to a minimum.

Acknowledgements

I would like to thank all the people who contributed to the article, namely: The Sardinian Region, which financed the Master and Back Research Program, Stéphane HANROT, Jean-Louis IZARD.

References

1. **BSRIA .** Review of the World Air Conditioning Market 2007. *bsria.co.uk.* [Online] 06 2008. [Cited: 28 03 2011.] http://www.bsria.co.uk/news/1997/.
2. **Ministero Attività Produttive.** scenario energetico tendenziale al 2020. *Ministero dello sviluppo economico.* [Online] 05 2005. [Cited: 13 08 2010.] http://dgerm.sviluppoeconomico.gov.it/dgerm/scenarioenergetico.asp.
3. **FORD, Brian, et al.** *The Architecture and Engineering of Downdraught Cooling: A Design Source Book.* UK : FORD, Brian; SCHIANO-PHAN, Rosa; FRANCIS editors , 2010. p. 199. ISBN 978-0956579003.
4. **GROSSO, Mario.** *Il rafrescamento passivo degli edifici in zone a clima temperato.* [ed.] Maggioli Editore. San Marino : Maggioli Editore, 2008. p. 648 . ISBN 978-88-387-3963-3.
5. **PHDC.** Cooling Without Air-Conditionning. *01_02-PHDC_Downdraught Cooling a Primer P47.* [CD-ROM]. Bologna, Italie : s.n., 29 10 2009. Conference PHDC Bologna 29-30/10/2009. P10006183248.
6. **LE MOIGNE, Jean-Louis.** *La théorie du système général théorie de la modélisation.* [ed.] http://www.mcxapc.org. 4e édition. internet : Modélisation de la CompleXité, 2006. p. 360. version publiée sur le web http://www.mcxapc.org. ISBN 2130465153.
7. **PLEA2009 Manifesto.** plea 2009 Manifesto. *plea2009.* [Online] 24 06 2009. [Cited: 05 08 2011.] http://www.plea2009.arc.ulaval.ca/En/Manifesto.html.
8. **RECHTIN, Eberhardt and MAIER, Mark W.** *The Art of Systems Architecting.* [ed.] Taylor & Francis Group. 3eme edition. New York : CRC Press, 2009. ISBN 978-1-4200-7913-5.
9. **HANROT, Stéphane.** *Modélisation de la connaissance architecturale pour un outil de CAO intelligent.* PARIS : Plan Construction et Architecture, 1989. p. 246 . ISBN 2100 85419-7.
10. —. Evaluation relative de la qualité architecturale : une approche par le point de vue des acteurs. [ed.] Editions De La Villette. *Cahiers Ramau - La Qualité Architecturale - Acteurs Et Enjeux* . 2009, 04 2005, 5.
11. **TRAISNEL, J.-P.** Note sur la décomposition du coefficient G. [ed.] COFEDES. *CAHIERS SCIENTIPHIQUES ET TECHNIQUES CO.F.E.D.E.S. Architecture Climat Energie.* 1986, p. 240.
12. **BRAID, George.** *The Architectural Expression of Environmental Control Systems.* London : Spon Press, 2001. p. 264. ISBN 0-419-24430-1.
13. **MANSOURI, Yasmine, dir. ALLARD, Francis and co-dir. MUSY, Marjorie.** Conception des enveloppes de bâtiments pour le renouvellement d'air par ventilation naturelle en climats tempérés : Proposition d'une méthodologie de conception. [Thèse de doctorat : discipline Science pour L'ingénieur, spécialité Architecture]. Nantes : Université de Nantes, Ecole polytechnique de l'Université de Nantes, 2003. p. 320.