Low cost, energy and impact ceramic cladding cooling system by means of evapotranspiration or ‘botijo-effect’.

Javier García-López.
Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla. Email javigalo@us.es

Abstract: A new ceramic cladding system was first applied in the house prototype named "SOLARKIT”, representing the University of Seville in the international competition Solar Decathlon Europe 2010, where its effectiveness was registered by thermographs y and the monitoring of the building.
Therefore, as a result of this R+D+I experience derived from the search of a low energy and innovative cooling bioclimatic strategy, a new cladding system has been invented and patented.
Consequently, the patented invention relates to an external cladding system using tiles made from a porous-ceramic material or similar, named as a façade with “botijo-effect”. Thus, the system can be applied directly as a final cladding or used in external sheets of ventilated façades. Compared to traditional claddings, this system provides de possibility of cooling its surface by means of evapotranspiration generated by supplying water through a network of canaliculi inside the tiles.
An estimated superficial cooling power of over 80 W/m² can be considered, plus an 8 to 10ºC cooling effect on the air temperature
Its application is particularly interesting at locations with hot-dry climates where there is a high cooling energy demand or where is intended to mitigate the "heat island" effect in urban environments.

Keywords: evapotranspiration, botijo effect, ceramics, patent, biomimetic technology

Introduction

The use of techniques of using water cooling or "evaporative cooling" in buildings has been present in architectural culture Andalusian, North Africa and the Middle East for centuries (J.Neila). Examples have survived until the present day in the form of archetypes such as the Andalusian patio, or monuments of the Nasrid Alhambra and Generalife of Granada architecture. Ventilation chimneys, originating in the Middle East, also use the cooling by humidification and dehumidification to downdraught cooling the interior of the buildings (B.Ford, S.Álvarez et.al).

Contemporary examples of the use of surface evaporation in ceramic materials as passive conditioning technique can be found in the forest of ceramic pillars of the Pavilion of Spain at Expo-Zaragoza 98 designed by Francisco Mangado, or in the ‘bioskin’ ceramic tube brise-soleil façade of the Sony Osaky Building in Tokyo (V.Lerum), designed by Nikken Sekkei.

Figure 1 SolarKIT prototype at Solar Decathlon 2010 with ceramic ventilation towers ©R. Santoja

Fundamentals

The ambient water surface evaporation is an endothermic process, which absorbs energy. This energy or heat of evaporation is provided by direct conduction through the materials from the environment such as water or a solid saturated of humidity as the ceramic element or other porous materials. This phenomenon is based on traditional techniques of cooling as the botijo (Fig 2), a type of Spanish handmade ceramic jug, which keeps it cool the water content for your drink thanks to its surface evaporation.

The operation of the botijo has come to be described through a very complex formulation, according to published authors J.I. Zubizarreta & G. Pinto (J.I Zubizarreta et al, 1995).

There is something which, however, is not so difficult to quantify, as it is cooling due to the water evaporation capacity. The energy used in the evaporation of water at room temperature is called heat or enthalpy of evaporation, and can be obtained from the electricity tables. At room temperature, we can consider it as 580 kcal/kgH20 (2426 kJ/kgH2O), i.e. 580 kilocalories are absorbed for a kg of water evaporates.

Figure 2 Botijos from La Rambla ©M. Ruiz Díaz

The so-called "mass transfer coefficient" or k' (kgH2O/hm²), estimated at 80 kg water/hm² according to (J.I Zubizarreta et al, 1995), describes the amount of water that "sweat" or passes the jug to its surface per unit area and time. This factor is the key to the ability of a surface cooling with cooling by evapotranspiration, as in the case of crops, where they join the phenomena of evaporation of water from the ground and plants.

The amount of energy extracted per unit area "botijo" and time will be

Q=k'*H ,Being H = enthalpy or heat of vaporization (580 kcal/kgH20 = 2426 kJ/kgH2O) k'=80 (kgH2O/hm²) [1]

Then for each surface unit is would extract 53.9 joules per second, equivalent to a cooling of 53.9 Watts power per unit area (m²).

B. Morillo recent experiment has measured up to 0.224 kg/hm² of surface evaporation, equivalent to a 140 W cooling power per m².

This cooling capacity described as energy removed per unit time is getting cool the water of the pitchers, and in practice can be used in other applications as thermal building conditioning, as we will see below.

Considering these fundamentals, the geographic areas with greatest potential for exploitation of surface evaporation for the new or the refurbishment of the buildings will be those with a climate of warm, dry summers as regions with Mediterranean climate.

Problem to be solved

This section discusses the technical problem which is given solution by the new invented system. This problem could be formulated using the following questions:
Is it possible to incorporate the surface cooling to the wall of a building by means of a simple and passive technology?

Would it be possible to take advantage of this effect of surface cooling to provide air cooled flows without the contribution of additional moisture?

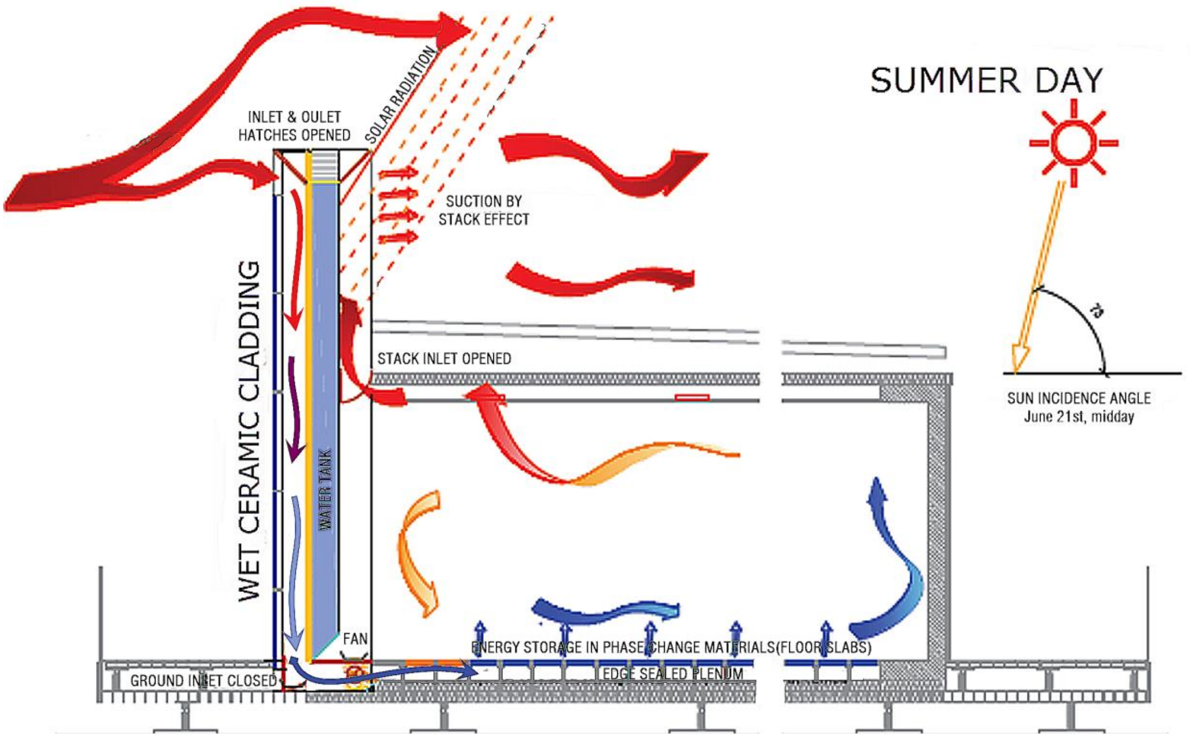

Figure 3 SOLARKIT's Ventilation tower scheme. Summer-day period.

[1] According to experiment described in article of *J.I Zubizarreta y G.Pinto*

Origin

The origin of the invention arises during the design of a low-energy system for ventilating a housing prototype, SOLARKIT for the Solar Decathlon 2010. To this end an initial design of a ventilation chimney was developed resulting in an innovative ventilation tower (Fig 3) from the combination of solar chimney and breezes capture tower, through which the air intake and expulsion is resolved.

That new bioclimatic component combined the downstream or downdrought cooling effect to cause outside air intake, pre-cooling it by means of the evaporative cooling effect of the ceramic cladding of the north face duct before being fan-forced distributed into the building through an edge-sealed raised-floor plenum. Subsequently, the effect of solar chimney of the south face of the tower provides the extraction of indoor air without mechanical support by stack effect, since the thermal inertia of a water reservoir placed in the core of the tower keeps the thermal draft effect even when no solar radiation is available.

Tests and prototypes.

We found the first example of realization of this ceramic cladding tile in SOLARKIT, (Figs. 1 and 4) as it has been described in the previous point.

Figure 5 Porous ceramic cladding tile designed for SOLARKIT's ventilation towers

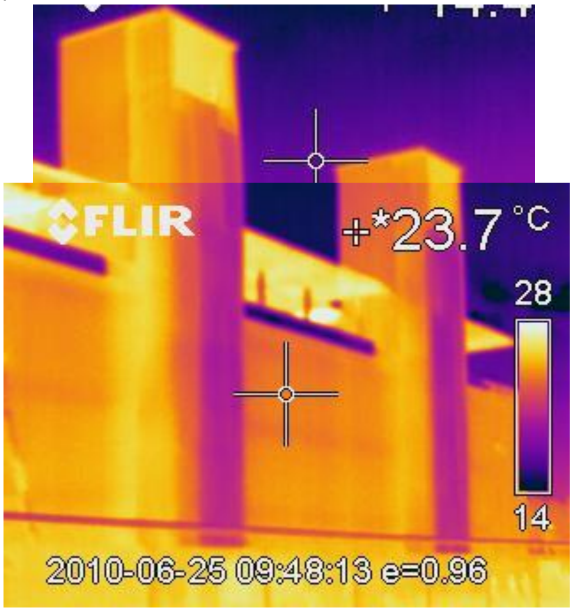

Figure 4 Thermograph image of ventilation towers with activated ceramic cladding cooling system of SOLARKIT

As a proof of system operation by thermographic images (Fig 5) it can be observed the difference in surface temperature of the wetted ceramic facings (front side) against those who are not (left and right sides)

Regarding air temperature, there has also been recorded and monitored up to 7 degrees differences between the outside (29°C) and the output of the tower at its base into the housing (22° C) without the addition of extra moisture.

The second experience where the system has been applied was in the prototype “Patio 2.12” participant in Solar Decathlon 2012 (Terrados-Cepeda F.J, 2014). However, in this case its application did not follow all the patent requirements, such as the use of a ceramic material with a high degree of porosity. The baking treatment and the surface glazing of the commercial terracotta tiles used prevented an effective evaporative desired for the passive conditioning effect (Fig 6) of the prototype as originally planned.

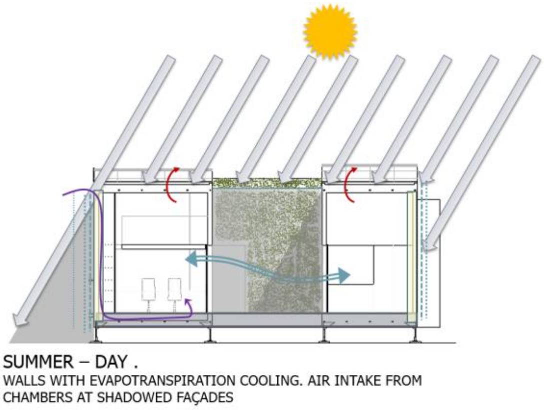

Figure 6 “Patio 2.12” bioclimatic strategy combining green-house and botijo-effect

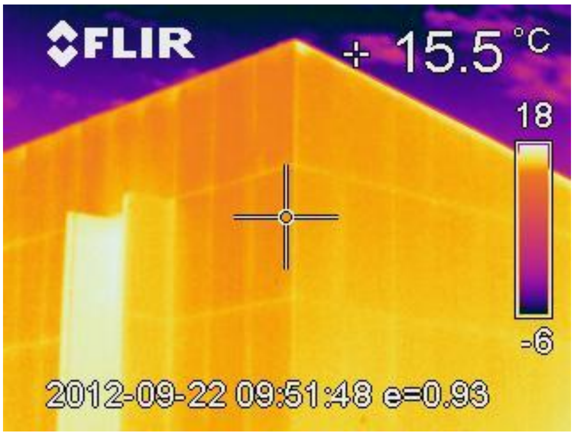

Figure 7 Patio 2.12 corner with (left) and without watering (right) at the same surface temperature

Thermographic images (Fig7) show little difference between the ceramic facades with activated watering effect and the conventional ones without water supply.

Nevertheless, this experience helped to document the influence or effect of water evaporation and the degree of porosity to allow its outcrop in the appearance of the surface cooling phenomenon. Its actual low performance in the prototype did not avoid, however, that the concept were widely celebrated by the jury and the public of the competition, which resulted in an excellent 2nd place in the competition.

Patent.

Finally, in 2012, after the first satisfactory experience with SOLARKIT it was decided to promote the patent process since a high degree of innovation and novelty was detected.
Patent with prior review process has finally been completed (Patent nº ES2455415_A1) with granting a protection for 20 years.

IBI international search and reports on the State of the art in the PCT process remarks the high degree of novelty of the invention by granting a "class A-not relevant" international reference patents[2], to the main claims

In particular, it highlights the fact that provided moisture happens in the entire piece and that the contribution of water occurs by gravity, from the interior alveoli to its surface in a natural way.

Description of the system

The invention consists of a novel solution of cladding for buildings or constructions using a covering ceramic tiles or other porous material similar with a controlled water supply through a system of internal canaliculi where water flows by gravity. The evaporatation of the water absorbed by the pieces on its outer surface produces a surface cooling wich helps to reduce the surface temperature of the enclosure, and therefore, the Interior of the building.

[2] (see final patent references)

The solution consists of elements and traditional building materials. For the operation or activation of the cooling it only needs a small supply of water to evaporation (about 0,22 dm^3/h or 1,45 dm^3/day per m^2 of façade), which can come from retrieval systems of water rain or recycling within the same building, thus reducing the demand for drinking water for their operation.

The system can be applied to walls of buildings and constructions as direct liner, using fixing techniques applicable to other stone or ceramic claddings. Equally, the system can be arranged in an indirect mounting as outer foil in ventilated facade constructive solutions.

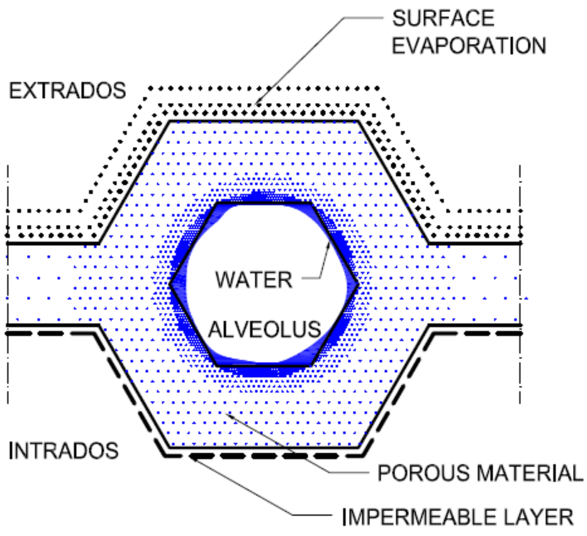

Figure 8 Horizontal section by alveolus type. Evapotranspiration functioning.

The cooling of the surface can be used to reduce the external temperature of the enclosure, and therefore, the gain of heat transmission.

In addition, applied as the outer sheet in "ventilated facade" solutions, it can be applied for cooling the air at the chamber, which, in turn, can be used as cooled passive, natural and free of charge flow for the ventilation of the interior spaces of the building,

Functioning.

Surface of this facade system cooling capacity is especially suitable for buildings or constructions at hot and dry summers climates, and wich facades prevail massif front windows. The watering system should be activated during periods of maximum insolation and higher outer temperature to optimize or cold seasons it should remain disabled.

The effect of surface evaporation benefits on the one hand inside the building by lowering their surface temperature, but also affects the near environment of buildings, since the contribution of additional moisture contributes to lowering the temperature around the building, and thus reduce the "heat island" effect.

Application.

This described finishing system can be applied to the closure of the buildings in two ways:

The first or "direct fixing" consists of a solution of fixing the elements directly to the facade, whether by anchors mechanical or even with epoxy-type adhesive, to the outer layer of wall, as in a conventional solution of cladding with pieces of stone, ceramic tiles, etc. In this case the surface cooling by evaporation, when environmental conditions demanded it, would lower the temperature of the outer face. Cooling is directly transmitted this way by "transmission" to the Interior of the wall layers, which would reduce heat gain through the facade in summer conditions.

The second mounting option would be "indirect fixing", consisting of the use of a substructure or auxiliary support to hang it from. It should provide a continuous air chamber of approximately between 3 and 10 cm thickness between the outer ceramic tiles and the interior of the wall sheet.

At the bottom and the top of the façade there should be some adjustable openings in order to regulate the entry of an airflow to the air chamber. Finally, air intakes will be installed at the air chamber connecting to the inner spaces or to the mechanical ventilation of the building.

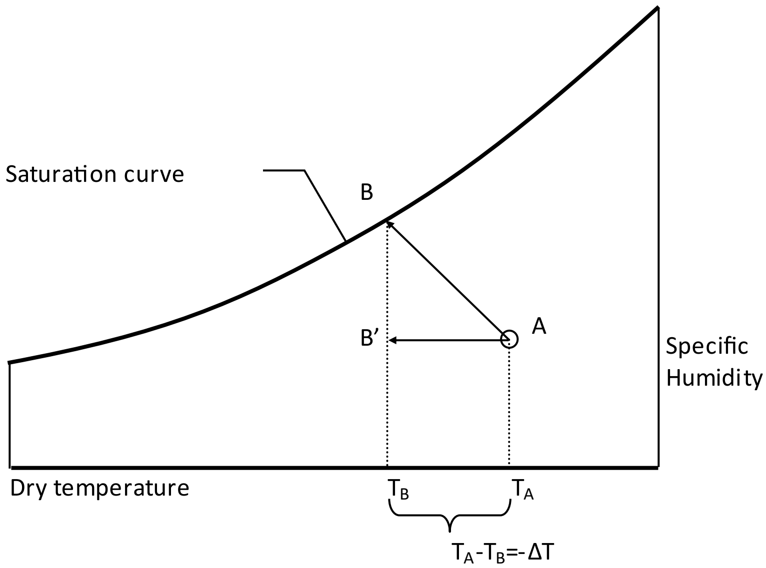

Figure 9 Sensible cooling process AB' Vs evaporative cooling AB

When reaching the thermal equilibrium, thanks to the evaporative cooling process in the outer layer surface, the air contained in the chamber will cool from the dry temperature point "A" of the outside environment until the wet bulb temperature at which the outer layer will be, but without having increased its moisture content, thus running a "sensible cooling" psychrometric process (AB' in Fig. 9).

Air cooled this way can then be introduced into the building through the admission intakes placed at the air chamber and used as a naturally and free of charge pre-cooled (-ΔT in the figure) ventilation air-flow.

This technique can reduce or even eliminate the ventilation loads in summer as the air brought in from outside, and previously cooled through the chamber reaches the interior with a temperature close to summer comfort conditions. This is particularly interesting in commercial buildings with large ventilation requirements.

It has been registered (F.J.Neila) that natural convection phenomena generally manifest at air chambers over 10 cm thick. During the surface cooling operation of the facade, air cooled in the thicker than 10 cm chamber will flow to the bottom by a natural downdraught effect. This is of particular interest in implementing this as a cladding system of bioclimatic elements such as ventilation towers used for low energy and passive air conditioning of buildings. The described ceramic coating would help to enhance the downdraught cooling effect at breezes-capture and ventilation towers as tested in Solarkit.

Conclusions

There has been presented a new and original system for passive cooling buildings, which originality has been certified by the patent authorities.

Not only is able for cooling buildings and constructions façades, but also to produce fresh air for buildings spaces' conditioning and ventilation.

Its functioning requires no energy supply but a continuous small amount of water in order to generate the cooling effect named "botijo-effect".

A set of simple devices for temperature and humidity monitoring with a control system acting over the watering system is required to optimize and manage its performance.

The surface cooling effect highest potential is located at regions with hot a dry summer periods, with a high range for evaporative cooling capacity.

The system performance will be increase when applied in façades without direct sunlight.

Arising from the state of the art and the built experiences described an estimated superficial cooling power over 80 W/m² can be considered, plus an 8 to 10°C cooling effect on the air temperature, with a total 1,45 l/m² of water per day. Both characteristics has been confirmed by means of direct measuring and thermography images.

A high potential for future developments can be foreseen considering its low cost, energy and impact for easily cooling buildings surfaces with tradition rooted techniques.

Acknowledgments

Sendra J.J, Navarro J, Muñoz S., Domínguez S., Ordóñez M., Ballesteros J.E., Galán C., Terrados F.J, Rodríguez C., García-Blanco J.M, Morillo B., Quesada A., Infante J.M., Tineo J.M, Guillén A., Delgado R., Sosa C, Mendoza M.V. & Barrena A.

References

B.Ford, S.Álvarez, P.Thomas, R.Schiano-Phan & E.Francis. 2010. The architecture & engineering of downdraught cooling. PHDC Press. 26-43

V. Lerum (2016). *Sustainable Building Design: Learning from nineteenth-century innovations*, Routledge: pp,184-187.

B.Morillo.2011 Cerramientos autorregulados en climas cálidos V3.1. TFM-MIATD-Univ. Sevilla. P143

F.J. Neila. (2004). *Arquitectura bioclimática en un entorno sostenible*.Madrid: Munilla-lería.

Terrados-Cepeda F.J, (2014) "Patio and Botijo" Energetic strategies and architectural integration in "Patio 2.12". *Energy and Buildings.2014* Vol 83. Pp 70-80.

Zubizarreta J.I, Pinto G.(1995). An ancient method for cooling water explained by mass and heat transfer. *Chemical Engineering Education*, Vol 29, nº2, Spring 1995:pp, 96-99

SolarKIT. http://www.solarkit2010.org/ (pdf. Pág 19)

Casa Patio 2.12 http://andaluciateam.org/

Patents reference

García-López J. Sistema de Revestimiento Cerámico con Enfriamiento Por Evapotranspiración. Patent nº ES2455415_A1. Presentation date: 2012-09-13.

Terrados-Cepeda F.J. Fachada cerámica para acondicionamiento pasivo de espacios interiores. Patent nº ES2406704_ A1. Presentation date: 2013-02-15.

WO 2011134254 A1 (HE YUCHENG) 03/11/2011; AN CN-2010078641-W

JP H08312018 A (AOKI CORP) 26/11/1996; AN JP-14387695-A

CN 202090431U U (WENJUAN DU) 28/12/2011; AN CN-201120109617-U

JP 2000144963 A (INAX CORP ET AL.) 26/05/2000; AN JP-31924698-A