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Environmental and Economic Analysis of Thermal Active Building System

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ABSTRACT
This paper is regarding one promising technological solution – which is so called Thermal Active Building Systems (TABS) –for one of the most critical problems both in environmental and economic aspects, which is the raising energy consumption. Buildings are the principal application target of the solution once that population spends most part of their time inside them. Therefore, more energy is required to supply an increasingly demand in lighting, air conditioning, heating, electronic devices and so on. In this context, TABS emerge like a possible solution. To ensure the system efficiency or, in other words, prove its viability, it will be applied an environmental management tool (SWOT Analysis) weighting all the pros and comparing with its drawbacks, based on previous experiences in implantation of such system, available in literature. A basic theoretical background, which is extremely important to a better comprehension of the system, covering both engineering and environmental management areas, is presented on this paper. Results shown that TABS are efficient mechanisms in the reduction of power consumption, committed with sustainable development, and which worth the investments in a Life Cycle Cost evaluation.
Keywords – *sustainable development, TABS, energy consumption, Indoor Air Quality, , engineering.*

I. INTRODUCTION

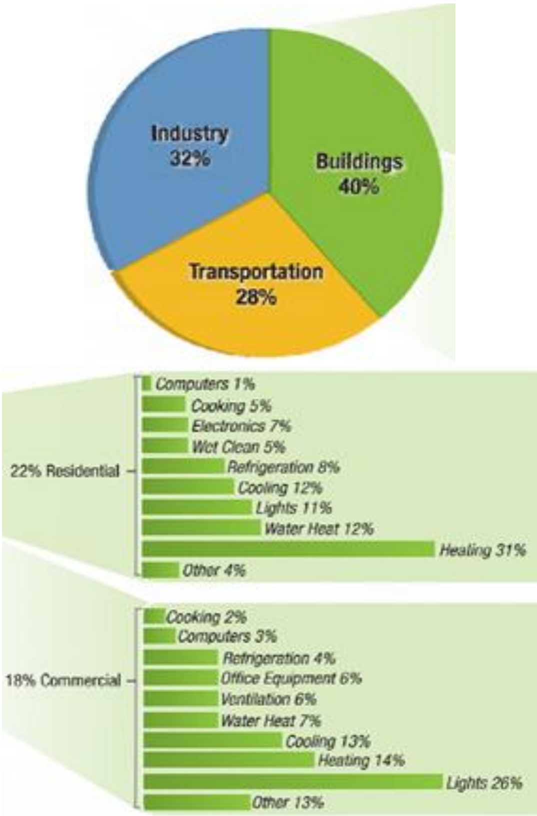
Paraphrasing one of the most important economic laws, every action, decision and investment executed, to be effective and meaningful must have a demand. Demands can come from people, process, sectors of the society and so on.

Among the most important actual demands on society, we have those ones regarding life quality, environmental-friendly techniques, cost reductions, preservation of natural resources, which are, in other words, solutions in the direction of sustainable development.

Keeping it in mind, this technique may be capable to guarantee comfort inside office buildings, using less energy and consequently, ensure lower expenses with building service equipment and electricity. The answer has a name: it is so called Thermal Active Building Systems (TABS), which is a scheme where, embedding pipes that carry water in the concrete slabs of the building is possible to create an interaction between its structure and the surrounding room air. Such interaction is able to guarantee indoor thermal comfort, an important factor in life quality while in indoor ambient.

This approach is extremely important because it supports one of the biggest sources of primary energy consumption, HVAC (Heating, Ventilating and Air Conditioning) equipment, and suggests an alternative technology that can deal with Indoor Environmental Quality (IEQ), encompassing the conditions inside a building – air quality, lighting, thermal comfort, ergonomics – and their effects on occupants or residents. Strategies for addressing IEQ include those that protect human health, improve life quality, and reduce stress and potential injuries. Better indoor environmental quality can enhance the lives of building occupants, increase the resale value of the building, and reduce liability for building owners" (U.S. Green Building Council).

To quantify the importance regarding to energy and buildings, one can look at the figure 1, which shows that in USA, 40% of the primary energy consumption takes place into the buildings, where 18% of them are commercial ones. In the same figure, it is also possible to see that inside buildings, the expenses with cooling and heating (usually carried out by the same device) represents 27%. In addition to economic reasons, the indoor quality also plays a role, once, as reported by the Environmental Protection Agency (EPA), "the potential impact of indoor air quality on human health nationally is considerable, for several reasons. Americans, on average, spend approximately 90% of their time indoors". [1]



1. Figure: U.S. Primary Energy Usage
Source:
http://www.unep.org/sbci/pdfs/Oct_symposium/Envi romental_Performance_of_Buildings_RC.pdf

Through this paper, it is presented a clear definition of TAB systems, showing its characteristics and variations. A comparison with another sorts of HVAC systems designed to provide thermal comfort and indoor quality is also carried out. Using an important management tool, such SWOT analysis and Life Costs assessments, the sustainable aspects of TABS are explained, as well as its benefits, drawbacks and limitations.Hopefully, at the end of this paper, conclusions about the TABS based on technology, costs, efficiency, environmental impacts, efficacy will be present and doubts about this system will be clarified, contributing to a better exploration of this technology in a near future transforming it in a widespread consistent tool.

II. THERMAL ACTIVE BUILDING SYSTEMS

Thermal control is very important for the human comfort and for some type of processes as well. When it is in the winter season, the houses, apartments, commercial buildings and other kind of indoor environments have to be heated up while during the summer season they must be cooled down.

There are sorts of equipment nowadays to achieve these human's necessity. However, these equipments are consuming a large amount of energy and, as the world is in expansion and rising the number of buildings, factories and so on are doing the same. Therefore, it is time to care about the energy's sources.

Natural ventilation combined with solar protection are the most effective building bioclimatic design strategy in order to improve thermal comfort by passive means. Despite these favorable conditions, the number of buildings relaying in active systems as the main cooling design strategy continues increasing inexorably. [2]

Then, the term sustainable buildings (green buildings) turns up, which are environmental responsible and resource efficient structures during their life's cycle.

A green building means to reduce the overall impact of the built environment on human health and the natural environment by efficiently using energy, water, and other resources, protecting occupant health and improving employee productivity & reducing waste, pollution and environmental degradation.

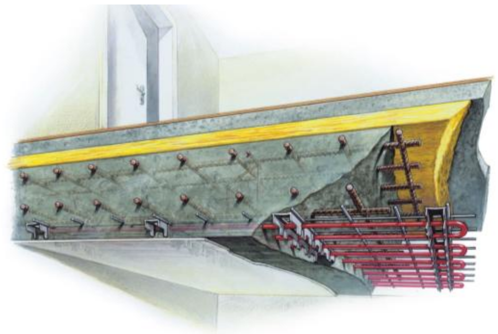
A newer and different method on improving equipment's efficiency is the thermal active building system (TABS). This technology aids the building to cool down or harm up utilizing the environmental energy.

For the TABS application, some measures must be taken during the building general design, such as sun protection, sufficient thermal storage capacity (in the building), very good thermal insulation and basic ventilation with hygienically necessary air renewal. All these characteristics can be achieved by a willing area position of the building and correct constructions materials.

III. TAB SYSTEM STRUCTURE

This system is based on a structure of tubes that works as heat exchangers. This structure is integrated in the TABS, and then it interconnects to environmental natural sources of cooling/heating energy. Depend on the position of the tube inside the slab, the TABS can be named in many ways. The TABS is integrated into building's elements conditioning the interior climate or mostly working as an auxiliary system reducing another equipment's usage, such as air conditioners. [3]

The TAB system to be introduced on this paper is the Concrete Core Temperature Control (CCTC). The figure 2 illustrates the CCTC. The water circulates inside the tubes, which are in red color and positioned inside the slab (between building's floors). Above it there are, respectively, the slab, insulator reinforcement, floor and floor covering.



2. Figure: Concrete Core Temperature Control Scheme

Source: http://www.emg-pr.com/en/prfitem.aspx?id=4707

The tube heat exchangers are positioned right in the concrete core of the slabs in a serpentine or spiral-shaped coil path. The coils are made of plastic tubes or multi-layered composite tubes (made of PE and aluminum). These tubes have a diameter of 15 to 20 mm. The distance between tubes is about 10 to 30 cm. The heat transfer is higher via the ceiling (around 67%) then via the floor (33%). [3]

The floor slab must be formed for concrete with high thermal conductivity and a good thermal storage capacity. Therefore, it will be able to store a great quantity of heat or “cold”. Another important point is the floor cladding because it may affects in the convection and radiation heating transfer processes. The ideal condition could be a floor without cladding, but acoustical problems would appear. Sound absorbent materials are necessary in the room against sound waves propagation but, at the same time, they are thermally insulators and radiation inhibitors. Therefore, a moderated application is required for attending both acoustics and heat transference needs. [3]

Corner rooms are mostly critical, as they have higher solar loads due a larger exposed surface area to the sunshine. Then, it is also important to reduce the energy transmission coefficient of the building facade, in order to reduce the influx of solar heat into the rooms. All these measures can be reached by using moderated window surface area and sun protection. [3]

Nevertheless, it is necessary a good thermal insulation of the facade as well to reduce the heating requirement during the winter, reducing also the heating load. Particularly careful planning is necessary for rooms with higher heat transmission losses on the top floor, on the ground floor and on the corner, especially if the facade has large glass surfaces.

As this system is more about to be auxiliary, different combinations are managed to reach any demand. The possible CCTC’s combinations are:

1 - CCTC solely for building element cooling; combined with conventional heating systems (radiators) and natural or mechanical ventilation. In this application, concrete core temperature control replaces a conventional cooling system.
2 - CCTC as the room's sole heating and cooling surface, combined with mechanical ventilation.
3 - Supplementary systems: due to the thermal inertia and the resultant insufficient controllability of CCTC systems, supplementary heating and cooling systems are sometimes implemented. The CCTC system serves as the base load system for heating and cooling, supplemented by an additional system in the room, for individual, demand-oriented room control. Possibilities include subsurface convectors in the facade, but also system combinations that thermally activate the slab in a layer near the surface (edge strip element, capillary tube mats) as well as in the concrete core. The combination of a CCTC system with radiators or convectors must be considered critically in the planning phase. [3]

The CCTC operation can be divided into three stages. At first, there is the Charging, which the slab is charged with cooling or heating energy thanks to cold or hot water circulating inside the tubes, this way thermally controlling the slab. Then, the second stage takes turn, which there is an energy Storage in the slab that will control the room thermally later. Finally, the Discharging occurs dissipating the storage energy to the room. The heat transfer during the discharging happens by convection (around 40%) and radiation (around 60%). [3]

It is important to notice that these steps occur in a relative passive way; due to it be a natural process of heat transfer. However, as lower is the temperature difference between the room and the CCTC quicker will be the thermal controlling, it thanks to the large surface area provided by the tubes path inside the floor. [3]

The heat and cold can come from three different environmental systems. At the first, they can come from the ground. At deep underground (up to 100 m) the temperature is almost constant and can be utilized for direct geothermal cooling/heating. It can be done by sinking borehole heat exchangers or energy piles in the ground, for example. [3]

Borehole heat exchangers generally consist of 2 to 3 double pipes made of plastic, with a diameter of 32 mm, which are sunk into a 50 to 100 m deep borehole. Water is pumped through this system that exchange heat with the ground. If designed appropriately, borehole heat exchangers and energy piles can be used not only in summer for cooling, but also in winter as a heat source, always in combination with a heat pump. [3]

Energy piles are foundation piles of a building, which protrude 20 to 30 m into the ground and are used as borehole heat exchangers as well. Both borehole heat exchangers and energy piles utilize the seasonal heat storage capacity of the ground, or ground water's heat flows. During the summer the ground temperature is lower that the ambient temperature and during the winter it is higher than the ambient temperature. [3]

At depths of 30 to 100 m, the ground's temperature is just 1 kelvin above the annual average air temperature of the location. The seasonal fluctuations in temperature can be measured to depths of 5 m, but deeper underground, temperatures remain almost constant along the year. [3]

As a second source of environmental cooling, the cool night air is utilized. The cool night air can be used as a further natural heat sink with an application of a cooling tower the ease the heat exchange between the TABS and the night air. Moreover, it can use both dry and wet coolers as well. [3]

With dry coolers, recooling of the water is only possible if the outdoor temperature is below the required water temperature. That is why during the warm seasons the recooling period is restricted to the night, and the early hours of the morning. On the other hand, with wet coolers heat exchanger on the airside is also sprayed by means of a secondary water circuit. The evaporation of the water allows the heat exchanger surface temperature to be reduced until the wet-bulb temperature, therefore it can be taken into account instead of the outdoor air temperature. The wet-bulb temperature is significantly lower than the outdoor air temperature. [3]

The lower temperature also has a positive effect on the energy efficiency and the maximum cooling capacity. The efficiency of recooling with a cooling tower increases with decreasing night outdoor temperatures. Nevertheless, unlike the ground, or ground water, outdoor air cannot be used as a heat source for operation in winter because the building needs heat energy and the outdoor temperature is lower than the indoor one. [3]

Finally, the last source of environmental energy is the water ground. For this one, it is necessary to sink down the water carrying layers. Ground water is extracted from a supply by utilizing a submersible pump. This water transfers heat or cold to the water of the CCTC circuit via a heat exchanger, then it is returned via an injection back. The distance between the supply and the injection should be at least 10 m, in order to prevent thermal short-circuits. [3]

Ground water can be used as a heat source sink at any time, all year round, given that the ground temperature, in a deep level, remains almost constant during the year. The performance of this source utilization is primarily dependent on the volume of the available ground water.

IV. SWOT ANALYSIS

This section in dedicated to identify and clarify important concepts and tools involved on the analysis of TAB Systems viability, carried out by the authors. Important information that describes the operation of TABS and some of their different configurations are shown.

SWOT analysis is a business analysis that an organization can perform when deciding on the best way to achieve future growth. Such process involves identifying the strengths and weaknesses intrinsic to the analyzed object and opportunities and threats present in the market that it operates in[11].

Aside the business reality, SWOT analysis is an important tool that can be applied also on evaluation of processes, products and even in new technologies and techniques analysis, as will be presented in the following sections.

“As a methodology for strategic positioning, SWOT analysis has been extended beyond companies to countries and industries (...)”[12].

SWOT analysis is one of many possible strategic planning tools, used to evaluate any situation that requires a decision. Among these situations, one can includes the evaluation and decision about if the implementation of such HVAC technologies, as TAB Systems, are viable, performable and sustainable in long term[13]., which is the main propose of this paper

In the analysis proposed by the authors, the Strengths can be understood as the benefits that TAB systems technologies can bring by itself, as reduction in energy consumption and being connected to sustainable development. As Weaknesses, one can have the problems brought by TABS itself as well, such as considerable modifications in building structure and high quality materials demand, that usually are more expensive. Whereas thinking about Opportunities and Threads, the evaluation depends of the external environment and its implications regards the TABS, and not about the technology itself. Thereby, an Opportunity example can be the governmental policies that aims to reach more and more environmental-friendly solutions in HVAC systems and a Thread can be the distrusts around the functionality on this device.

A good and trustable SWOT analysis, focused on check the viability of a technology, carefully evaluates the scenario, acquiring relevant data and useful information from literature and past experiences to prove the points raised. This is the only way to attest the veracity of the analysis avoiding that it becomes a superficial and poor based study. The most relevant results obtained by authors' analysis are presented in this section through a chart, followed by some justifications about the points raised, which were based on literature. Not all of them were justified, just the most important ones.

It is important to mention that a deeper analysis, providing a Life Cycle Cost for TABS and which takes into consideration the advantages, drawbacks and trade-offs when using TABS rather than other HVAC devices like the conventional air conditioning, chilled beans, fan coil units and so on, are not presented in this paper. However, the available literature containing such kind of information, also corroborates with the high potential that TABS have to be a wide spread technology soon, mainly in Europe.

The Table 1 indicates the covered points in SWOT Analysis. It aims to provide an analysis, which deals with both thermal comfort and productivity aspects, limitations in the building construction, energy benefits and money savings.

Internal	**Strengths**
	• It is in harmony with sustainable development • Cool down a building with renewable energy • Elimination of radiators • Costs with maintenance are lowered • Uniform temperature distribution • Energy consumption 2-3x lower • Capable to maintain the temperature in a comfortable range • Cheaper installation costs • Better performance when compared under "whole life cycle" approach • Reduce the peak loads when utilized in parallel to another HVAC systems • Allows a downsizing in ventilation systems • The absence of additional devices in the room reduce the risk of accidents
Internal	**Weaknesses (limitations)**
	• Extremely dependent on an efficient architecture • Moderate surface windows is a must, as well as shading • Materials with low U-values have to be applied • The building materials have to have high conductivity and storage capacity • High ceilings shall be avoided • Does not allow individual temperature control • Later maintenance is hard to handle • Heat gains from other sources have to be diminishing • Ventilation system is still necessary
External	**Opportunities**
	• Comfort conditions also reflect in clients, then a better IE may reflects in the customers decisions • The increasing number of succeed studies that demonstrate effective benefits brought with the adoption of measures that contributes for a better IEQ. • Regulation standards that arising even stricter in the direction of sustainable alternatives • Countless successful cases that are self-marketing for TABS
External	**Threats**
	• Building acoustics • Does not ensure IAQ • Difficult in convince the buyers about the effectiveness and reliability of the system

1. Table: SWOT Analysis for a CCTC Based Source: own work based on previous literatures mentioned in this work

Starting from the Strengths, the first point is about sustainable development. Sustainable development is based on a systemic relationship between the "3P's" named: "Profit, People & Planet" [14]. Still, understanding the main aim of HVAC systems, an HVAC system such as TABS, which can bring thermal comfort for the occupants on indoor environments (People), consequently improving their performance while working (Profit), costing less electric and energetic resources (Planet/Profit) is committed with sustainable development and is sustainable itself. These connections proposed here, as enhancing on work performance due to thermal comfort and Indoor Air Quality (IAQ) conditions, resulting in profit raising, as well as better performance on energy resources consumption, maintenance and emissions (Profit/Planet) can be verified on references like.[5][6][7][8][9][10]Another strength regards to maintenance and investment costs. Costs with maintenance are also reduced, once "with less mechanical parts in the system and less total energy use, the annual operational and maintenance costs are lowered and with careful engineering and design, the investment costs can be reduced as well."[5] Some of the other strengths mentioned on Table 1, can be justified through the Whole Life Cycle Analysis (WLCA), which can be found on [5].Considering the Weaknesses, firstly, to size the system properly, meeting the comfort requirements (air quality, temperature), the conditions desired have to be clearly specified, once that for such cooling system (without mechanical devices) there are limitations connected to the architectural design. An integrally planned building concept – linking optimal coordination of architecture, construction physics and building services equipment – with consistent limitation of heating and cooling loads is a prerequisite for the implementation of TABS following the CCTC arrangement[3]. Still talking about the concepts of the building construction limitations, to increase the heat transfer due to convection – once the hot air goes up while the cold one goes down – the high ceilings shall be avoided. In addition, , the surface of the slab should not be covered (exposed concrete) to increase the heat transfer; however, it might bring some acoustics constrains[6].

In terms of Opportunities, regulations around energy consumption for buildings play an important role, once they have become stricter, as can be seen on EPBD (Energy Performance of Buildings Directive), which aims to reach "nearly zero" energy consumption until 2020. TAB system has demonstrate cost savings from 10% up to 30%

compared to other traditional HVAC systems in UK conditions, which represents an important step ahead in the direction of the EPBD. Thereby, TABS has proven to be capable to fill the external requirements in a positive way, meaning that such scenario is an Opportunity[8].To conclude the SWOT analysis, drawbacks with external origins must be justified. The most latent of them is the difficult in convince the buyers about the effectiveness of the system and that is worth to invest on it. It happens because personnel costs dominate all other costs related to building operation (including energy) by two orders of magnitude[15].Still, whereas the cost of energy is too small to garner the attention of many businesses, the promise of simultaneous productivity gains, that are financially much more significant, is less easily ignored"[9]. So, maybe it is preferred to guarantee appropriate workplace conditions, which are of utmost importance for the economic success of companies, applying other devices, with although do not provide the environmental advantages as TABS do, are capable to guarantee profitability and people performance, asking for less building structure modifications and quality of materials (which are an internal disadvantage for TABS). Thereby, the characteristics and advantages that TABS can provide are not enough to convince the business people to adopt them rather a conventional air conditioning for example. This is a negative external factor, being interpreted as a Thread on SWOT context. These results are grounded on a careful review on literature and corresponds to the reality observed when TABS in Concrete Core Temperature Control arrangement are applied. The discussion have been done considering some of the most important points raised on SWOT analysis and aiming to allow a mapping for better understanding of the technology characteristics under many perspectives.

V. CONCLUSION

Firstly, some basic engineering concepts were covered, aiming to introduce the technology under a theoretical and technical point of view. Secondly, the basic work principles of the TAB system were explained, as well as its integrated devices, limitations, variations and so on. However, the focus was always around the Concrete Core Thermal Control (CCTC).

After provide a better understanding of the TABS technology, through SWOT analysis, the impacts coming from its utilization were showed. As well as its advantages in provide thermal comfort by a more energetic efficient way and even offering clever solutions under architecture and design point of view; everything supported by reliable sources, such results of researchers that deals with this topic and manufacturer catalogues.

Of course that such technology has its disadvantages, limitations and trade-offs (as everything in life). However, it is possible to offer good solutions for most of them, as using efficient materials, reducing the heat gains, choosing good solutions for ventilation and so on.

Bottom lines, it can conclude that TABS represents a valuable tool that is able to provide improvements on life quality in buildings through an economic, efficient and environmental-friendly way. All the studies qualify TABS as an efficient system, capable to help in Indoor Environmental Quality at the same time that guarantee good economic answers, such increasing productivity and reduction in costs with building maintenance. The reduction in primary energy consumption and in CO_2 emissions also tags it as an environmental-friendly answer to society's demands.

The TAB Systems are aligned with the sustainable development requirements and have a great potential to become a widespread and successful technology in different parts of the world.

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