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Hybridation of architectural systems with energy harvesting & delivery systems

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Abstract
Until very recently, technical systems such as solar thermal systems, and other HVAC elements have been conceptualized based uniquely in their thermal performance levels, and its integration with other architectural elements (envelopes, slabs,…) limited to mechanical fixation.

However, with steadily increasing use of technologies for the reduction of the non-renewable energy needs in buildings, already developed in the last decades, deeper architectural integration is needed, also considering on cost and assembly process optimization to ensure wide market adoption.

In this context hybridation of traditional envelope systems and structural components towards the integration of solar thermal collectors and activation of thermal mass is increasingly based on the pre-existing architectural solution and adaptation of the thermal technology to the capacities and limitations of these systems. Solutions such as External thermal insulation systems are upgraded, in which unglazed collectors are integrated as part of renders, claddings, etc. to obtain neutral aesthetical impact.

Architectural, constructional and thermal results are discussed, not only based on design assessments, but also on manufacture, assembly and assessment results from experimental data.

1 Introduction

Built to facilitate the development of human activities, buildings have developed, and several subsystems have been generated to provide increasing levels of performance. Structural systems; building Envelopes; Heating, Ventilation and Air Conditioning (HVAC) systems; Information and Communication Technology (ICT) systems; etc. have been developed with increasing levels of complexity.

Within building envelopes users expect modern systems to provide not only shelter (mechanical stability, air and water tightness), but also comfortable levels of daylighting, thermal insulation, and even solar energy harvesting. Furthermore, users expect all these functions to be provided by envelopes which also provide an overall good level of integration in the architectural concept of the building, seamless integration with other systems in the building (neighbouring envelopes, structural junctions, HVAC, electricity,...), and with limited costs.

Equally, integration of thermal functions is increasingly common in internal systems such as structural elements, partition systems, etc. This allows increasing the possibilities of buildings to incorporate passive or low energy technologies such as thermal mass activation.

With energy efficiency and an ultimate need to reduce primary energy consumption of buildings towards sustainability, energy systems are increasing its presence in building envelopes. Solar energy systems such as solar thermal and photovoltaic systems are increasingly present in buildings, boosted by energy procurement policies and user/owner will to reduce the overall energy costs in buildings.

With increasing space needs of energy systems in façades, its integration in architectural systems seeks the reduction of aesthetical and space impact in buildings. However, since a deeper integration is pursued, the interaction of the thermal function with other functions must be understood and placed as a key issue to be solved in the design process.

Focused on a seamless architectural integration, a new trend appears, in which solar systems are not integrated towards building envelopes, but in which façades are hybridated and activated to house solar systems. This approach makes use of unglazed solar thermal technology, and PV coating solutions which are engineered to ensure that users would not differentiate between hybridated and regular envelopes.

These systems commonly are integrated as part of advanced or even new concepts of HVAC systems in which solar systems are connected with thermal storage, heat pumps and low energy delivery systems such as radiant floors, or even thermal mass activation.

2 Integrated solar systems in façades

Solar thermal collectors transform solar energy to heat water at useful temperature. A solar thermal system consists of several components having the role to absorb, transfer and to store the heat, being solar collectors responsible for the first of these functions. Most commonly, solar systems use liquids as heat transfer medium.
In [1], deep research on envelope integration of solar systems in façades was conducted, and market available solutions identified.

2.1 Thermal performance

The thermal performance of a solar collector is determined through a heat balance such as in [HWB].
The efficiency of solar thermal collectors can be broadly defined based on the type of solar thermal collector. From figure 1, it can be evaluated that performance levels are driven by the average temperature of the fluid for a given environment (ambient temperature and solar radiation are set by the location of a building).

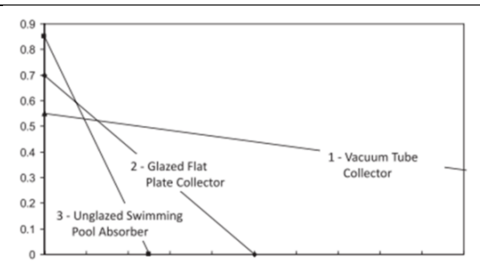

Figure 1: Solar collector performance depending in x-axis on fluid-ambient temperature gradient divided by incident solar radiation Source: [2]

Flat plate technologies being the most common ones, these are not suitable for high temperature systems such as solar cooling systems, where vacuum tube technologies are more suitable. Unglazed technologies, presently used for services such as swimming pool heating systems, are only sufficiently performing for relatively lower fluid temperatures such as those in heat-pump based combined solar systems for heating.

As unglazed collectors are defined as the most promising solution for widespread integration of solar systems in building envelopes, the limits stated in the paragraph above should be clearly bearded in mind.

2.2 Outstanding building integration solutions for solar thermal systems

Vacuum tube collectors are glass tubes containing the absorber suspended in the vacuum. The integration of this technology implies that arrays of glass cylinders need to be integrated into the building envelope. Most promising integration proposals for this technology are those who integrate these systems in balcony parapets and similar locations.

Flat plate collectors are composed of an absorber plate, assembled with an insulation layer behind and a glass cover above it. These let solar radiation in, but minimize heat losses. Envelope integrations of these systems are available on the market, commonly based or adapted to specific lightweight façace, and overcladding systems.

Unglazed collectors are the simplest typology of solar thermal collector, as they only consist on absorber in metal (polymeric absorber alternatives are also market available). Alternatives with metal absorbers can reach higher temperatures than those with plastic absorbers, due to its better conductivity parameters. Unglazed collectors are commonly used for applications requiring delivering water at low temperatures, such as swimming pools, low temperature space heating and to pre-heating of Domestic Hot Water (DHW).

(a) (b) (c)

Figure 2: Integration solutions of (a) vacuum tube [3], (b) flat plate [4] and (c) unglazed technologies [5]

2.3 Review of alternatives and identification of alternative applications.

Although not mainstream in the solar collector market, there is an increasing number of solutions for the architectural integration of solar systems in building envelopes. However when addressing integration solutions for opaque areas of the building envelope, these solutions are commonly conceptualized by a technification of the appearance of the façade, as only glazed or metallic finishes are available. Other considerations such as modularity and compatibility with neighboring façade elements are also constraints of these solutions.

Still market space is present for solar thermal technologies adaptable to building envelopes such as mortar render finished façades, ventilated façades, sandwich panels, etc., as long as the proposed concept keeps all aesthetic qualities (shape, color, texture, modularity,…) and all pipework remains hidden from the observer.

2.4 Advances towards hybrid façades

Hybridation of building envelopes has already started, and several research projects have developed solutions towards activation of building envelopes without modification of its external appearance, and other functional capacities.

Within [6], a façade system was developed based on external thermal insulation systems in which a water-based capillary system was integrated in the external render of a façade. In this case, the system was coupled with a heat pump system for decentralized space heating.

Within [7], a steel façade cladding system was adapted for the integration of capillary tubes in its internal side. [8] is focused on the integration of capillary tubes in steel-based sandwich panels for façade energy retrofits.

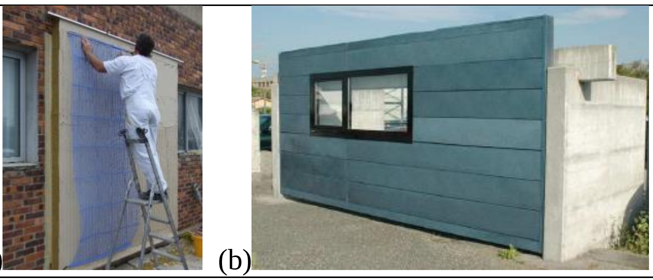
(a) (b)

Figure 3: (a) Capillary tubes in façade render [6], and (b) steel cladding systems [7]

Although with differences in the implementation of the solar collector field, all three developments have a common approach to the architectural integration of solar collectors with neutral impact on the architecture of solar façades. This imposes a design in which pipework, connections, etc. are handled within the façade system.

Also, due to the use of unglazed collectors the average fluid temperature of these systems along the year is relatively low when compared to glazed systems, which is easily explained according to figure 1. This imposes the use of heat pumps, storage tanks and/or other auxiliary devices in order to ensure that heat delivery is performed with fluid temperatures above that of the façade, and according to the needs of systems such as space heating or Domestic hot water.

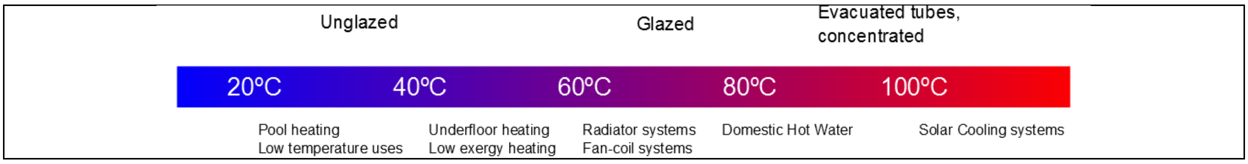

Figure 4: Temperature levels of unglazed solar collector systems, when compared to HVAC services in buildings.

3 Need of flexibility (1p)

The integration of thermal systems in architectural elements, faces not only technological barriers in the field of HVAC systems, or related to the aesthetics of the system itself, but also those related with the adaptation of the architectural solution to each specific building project.

Solar thermal collectors are constructed according to manufacturing constraints such as standard sizes, limits in modulation, standard shapes (rectangular,…). Furthermore, most building façades are suitable for energy harvesting- in fact only unobstructed south orientations are- while the full building need for a formal integration of envelope systems.

Commonly, these constraints lead to the need for adaptation flexibility. In [8], several alternatives are evaluated. Unglazed solar thermal collectors, when integrated into systems such as sandwich elements, or other cladding materials provide for the opportunity to integrate it with standard cladding systems. Commonly these elements are so-called "dummies" as they integrate all the functions of the solar thermal collector, except for the solar harvesting.

As these elements will not harvest energy, their design should be such that its cost is similar to that of traditional building materials.

4 Low energy concept – High performing in all steps

Low energy systems are an ultimate goal that requires of a large share of design efforts to ensure outstanding results. It is not only a matter of the available surface for solar energy harvesting, and performance levels of HVAC devices. The delivery of low energy systems is mostly bound to the design of a system which will meet all user needs profiting of a fluctuating solar energy, through carefully planned storage, and delivery system.

4.1 Thermal storage

Solar thermal systems face fluctuating energy availability (solar radiation, ambient temperature…) and energy needs (discontinuous building occupation, domestic hot water needs, changes in heating temperature setpoint). This imposes the need for thermal storage to ensure a smooth and optimal performance of solar thermal systems.

Depending on the expected fluctuations, available space, and cost on installed power of HVAC devices, thermal storage may be needed as follows:

- Source-side thermal storage will provide a stable output temperature of the solar thermal field, ensuring that instabilities such as clouds (intra-daily or inter-daily storage), or even solar geometry and ambient temperature (inter-seasonal storage). The level of inertia provided by the storage system will be largely dependent on the size of the storage medium, and the level of insulation on it.

- Load-side thermal storage will level the needs of the generation system to meet variable needs of buildings. This kind of storage also serves for cost –reductions with time-dependant price variations in energy (most common in electric-driven heat pumps), and in situations in which capital investment in thermal equipment needs to be limited (more relevant in co-heating or heat pump systems).

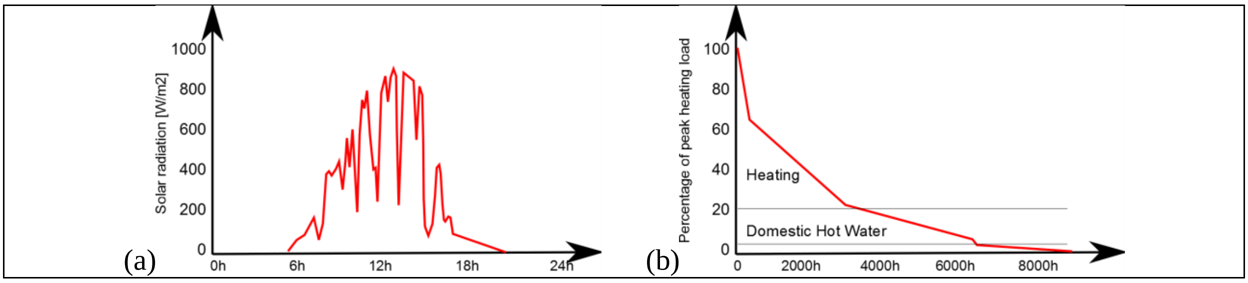

Figure 5: typical solar radiation scenario on a cloudy day (a).Load curve for a residential building in Central Europe (b)

4.2 Performance

The performance of thermal systems is mainly related to the temperature at which heat is delivered. In heating systems, higher energy output is obtained for the same input at lower output temperature, while the opposite happens for cooling systems. Under this principle, low exergy systems target at low energy delivery systems such as radiant floors (see figure 4).

Ventilation heat recovery systems allow for a reduction on the heating/ cooling loads as heat flows through ventilation are reduced by up to 60-70%, depending on the used technology.

Buildings integrating solar thermal systems commonly make the most use of heat recovery and energy optimization design principles. It will be under these situations that solar thermal collectors will provide its best performance, however, under some circumstances, their integration into not-so optimal situations should be allowed. Scenarios such as building retrofits or integration in very complex systems in which envelope integrated solar-thermal is one of many integrated technologies may require of different approaches.

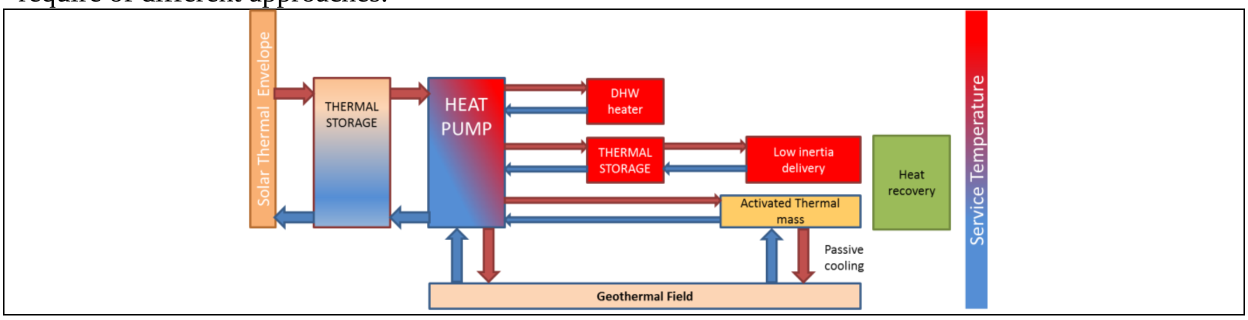

Figure 6: Schematic of high-performing HVAC system

4.3 Overall outcome

Several experiences from the field demonstrate that combined solar thermal systems, if properly sized, provide a relevant increase in overall system efficiency. In [6] experience from simulation provided an overall increase of COPs by 30-40% when compared with regular air-source heat pumps.

Table 1: Coefficient of Performance of heat-pump driven thermal system [6]

Season	Air-source Heat pump	Combined Solar Thermal	Combined Solar Thermal (fuzzy-control)
Heating	2.6	3.4	4
Mid-season	3.3	4.1	5.9

5 Hybridation of structural elements

Hybridation of architectural elements is not only a matter of façade systems. Structural systems such as slabs are also suitable for the introduction of thermal functions. In traditional construction systems, elements such as integrated ventilation ducts, underfloor heating, chilled beams, and thermal mass activation systems among others have been integrated in slabs. This has been relatively easier than in façade systems as these technicalities have most commonly been covered in concrete layers (underfloor heating) or technical ceilings and floors, jointly with electricity, water, ICT and other services in the building.

Slabs are most commonly characterized for being unexposed to external ambiences and containing a relatively large share of the available thermal mass of buildings. Furthermore in modern construction in which light walling systems are increasingly common. This positions these elements as the ideal location for the smooth delivery of energy in buildings as its thermal mass reduces the oscillations in HVAC loads of buildings. For this reasons, concepts such as thermal activation arise, in which the energy delivery pipework is made several cm within the structural element (up to 5cm into the concrete layer) to ensure that all this thermal mass is activated. This allows for stable heating strategies, load-switching strategies in smart building management environments, and even free-cooling/heating strategies, if HVAC plants of building are sufficiently flexible.

Also, the use of slabs as diffusing elements provides very large heat exchange surface areas (when compared to radiator systems), which allows for a relevant reduction of the fluid temperature to provide a set heating value. This provides for an automatic increase in the performance level of heating devices.

However, most of thermally activated slabs are constructed on-site where heavy personnel costs are incorporated in the integration of flexible water pipes in the casting process of the concrete. Complex layouts need to be performed attached to the steel reinforcement, and pressure testing performed prior to the pouring of the concrete. In [10], research is under performance for the integration of energy delivery systems as part of prefabricated slabs based in the COFRADAL 200 series. In this solution, fully prefabricated slabs would be delivered on-site, requiring only minor craft intervention on site-connection of modules instead of full laying of the system.

Figure 7: Test on prefabricated slabs [10] in the Kubik by Tecnalia test facility.

6 Conclusions

Although still under R&D and early deployment scale, the field of envelope integrated solar thermal is evolving into hybrid concepts, far beyond the adaptation of solar thermal collectors into the hybridation of building envelopes. Hybridation of the main building envelope systems are already in its way (mortar renders, steel-based cladding solutions and sandwich envelope systems), which will seamless integrate in virtually any building in Europe.

However, the weak point of these solutions is the size and shape adaptability to match architectural designs and buildings to be retrofitted. For this reason, a deep understanding on the architectural implications of product design alternatives, and standard variants to be offered for the system is needed.

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