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Observation of the energy exchanged by a concrete slab submitted to solar radiation in winter: small scale experimentation

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Abstract

In a context where buildings are more and more insulated, the energy gains through windows have an increasing impact on the energy balance of a room. The solar energy enters the building through the glazing and is intercepted by the surfaces of the floor and walls. Depending on the characteristics of the surface and materials, the energy can be more or less absorbed into the walls/floor, and released later on. The quantity of energy stored and the delay with which it is released depend strongly on the thermal mass and conductivity of the materials, as well as of the absorptivity of the surface.

Concrete is known to have a very good thermal inertia, as it combines a high thermal mass and conductivity. However concrete is mostly covered with flooring materials or coatings. This paper presents an experimental study carried out in order to evaluate how much energy could store a concrete slab, how long, and what was the impact of the thickness of the slab. Different flooring materials were also compared.

Results show that the thick slabs can absorb solar energy during a sunny day and release it during the 2 following days and nights in the absence of sun. A thinner slab can release energy during the following night but not longer. While tiling and linoleum doesn't affect much the storage potential of the concrete slab, parquet reduces nearly by 2 the energy stored and released by the slab. This study shows that an appropriate choice of the covering material is important to use correctly the storage potential of concrete. An important thickness helps storing energy for longer periods and can smooth energy demand on non-sunny days

Keywords – thermal inertia, concrete slab, experiment, heat transfer, solar radiation

1. Introduction

In a context where buildings are more and more insulated, the energy gains through windows have an increasing impact on the energy balance of a room. The solar energy enters the building through the glazing and is intercepted by the surfaces of the floor and walls. Depending on the characteristics of the surface and materials, the energy can be more or less absorbed into the walls/floor, and released later on. The quantity of energy stored and the delay with which it is released depend strongly on the thermal mass and conductivity of the materials, as well as of the absorptivity of the surface.

Concrete is known to have a very good inertia, as it combines a high thermal mass and conductivity. However concrete is mostly covered with flooring materials or coatings. This paper presents an experimental study carried out in order to evaluate how much energy could store a concrete slab, how long, and what was the impact of the thickness of the slab. Different flooring materials were also compared.

2. Experimental set-up

a. Concrete slab samples

Five concrete samples were cast in 30*30cm square moulds, four of them being 16cm thick and one 4cm thick. The cement used was CEM I. They were surrounded with 4cm extruded polystyrene one the 4 sides and in the bottom in order to reduce the heat losses. This was to have a close to 1D heat transfer. In addition, we prepared a sample with no inertia by gluing a wooden parquet on 5 cm polystyrene.

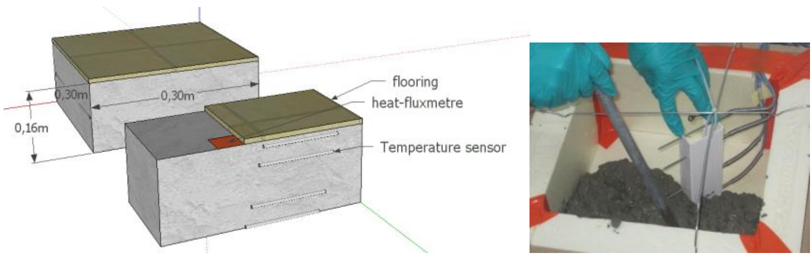

Fig. 1 : schema of the slabs instrumentation and picture of their making

As shown in Fig. 1, temperature sensors at different depths have been set up in each slabs of 16cm thick: just beneath the surface, 4cm from the surface, 12cm from the surface and at the bottom (16cm from the surface). The temperature sensors chosen were platinum sensors both for their reliability and because they were able to resist the mechanical and chemical stress of the concrete cast. In the sample of 4cm thickness only 2 temperatures are measured: under the surface and at the bottom (4cm from the surface). Fig. 1 (right) shows a picture of the cast of the sample; the sensors were placed in a plastic frame to maintain them during the cast.

In addition, a heat-fluxmeter was planned to be positioned underneath the flooring material (if any); for the samples left uncovered, the heat-fluxmeter was placed inside the fresh concrete, just under the surface.

Two slabs were left uncovered: one of 16cm thickness, and the one of 4cm. The three other slabs of 16cm were covered with flooring materials: one with a light grey tiling, one with a dark grey linoleum, one with a light brown wooden parquet. The covering material was glued in all three cases. The colour of the flooring material was chosen as close as possible to the colour of the concrete in order to reduce the effect of the absorptivity. However it was not possible to have the exact same colour. This is why, in the end, they were painted with a black, mat paint, to make additional measurements. Table 1 summarises the description of all samples.

Table 1 : sample description

	slab		flooring		
Ref.	material	thickness	material	thickness	colour
A	concrete	16cm	-	0cm	light grey
B	concrete	16cm	tiling	0.5cm	light grey
C	concrete	16cm	massive oak parquet	1,2cm	light brown
D	concrete	16cm	linoleum	0,2cm	dark grey
E	concrete	4cm	-	0cm	light grey
F	polystyrene	5cm	massive oak parquet	1,2cm	light brown

Table 2 : Experimental stages

Steps	Covering state	Thermal Stress
0	uncovered	No radiation, controlled temperature room
1	uncovered	Radiation with Artificial Solar Bench
2	Covered, original colour	Radiation with Artificial Solar Bench
3	Covered, original colour	In-house – behind south oriented windows
4	Covered, black painted	Radiation with Artificial Solar Bench

One month after the cast of the samples, the platinum sensors were tested to check that they were still working and reliable. This was done by installing them in a climate chamber at constant temperature. All of the sensors gave satisfying results, except for one of them (see later). Unfortunately, during the installation of the flooring materials 2 sensors (close to the surface) were damaged and could not be used any more: in the sample B (tiling) and C (parquet).

These samples have been tested in two different configurations: an Artificial Solar Bench and in a real-house. These two experimental devices are presented here

b. Artificial solar exposure bench

The Artificial Sun Bench is an experimental device which allow to expose components up to 12m² to different level of controlled radiation. The device is made of a sun: 8 lamps which generate the radiation, a cool-sky simulated by an cool air-flow under the lamp (so that the tested components do not see the lamps temperature. In this campaign, both lamps and tested components have been set up horizontally as shown in Figure 1.

Figure 1 : Artificial Sun Bench

One of the limitation of this bench is the uniformity of the radiation on the tested surface. It depends on the lamps position and the distance between lamps and the tested surface. Positions of both lamps and samples have been optimized to have a similar radiation on every sample. In order to estimate this limitation, the slabs have been tested under the artificial solar bench without covering materials (Step 1). Previous tests made in a temperature controlled room (Step 0), have highlighted that all sensors give a similar temperature (difference < 0.5°C) except for one sensor (in slab D, at 4cm depth) which is lower of 1°C. Figure 2 shows the temperature evolution during the test under the Artificial Solar Bench. The difference of the sensor slab D 4 cm depth is still visible. Slabs A, C and D have similar temperatures, while slab B gives temperatures lower than the other slabs from 0.5 to 1°C. This can come from the non-uniformity of the radiation. This preliminary test highlights the limit of the next results.

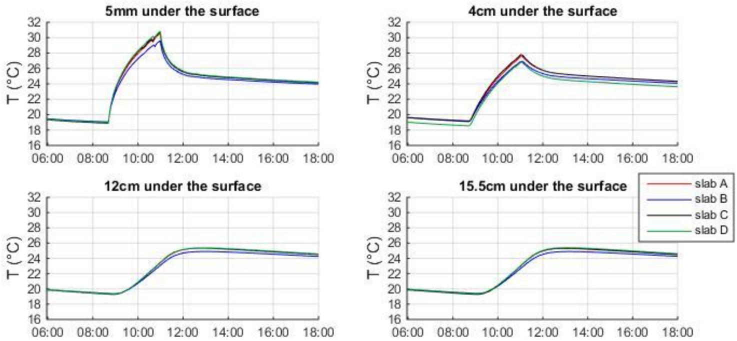

Figure 2 : Temperature evolution at different depth for slabs without covering materials under the Artificial Sun Bench

With this bench two different scenarii have been tested. First a radiation of 600W/m² during two hours/day each day which corresponds to an average daily irradiation at winter time, and secondly, 600W/m² 5 hours/day every 2 days.

c. In-house exposure

The slabs have been settle inside a real house behind some south oriented French windows (step 3). The house is an experimental house from the INCAS platform at INES, Le Bourget du Lac, France.

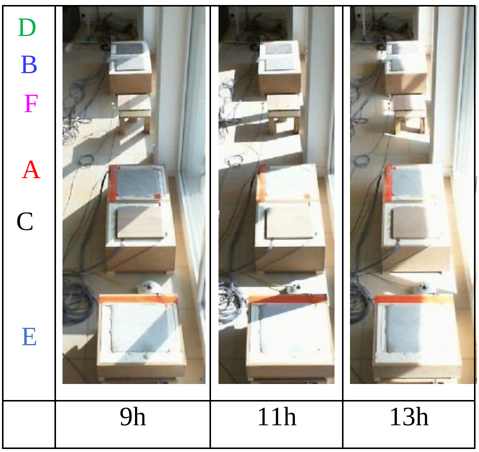

Fig. 2 : exposure of the samples in the test house

3. Results

In this section, the results are presented. The first part will be dedicated to the temperature measurement, and secondly to the heat flux.

a. Temperature evolution at different depths

Figure 3 illustrates the temperature evolution in the 5 concrete slabs with covering materials in their original colour (A to D = 16cm, E = 4cm thick) for an irradiation of 600W/m² during 5 hours, following by 2 days without irradiation (Step 2). Temperature is plotted at 2 depths: under the surface and at 4 cm below. For all the slabs, the temperature increase at both thickness. In the slab of 4 cm thick, the temperature is similar at both depths with the same dynamic, contrary to the slabs of 16 cm, where the temperature at 4 cm from the surface is inferior of 2°C (slab A) to 4°C (slab D). Figure 4 shows that the temperature at 12 and 16cm are really similar (non discernible curves).

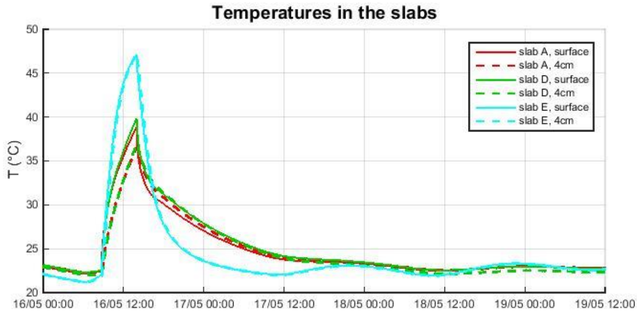

Figure 3 : Temperature evolution for the different slabs with flooring unpainted under the solar Bench

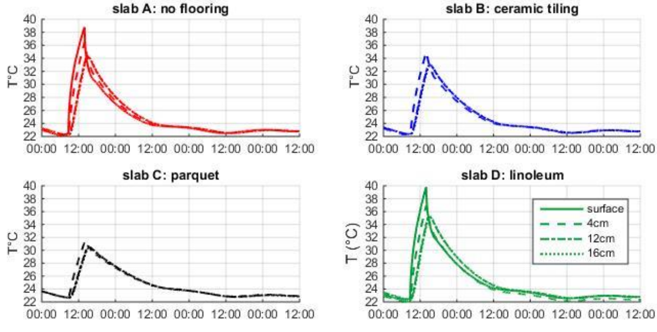

Figure 4 : Temperature evolution in the 4 slabs of 16cm

b. Energy flows under the articificial solar bench

In this part, we will look at the heat flux measured under the surface for the different slabs with coveinrg materials and painted in black (same absorptivity) when they were exposed to the Artificial Solar Bench at 600W/m² during 5 hours the 14/01 and with free evolution the 2 days after (Step 4). Figure 5 shows the integrated daily heat flux for the 3 days from 14/01 to 16/01 at the surface each slab. The upper graph is the sum of all fluxes, the middle graph is the sum of positive heat fluxes (energy entering the slab), and the lower one is the sum of negative heat (energy leaving the slab).

If we look at the positive heat flux, which corresponds to the energy stored in the slab during the irradiation of the artificial sun bench, it can be seen that the energy stored depends on the slab thickness and on the covering materials. The 4 cm slab (E) stores less than 65% of the energy stored in the slab of 16cm (A – both being without flooring). Regarding the covering materials, the massive oak parquet limits the energy storage in the slab compared to the other materials (around 60%). The three other floorings (none, tiling or linoleum) allow a similar storage (the difference being in the range of uncertainties).

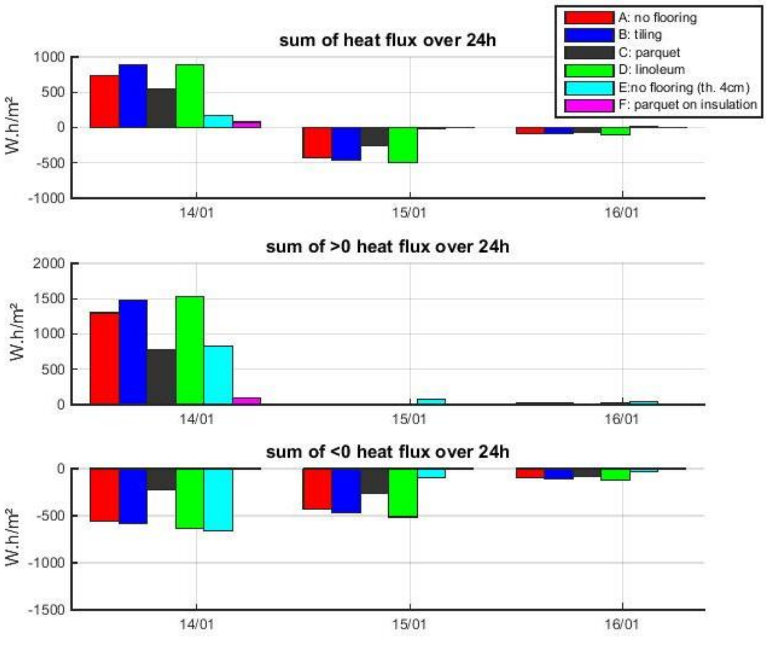

Figure 5 : Heat flux in the different slabs

Regarding the energy release in the first night (lower graph, day 14/01), the tickness of the slab does not have an impact on the global amount of energy. Conversely, the flooring materials has a significant impact. The slab C with massive oak parquet releases twice less than the other flooring materials.

Regarding the energy restitution during the second night (lower graph, day 15/01), the 4 cm slab has already released all the energy stored the day before contrary to the 16cm slabs which still restitute around half of the energy released during the first night.

c. Energy flows in real conditions.

The samples covered but unpainted have been settle in a house behind a large French window as shown in Figure 2 (Step 3). The objective of this step is to know the behavior of the different slabs in real conditions (radiation intensity, time dependent, and duration). The lower graph of Figure 6 illustrates the incident solar radiation measured inside the house. The first three days are sunny. The 22th of March is really cloudy with no solar radiation. The 23rd of March have limited solar radiation. The upper graph of Figure 6 illustrates the heat flux measured in the different samples. There are larger difference than the previous paragraph since the samples where covered but not yet black painted. So it can be seen that the color does impact the heat flux going through the slab.

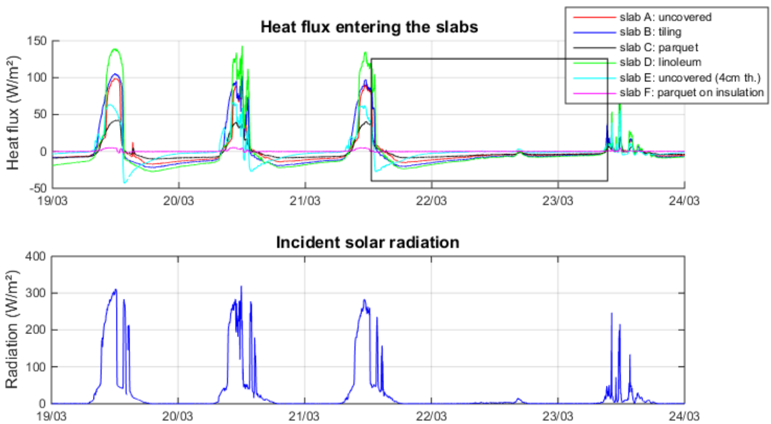

Figure 6 : Heat flux and solar radiation for 5 days in March

Figure 7 is a zoom on the heat flux from the 21st of March noon to the 23rd of March 06AM. As mentioned, the 22nd is a really cloudy day without solar radiation. Figure 7 illustrates that the thin slab (thickness = 4cm) release the maximum of energy between 3 and 4 pm, when the direct solar radiation disappear and decrease quickly to be close to zero at 06am the day after. Conversely, the 16cm slabs release the maximum of energy at 8pm (same timing for all the slabs) which fits to the energy demands in a house. The released energy then decrease slowly and some heat flux still remind on the day after.

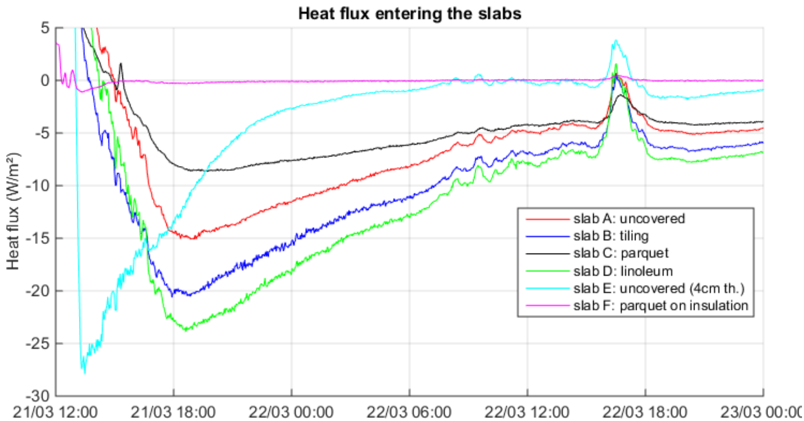

Figure 7 : Zoom on the heat flux for 2 days without solar radiation

4. Conclusion and Perspectives

This work presented an experimental study on thermal response of concrete slab samples to solar radiation depending on the flooring material and the slab thickness.

It has been highlighted that the whole thickness of a slab is impacted by solar heat flux with an increase of the temperature. For a small slab (4cm) the temperature remains homogeneous in the thickness contrary to the 16cm slabs where the temperature decrease in the depth, and the maximum occurred later in the lower part of the slab.

The thickness of the slab both impact the energy stored when the sunshine and the time to release this energy. For a thin slab (4cm) less than 65% of energy is stored compared to a 16cm slab in the configuration tested. This energy is almost fully released in the night after the storage. For the thin slab, the energy is released just after the solar radiation stops, whereas it is delayed to a few hours for the thick slabs which better corresponds to the energy demand of buildings

The flooring material also impact the energy stored. With the same absorptivity (flooring painted in black in this study), tiling, linoleum and uncovered concrete stored and released the same amount of energy in the same timing. The massive oak parquet acts as an insulation layer and decreases the heat flux between the air and the concrete slab of 40%.

Some limitation have been highlighted in this study which need some complementary work to go further. First step could be the upscaling from samples to a real house and from 1D to 3D transfer. This study is on the way with a new experimental house in which some sensors have been set up in a slab at the construction stage. Secondly, the impact of the flooring material and the way it is coupled to the slab (stick, free floating, …) will also be a point of interest which will impact the performance of the slab in its thermal regulation.

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References

[1] Palmer, J M, Thermal mass in buildings - Practical issues with concrete construction, Proceedings of the International Conference on Application of Codes, Design and Regulations, 2005, Pages 473-482

[2] BALCOMB J.D.: Heat storage and distribution inside passive solar buildings, Conférence Second International PLEA Conference, 1983, pp. 547–561.

[3] LAGESSE, A, JAY A., Impact of Thermal mass on Summer comfort in building: a numerical approach leading to a decision support tool, Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, 2013 August 26-28

[4] A. Arnault A, Internal surfaces including phase change materials for passive optimal shift of solar heat gain, International Journal of Thermal Sciences, Vol 49, Issue 11, Nov 2010 p2148-2156

[5] TSILINGIRIDIS G., SOTIROPOULOS V.: Three-year measurements of ambient and indoor air temperatures in Solar Village-3, Athens, Greece, Energy and Buildings, Vol. 28, pp. 127-136, 1998

[6] ANTONOPOULOS K.A., KORONAKI E.: Apparent and effective thermal capacitance of buildings, Energy, 23(3) (1998) 183-192

[7] ASAN H.: Effect of wall's insulation thickness and position on time lag and decrement factor, Energy and Buildings, 28 (1998) 299-305

[8] ASTE N., ANGELOTTI A., BUZZETTI M.: The influence of external walls thermal inertia on the energy performance of well insulated buildings, Energy and Buildings, Vol. 41, pp. 1181–1187, 2009

[9] ASTE N., ANGELOTTI A., BUZZETTI M.: The influence of external walls thermal inertia on the energy performance of well insulated buildings, Energy and Buildings, Vol. 41, pp. 1181–1187, 2009

[10] KOSSECKA E, KOSNY J. The effect of insulation and mass distribution in exterior walls on the dynamic thermal performance of whole buildings. In: Conference proceedings: "thermal performance of the exterior envelopes of buildings VII" December 6-10, 1998, Clearwater Beach, Florida. p 721-731