EVALUATION OF THERMAL ENERGY STORAGE POTENTIAL IN LOW-ENERGY BUILDINGS IN FRANCE

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1. Abstract

As demands in thermal comfort of buildings rises, the energy consumption is correspondingly increasing. For example, in France, the energy consumption of buildings has increased by 30% over the last 30 years. Housing and tertiary buildings are responsible for the consumption of approximately 46% of all energy produced and approximately 23% of the total CO_2 emissions. Nowadays, thermal energy storage systems are essential for reducing dependency on fossil fuels and then contributing to a more efficient environmentally benign energy use.

In buildings, thermal energy storage can contribute to:

- rationalize the use of renewable energy by phasing energy demand and solar energy production,

- rationalize the use of electricity by shaving the peak loads.

Thermal energy storage can be accomplished either by using sensible heat storage, latent heat storage or sorption of chemical reaction. Of course, these physical phenomena lead to different energy densities that can be stored in the materials involved (kWh/m^3).

The objective of the paper is to present, for the case of France, the results concerning the volume of storage required in low energy buildings depending on the following parameters:

- the storage criteria (inter-seasonal, 40 coldest days, load peak shaving only,...),

- the physical phenomena involved in the storage/release process,

- the location of the building.

The software TRNSYS is used to model and to calculate the energy storage system requirements for the different parameters in a low-energy house, which has been tested. Then, sensible, latent, sorption and chemical heat storage volumes are evaluated. The conclusions concern the potential for using different technologies of thermal energy storage in France.

2. Introduction

According to the latest reviews on energy consumption in building (Kuznik et al., 2011 ; Marszal et al., 2011 ; Castell et al. 2010 ; Ma and Wang, 2009) and notably in housing, it appears that it has constantly been increasing over the 30 last years. Moreover, peak loads are always rising and thus more difficult to manage by the energy supplying companies.

In order to overcome these problems, the usage of renewable energy would be relevant. The sun is the most available source of energy on earth, but one of the main difficulties encountered is the phase shift between the energy need and the energy availability.

Therefore, thermal energy storage would be a suitable solution. It can either be done by using sensible heat, latent heat, sorption or chemical reactions.

It would now be interesting to evaluate the volumes needed by varying different parameters (storage criteria, physical phenomena and location) for a low-energy house in France. Indeed, if the volumes needed are too great in quantities, it would be difficult to install the storage unit and notably when the amount of space available is limited (house renovation for instance). This is what will be presented in this paper.

To begin, a description of the different parameters will be given, followed by a description of the modeling hypothesis and finally, the results and conclusions will be presented.

3. Parameters descriptions

In this study, it is necessary to examine the three parameters and their effects on the heating energy demand and therefore on the storage volume.

2.1. Storage criteria

To begin, it would be relevant to examine whether or not the volume needed to cover the annual energy demand for heating would be too big.
However, because the volumes may be too large, only certain periods of time could be studied: for example the coldest days and the peak loads (which usually appear between 5:00-8:00 PM).
Therefore, six different storage criteria will be studied:

- Annual
- Annual (peak loads only)
- 40 coldest days
- 40 coldest days (peak loads only)
- 22 coldest days
- 22 coldest days (peak loads only)

2.2. Physical phenomena

There are four different physical phenomena available for storage/release:

- Sensible heat
- Latent heat
- Sorption
- Chemical reactions

Each of these physical phenomena has a different energy density that can be stored in the materials involved.

Tab. 1: **Energy density for the four different physical phenomena studied (Hongois,2011)**

	Sensible heat	Latent heat	Sorption	Chemical
Energy density (kWh/m^3)	55,8	50	200	2500

The energy densities given in the table above are common values, which will give the capability to evaluate the volumes of storage materials needed to cover the heating energy demand.

2.3. Building's location

The building's location is a parameter that will greatly affect the results. The original study was conducted in eight different thermal zones in France as defined in the RT2005 (CSTB, 2005). The results of the heating energy demand have shown that these could be grouped in three main thermal zones.

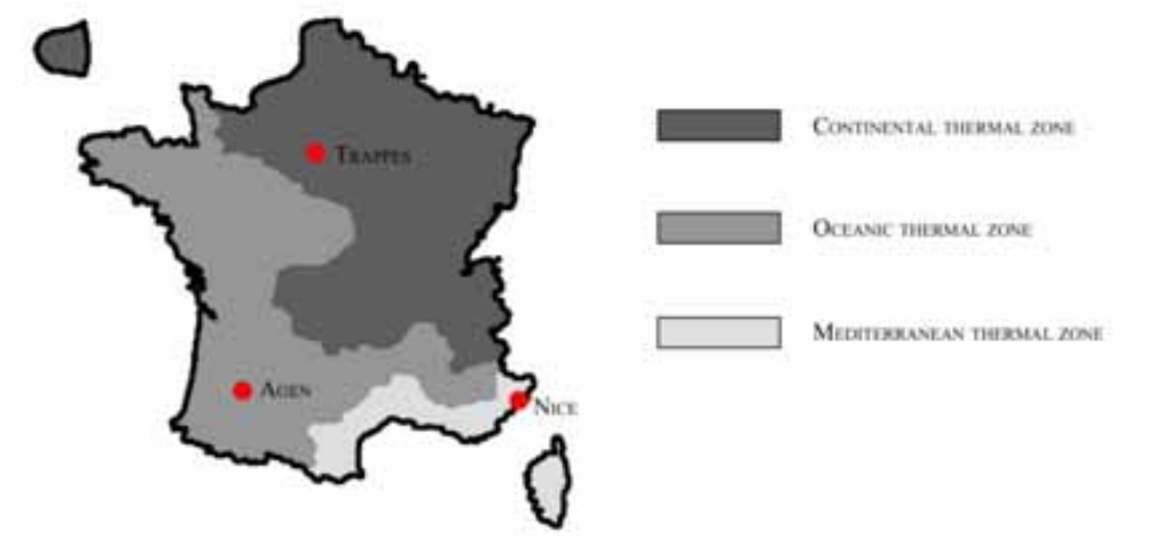

Fig. 1: Map of the three main thermal zones

For each of these thermal zones a representative city with its weather pattern has been associated.

Tab. 2: Thermal zones and city associated

Thermal zone	Continental	Oceanic	Mediterranean
City	Trappes	Agen	Nice

4. Modeling's hypothesis descriptions

In order to evaluate the volume of materials needed to store enough energy in the different criteria cases for a specific house, it's important to know the energy required for this house. Thus, the software TRNSYS (TRaNsient SYstem Simulation program) has been used. TRNSYS is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings (Klein et al., 2010). With this software it will possible to model a house and to estimate the energy need for this house during the course of one year.

In the following parts, we will shortly describe the house that has been chosen for the study and the hypothesis that were set for the modeling.

3.1. General house description

The house that has been chosen for this study is called house INCAS (Wurtz et al., 2006).

Fig. 2: View of the South and East façades of the INCAS house

It is a low-energy house created by the INES (National Institute of Solar Energy in France). It is an experimental tool, which allows full scale solar technology testing.

The floor area of this house is 98m² divided in two equal levels and the main façade (with its windows and solar panels) is oriented to the south.

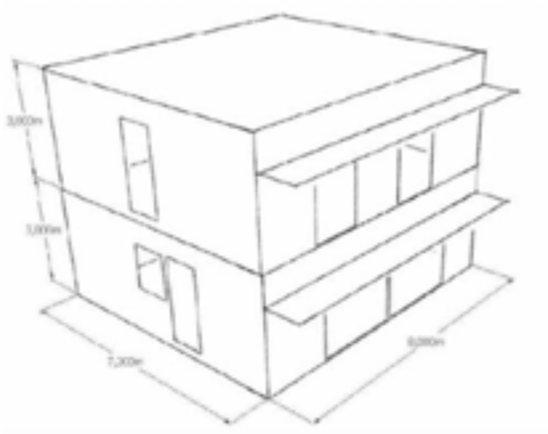

Fig. 3: 3D view of the geometrical hypothesis for the modeling

For the modeling, the house has been divided in two thermal zones: one for each floor. A third zone has been modeled to take into account the effects of the crawl space. This zone is in contact with the ground and the floor of the first level zone and is highly ventilated (5 vol/h).

It has also been assumed that the ceiling of the second level zone is directly in contact with the exterior.

3.2. Walls description

The emissivity of the walls is set to 0,9 and the absorption coefficient (internal and external) to 0,6 for short wave radiations.

Because the INCAS house is a low energy building, the walls are well insulated: the width of insulation goes from 20 up to 40cm.

Tab. 3: Description of the walls (Hongois, 2011)

Wall type	Matérial	Width (m)	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)	Density ($kg\ m^{-3}$)	Specific heat ($J\ kg^{-1}\ K^{-1}$)
External walls	Concrete blocks	0,15	0,74	800	648
	Glass wool	0,2	0,035	12	840
	Concrete blocks	0,15	0,74	800	648
Bottom floor	Extruded polystyrene	0,25	0,029	15	880
	Slabs	0,16	1,23	1300	648
	Heavy concrete	0,04	1,75	2400	880
Top ceiling	Glass wool	0,4	0,035	12	840
	GYPSUM board	0,013	0,32	850	799
Intermediate floor	Concrete	0,22	1,75	2400	880

The carpentry is also of good quality. In fact, it is a double-glazed window with a high-solar gain low-E glass with argon gas fill.

Tab. 4: Description of the window (Hongois, 2011)

Exterior glazing	Width	0,006 m
	Exterior emissivity	0,837
	Interior emissivity	0,837
	Solar transmission	0,781
	Exterior reflectance	0,071
	Interior reflectance	0,071
	Thermal conductivity	1 $W\ m^{-1}\ K^{-1}$
Argon gas	Width	0,016 m
	Thermal conductivity	0,0163 $W\ m^{-1}\ K^{-1}$
	Specific heat	521,9 $J\ kg^{-1}\ K^{-1}$
	Density	1,78 $kg\ m^{-3}$
Interior glazing	Width	0,006 m
	Exterior emissivity	0,103
	Interior emissivity	0,837
	Solar transmission	0,571
	Exterior reflectance	0,229
	Interior reflectance	0,156
	Thermal conductivity	1 $W\ m^{-1}\ K^{-1}$
Frame	Thermal heat loss coefficient U	1,3 $W\ m^{-2}\ K^{-1}$
	Frame fraction	15%
	Absorptivity	90%

The convective exchange coefficients are supposed constant for each wall.

Tab. 5: Convective exchange coefficients for the different walls (W m^{-2} K^{-1}) (Hongois, 2011)

	Bottom floor	Top ceiling	Vertical walls	Vertical window walls	Middle floor
Internal	1,78	4,59	3,29	3,29	4,59
External	3,33	18,9	14,9	14,9	1,78

3.3. Internal gains

Different types of internal gain have been taken into account here:

- The human presence
- Electrical devices

For the internal gains due to human presence, it has been assumed that 4 persons generate each 80 W of convective heat. The scheduled human presence within the house is as followed:

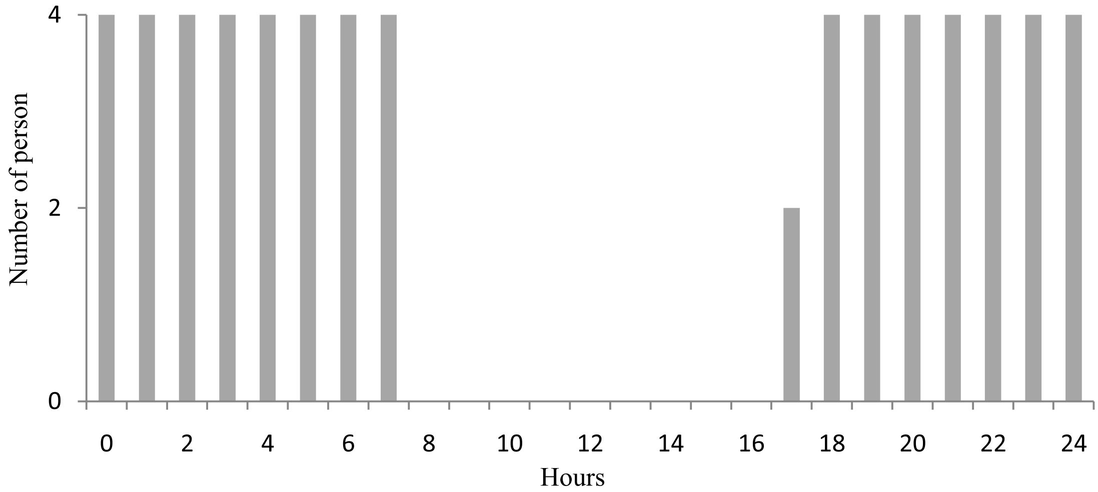

Fig. 3: Schedule of the human presence in the house

The house is equipped with energy efficient devices. Therefore, the internal gains due to electrical devices are low. The convective heat exchange resulting from these devices is as followed:

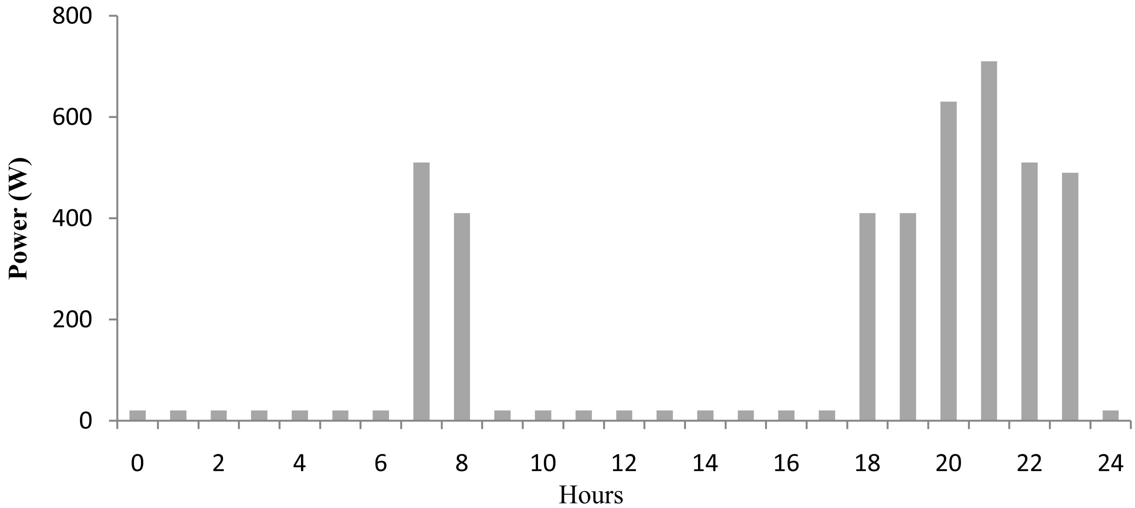

Fig. 4: Schedule of the internal gains do to electrical devices

No vacation weeks have been taken into account.

3.4. Heating and cooling

The heating system is set to 19°C. The heat exchange has been assumed to be only convective.

There is no cooling system.

3.5. Ventilation and air leakage

The ventilation is done with an ERV (Energy Recovery Ventilator) which has an efficient of 75%. While the thermal comfort is acceptable (inside operative temperature between 19 and 26°C), the air flow rate is set to 0,5 vol/h. However, when the inside operative temperature reaches 26°C or more, a night natural ventilation of 5 vol/h starts to cool down the house.

Furthermore, the air leakage is constant and is set to 0,042 vol/h.

5. Modeling results

The following results will be presented by thermal zone. It is assumed that the power is not taken into account. In fact, the power depends on a lot of other variables (the way the storage/release process is done for example). It is also assumed that there is no energy loss while the energy is being stored.

- Continental thermal zone

Tab. 6: Volume results for the Continental thermal zone (m^3)

	Sensible heat	Latent heat	Sorption	Chemical
Annual	40,8	45,6	11,4	0,9
40 coldest days	14,8	16,5	4,1	0,3
22 coldest days	9,3	10,3	2,6	0,2
Annual (peak loads only)	4,4	4,9	1,2	0,1
40 coldest days (peak loads only)	1,9	2,1	0,5	0,04
22 coldest days (peak loads only)	1,2	1,4	0,3	0,03

- Oceanic thermal zone

Tab. 7: Volume results for the Oceanic thermal zone

	Sensible heat (m^3)	Latent heat (m^3)	Sorption (m^3)	Chemical (m^3)
Annual	22,2	24,8	6,2	0,5
40 coldest days	10,8	12,0	3,0	0,2
22 coldest days	7,1	7,9	2,0	0,2
Annual (peak loads only)	2,1	2,4	0,6	0,05
40 coldest days (peak loads only)	1,2	1,4	0,3	0,03
22 coldest days (peak loads only)	0,8	0,9	0,2	0,02

- Mediterranean thermal zone

Tab. 7: Volume results for the Mediterranean thermal zone

	Sensible heat (m^3)	Latent heat (m^3)	Sorption (m^3)	Chemical (m^3)
Annual	3,4	3,8	0,9	0,08
40 coldest days	2,4	2,7	0,7	0,05
22 coldest days	1,8	2,0	0,5	0,04
Annual (peak loads only)	0,3	0,4	0,09	0,007
40 coldest days (peak loads only)	0,2	0,3	0,07	0,006
22 coldest days (peak loads only)	0,2	0,2	0,05	0,004

It appears that in certain cases the volume needed is very great (from a few m^3 up to more than 40 m^3) and in other cases the volume is more acceptable (less than 1 m^3). The next step would be to examine the influence of each of the three parameters. Therefore, two of the parameters will be set. It was observed through the experiment, that whichever values are chosen for the two set parameters, the tendencies and the conclusions will be identical.

4.1. Influence of the storage criteria

In order to evaluate the influence of the storage criteria, the building's location and the physical phenomena have been set:

Tab. 8: Set parameters for the study of the storage criteria's influence

Physical phenomena	Building's location
Sensible heat	Continental thermal zone

Here are the results:

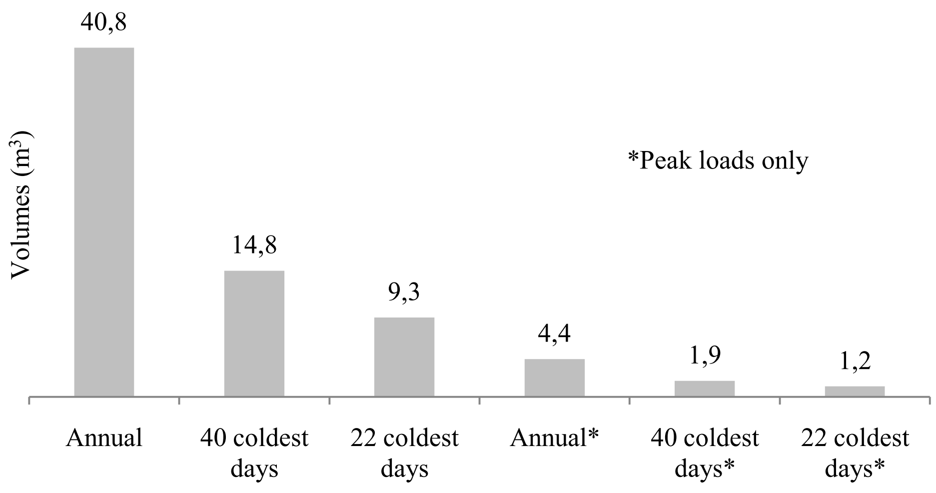

Fig. 5: Comparison of the volumes for the different storage criteria

The volume is very dependent on the storage criteria. According to the graph above it is shown that the storage volume decreases significantly when a shortest period of time is considered.

4.2. Influence of the physical phenomena

In order to evaluate the influence of the physical phenomena, the building's location and the storage criteria have been set:

Tab. 9: Set parameters for the study of the physical phenomena's influence

Building's location	**Storage criteria**
Oceanic thermal zone	Annual (peak loads only)

Here are the results:

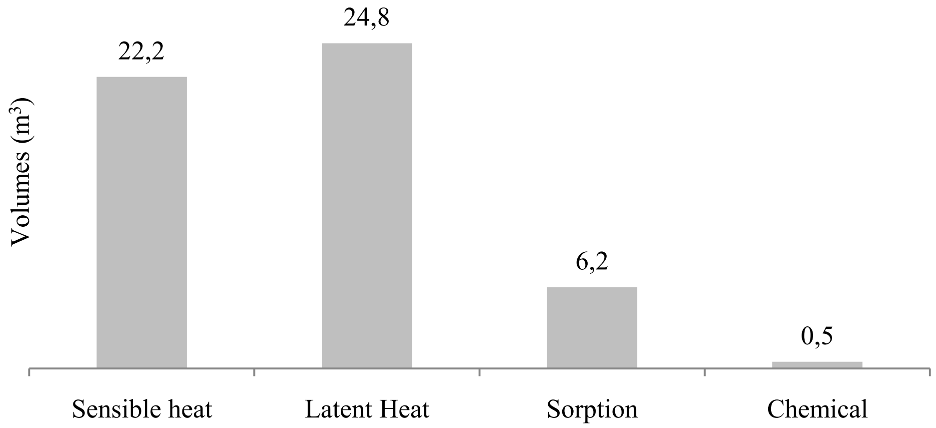

Fig. 6: Comparison of the volumes for the different physical phenomena

It appears that the volume needed to cover the energy demand for a certain period of time and in a specific location, is closely related to the material used. In fact, the volume is forty times more important for sensible/latent heat storage, than for chemical heat storage.

4.3. Influence of the building's location

In order to evaluate the influence of the building's location, the physical phenomena and the storage criteria have been set:

Tab. 8: Set parameters for the study of the building's location's influence

Physical phenomena	**Storage criteria**
Sorption	22 coldest days

Here are the results:

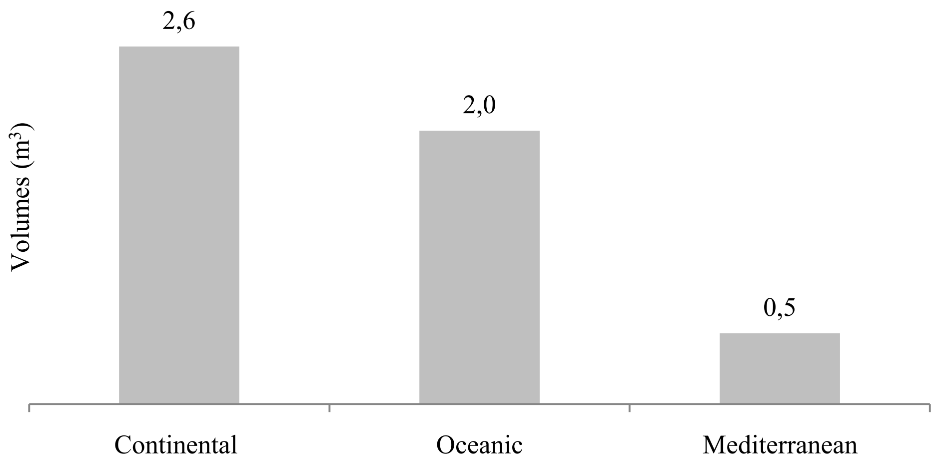

Fig. 7: Comparison of the volumes for the different locations

The graph above shows that the volume needed to cover the energy demand is closely related to the thermal zone. For example, the volume needed to cover the energy demand of the 22 coldest days of the year, using sorption phenomena, is five times greater in the Continental thermal zone, than it is in the Mediterranean zone.

6. Conclusion

Through this paper, it has been shown that the volumes needed to cover a certain energy demand have a wide range of variations which closely depend on the parameters. The storage criteria influence study has pointed out that the volumes are too important to cover the total annual heating energy demand, except maybe in certain warm Mediterranean climate. Therefore, it seems required to select a certain period (coldest days and/or peak loads), during which the heating energy demand will be covered by the storage unit. The results are also very dependent on the physical phenomena. In fact, the study shows that it is not practical to use sensible and latent heat storage material, because the energy density that can be stored by them is too low. Moreover, there would be a loss of energy while it is being stored, because the enclosure wouldn't be adiabatic except for chemical reaction. However, it is important to keep in mind that the results are closely related to the climate.

In this study, it has been assumed that the storage unit will only store energy during the warm and sunny months of the year and will only use this energy during the coldest days of the year: this is called strict inter-seasonal storing. However, this system could be utilized in a more efficient manner by storing the energy at any time of year when it's warm and sunny and using it during periods of cooler weather. Thus, for equal heating energy coverage, the volume of the unit could be decreased.

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