463: INFLUENCE OF THERMAL MASS IN THE FAÇADE ON THERMAL BEHAVIOR OF RESIDENTIAL BUILDINGS IN THE MEDITERRANEAN CLIMATE.

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Abstract

A Light-weight façade and a Heavy-weight façade system are compared in a residential block in Barcelona to investigate the influence of their thermal inertia [1, 2] on the building performance. High thermal inertia in the façade is commonly considered a key factor in Mediterranean climate in the thermal behaviour of houses. The thermal simulation shows that in the studied housing block the incidence of thermal mass in the façade is not very relevant for both energy demand and thermal comfort. Moreover other factors like internal gains and ventilation loads have more incidence than fabric loads.

Keywords: energy, comfort, thermal inertia

1. Introduction

The influence of thermal mass of the façade on the thermal behaviour of residential buildings in the north Mediterranean climate is investigated.
The topic focuses on the comparison of a light-weight façade with a heavy-weight façade. Heavy-weight façades are usually adopted in residential buildings in Spain.

The comparison is performed in a specific case of study of a residential block in Barcelona where both façade solutions are tested.
The approach to the theme is not an extended investigation, but an investigation on a single case of study to get more detailed and specific results that could be a first stage of a larger process of predictive analysis and verification (with simulation and monitoring).

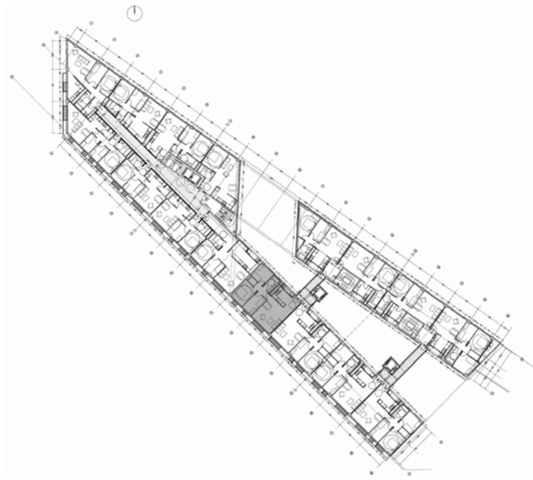
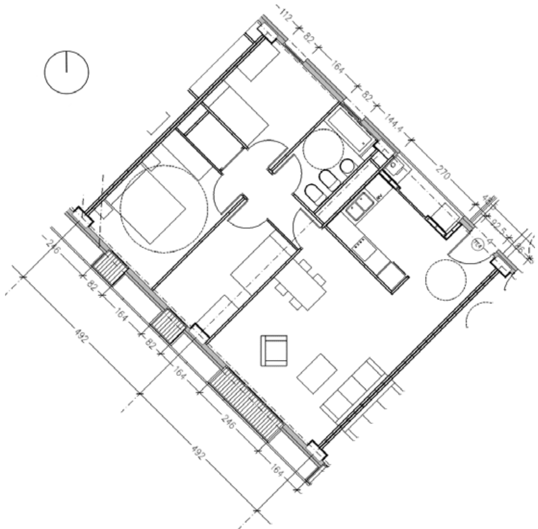


Fig 1. Plan of the third floor

2. Case of study

The case analyzed is a project developed by SaAS - Sabaté associates Architecture & Sustainability.
The building, promoted by Patronat Municipal de l'Habitatge de Barcelona, is a social housing apartment block that will be built in Carrer Roc Boronat, in the urban area of Poblenou in Barcelona [3].



The building of 7 floors has 95 housing units of 2 and 3 bedrooms with roughly 60 and 70 m2 respectively. It is organized in two lines of flats that converge in a corner and form the internal yard where the vertical connections are placed. Almost all flats have one side to the street and the opposite to the yard.

Fig 2. Plan of the modelled flat at the third floor.

The façade solution adopted is a light weight solution composed by an external cladding fibre cement board, a ventilated air gap, a plasterboard, an insulation layer and a double plasterboard.

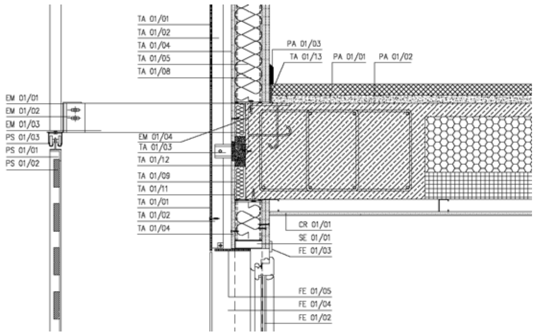


Fig 3. Detail of the light-weight façade with the thermal bridges treated in the intersections with the structure and with sliding solar protections of windows.

Sliding solar protection devices made by timber horizontal elements are mounted outside the balconies to protect the windows in the south west façade. An analogue fixed device encloses the balcony of the kitchen in the north-east façade.

3. Methodology

The comparison is performed with a simulation defining a thermal model with the software Ecotect v5.20 that applies a dynamic simulation method, the Admittance Method.

Thermal lag of building components applied in the admittance method has been calculated according to the standard ISO 13786:1999 [4].

A flat on the third floor south-west oriented is simulated, because of its unfavourable condition for possible overheating in summer.
Building behaviour along one year is simulated with the weather conditions of Barcelona. The parameters of use are established according to the building programme and the Spanish regulations. The adjustments made in the investigation to these profiles take into account the limitations of the simulation tool and a critical review of regulation settings.
As it's not possible to know the boundary conditions for adjacent zones, the criteria to assume heat transfer with adjacent zones equal to zero is accepted with the purpose to compare façade options.

Two options of the building model are compared employing the two different façade solutions:
- **Lwt** option with Light-weight façade (adopted in the project),
- **Hwt** option with Heavy-weight façade system.

The criterion is to compare two façade systems with the same Transmittance (see 4.2).

A third façade is applied in the Hwt070 building model, taken as reference for its total energy demand, even if it is not specific object of this investigation. In this option a Heavy-weight conventional façade system with the U value required by the current regulation [5] is considered. In the conventional façade the insulation layer is located inside the brickwork.

All the other building components are modelled according to the project.
The following results are analyzed:
1. Annual and monthly energy demand of heating and cooling loads. With these results the energy efficiency of the façade solution is investigated.
2. Interior temperature in free-run simulation (without any HVAC system in function). Hourly evolution in the hottest peak day and coldest peak day is calculated. Frequencies distribution of temperature is analyzed. Mean Radiant Temperature and Predicted Mean Vote are analysed too. Inside comfort conditions are studied with these results.

4. Simulation

No external obstructions of the site are considered, so that the comparison is only affected by building parameters.

4.1 Zones

The analysis is performed on one single flat (identified in the model as PISO_A). The zone modelled represents a unit with three bedrooms and roughly 70 m2.

The rest of the building is defined by three single macro-zones representing respectively the spaces situated over the flat PISO_A, the spaces under it and the adjacent spaces at the same floor.

4.2 Opaque elements definition

Opaque elements of the envelope of the thermal zone PISO_A and its internal partitions are defined by the properties of their materials.
Then the software calculates the element's thermal properties apart from Thermal Lag that is calculated according to ISO 13786 [4] and then inserted into the model.
Note that the Thermal Lag of standard elements is experimentally known, but the ISO 13786 calculation method allows the determination of the Thermal Lag of a particular construction element with its own composition. This permitted to bypass a limit of the simulation tool.

The opaque elements types are
- FAÇADE (the compared options)
- PARTITION with adjacent flat (0.12m, Plasterboard/Rock Wool/Plasterboard)
- FLOOR upper and lower (0.40m, Reinforced Concrete/Mortar/Ceramic Tiles)
- INTERNAL PARTITION inside the flat (0.12m Plasterboard/Air Gap/Plasterboard)

Table 1. The façade options compared in the model.

Lwt - Light-weight pannel façade

Layer Name. outside to inside	Resistance {M**2K/W}. (Air Gap only)	Thickness {m}.	Conductivity {W/m-K}.	Density {kg/m3}.	Specific Heat {J/kg-K}.
Fibre Cement Board	-	0.008	-	-	-
Ventilated Air Gap	-	0.060	-	-	-
Fermacell_HD	-	0.015	0.400	1000	1000
Rock Wool	-	0.100	0.034	200	710
Plasterboard	-	0.0125	0.160	950	840
Plasterboard	-	0.0125	0.160	950	840
	U {W/m2-K}. (by Ecotect)	Thickness {m}.	Solar Absorption.		
façade	0.30	0.21	0		

Hwt - Heavy-weight façade system (same U as Lwt)

Layer Name. outside to inside	Resistance {M**2K/W}. (Air Gap only)	Thickness {m}.	Conductivity {W/m-K}.	Density {kg/m3}.	Specific Heat {J/kg-K}.
Fibre Cement Board	-	0.008	-	-	-
Ventilated Air Gap	-	0.060	-	-	-
Rock Wool	-	0.093	0.034	200	710
Brickwork'	-	0.140	0.512	1000	900
Air Gap	0.16	0.050	-	-	-
Plasterboard	-	0.015	0.160	950	840
	U {W/m2-K}. (by Ecotect)	Thickness {m}.	Solar Absorption.		
façade	0.30	0.37	0		

Hwt070 - Heavy-weight conventional façade system (minimum regulation U)

Layer Name. outside to inside	Resistance {M**2K/W}. (Air Gap only)	Thickness {m}.	Conductivity {W/m-K}.	Density {kg/m3}.	Specific Heat {J/kg-K}.
Fibre Cement Board	-	0.008	-	-	-
Ventilated Air Gap	-	0.060	-	-	-
Brickwork'	-	0.140	0.512	1000	900
Rock Wool	-	0.028	0.034	200	710
Air Gap	0.16	0.050	-	-	-
Plasterboard	-	0.015	0.160	950	840
	U {W/m2-K}. (by Ecotect)	Thickness {m}.	Solar Absorption.		
façade	0.70	0.30	0		

In all the alternative options the façade is “highly” ventilated (more than 1500 mm2 for m of air gap in plant) [6].
To define it in the thermal model neither the external cladding nor the air gap are included as façade layers and a Solar Absorption of 0 is adopted to represent the protection of external cladding.

Note that the simulation tool doesn’t take into account thermal bridges that in light weight solution are corrected by the continuity of insulation in the intersections of the façade with the building structure.
On the contrary in the Hwt0.70 conventional system thermal bridges are relevant, as the insulation continuity is interrupted by the structure. The U value of 0.70 W/(m2•ºK) must be considered the mean value of the façade including thermal bridges (higher than the U value of the façade only).

The Thermal Lag of each façade is calculated according to its material properties and inserted into the model:

	Thermal Lag
Lwt -Light-weight panel façade	3.58hours
Hwt -Heavy-weight façade system	8.79hours
Hwt0.70 -Heavy-weight conventional	5.11hours

Note that the reduction of the Thermal Lag between Hwt and Hwt0.70 is affected by the thickness reduction of the insulation layer and by moving the insulation inside the massive layer. The massive layer is the same.

Thermal Lag of the other opaque elements is calculated according to their material properties

Partition	2.86hours
Floor	10.93hours

4.3 Semi-transparent elements

Two semi-transparent elements are defined in the model to simulate the same window type without solar protection and with solar protection, activated during the year according to an hourly profile.

The window is double glazed with timber frame.
The U value and Shading Coefficient of the windows [7, 8] are calculated according to Spanish regulations and then entered into the model [9].

Table 2. Window properties.

Window properties	ProtectionOff	ProtectionOn
U (W/(m2-ºK))	2.70	2.70
Shading Coefficient	0.61	0.30
Admittance (W/(m2-ºK))	2.70	2.70
Alt. Solar Gain - heavywt	0.34	0.17
Alt. Solar Gain - laightwt	0.43	0.22

The Admittance is approximated to U.
For the Alternating Solar Gain factors [10, 8] the values of standard Double Glazed window with Timber Frame are assumed [10].
In the window with solar protection activated Shading Coefficient and Alternating Solar Gain factors are reduced to a half, which result on typical values for the external blind adopted by the project [10].

4.4 Condition of the thermal zones

The parameters of use are established according to the building programme and the Spanish regulations [6, 9].
The adjustments made in the investigation to these profiles take into account the limitations of the simulation tool and a critical review of regulation settings.

Table 3. Operational conditions of the zone PISO_A.

	upper limi	lower limit
T(ºC) comfort	19	26

	Apr-Oct 10:00-20:00
Solar Protection	on

	1:00-7:00	8:00-18:00	19:00	20:00-23:00	24:00
Sensible Gains Equip (W/m2)	0.88	2.64	4.40	8.80	4.40

	Working Day			Week-end
	0:00-7:00	8:00-15:00	16:00-23:00	00:00-23:00
Sensible Gains Occup (W/m2)	2.81	0.70	1.40	2.81

	July-August		Sep.-June
	1:00-8:00	9:00-24:00	1:00-24:00
Ventilation(ac/h)	4	0.6	0.6

The comfort band limits are calculated as the mean of the limit temperatures of Spanish regulation during the system operation.

Parameters of occupancy defined by this investigation approximate the prescriptions of Spanish regulation adopting the maximum occupancy of 3 people by the project.

Sensible Heat Gain from equipments is the sum of the schedules prescribed by the Spanish regulation for the equipments and the lights.

Latent Heat Gain is not considered, because of tool limitations; Ecotect doesn't take into account latent heat gains. The approximation is acceptable given the purpose of the investigation to compare façade options.

The ventilation profile prescribed by the Spanish regulation has been corrected to adapt it to the specific climate conditions reducing the months of night cooling and respecting the air quality minimum requirements [9].

4.5 Calculation parameters of the comfort indicators

For the calculation of the comfort indicators constant values are defined in the zone for Clothing 1clo, Air Velocity 0.5m/s and Relative Humidity 60%.

Varying parameters -air temperature and mean radiant temperature- are obtained by the dynamic simulation.

5. Analysis of results and Comparison between the options Lwt and Hwt

The following results are analyzed:

1. Annual and monthly energy demand of heating and cooling loads (to investigate the energy efficiency of the façade solution).
2. Load distribution (to investigate the incidence of the fabric loads compared with the other loads).
3. Interior temperature in free-run simulation and Predicted Mean Vote (to investigate comfort conditions):

- Frequencial distribution of temperature.
- Hourly evolution during the hottest peak day and coldest peak day.
- Mean Radiant Temperature.
- Predicted Mean Vote (PMV).

5.1 Heating and cooling loads

This study is referred to the energy demand of inside environment. The energy consumption, which depends on the HVAC system efficiency, is not analyzed.

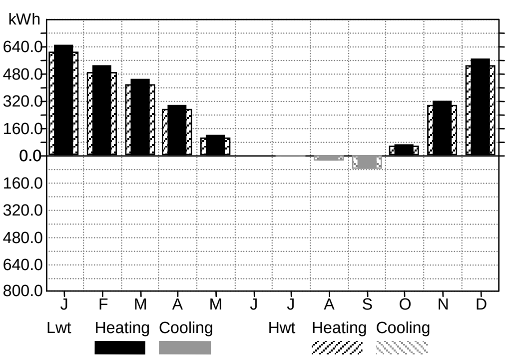


Fig 4. Lwt vs Hwt. Monthly heating and cooling loads of the flat PISO_A.

Monthly loads along the year of the Lwt option exceed the Hwt both in cooling and in heating demand. The total annual energy demand is 7% lower in the Lwt than in the Hwt façade solution.

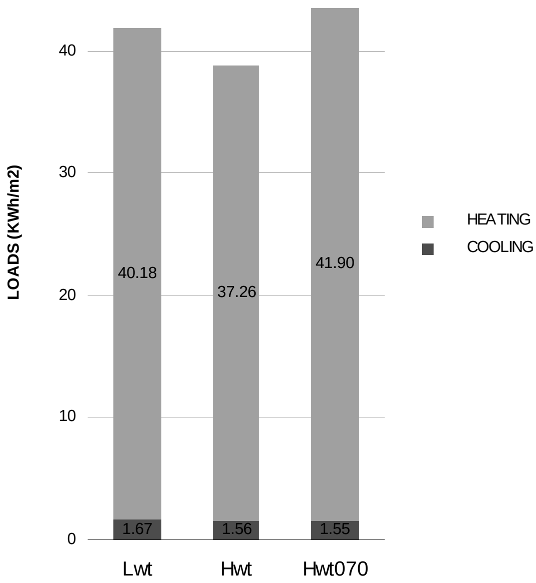


Fig 5. Comparison of annual heating/cooling demand.

Table 4. Comparison of annual heating/cooling demand.

	HEATING LOAD(kWh/m²)	COOLING LOAD(kWh/m²)	TOTAL LOAD(kWh/m²)	TOTAL %
Lwt	40.18	1.67	**41.85**	**100%**
Hwt	37.26	1.56	**38.82**	**93%**
Hwt070	41.90	1.55	**43.45**	**104%**

As heating represents the main component of demand the difference is more evident in heating loads.

Comparing the Lwt option with the Hwt070 option, the annual demand of Hwt070 is 4% higher than Lwt demand.

5.2 Load distribution

Apart from heating and cooling, the other annual loads divided in different components are compared:

Fabric Gains includes conduction loads through the fabric due to differentials in air temperature between the inside and the outside space, plus indirect solar loads due to the effects of incident solar radiation on the external surface of exposed opaque objects.

Different loads may be in favor of heating and cooling or not, so they don't represent energy demand, but they shows which gains are more relevant.

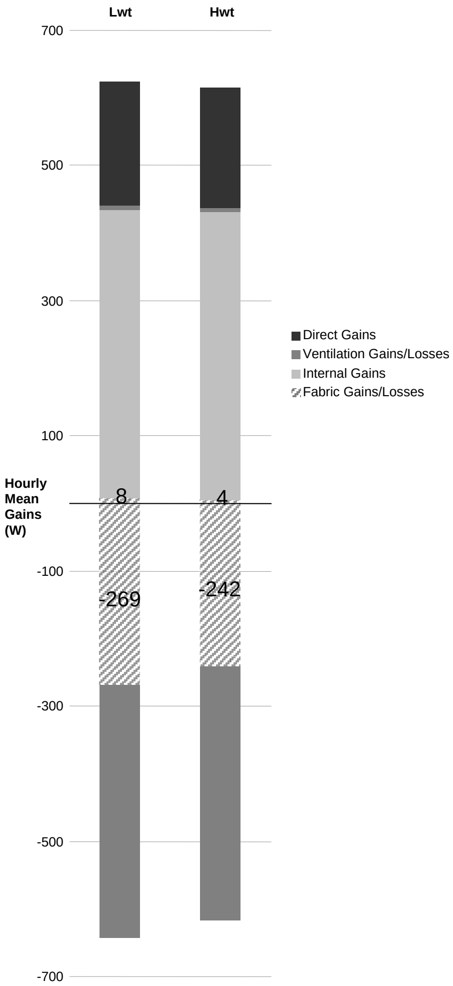


Fig 6. Load distribution in Lwt and Hwt options.

In both options Fabric Losses are the third in relevance (about 20%), after Internal gains (35% about) and Ventilation losses (30% about).

Comparing the two options, Fabric Loss in Lwt is slightly higher than in Hwt (22% and 20% respectively).

5.3 Temperature and PMV

To evaluate comfort conditions inside the building Dry Resultant Temperature [11] and PMV (Predicted Mean Vote) [12] indicator are analyzed. This calculation is performed in free running conditions: no comfort conditions are imposed to appreciate the passive behavior of the building.

• Temperature distribution in time is considered to get a synthetic result on comfort.

• Two daily conditions are considered, Hottest Peak Day and Coldest Peak Day, to evaluate comfort in critical specific periods.

• Two hourly extreme conditions are considered, hottest and coldest outside temperature, to evaluate spatial comfort in critical hours.

The last set of analysis considers Mean Radiant Temperature and PMV.

5.3.1 Temperature distribution

Temperature distribution expresses the fraction of time, over the entire year, in which there is certain inside temperature.

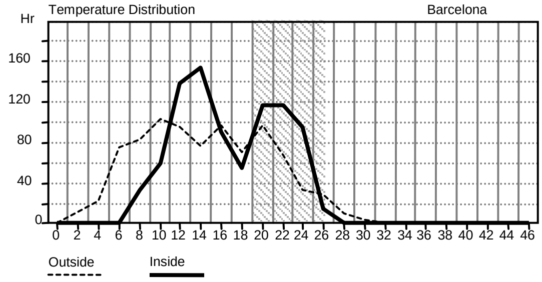


Fig 7. Lwt and Hwt Temperature distribution over the year in free running conditions (Hwt cannot be distinguished by Lwt).

The difference between the two options is not relevant.

During a fraction of time of 60% the temperature is under the comfort band (19º-26ºC) and just for a negligible fraction it is over. During a fraction of time of 39% the temperature is in the comfort band.

5.3.2 Temperature – Hottest/Coldest Peak Day

During the Hottest and the Coldest Peak Day when the hourly peak temperature over the year is reached- differences between the two options is not very appreciable.

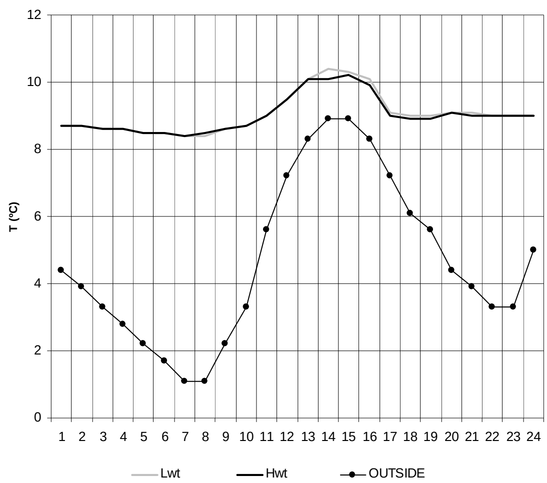


Fig 8. Lwt and Hwt Hourly temperature of the Coldest Peak Day

The most relevant difference between the two options occurs in the Coldest Peak Day (6th December).at 14:00 with 0.3ºC of difference.

5.3.3 Mean Radiant Temperature and PMV resume

In the hour of the year of peak outside air temperature neither mean radiant temperature nor PMV do differ significantly between the two options.

Table 5. Mean values in zone of comfort indicator at 1m over the floor level in free running conditions.

Mean values in zone of comfort indicators				
	coldest hour		hottest hour	
	Hwt	Lwt	Hwt	Lwt
PMV	-3.32	-3.33	0.36	0.39
PPD	95%	95%	8%	9%
MRT (ºC)	13.96	13.93	25.71	25.79

6. Conclusions

In the residential block studied in the climate of Barcelona thermal inertia in façades is not as relevant as internal gains and ventilation with regards to energy demand.

It is not relevant even with regards to comfort conditions.

It must be taken in to account that façade's surface is relatively little in residential blocks. The main part of the thermal envelope of the flat consists of floors and partitions and it isn't in contact with the outside environment.

Moreover it must be observed that the constant temperatures of the comfort band as hypothesis may be relevant in energy demand and in the comparison result. For this reason the comparison with variable temperature schedules is a possible target for a future investigation.

6.1 Thermal mass and conventional façade construction

Comparing the two energy efficient façade systems analyzed (light-weight and heavy-weight) there isn't any relevant difference, although higher thermal mass is more efficient; by the other hand comparing the light-weight and the conventional system the opposite occurs: the light-weight solution adopted by the project is more efficient, even if not relevantly, than the conventional façade.

6.2. Future investigation

This work helped to individuate some critical themes that should be investigated.

1. comparison of the façade system in relation with
   - set point temperature schedule
   - ventilation schedule
   - a more exact calculation method of element conduction (response factors)
2. measurement and monitoring of the building and of building elements.
3. influence of the thermal mass inside the building (floors and other internal masses) rather than in the envelope.

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