DOUBLE SKIN FAÇADES – CAVITY AND EXTERIOR OPENINGS DIMENSIONS FOR SAVING ENERGY ON MEDITERRANEAN CLIMATE

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ABSTRACT

Taking into account Mediterranean climate particularities for Barcelona, Spain, a whole year study using TAS simulation software was carried out for a Double Skin Façade corporative office building. It is a typical office building with an extended working hours schedule for acclimatization. Four different cavity widths were simulated – 40cm, 60cm, 80cm, 100cm - as well as three different external opening areas for cavity's natural ventilation purpose. Two Double Skin Façade typologies were simulated – a corridor façade and a multistory façade. Simulations showed cooling loads are much greater than heating loads on a double glazed skin façade building south oriented in a Mediterranean climate town like Barcelona. Results demonstrated that a Multistory Façade, depending on its configuration, might save up to 5% on annual cooling loads respect to a Corridor Façade. Different opening areas and cavity depths shall be used for different typologies in order to obtaining good energy results.

KEYWORDS

Building simulation, Double Skin Façade, Energy Efficiency, Cooling Loads, Energy saving.

INTRODUCTION

Climate change all over the world and its immediate and future consequences are making up a responsive ecological conscience that claims for energy responsive buildings. This idea is being reflected on construction standards in some countries, like is happening in Spain. The new construction standard "Código Técnico de la Edificación" (CTE – 2006)) shed light on the scope of energy saving on buildings and adopts more restrictive rules for construction, limiting heat gains and losses through the skin of the building. With the application of the new Spanish standard for thermal performance of buildings, a decrease of 30 to 40% on energy consumption with heating and cooling, ventilating and lighting, respect to actual consumption is expected.

Double Skin Façade (DSF) typology is being adopted as façade system on many new corporative buildings in Europe with the promise of saving energy while maintaining a transparent façade.

DSF offers many configuration possibilities, like using the cavity as a conduit to fresh air intake and to exhausting vitiated air from offices (Gratia and De Herde 2003). Also, it is possible to use a DSF together with the heating, ventilating and air conditioning (HVAC) system, in a symbiosis process (Stec 2006). An energy performance assessment of a single storey multiple-skin façade was carried by Saelens (2003) and a study about total solar energy transmittance of a DSF with free convection was led by Manz (2003). Combined heat transfer in turbulent mixed convection fluid flows in DSF was done by Zöllner (2002). Some studies using Thermal Analysis Software (TAS) simulation software about DSF thermal behavior were done (Gratia 2003, Hien et al. 2004). DSF typologies, advantages, disadvantages, uses and many examples were compiled by Oesterle et al. (2001).

In spite of all, investigations about DSF thermal behavior and energy performance for the Mediterranean climate are just starting, while DSF buildings are being constructed adopting recommendations from investigations and experiences from other latitudes. Location data and mechanical conditioning data from Barcelona are shown on table 1. Reference temperatures for cooling and heating refer to working hours of a typical office building (8 AM to 20PM).

Table 1 Location and mechanical conditioning data from Barcelona

Latitude	Longitude	Altitude	Cooling Degree-hours (24ºC reference)	Heating Degree-hours (21ºC reference)
41.3	2.1	6	3160	485

OBJECTIVES

The main focuses of these simulations are:

- Distinguishing the influence of cavity depth and height on annual cooling loads (CAL), cooling peak loads (CPL), annual heating loads (HAL) and heating peak loads (HPL) for the DSF building.

- Verifying the influence of the exterior opening (EOp) dimensions on annual energy demands and peak loads for the DSF building.
- Verifying the significance of combining different external opening areas with different cavity depths and heights for saving energy.

SIMULATION

Simulation by TAS software

The TAS software works solving the dynamic fluid equations at the studied building zones using hourly conditions according to local climate data. The equations together describe mass transfer and thermal transmission on each of its process – conduction, convection and radiation. The software also takes into account internal loads like equipments (computers, printers, etc), artificial lighting and people’s load for the building. It also considers infiltration through openings, ventilation and air exchange between zones.

The simulation software is fed with climatic data and predefined internal loads, plus the construction materials thermal characteristics. Energy demand to supply the mechanical conditioning of the building is obtained from a balance between internal and external loads, construction materials thermal and optical characteristics plus the resulting heat exchange between the building and the external environment. All these parameters and the required level of comfort maintenance will determine the necessary energy to keep the system working properly. The study is focused on the thermal performance of the building by means of its energy demands comparison for heating and cooling annual and peak loads.

The building

The model is an isolated office building, counting on a ground commercial floor plus 6 office floors. There are 8 offices per floor and the building is totally air conditioned based on an extended working hour’s schedule (weekday from 8 AM to 8 PM). DSF cavity is naturally ventilated 24 h during the whole year through a corridor façade, partitioned on each floor. The air flows diagonally, entering by bottom opening and exiting by top opening on the exterior skin. It prevents vitiated air from lower floor entering the floor above. This typology is called Corridor Façade (CF). The model was simplified to obtaining non dependent results from others solar orientations. In this way, solar gains from other solar orientations and internal heat transmissions were minimized focusing results on south façade configuration. The only double glazed façade simulated was south façade. The perspective of the building can be seen on figure 1.

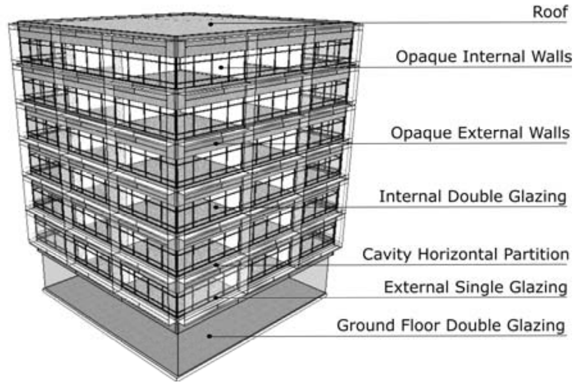

Fig. 1 . Perspective of the corridor façade office building

The orientation of the building matches exactly with the 4 main natural solar orientations – north, south, east and west, as seen on figure 2.

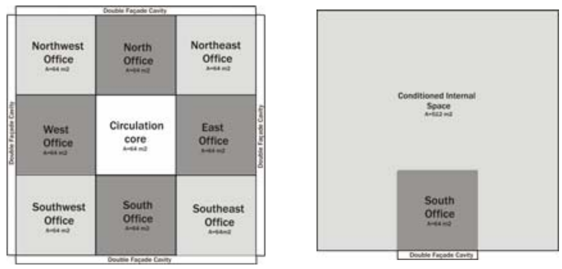

Fig. 2. Building organization and solar orientation for the complete model(left) and for the simplified model (right)

The corridor façade and its components can be seen on figure 3.

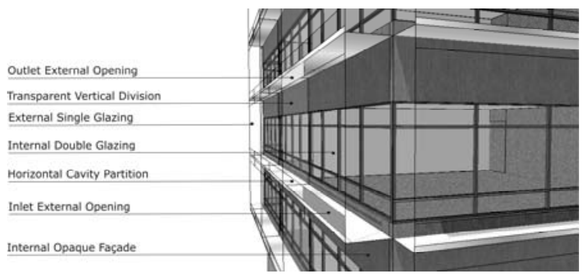

Fig.3. Corridor façade detail

Other solar orientations but south façade are treated as opaque surfaces, icluding ground floor walls. The entire building is air conditioned except façade cavities. Figures 4 shows the CF buidling.

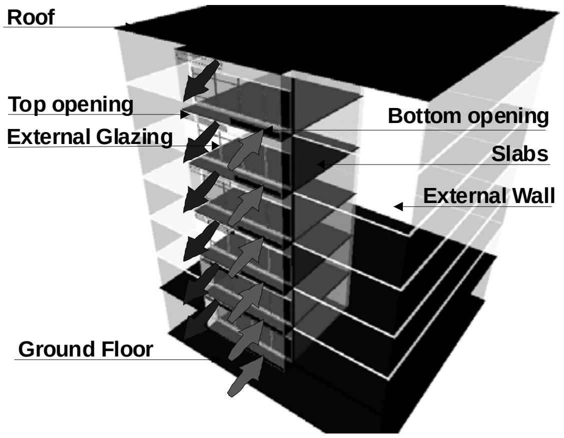

Fig. 4. Building's corridor façade south offices

The interior skin of the building is a typical Curtain Wall typology 60% double glazed while exterior skin is tottaly single glazed. Table 2 shows the studied zone dimensions.

Table 2 Studied zone dimensions

Office area per floor (south office)	64m^2
Office volume per floor (south office)	236.8m^3
Cavity area per floor (south cavity)	6.4m^2
Cavity volume per floor (south cavity)	24.96m^3
Vertical distance between external openings	3.5 – 23.5m
Transparent external façade area per floor	32 m^2

A multistory façade (MSF) is obtained by removing horizontal partitions on each floor of the building and by closing all EOp, except the bottom opening at the first floor and the top opening at the sixth floor. The cavity of this typology becomes totally integrated and the air enters the cavity by the bottom opening and exits by the top opening.

The simplifications on the models will not provide the exact energy demands for cooling and heating the offices, as they isolate south offices from the influence of others solar orientations and internal asymmetric temperatures for different zones. The results accomplish with the purpose of a qualitative comparison of the different models. Figure 5 shows the MSF simplified model.

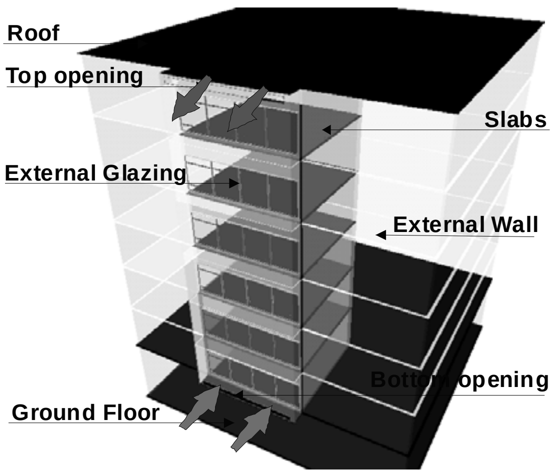

Fig.5. Building's multistory façade south offices

Simulation Parameters

Input data is the necessary information to feed the simulation software in order to perform the thermal analysis. It is divided in two groups - the variable data and the fixed data. The variable data is DSF cavity and exterior opening dimensions that are being analyzed and compared, as can be seen on table 3.

Table 3 Variable Input data

	Corridor façade	Multistory façade
Exterior openings dimensions	5%=1.6m^2 10%=3.2m^2 15%=4.8m^2	0.8%=1.54m^2 1.6%=3m^2 2.4%=4.6m^2 1.6%(7.5m wide)= 3m^2 3.2%(7.5m wide)= 6m^2 4.8%(7.5m wide)= 9.2m^2
Vertical distance between external openings	3.5m	23.5m
DSF cavity depth	40cm, 60cm, 80cm, 100cm	

Fixed data is the information repeated on every simulation and is not subjected to analysis. These non variable parameters are seen on table 4.

Table 4 Fixed Input Data

Parameter	Value
Artificial lighting thermal load	15 W/m^2
Equipments thermal load	10 W/m^2
Occupancy sensible gain	6.5W/m^2
Occupancy latent gain	4.2W/m^2
Working schedule	8am to 8 pm
Barcelona's climate database	Meteonorm
Air leakage	0.05 – 0.1ACH
Floor Height	4m
Ground solar reflectance	0.2
Building's Height	30 m
Mean height of surroundings	30 m
Exterior glazing width	6mm
Exterior glazing solar factor	0.3
Double Glazing interior pane width	6mm
Double Glazing cavity width	10mm
Double Glazing cavity filling	air
Double Glazing exterior pane width	6mm
Exterior glazing U-value	5.73 W/m^{2}C
Internal floors U-value	0.9W/m^{2}C
Ground floor U-value	0.27W/m^{2}C
Roof U-value	0.25W/m^{2}C
Exterior Walls U-value	0.5W/m^{2}C
Cavity partition elements U-Value	6W/m^{2}C
Windows frame conductivity	0.14W/m^{2}C

Output data will be the CAL, CPL, HAL, HPL, maximum cavity temperature and air flow rate in the cavity.

CAL and HAL represent the maintenance energy required to accomplish with users minimum thermal comfort. It means how expensive thermal comfort will be for such building typology. CPL and HPL represent the necessary power for the HVAC plant to accomplishing with maximum HVAC demands for thermal comfort maintenance. It means how much money will be invested on HVAC equipment acquisition.

Simulations were run hourly for the whole year, with 15 days of precognition air-conditioning of the building.

d) Simulations sequence

External openings area simulation

At first, the 1 floor height CF was simulated varying its EOp area, according to table 3.

Cavity depth simulation

At this moment, simulations were carried out varying façade's cavity width among 40, 60, 80 and 100cm. Each of these typologies was tested with the different EOp areas listed on table 3.

Cavity height simulation

The MSF was then simulated, varying its EOp areas and cavity depths according to table 3.

Then, the area of the EOp was doubled for the multistory façade, as shown on figure 3. The width of these openings passed from 3.75m to 7.5m, as the possible problem of warm air reentering the façade through openings does not exist for this case.

RESULTS

Simulations results refer to annual loads and peak loads for the six south facing offices, totalizing 384m^2 of analyzed floor area. Cavity temperatures refer to the 6th floor cavity. Air flow volume (Air changes per Hour, ACH) represents the ventilation rate of the cavity – 1 floor height in the CF case and 6 floors height in the case of the MSF. The air flow rates also vary according to the cavity widths simulated.

1 FLOOR CORRIDOR FAÇADE (CF)

CAL results for 1 floor height CF demonstrated that wider cavities perform better than narrower cavities, as can be seen on figure 6. The same figure shows the bigger the opening areas the lower energy demands for CAL. However, it is possible to sense a bigger difference on these loads when changing from 5% to 10% the EOp areas, rather than when changing from 10 to 15%. Increasing EOp has a more important influence on decreasing CAL than increasing cavities' depth. By increasing opening areas from 5% to 15% for a 40cm cavity depth, a 2.06% less energy demands is obtained. For a 100cm cavity depth, it lowers demands by 2.48%.

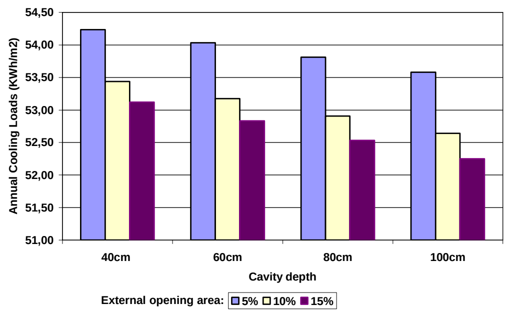

Fig 6 Annual Cooling Loads for 1 floor Corridor Façades

Wider cavities with bigger EOp also presented lower CPL, as showed on figure 7. Again, increasing openings area represents a more important influence on decreasing CPL than increasing cavity depth.

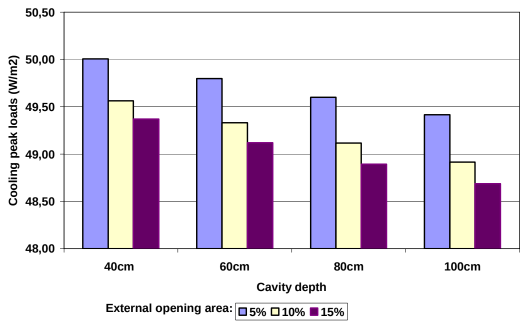

Fig 7 Cooling Peak Loads for 1 floor Corridor Façades

HAL for 1 floor height CF are shown on figure 8.

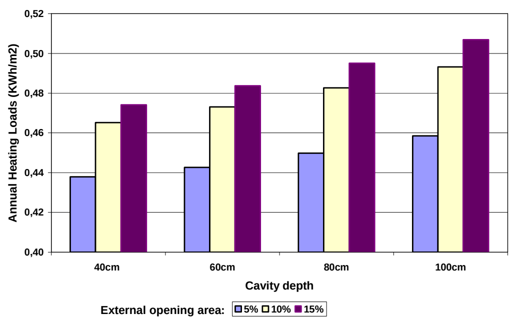

Fig 8 Annual Heating Loads for1 floor Corridor Façades

HPL depend more on EOp than on cavity depth, just as HAL, as shown on figure 9. For both of them, the thinner the cavity and the smaller the EOp areas, the less energy for heating is demanded.

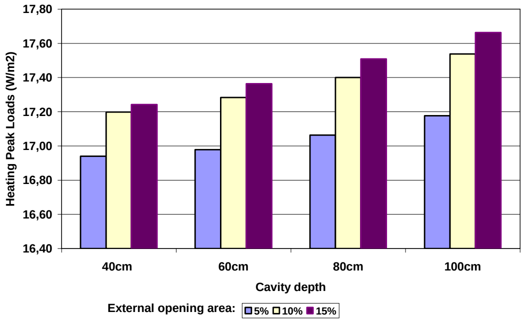

Fig 9 Heating Peak Loads for 1 floor Corridor Façades

Maintaining the EOp area fixed while increasing cavity depth from 40cm to 60, 80 and 100cm produce an average decreasing on ACH of 32%, 49% and 59%, respectively, as can be sensed on figure 10. On the same figure, it is possible to perceive that increasing exterior opening areas from 5% to 10% and from 5% to 15% produce an average lift on ACH of 83% and 147%, respectively, for the same cavity depth.

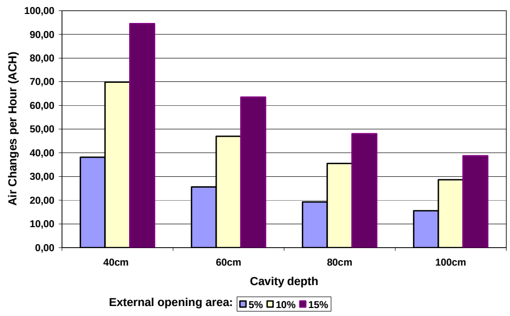

Fig 10 Air changes per hour at the 6th floor of the 1 floor Corridor façades

Maximum cavity temperature at 6th floor cavity demonstrated to be more self dependent on EOp areas variance than on cavity depth changes, as can be seen on figure 11. Increasing EOp areas from 5 to 15% can lead to decrements on these temperatures by 5.6%, while increasing cavity depth from 40 to 100cm, and maintaining the same opening area, may lift 6th floor cavity temperature by 1.1%.

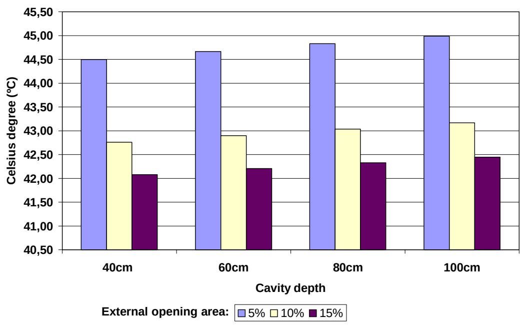

Fig 11 Maximum temperature for 1 floor Corridor façades

MULTISTORY FAÇADE (MSF)

MSF with 3.5m wide external openings perform on a different way than 1 floor height CF when concerning CAL. As there is a sharper temperature gradient occurring along the MSF cavity due to its height, the heat tends to accumulate on the higher levels of this space before exiting by the external top opening. Greenhouse effect on these façade will be more accentuated and will help warm air to moving upward inside the cavity, increasing its ventilation rate.

Variation on CAL for the 5% EOp model is almost the same for all depths tested. As this EOp percentage can not ventilate the cavity efficiently, most of the upward airflow depends on the stack effect. Larger openings perform better to diminish CAL when used together with narrower cavities, as shown on figure 12. This is because of the increment of the ventilation rate that helps the stack effect on extracting air from the cavity.

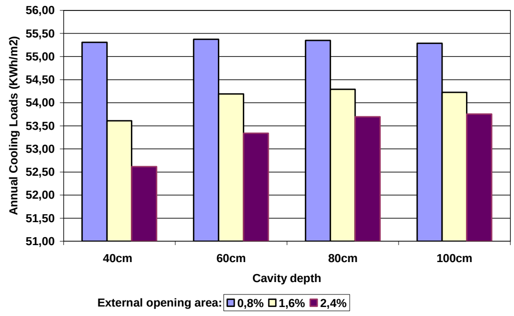

Fig 12 Annual Cooling Loads for Multistory Façades

CPL for this typology presents a very similar behavior, as seen on figure 13. The 40cm cavity depth, together with 15% EOp presents the lowest demands for CAL and for CPL. This occurs because the warm air volume is more effectively extracted from the cavity. Furthermore, this façade typology presents the highest maximum temperature rates as can be seen on figure 16, therefore the stack effect helps extracting air from the cavity.

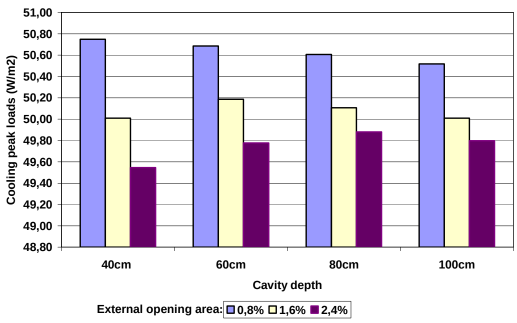

Fig 13 Cooling Peak Loads for Multistory Façades

Maximum cavity temperatures coincide with lower cavity ACH, which is the case of the 5% EOp together with the narrower cavity depth that heats up easily, thus causing lower demands for HAL. Indeed, these loads diminish predominantly because of the variance of the EOp, as seen on figure 14.

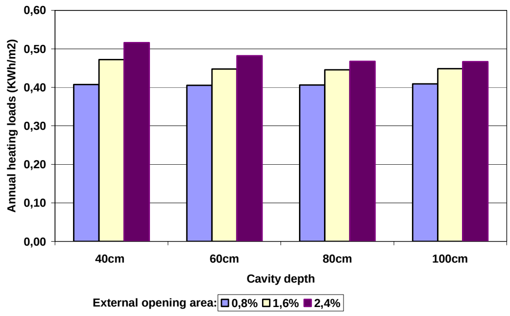

Fig 14 Annual Heating Loads for Multistory Façades

In this case, when upward airflow is slow and depending predominantly on the stack effect, the cavity works as a thermal buffer, insulating the building and lowering heat losses. It also contributes to lowering HPL, as shown on figure 15.

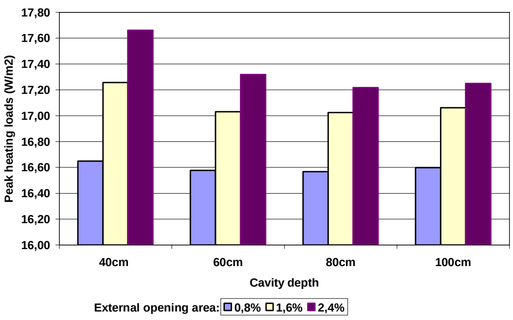

Fig 15 Heating peak Loads for Multistory Façades

Maximum resultant temperatures on the 6th floor cavity depend more on EOp area than on cavity depth, as shown on figure 16. Thinner cavities with bigger openings present a higher air flow rate than ticker cavities with smaller openings, thus lowering the maximum temperatures.

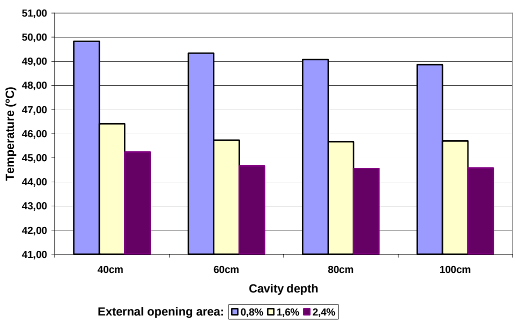

Fig 16 Maximum temperature at 6th floor cavity for multistory façades

Wider cavities used together with small EOp depend mainly on stack effect to extracting air from cavity. In this way, as can be seen on figure 17, typologies that depends predominantly on the stack effect to extracting air present the lower rates of ACH.

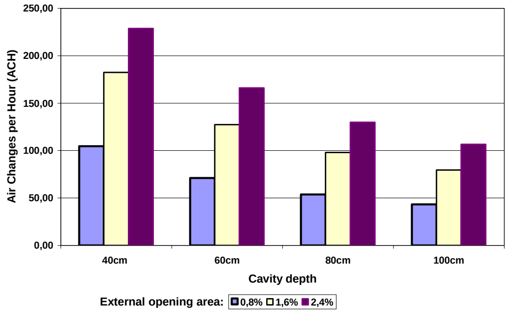

Fig 17 Airflow rates at 6th floor cavity for the multistory façades

Furthermore, on wider cavities with small EOp, the airflow inside the cavity tends to adopt a recirculation behavior, ascending and descending along the cavity height before exiting, thus overheating the cavity space.

MULTISTORY FAÇADE WITH 7.5 METERS WIDE TOP AND BOTTOM OPENINGS

This DSF typology doubles the EOp area of the 6 floors height MSF previously analyzed by extending its bottom and top exterior openings. In this way, the openings occupy almost the total width of the analyzed façade.

As EOp areas are doubled, an increment on the ACH of the cavity is expected for all typologies, as well as a decrement on maximum cavity temperatures. As a consequence of that, lower CAL and CPL are expected as well as higher HAL and HPL.

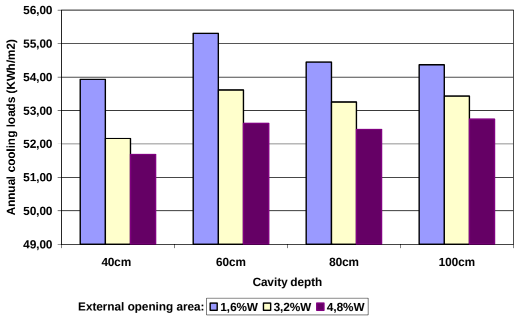

Fig 18 Annual Cooling Loads for Multistory wide openings façade typology

The chart on figure 18 confirms expectations about CAL, which has lowered in comparison to the 6 floors MSF with 3.5m wide. The same has happened to the CPL, demonstrated on figure 19. The larger openings help warm air extraction from the cavity as higher air flow rates start occurring.

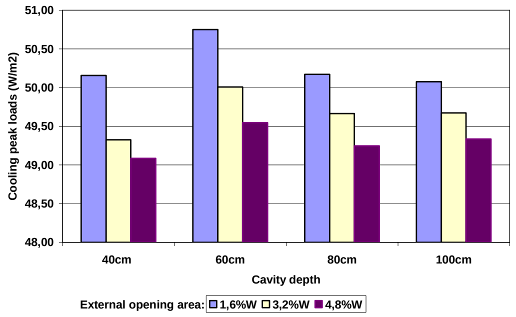

Fig 19 Cooling Peak Loads for Multistory wide openings façade typology

HAL for this typology are a little bit higher than for the 3.5m EOp wide MSF, as can be seen on figure 20. As the higher air flow helps the stack effect on extracting warm air from the cavity, the effectiveness of the cavity space as a thermal buffer is prejudiced and increasing heat losses. The effect of air recirculation inside the cavity also diminishes, as wind driven force is more effective on extracting air from the cavity.

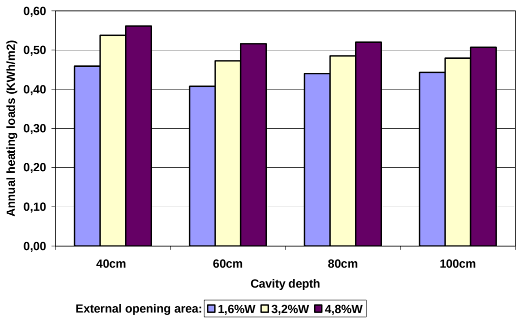

Fig 20 Annual Heating Loads for Multistory wide openings façade typology

As a result of increases on heat exchanges between façade and exterior environment, HPL also increases, as warm air is easily extracted, as shown on figure 21.

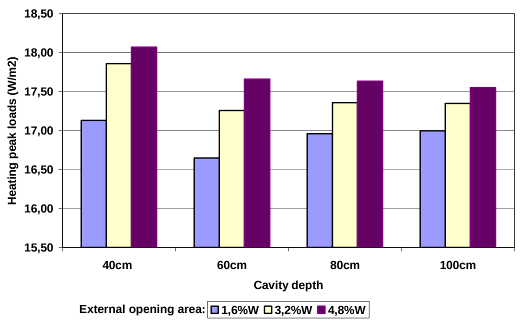

Fig 21 Heating Peak Loads for Multistory wide openings façade typology

As expected, maximum resultant temperatures on these façades have also diminished (figure 22), because of the higher rates of the ACH in the cavity, as seen on figure 23, due to the larger EOp. These relations are very similar between all cavity depths and opening areas.

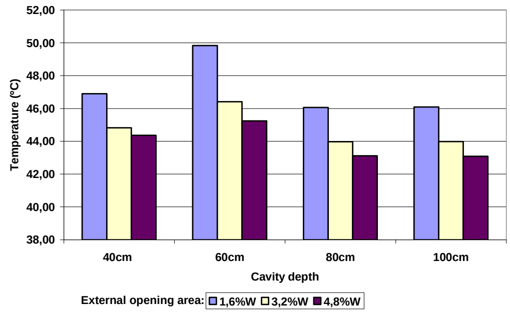

Fig 22 Maximum temperature at 6th floor cavity for the multistory façades

Thinner cavities with large openings present a larger ventilation rate, as seen on figure 23. Counting on larger openings to ventilate smaller spaces, plus the greenhouse effect heating up smaller spaces, a higher ACH is achieved.

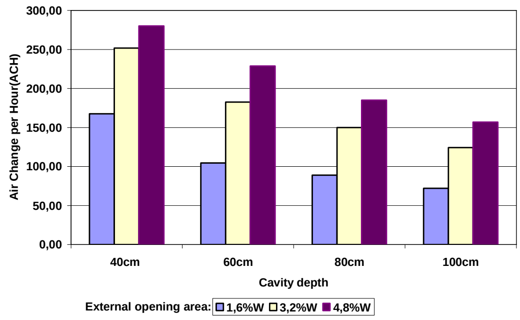

Fig 23 Airflow rates at 6th floor cavity for the multistory façades

Minimum loads and its correspondent DSF typology can be seen on table 5.

Table 5 Minimum loads for analyzed typologies for the south offices

	DSF Typology	Dimensions	Minimum Value
Cooling Loads (KWh/m2)	Multistory 6 floors WEO	40cm - 2,4%	51.69
Cooling Peaks (W/m2)	Multisoty 6 floors WEO	40cm - 2,4%	49.09
Heating Loads (KWh/m2)	Multistory 6 floors	40, 60, 80, 100cm – 0.8%	0.41
Heating Peaks (W/m2)	Multistory 6 floors	80cm – 0.8%	16.57

CONCLUSIONS

Simulations showed cooling loads are much greater than heating loads for south oriented DSF building, under Barcelona climate conditions. Thus, preventing overheating of the cavity through adequate ventilation is necessary for energy saving. Optimum cavity ventilation might be achieved by equilibrating its dimensions – height, width and depth – as well as its elements dimensions, such as the EOp. All these factors are linked and demonstrated on the simulations on this study.

Building a DSF involves high costs, including maintenance costs of two additional surfaces. It also requires integrated elements and implies on losing office occupancy area for cavity space purpose. Indeed, costs might increase significantly not only by the building of the second skin and its components, but also by the acquisition of a more powerful HVAC plant and the higher loads for thermal comfort maintenance that it probably implies.

Simulations demonstrated that a narrower cavity with no horizontal partitions may demands less energy on CAL and CPL than a wider cavity partitioned on each floor. The lower energy demand for CAL for the 1 floor CF was 52.25 kWh/m^2. The 6 floors MSF with wide EOp demands 1.07% less energy for the same purpose. Apparently, this saving is little significant, but it implies on others advantages. It is due to the greater ventilation rate of the cavity and to the accentuated stack effect occurring inside the cavity. The air heats up rapidly in this space due to the great distance between exterior bottom and top openings, causing a higher temperature gradient along the height of the cavity. The larger exterior opening areas proportionate better ventilation for narrower spaces.

These advantages would be the less space dedicated to the cavity space, which could be used as office area; the less material used on the cavity, as well as the lower weight of the additional structure. A better sound insulation would be another advantage due to the less exterior openings, as it can be significantly helpful on noisy areas of a town.

For using a 40cm wide multistory façade, the cavity space should be accessed by the offices through interior openings, for maintenance reasons. If maintenance service is to be made by walking over rails inside the cavity space, then its depth should be wider than 40cm.

Simulations demonstrated the predominant influence of the exterior opening areas on diminishing cooling loads on all models.

Results for cooling and heating are quite similar because of the little sensitivity of the model. The opaque surface of the façade's interior skin, as well as the double glazing are very well insulated, diminishing heat exchanges between offices and cavity space. If a poorer insulated opaque wall were used instead, higher fluctuations on cooling and heating annual and peak loads would be obtained.

DSF offers a lot of construction possibilities such the adding of controlled shading devices inside cavity and controlled external and internal openings for night ventilation of the cavity or even natural ventilation of the offices.

This is a simulation study for some particular simplified DSF models under particular climate conditions. The results of this study can not be adopted as reference for others climates. This study is not sufficient for technically designing a DSF, as there are many other DSF components and parameters to be taken into account.

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