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Greenhouse effect in double-skin facade

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Abstract

In these last years, a great deal of interest has been devoted to double-skin facades due to the advantages claimed by this technology (in terms of energy saving in the cold season, high-tech image, protection from external noise and wind loads).

One of the great characteristics of the double-skin facade is the greenhouse effect. We identify the factors that influence the greenhouse effect.

The identified parameters are solar radiation level, orientation and shading devices use, opaque wall/window proportion of the interior facade, wind speed, colour of shading devices and of interior facade, depth of the cavity of the double-skin, glazing type in the interior facade and openings in the double-skin.

We analyze the impact of these parameters on the mean air temperature evolution in the cavity.

After that analyse, the article answers the question: is greenhouse effect favourable?

The answer is moderate according to the double-skin orientation.

Keywords: Double-skin facade; Greenhouse effect; Thermal simulation; Office building; Cooling strategies

1. Introduction

The double-skin facade is an architectural phenomenon driven by the aesthetic desire for an all-glass facade.

The transparency is often seen as the main architectural reason for a double-skin facade, because it creates close contact to the surroundings. This in fact is also derived from a client's point of view saying that physical transparency of a company gives a signal of a transparent organization with a large degree of openness [1].

This ‘‘emerging technology’’ of heavily glazed facades is also often associated with buildings whose design goals include energy efficiency, sustainability, and a ‘‘green’’ image.

So, there is an increase of the number of this type of building. The success of these facades also lies in that they admit a high degree of daylight and have an outdoor uniformity and attractive aesthetics [2,3].

The costs of double-skin facades are higher than normal facades, but claims of energy and productivity savings are used to justify some of them [4].

The recent advent of computers and other office equipments increased the internal heat gains in most offices. Highly glazed facade, often with poor shading, have become very common. This, together with the extra heat gains from the electric lighting made necessary by deep floor plans, and the wider use of false ceilings, increased the overheating risk.

The addition of a double-skin still increases this risk. A faulty operation of the double-skin facade openings can generate catastrophic scenarios such as the injection of the hot air of the double-skin facade in the offices [5–8].

Double-skin facades are assuming an ever-greater importance in modern building practice. They are already a common feature of architectural competitions in Europe; but there are still relatively few buildings in which they have actually been realized, and there is still too little experience of their behaviour in operation [9–11].

There are many unknowns: optical and thermal modelling of these systems is not routine and coupling heat transfer and air flow from an isolated facade system to the whole building is complex. A variety of thermal coupling strategies between the facade and the whole building must be adequately simulated [12,13].

More, it is extremely difficult to find any objective data on the performance of actual buildings implementing double-skin facades. Only, subjective claims abound in the architectural literature.

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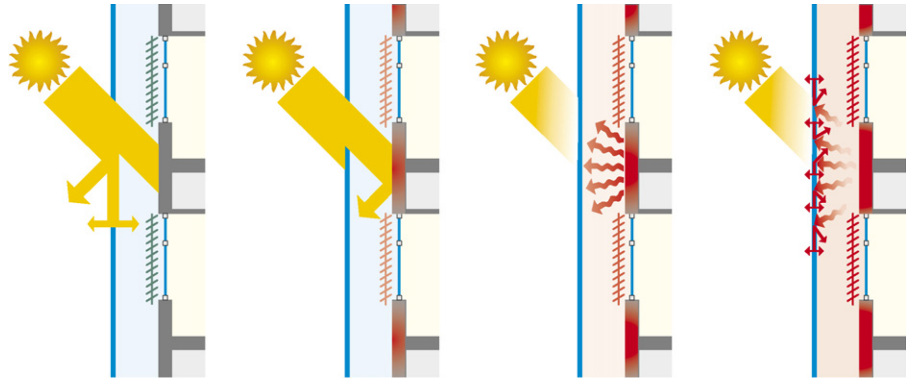


Fig. 1. Greenhouse effect in a double-skin facade.

So, it is important to identify the factors that influence the greenhouse effect, to analyze the impact of these parameters on the temperature evolution in the cavity and answer the question: "is greenhouse effect favourable?"

A double-skin facade consists in an entirely glazed external wall and an interior wall often more massive, composed of glazed walls and opaque walls able to accumulate heat. The double-skin facade applies the same principles as those of a greenhouse, but it does not propose liveable space. The air layer can be used multiple ways according to climatic conditions, hours of occupation, orientation, type of construction and system of air-conditioning . . .. The temperature of the air in this one is influenced by many factors (solar radiation, outside temperature, wind speed, windows openings, type of glazing, presence of shading systems . . .).

When the solar radiation strikes the external skin, it is partially reflected, absorbed and transmitted. The solar radiation which crosses the glazing is then absorbed by the interior skin which warms up. This one re-emits in all the directions a long wave radiation. Almost the whole of this radiation arrives on the external skin, consequence of the morphology of the double-skin. When this long wave radiation strikes the external facade, it is partially reflected and partially absorbed. The absorptive fraction is re-emitted on both sides glazing. Part of the radiation is thus trapped, involving the increase of the interior air temperature due to convective exchange between walls and air of the double-skin. This process is known as greenhouse effect (Fig. 1).

The first element which influences the greenhouse effect is the solar radiation quantity which penetrates in the double-skin. It is directly proportional to the solar radiation level, to the glazing percentage of the external skin (generally near to the 100%), to the solar factor of the external glazing, function of the orientation and the slope of the external skin and to the solar masks generated by environment and building itself.

2. Method

2.1. TAS program

The simulations were realized with TAS. It is a software package for the thermal analysis of buildings. It is a complete solution for the thermal simulation of a building, and a powerful design tool in the optimization of a building environmental, energy and comfort performance [14].

2.2. Studied building

The simulations were realized on the building proposed in the frame of the subtask A of the Task 27 (performance of solar facade components) of the International Energy Agency, Solar Heating and Cooling Program. Some modifications were made to adapt this one to the practices of Belgium.

The building is a middle-size office building with office modules aligned on two facades, separated by a central corridor, with staircase/service spaces at both ends of the building.

The office building comprises 150 office modules, distributed over 5 floors and 2 orientations: 15 office modules per floor at each of the 2 orientations. The schemes are shown in Fig. 2.

Geometrical data of the office building are described here. Vertical cross-section of office module with main measures is shown in Fig. 3.

The internal wall between office module and corridor has an openable window above the door to facilitate the air flow between northern and southern spaces (the false floor is not comprised in the drawing).

Each office has four windows (two top and two below) to allow natural day or night ventilation.

2.2.1. Thermal characteristics

Building envelope:

Roof, $U = 0.3$ W m^{-2} °K^{-1}; ground floor, $U = 0.379$ W m^{-2} °K^{-1}; opaque part of facade, $U = 0.373$ W m^{-2} °K^{-1}.

Low-e double glazing, $U = 1.8$ W m^{-2} °K^{-1}; direct solar transmission, 0.62; total solar transmission, 0.708.

Double-skin:

Clear single glass, $U = 5.33$ W m^{-2} °K^{-1}; shading factor, 0.76.

Width of the air cavity: 1.2 m.

H (double-skin facade) = H (building) + 1 m.

Internal gains in the offices: 29.37 W m^{-2}.

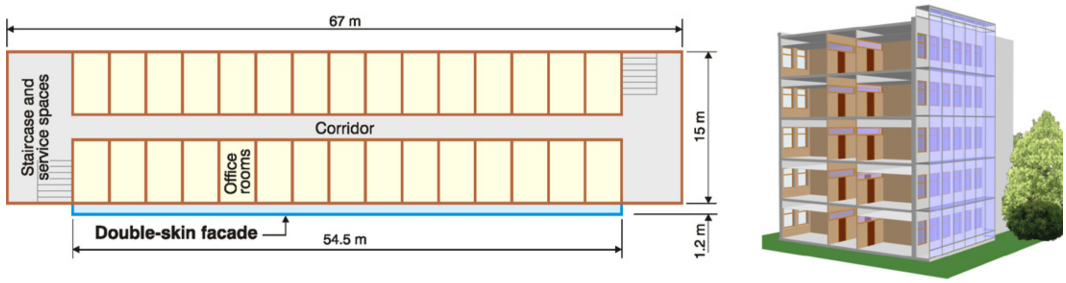
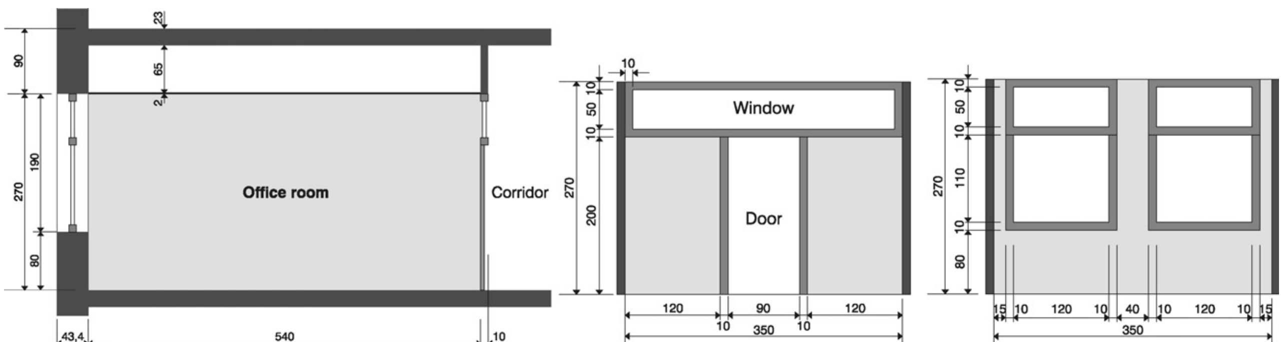


Fig. 2. View of the office building studied.



Vertical cross section of office module. Internal wall between office External wall of the office.

Fig. 3. Geometrical data of the office building.

2.3. Climatic data assumptions

We chose to analyze Belgian standard days (week day). Each modelled day is preceded by the simulation of ten previous days to take account of the effect of inertia.

3. Parameters influencing greenhouse effect

3.1. Solar radiation level

Fig. 4 gives temperature evolution in a closed southern double-skin, according to the cloud cover.

Three types of sky are analyzed:

- clear sky conditions;
- mean sky conditions;
- cloudy sky conditions.

Solar protection devices are shut down in all the cases. One could have imagined that they are up when the sky was covered. We did not do it with the aim of making possible the comparisons. Whatever the season, the southern double-skin always reaches its maximum temperature at 1 p.m.

By clear sky, the maximum temperature in the double-skin is:

- 38.6 °C in winter, in other words, a 35.8 °C increase compared to the outside temperature. Sunning duration is short (8 h) but solar radiation is almost perpendicular to the external glazing. The quantity of radiation crossing the single glazing is thus significant.
- 50.6 °C in spring, in other words, a 38.3 °C increase compared to the outside temperature. Sunning duration is 12 h, the incidence angle of the sun rays on the double-skin being lower than 60°, solar radiation crossing glazing remains significant.
- 47.8 °C in June, in other words, a 23.7 °C increase compared to the outside temperature. Sunning duration is longest (16 h) but the double-skin receives sun radiation only during 12 h. The sun being high in the sky, incidence angle of solar radiation is important; the quantity of solar radiation crossing glazing is weaker. Moreover, the meteorological data of this day correspond to more significant wind speeds which cause cooling of the external single glazing.
- 65.8 °C in September, in other words, a 43.2 °C increase compared to the outside temperature. This period presents the greatest increase in temperature. Sunning duration is 12 h, sun path is identical to that of March, and solar profits are thus significant. Moreover, the outside temperature is more significant than in March (10 °C moreover) thus the losses by transmission through the single glazing external skin are less important.

By cloudy sky conditions, whatever the season, the maximum temperature increase compared to the outside temperature is about a few degrees: 3 °C in winter, 7 °C in spring and autumn and 10 °C in summer. The increase in temperature is related to the diffuse radiation.

3.2. Orientation and shading devices use

Fig. 5 gives, by clear sky conditions, temperature evolution in a double-skin facade according to the orientation of this one

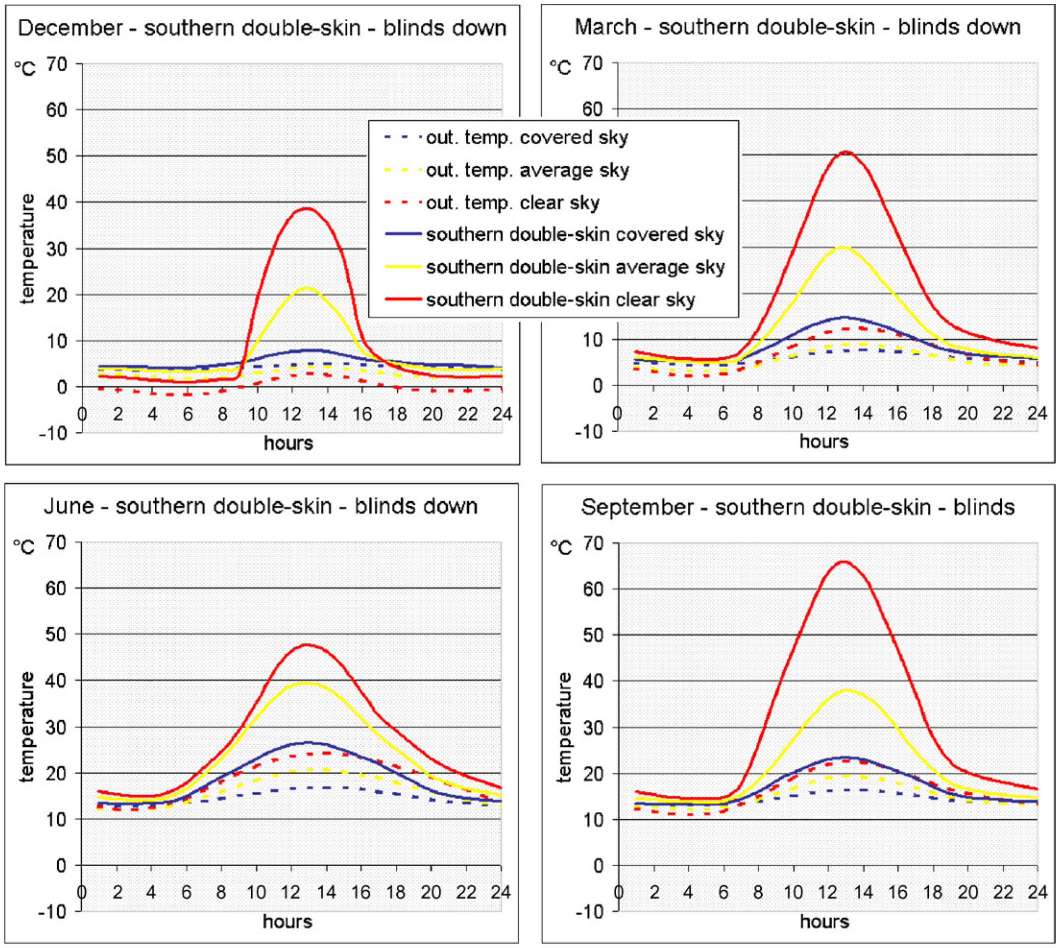


Fig. 4. Temperature evolution in a closed southern double-skin according to cloud cover.

and according to the use or not of mean coloured solar shading devices in the double-skin facade. All the openings of the double-skin are closed. When the solar protection devices are shut down, an important temperature increase is observed in the double-skin. The greenhouse effect increases since an additional part of the sun rays is absorbed by the solar protection devices rather than transmitted in the offices.

In winter, the increase in temperature compared to the outside temperature in the southern double-skin is of 35.8 °C. On the other hand, the building with northern double-skin facade is most sparing in energy. Indeed, the southern offices benefit from the direct sun profits and the northern offices are protected by the double-skin (Table 1).

In spring, if double-skin is used in a dynamic way, the buildings with a southern double-skin, and moderately with a eastern or western double-skin, can use hot air from the double-skin to contribute to heat the zones requiring a heating demand.

In summer, the most unfavourable orientations are east and west; building cooling consumption is higher. If double-skin is east oriented, overheatings appear early in the morning. If the double-skin is west oriented, largest cooling request appears at the end of the day. Solar gains are then cumulated with the internal gains of all the working day. On the other hand, these overheatings appearing at the moment of the employees' departure can be eliminated naturally later in the evening (Table 2).

In autumn, by clear sky conditions, the most unfavourable orientations are south, east and west. Cooling consumption of the building is higher. During this period, outside temperatures are still important and sun height is relatively low. So, autumn is the season when overheatings risks are significant.

3.3. Opaque wall/window proportion of the interior facade

The importance of the greenhouse effect depends on the capacity of receiving surfaces solar radiation absorption. Indeed, the short wavelength solar radiation is transformed after absorption by opaque surfaces into long wave radiation. This radiation trapped in the double-skin facade is responsible for the greenhouse effect. If the glazing proportion in the interior facade increases, most of solar radiation will not be absorbed by the opaque walls but will be transmitted directly in the offices.

If interior facade glazing is not absorbing, temperature in the double-skin is always lower in a double-skin facade which the proportion of glazed surface in the interior facade is 74.1%, than in a double-skin facade which the proportion of glazed surface in the interior facade is 39.5% (Fig. 6). In the case of a southern double-skin, if one examines the consumption of the two buildings during a sunny winter day, we see that heating need of the more glazed building (in spite of lower temperature in the double-skin) is lower than the heating need of the basic building

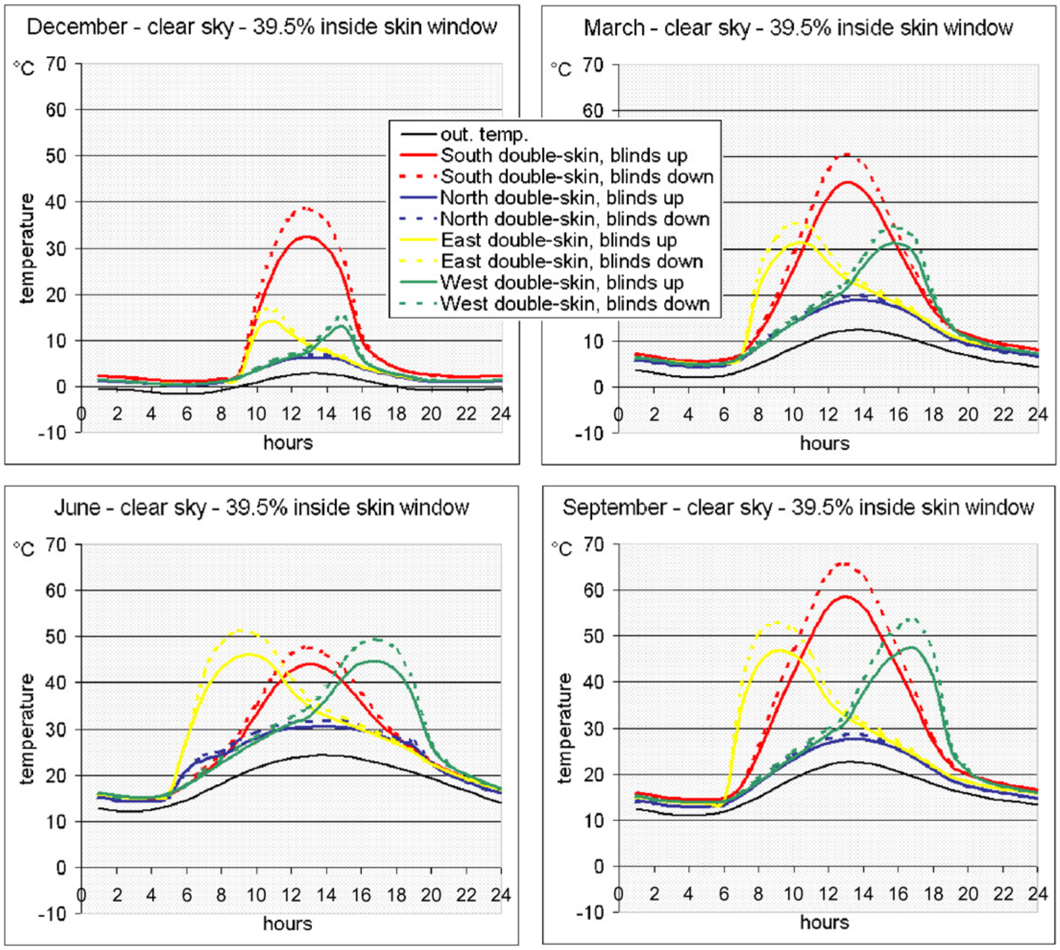


Fig. 5. Temperature evolution in a closed double-skin according to orientation and use of mean coloured solar shading devices.

thanks to the direct solar gains received by southern offices. On the other hand, during summer period, direct solar gains being higher, cooling need is higher in the more glazed building.

3.4. Wind speed

For this study we choose a constant wind speed during all the day and we place the building in open site. The wind speed has a significant influence on the external surface temperature of the single glazing of the external skin. Indeed, the external surface exchange coefficient (W m^{-2}) ''He'' is a function of the wind speed. Its standardized value is 23 W m^{-2} K for a 4 m s^{-1} wind speed. For other speeds, we apply the formula: He = 8.1 + 3.6v in W m^{-2} K, (with v, the wind speed at the considered surface in m s^{-1}). Double-facade external skin cools when wind speed increases. This external skin being made up mainly of not insulating single glazing, interior surface temperature also decreases. The single glazing constituting most of the double-skin envelope, its surface temperature influences in its turn the air temperature of this one.

A difference of 13.6 °C can be observed in December, by clear sky conditions, at 1 p.m. between the two following cases: a null wind speed and a 4 m s^{-1} wind speed (Fig. 7).

3.5. Colour of shading devices and of interior facade

Fig. 8 compares temperature evolution in the closed double-skin facade when there is no blind and when light coloured blinds or mean coloured blinds are placed. The characteristics of the solar protection devices are given below:

Table 1
Maximum temperature in double-skin facade and building consumption during a December sunny day

	South double-skin		North double-skin		East double-skin		West double-skin	
	Blinds up	Blinds down	Blinds up	Blinds down	Blinds up	Blinds down	Blinds up	Blinds down
T_{max} (°C)	32	38.6	6.3	6.9	14.2	16.6	12.8	14.9
h_{max}	1 p.m.	1 p.m.	1 p.m.	1 p.m.	11 a.m.	11 a.m.	3 p.m.	3 p.m.
Δt (dskin-out) (°C)	29.2	35.8	3.5	4.1	12.4	14.8	10.6	12.7
Heating (kWh day^{-1})	531	589	506	524	674	731	675	716

Table 2
Maximum temperature in double-skin facade and building consumption during a June sunny day

	South double-skin		North double-skin		East double-skin		West double-skin	
	Blinds up	Blinds down	Blinds up	Blinds down	Blinds up	Blinds down	Blinds up	Blinds down
T_{max} (°C)	44	47.8	30.5	31.7	45.8	51.2	44.7*	49.5*
h_{max}	1 p.m.	1 p.m.	2 p.m.	2 p.m.	10 a.m.	9 a.m.	5 p.m.	5 p.m.
Δt (dskin-out) (°C)	19.9	23.7	6.1	7.5	24.3	31.3	22.1	26.9
Heating (kWh day^{-1})	1223	999	1222	1105	1691	1374	1661	1388

* the maximum temperature in the west double-skin is slightly lower than that in the east double-skin because the solar radiation at 5 p.m. is lower than that at 9 a.m. and 10 a.m.

- Light coloured blinds:
  coefficient of solar absorptance, 0.17;
  coefficient of solar reflexion, 0.65.
- Mean coloured blinds:
  coefficient of solar absorptance, 0.42;
  coefficient of solar reflexion, 0.40.

As the percentage of glazed surface of interior facade is not very high, the influence of the colour of the solar protection devices on the interior temperature is only a few degrees. This impact would become more significant in the case of a more largely glazed facade.

Fig. 8 also compares temperature evolution in the closed double-skin when the brick of the opaque part of the interior facade is mean coloured (solar absorptance coefficient, 0.5) (our basic case) with an interior facade darker coloured (solar absorptance coefficient, 0.8). The colour choice of the opaque part of the interior facade is rather significant. Indeed, the temperature difference is far from to be negligible since the maximum observed difference reaches 8.0 °C in December in the case of a southern double-skin.

Moreover, Table 3 presents hot air flow from the double-skin when there is a slit of 1.5 cm in bottom and top of the double-skin between 11 a.m. and 4 p.m., in December, by clear sky conditions. This air can be recovered for northern zones heating.

The difference between the temperatures of the two cases remains important and the air flows by the openings are higher in the second case. The influence of the temperatures of the walls heated by the sun on the air temperature is significant in a double-skin. Temperature in a double-skin with an interior facade darker coloured is higher. So, chimney effect is also more significant and generates more important air flows.

3.6. Depth of the double-skin cavity

Fig. 9 compares temperature evolution in a 1.2 m depth closed double-skin (our basic case) with the same double-skin with a depth of 0.3, 0.6 and 2.4 m. Temperature in deeper double-skin is slightly lower than temperature in lower depth

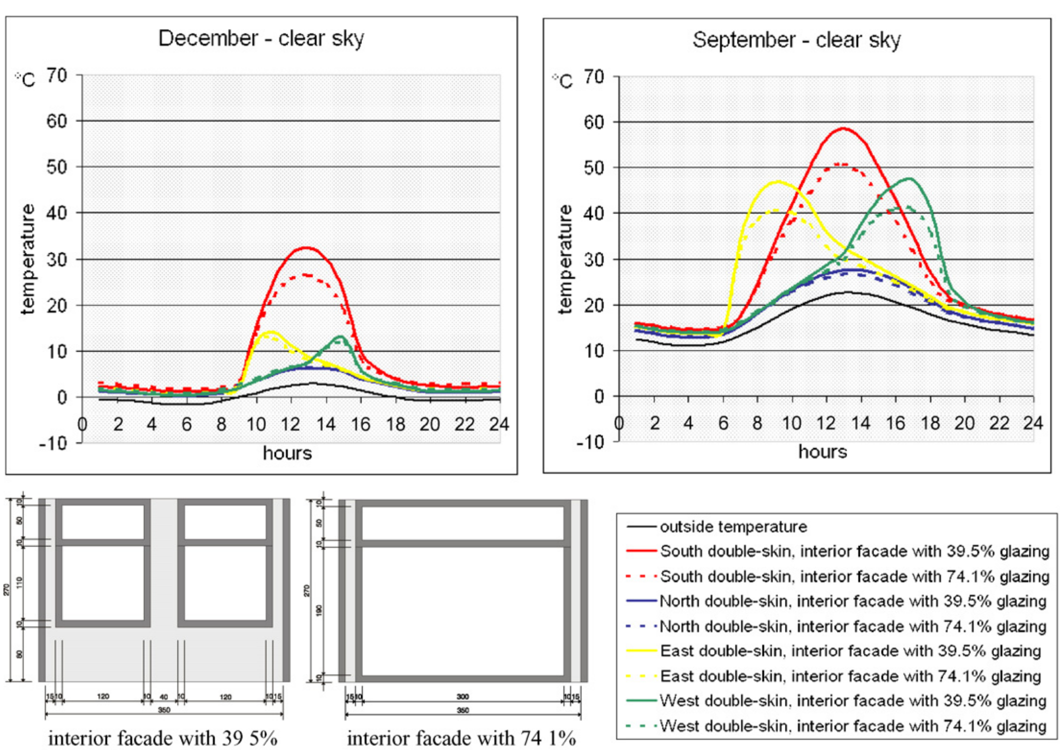


Fig. 6. Temperature evolution in a closed double-skin according to orientation and glazing proportion in the interior facade.

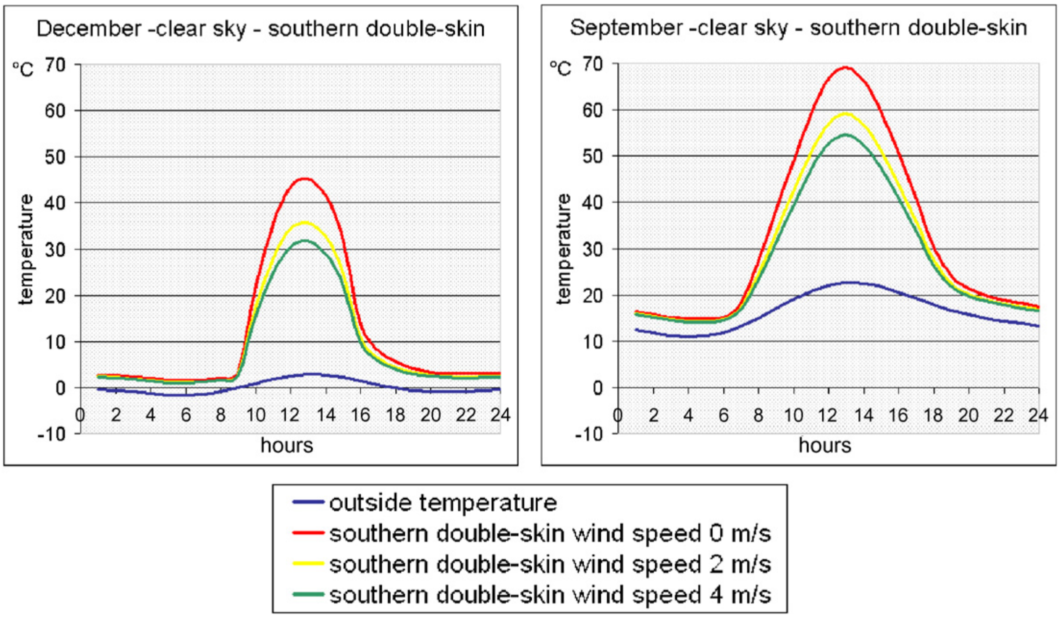


Fig. 7. Temperature evolution in a closed southern double-skin according to wind speed.

double-facade. The maximum difference observed is 5.8 °C in September when a 0.3 m depth southern double-skin is compared with a 2.4 m depth southern double-skin. If the volumes of hot air recoverable during winter to heat the zones requiring heat contribution are compared, we observe that the depth of the double-skin has little importance.

3.7. Glazing type in the interior facade

To know the impact of glazing type of the interior facade on greenhouse effect, solar protection devices are up and double-skin is closed. The interior skin is 39.5% glazed. Characteristics of the low emissivity double glazing of the interior skin are as follows:

- Clear glazing:
  - direct solar transmission, 53%;
  - solar reflexion, 19%;
  - solar absorption, 28%.
- Reflective glazing:
  - direct solar transmission, 13%;
  - solar reflexion, 51%;

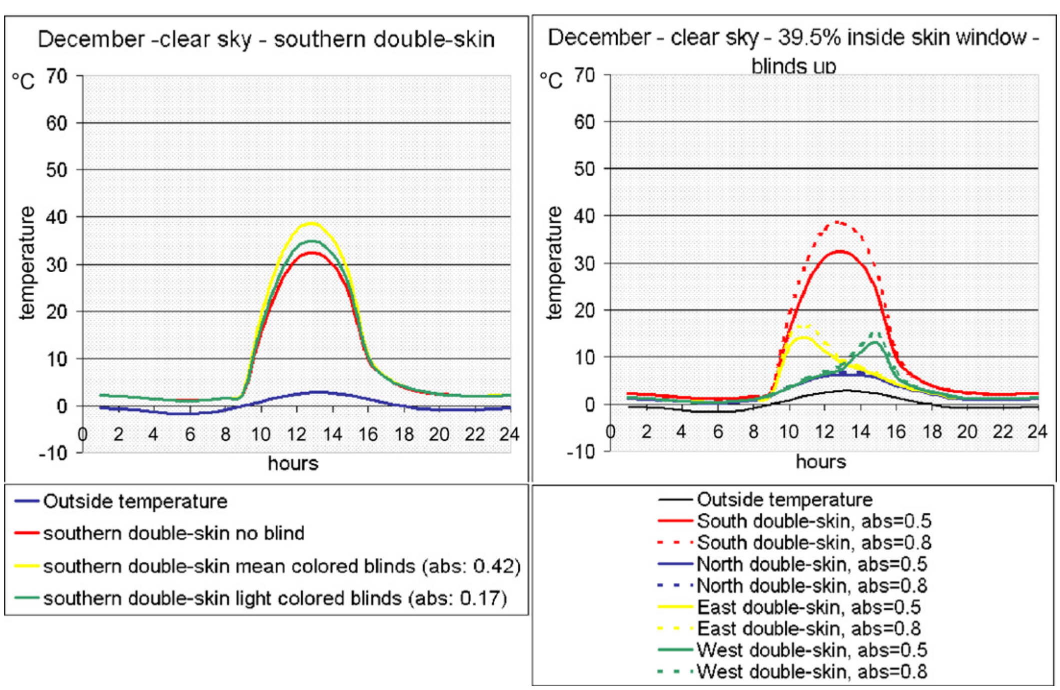


Fig. 8. Temperature evolution in a closed double-skin according to colour of shading devices and of interior facade.

Table 3
Temperature and hot air flow from the double-skin for a slit of 1.5 cm in bottom and top of the double-skin, in December, by clear sky conditions, according to colour of interior facade

	Temperatures (°C)		Hot air flow from the double-skin (kg s^{-1})	
	South double-skin, absorptance = 0.5	South double-skin, absorptance = 0.8	South double-skin, absorptance = 0.5	South double-skin, absorptance = 0.8
11 a.m.	18.7	22.4	2.1	2.3
12 a.m.	22.3	26.7	2.2	2.4
1 p.m.	23.2	27.8	2.2	2.4
2 p.m.	21.4	25.5	2.1	2.3
3 p.m.	16.6	19.6	1.9	2.1

solar absorption, 36%.
- Absorbing glazing:
  direct solar transmission, 11%;
  solar reflexion, 21%;
  solar absorption, 68%.

The impact of glazing type is weaker in June since the interior facade receives less direct solar radiation, the sun rays being more vertical (Fig. 10).

The clear glazing transmits most of the solar radiation (62%) in the offices adjacent to the double-skin.

The reflective glazing returns most of the solar radiation in the double-skin (51% is directly reflected and 31% is re-emitted towards the double-skin after being absorbed by the glazing). The reflected radiation is short wavelength and when it reaches the single glazing of the external skin, it is mainly transmitted towards outside. While the long wave radiation re-emitted towards the double-skin after being absorbed by the interior skin glazing is trapped in the double-skin. The temperature in the double-skin is more significant than in the case of the clear glazing due to the fact that there is only 18% of solar radiation transmitted towards the offices with reflective glazing.

If the interior skin is equipped with absorbing glazing, most of the solar radiation (68%) which strikes the glazing is absorbed. After absorption, radiation re-emitted towards the double-skin is long wave radiation and is trapped in the double-skin. Temperature in the double-skin is more significant than in both other cases since

- there is only 18% of solar radiation which is transmitted towards the offices;
- 61% of radiation is re-emitted towards the double-skin in the form of long wave radiation.

The difference in behaviour of the various glazing is clearly shown when one observes the superficial inside skin glazing temperature (double-facade side) at 1 p.m. during various seasons. Table 4 shows that temperature difference between clear glazing and absorbing glazing can reach 30 °C.

3.8. Openings in the double-skin

Simulations were performed for four sunny days representative of the four seasons. We made the assumption that wind speed is null. Thus, only stack effect is concerned (Fig. 11).

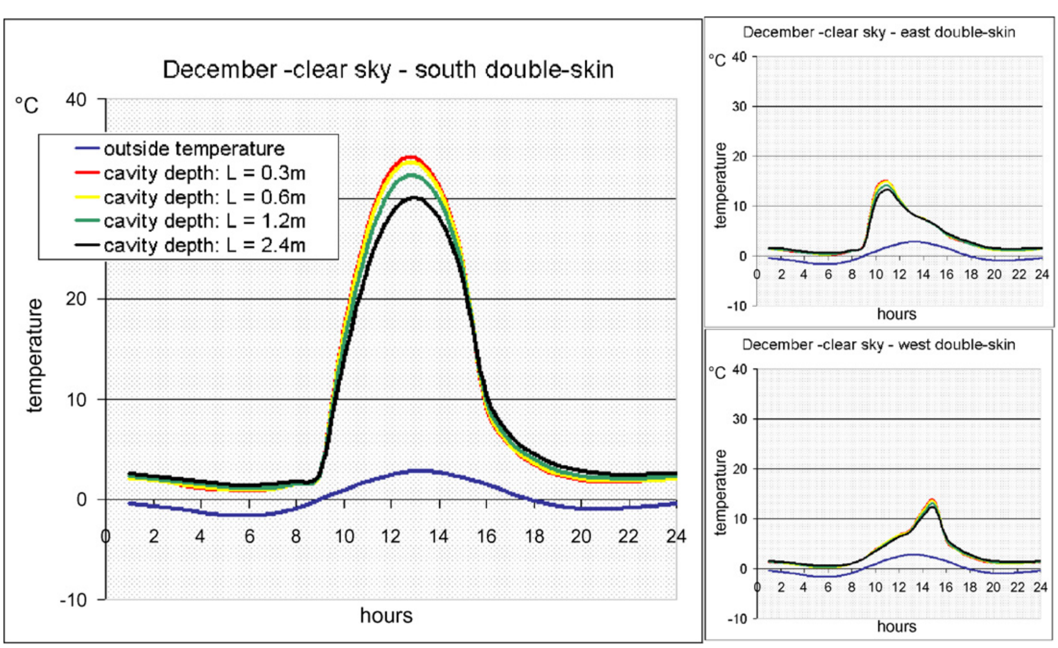


Fig. 9. Temperature evolution in a closed double-skin for various cavity depths.

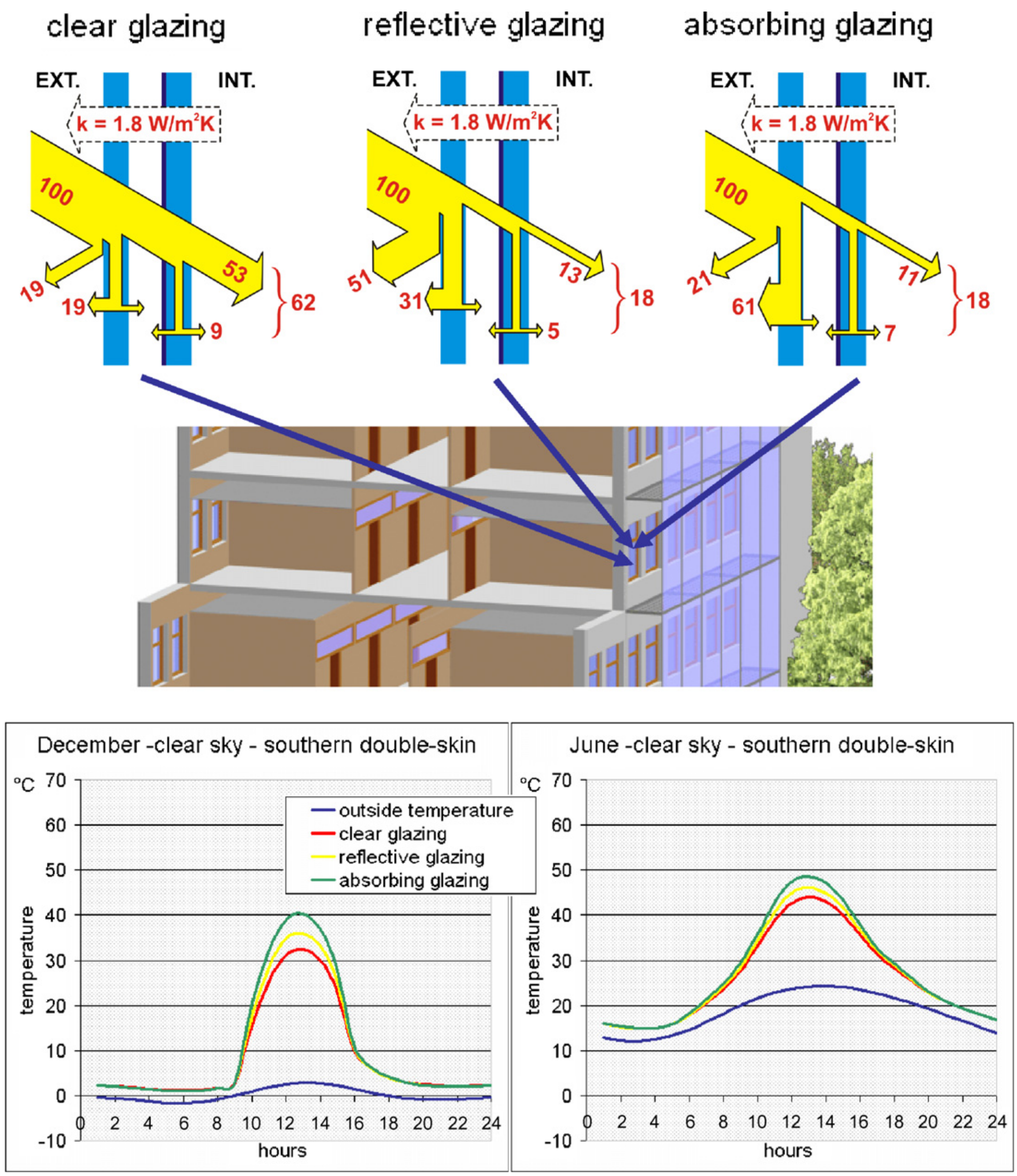


Fig. 10. Temperature evolution in a closed southern double-skin according to glazing type in interior facade.

The moment of double-skin opening and the openings size vary according to the season. The temperature reduction in the double-skin does not vary in a linear way with openings size. In fact the first centimetres of opening imply a greater temperature decrease.

Table 4
Superficial inside skin glazing temperature (double-facade side) at 1 p.m. during various seasons

	Superficial inside skin glazing temperature (double-facade side) at 1 p.m. (°C)			
	December	March	June	September
Clear glazing	42.2	51.6	48.6	65.6
Reflective glazing	53.3	62.3	56.3	78.8
Absorbing glazing	72.3	79.3	68.3	99.9

During winter, double-skin opening must remain lower than 5 cm in such way that temperature of the air leaving double-skin remains at a temperature higher than 20 °C. This air can then be recovered to ensure hygienic ventilation. A slit of 2.5 cm allows, for example, to recover 12198 m^3 air at 28.5 °C (Table 5). This air volume is sufficient to ensure hygienic ventilation of all the simulated office building. This air being at a temperature higher than 21 °C, it heats partially the office building.

During spring, double-skin hot air can be used to ensure hygienic ventilation as well as heating needs in northern offices and in halls. Heating need in southern offices is not necessary and cooling need is cancelled thanks to solar blinds (Table 6).

In summer and autumn, double-skin opening is necessary to evacuate surplus heat.

In summer, at 1 p.m., 10 cm slit opening reduces double-skin temperature from 59.3 to 34.4 °C. Fifty centimetres slit opening

Table 5
Air temperature and outgoing air flow by stack effect in southern double-skin for a top and bottom 1.5 cm slit, during winter

	Slit of 2.5 cm		
	Double-skin temperature (°C)	Outgoing air flow (kg s^{-1})	Outgoing air flow (m^3 h^{-1})
11 a.m.	23.9	3.9	11603
12 a.m.	27.6	4.1	12198
1 p.m.	28.5	4.1	12198
2 p.m.	25.9	3.9	11603
3 p.m.	19.8	3.5	10413

Table 6
Air temperature and outgoing air flow by stack effect in southern double-skin for a top and bottom 5.0 cm slit, during spring

	Slit of 5.0 cm		
	Double-skin temperature (°C)	Outgoing air flow (kg s^{-1})	Outgoing air flow (m^3 h^{-1})
10 a.m.	19.3	5.4	16066
11 a.m.	24.4	6.1	18149
12 a.m.	28.6	6.5	19339
1 p.m.	30.0	6.6	19636
2 p.m.	28.4	6.3	18744
3 p.m.	24.9	5.7	16959
4 p.m.	20.8	5.0	14876

brings back double-skin temperature to 28.2 °C. It is noted that first centimetres of opening are most effective. When double-skin has an opening of 50 cm slit, ventilation rate reaches 105 ach (Table 7). The double-skin opening decreases by 8.1% building cooling consumption during this sunny day. If interior facade was less insulated, ventilation impact would be more significant.

During autumn, at 1 p.m., 10 cm slit opening reduces double-skin temperature of 40 °C, that is to say from 77.6 to 37.5 °C! An opening of 50 cm brings back double-skin temperature to 28.4 °C and generates ventilation rate of 125 ach. Double-skin opening decreases by 14.8% building cooling consumption during this sunny day. If interior facade was less insulated, ventilation impact would be more significant.

4. Is greenhouse effect favorable?

In preceded chapter, we described how influence greenhouse effect. We will examine in this chapter the interest or not of significant greenhouse effect.

If no natural strategy is implemented to try to decrease cooling consumption (the double-skin remains closed, solar protections are not used, the strategies of day and night natural ventilation are not used), cooling loads in an insulated building are more important than heating loads.

Cooling loads are 2.5–3 times more significant in the case of a building well insulated, 2 times more significant in the case of a mean insulated building. In this case, it is preferable to reduce to the maximum the greenhouse effect to decrease cooling loads.

On the other hand, if everything is implemented to reduce cooling loads by natural cooling strategies use, the level of the optimal greenhouse effect is function of the orientation.

4.1. If double-skin is south oriented

Well insulated building:
heating loads = 67% of the energy demand;
cooling loads = 33% of the energy demand.
Mean insulated building:
heating loads = 76% of the energy demand;
cooling loads = 24% of the energy demand.
Not insulated building:
heating loads = 90% of the energy demand;
cooling loads = 10% of the energy demand.

Greenhouse effect must be sufficiently significant to increase the hot layer effect and to allow more significant heat recovery for the buildings heating requirement. The increase in the greenhouse effect will be more interesting less the building is insulated.

Table 7
Air temperature and outgoing air flow by stack effect in southern double-skin for a top and bottom 5.0 cm slit, during summer

	Slit of 10.0 cm		Slit of 50.0 cm	
	Double-skin temperature (°C)	Outgoing air flow (m^3 h^{-1})	Double-skin temperature (°C)	Outgoing air flow (m^3 h^{-1})
8 a.m.	21.6	17851	19.6	58314
9 a.m.	24.5	20231	21.8	65157
10 a.m.	28.1	23802	24.2	76760
11 a.m.	31.4	26479	26.3	85686
12 a.m.	33.6	28264	27.7	91041
1 p.m.	34.4	28860	28.2	92529
2 p.m.	33.9	27967	28.1	89851
3 p.m.	32.4	26182	27.3	83603
4 p.m.	29.8	23207	26.0	74083
5 p.m.	27.2	19934	24.5	63372
6 p.m.	25.2	17554	23.0	56231

A large opening of the double-skin during summer brings back the double-skin temperatures to a value close to outside temperature.

4.2. *If double-skin is east or west oriented*

Double-skin does not receive solar radiation during the coldest months, period during which greenhouse effect has a positive impact.

Heat recovery can be practiced only during March, April (under conditions of average sky) and October during the first hours of the day if the double-skin is east oriented and during the afternoon if the double-skin is west oriented. Moreover, only, the halls can benefit from this heat recovery. During this period, offices do not require significant heating need because of internal and solar gains. Moreover, the reached temperatures in the double-skin, at that period, are less important than those reached in a south double-skin.

On the other hand in summer period, double-skin high temperature represents a handicap for the building cooling.

We thus recommend rather to make greenhouse effect the least significant possible to decrease hot layer effect during summer period.

4.3. *If double-skin is north oriented*

The double-skin receives only very little solar radiation, only very early and very late in summer, when heat is not necessary.

Greenhouse effect does not have interest.

5. Conclusion

What to make to increase greenhouse effect and thus double-skin temperature

- to protect the building from the cold;
- to recover double-skin hot air to heat the coldest zones;

in winter, by clear sky conditions, at 1 p.m. (outside temperature 2.8 °C)?

Maximum sunning is reached for a south oriented double-skin; air temperature reaches 32.3 °C when the sky is clear. If mean coloured solar protection devices are down, a temperature increase is observed in the double-skin (38.6 °C). Greenhouse effect increases since an additional part of the sun rays is absorbed by the solar protection devices rather than transmitted in the offices.

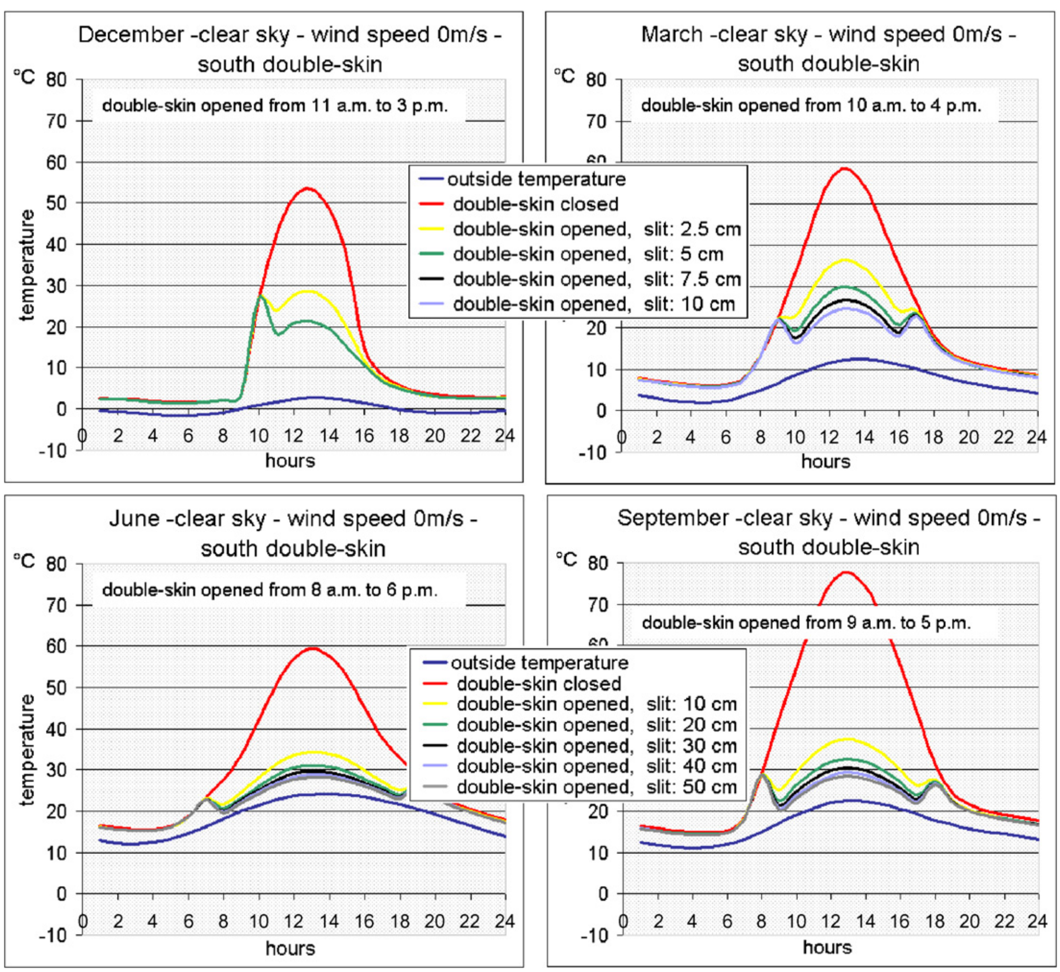


Fig. 11. Temperature evolution in a southern double-skin according to opening importance.

Table 8
Double-skin air temperature and percentage of solar radiation transmitted in the offices in summer, by clear sky conditions, at 1 p.m. according to various glazing type in the interior facade

	Double-skin air temperature (°C)	Percentage of solar radiation transmitted in the offices (%)
Clear glazing + light coloured blinds	45.4	11
Reflective glazing	46.2	18
Absorbing glazing	48.7	18

Temperature in the double-skin is always lower in a double-skin facade which the proportion of glazed surface in the interior facade is more important. In winter, by clear sky conditions, at 1 p.m.,

- if glazed surface in the interior facade is 39.5%, air temperature is 32.3 °C;
- if glazed surface in the interior facade is 74.1%, air temperature is 26.5 °C.

The colour choice of the sun blinds and of the opaque part of the interior facade is rather significant. Indeed, the temperature difference is far from to be negligible since the maximum observed difference reaches 8.0 °C in December in the case of a southern double-skin.

Temperature in deeper double-skin is slightly lower than temperature in lower depth double-facade.

The glazing type in the interior facade influences also greenhouse effect. In winter, by clear sky conditions, at 1 p.m.,

- if windows in interior facade is clear glazing, air temperature is 32.3 °C;
- if windows in interior facade is reflective glazing, air temperature is 36.0 °C;
- if windows in interior facade is absorbing glazing, air temperature is 40.3 °C.

What to make to decrease greenhouse effect and thus double-skin temperature and to not increase cooling loads in summer, by clear sky conditions, at 1 p.m. (outside temperature 24.1 °C)?

Minimum sunning is reached for north oriented double-skin, air temperature reaches 30.5 °C whereas it is 47.8 °C in south double-skin, 51.2 °C in east double-skin and 49.5 °C in west double-skin.

If proportion of glazed surface in the interior facade is more important, double-skin air temperature is less important but solar gains are more important in the offices.

If colour of the sun blinds and of the opaque part of the interior facade is light, double-skin air temperature is less important and solar gains are mainly reflected towards outside.

Glazing type in the interior facade influences also double-skin air temperature (Table 8).

Temperature in deeper double-skin is slightly lower than temperature in lower depth double-facade (45.8 °C in 0.3 m deep double-skin and 42.1 °C in 2.4 m deep double-skin). Ventilation is also easier in a deeper double-skin.

Double-skin temperature decrease does not vary in a linear way with the size of the openings. In fact the first centimetres of opening cause a greater temperature decreasing. In summer, solar protection devices down, an opening of 10 cm causes 25 °C temperature decreasing.

A difference of 10.2 °C can be observed in the double-skin, blinds down, in June, by clear sky, at 1 p.m. between the case of a null wind speed and a 4 m s^{-1} wind speed.

5.1. Is greenhouse effect favourable?

If natural cooling strategies are not used, greenhouse effect must be decreased.

If natural cooling strategies are used,

- greenhouse effect is favourable if double-skin is south oriented;
- greenhouse effect has no impact if double-skin is north oriented;
- greenhouse effect is defavourable if double-skin is east or west oriented.

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