SUMMER THERMAL COMFORT IN TYPICAL FRENCH RESIDENTIAL BUILDINGS: IMPACT ASSESSMENT OF BUILDING ENVELOPE INSULATION ENHANCEMENT

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ABSTRACT

New French construction programs must deal from 2013 with strongest regulation requirements intended to reduce building energy consumption : Thermal Regulation 2012. The envelope is one of the building major elements that is concerned by these regulatory demands and where insulation enhancement can give a suitable response. Therefore, increasing the insulation level and air-tightness will positively influence the heating needs during cold season, but the main difficulty resides instead during the warm season.

INTRODUCTION

The aim of this article consists in understanding the relative influence of various parameters on the summer thermal comfort in highly insulated residential buildings in accordance with the French Thermal Regulation 2012.

Recent developments have pointed out summer thermal comfort as a major issue that must be taken into account during the early phases of the building conception in order to reduce the risk of overheating.

Therefore, the thermal comfort is investigated by the intermediate of adapted indicators. These indicators are developed for assessing summer overheating but also to deal with the assessment of winter discomfort. In this article only the summer comfort analysis is presented.

Another objective of this summer comfort analysis is to promote and to contribute to the improvement of the current regulation indicators.

MAIN CASES AND HYPOTHESIS

Building

The analysis focuses on two types of residential buildings, both in accordance with the French Thermal regulation 2012. These typologies, are defined in such way to be representative of French new dwellings :

- A single floor family house of approximately 103 m² (Figure 1),
- A two floor (ground floor and attic) family house of approximately 130 m² (Figure 2).

The orientation of each building was chosen in order to maximize the natural light during winter. Thus, the main surface of windows of the building is south oriented.

A different orientation, less favourable, was taken into account as well and analyzed during the parametric study in order to quantify its influence on the building overall behaviour.

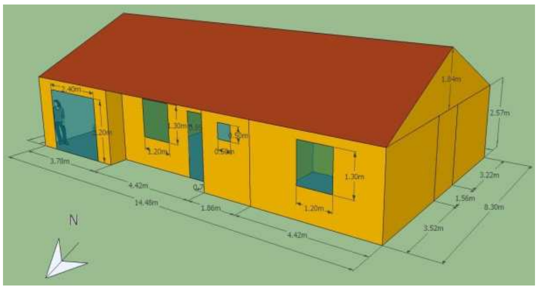


Figure 1. Simulated single floor house (SFH)

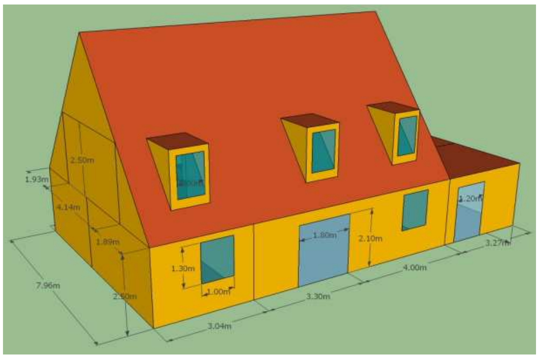


Figure 2. Simulated two-floor house (TFH)

The envelope of each building was defined in order to cover the new construction modes existing on the market. Thus, each of these modes was characterized by a different level of insulation (

Table 1).

Each building was subject to a detailed modeling according to the architecture plans. The volume was divided into several thermal zones according to space function. Each space (room) has its own thermal behaviour as a result of the boundary conditions (climate, adjacent spaces, etc.) and the internal conditions (internal loads, scenarios, etc.).

Table 1.Envelope characteristics

Wall type / Typology	Base	Performance	High performance	Very high performance
External wall	Brick + polystyrene (100 mm, λ=0.032 W/mK)	Brick + polyurethane foam (110 mm, λ=0.024 W/mK)	Brick + polyurethane foam(110 mm, λ=0.032 W/mK)	Brick + polyurethane foam(130 mm, λ=0.032 W/mK)
	U = 0.231 W.m^{-2}.K^{-1}	**U = 0.163 W.m^{-2}.K^{-1}**	**U = 0.163 W.m^{-2}.K^{-1}**	**U = 0.143 W.m^{-2}.K^{-1}**
Floor	Hollow block polystyrene with strip			
	U_e = 0.230 W.m^{-2}.K^{-1}	**U_e = 0.230 W.m^{-2}.K^{-1}**	**U_e = 0.230 W.m^{-2}.K^{-1}**	**U_e = 0.230 W.m^{-2}.K^{-1}**
Ceiling	Glass wool (220 mm, λ=0.038 W/mK)	Glass wool (220 mm, λ=0.038 W/mK)	Glass wool (380 mm, λ=0.038 W/mK)	Glass wool (380 mm, λ=0.038 W/mK)
	U = 0.168 W.m^{-2}.K^{-1}	**U = 0.168 W.m-2. K^{-1}**	**U = 0.098 W.m-2. K^{-1}**	**U = 0.098 W.m-2. K^{-1}**
Fenestration	Double glazing with Argon and PVC frame 4/16/4, Planitherm glass g=0.6, TL=76% with external solar protection			
	U_w = 1.70 W.m^{-2}.K^{-1}			

Applied scenarios

The thermal zones of the building, except the unheated zones, are subject to conventional scenarios (occupation, heating, cooling, ventilation, lighting, internal loads) defined in the French Thermal Regulation 2012 (CSTB, 2012).

The building is considered occupied continuously by four adults from 19PM to 10AM for 4 weekdays, from 15PM to 10AM during all Wednesdays and all day long during weekends. On an yearly basis, the building is considered unoccupied one week at the end of December and two weeks in August. A reduction of 30% of the internal loads due to occupants is observed during the nighttime.

The building set-up temperature value for heating is fixed conventionally at 19°C during occupation period, 16°C during an inoccupation period inferior to 48 hours and 7°C otherwise. The scenario for cooling is similar, the set-up values are 28°C / 30°C / 30°C.

Sanitary regulation imposed continuous mechanical ventilation for the buildings of approximately 0.5 ach at outdoor air conditions.

The internal loads considered are mainly due to lighting and appliances. For lighting, approximately 1.1 W/m² are considered (according to (CSTB, 2012), 80% of the 1.4 W/m² installed power is transformed in heat). Appliances contribution to internal loads are considered at a level of 5.7 W/m² from 7AM to 10AM and from 19PM to 22PM for 4 weekdays, 7AM to 10AM and from 15PM to 22PM during all Wednesdays and all day long during weekends. Otherwise, this level is reduced by 80%.

Bioclimatic scenarios (appropriate modifications of the fenestration and the ventilation strategy) were applied to the buildings. These modifications were applied in order to take into account strategies that could be used in new buildings and that can produce a favourable effect on the thermal comfort. These strategies applied in this article are concerning:

- the solar protection control which is based on the solar radiation arriving on the south façade. Thus, if the solar protections are closed, approximately 75% of the incident radiation on the facade is stopped,
- the nighttime natural ventilation (window opening). In order to take into account the window opening in a real uncomfortable situation three values of airflow (1, 2 and 3 ach) at outdoor conditions were considered. The opening strategy is described in Equation 1.

$$\boldsymbol{Window\ opening\ if} \begin{cases} \boldsymbol{Night-time,} \\ \boldsymbol{and} \\ \boldsymbol{T_{outdoor}} \leq \boldsymbol{T_{indoor},} \\ \boldsymbol{and} \\ \boldsymbol{T_{indoor}} \geq \boldsymbol{28}℃. \end{cases} \quad (1)$$

Other strategies can also be applied for new buildings like the optimisation of the indoor spaces function of the buildings orientation, reinforced solar protection control, maximisation of the climate potential with adaptation of the building envelope (i.e. insulation position, new materials, inertia, etc.).

Summer comfort indicators

Without detailing the general bases of thermal comfort analysis, traditional approaches try to define a comfort zone for temperature and humidity, which is then compared with the observed conditions.

These approaches do not enable a fine appreciation of the thermal comfort because they take into account the duration of discomfort but not its intensity (Figure 3). Therefore, it seemed necessary to introduce these two aspects simultaneously in the proposed approach.

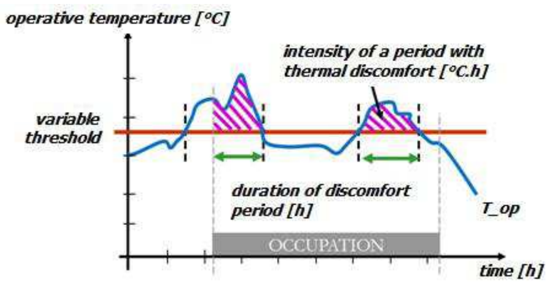


Figure 3. Summer comfort evaluation approach

For the analysis of the summer thermal comfort, we have developed a comfort analysis model based on the French Thermal regulation 2012. The proposed algorithms were introduced by the CSTB (CSTB, 2012) but for the moment, they are not operational within the official regulation software.

The main goal of this module is to verify for each time step if the operative temperature is within a comfort zone (AFNOR, 2007). The lower limit of this comfort zone is corresponding to the set-up temperature value for heating (e.g. 19°C).

The higher limit depends of the type of the cooling system (Figure 4). If an air-conditioning system is present then the value of this limit is equal to the set-up temperature value for cooling (e.g. 28°C). If a natural cooling system is present then the value of this limit will depend on the category of ambiance (Table 2) and on the running average ambient temperature (Figure 4). For this study, the considered ambiance category was C1.

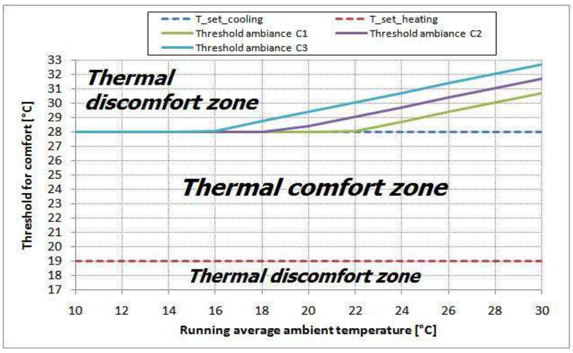


Figure 4. Thermal comfort and discomfort zones derived from (Afnor, 2007)

The proposed approach is simple and robust. It was developed and programmed to work with TRNSYS. It was linked then with the building module, which calculates the operative temperature.

At each time step, after calculating the operative temperature of each thermal zone of the building, a comparison is performed between this value and the correspondent threshold value. If the operative temperature exceeds the threshold value, a counter is incremented automatically. The counter is reset each month.

Table 2.Category of ambiance characteristics according to (Afnor, 2007)

Category	Explanation
1	High level of expectation [..] for spaces occupied by very sensitive and fragile persons with special requirements [..]
2	Normal level of expectation [..] used for new buildings and renovations
3	An acceptable, moderate level of expectation [..] used for existing buildings

Similarly, if the threshold temperature is exceeded, the model calculates the difference with the operative temperature. After the integration of this value, the intensity of the thermal discomfort is calculated.

These thermal comfort evaluation strategies (duration and intensity of discomfort) are applied during the occupation period of the building.

RESULTS AND DISCUSSION

The simulations were realised on an annual basis for all the combinations of six variables. These variables are:

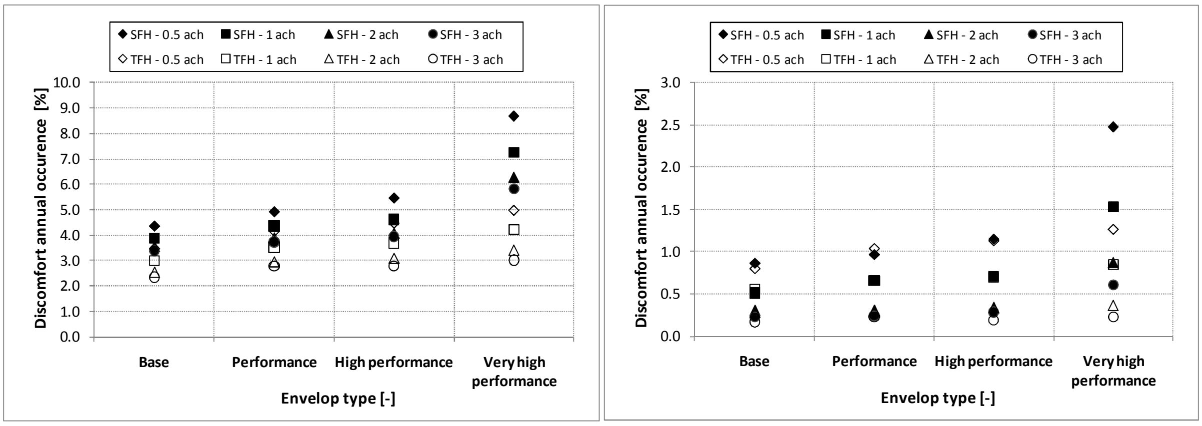
- The envelope type : **Base, Performance, High Performance and Very High Performance**,
- The presence of a night-time ventilation strategy with **1, 2, 3 ach**,
- The climate: **La Rochelle** (considered as average climate for France : average annual temperature 13.3°C, minimum and maximum average annual temperature 9.2°C and 17.5°C, average annual solar radiation 388 W/m²), Nice, Trappes,
- The thermal insulation position: **internal (ITI)** and external (ETI),
- The existence of an external solar protection system : **Yes**, No,
- The main orientation of the building according to the position of the living room: **South-North**, East-West.

For convenience, the results were given only for the most representative situation. This situation is characterized by the combination highlighted with bold text above. Concerning the building, only the results related to living room zone were illustrated in this article.

Figure 5 illustrates the annual evolution of thermal discomfort during occupation (a) and during nighttime (b) for the four envelope types described in

Table 1. First information highlighted by this comparison is that, under similar conditions, the SFH is more uncomfortable than the TFH. In the light of applied hypothesis, we observe that the enhancement of the external wall and ceiling insulation can increase the duration of thermal discomfort. This duration was found to be relatively important i.e. minimum 2.3% and maximum 8.7% of time when actual certification organism consider this limit between 0.6% and 1.1% of time with temperature above 28°C.

A special attention was given at the nighttime period, considered as more vulnerable, since that is during this period that insulated buildings are returning the major part of their accumulated heat during the day. During this period, we can also reveal an increased vulnerability of the occupants regarding to the duration and the intensity of the thermal discomfort compared to the daytime. In order to analyse this situation we have pointed up in Figure 5(b) the thermal discomfort during this period.



(a) *(b)*

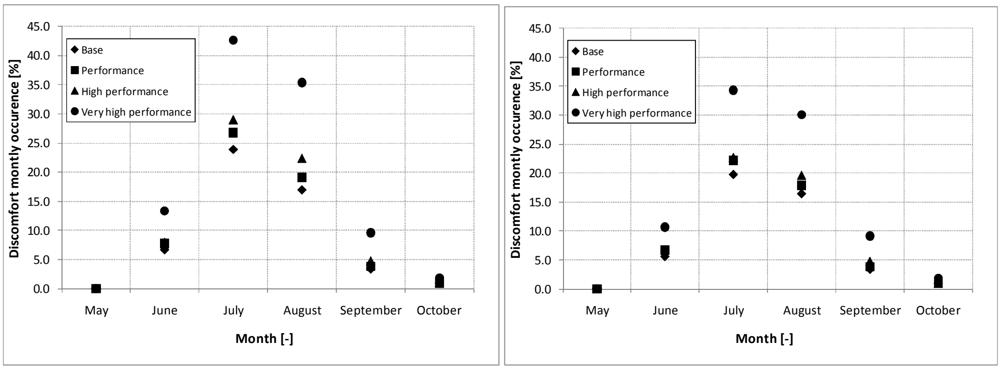
Figure 5. Annual thermal discomfort occurrences for the simulated building typologies function of envelope type. (a) – occupation period, (b) – night-time

The trend observed for the entire occupation period is observed for the nighttime as well. We can perceive that the duration of discomfort is reduced when nighttime ventilation strategies are applied. At identical nighttime ventilation strategy the enhancement of the envelope increase the number of hours of discomfort up to three times. This increase was found to be more pronounced for the Very High Performance type of envelope.

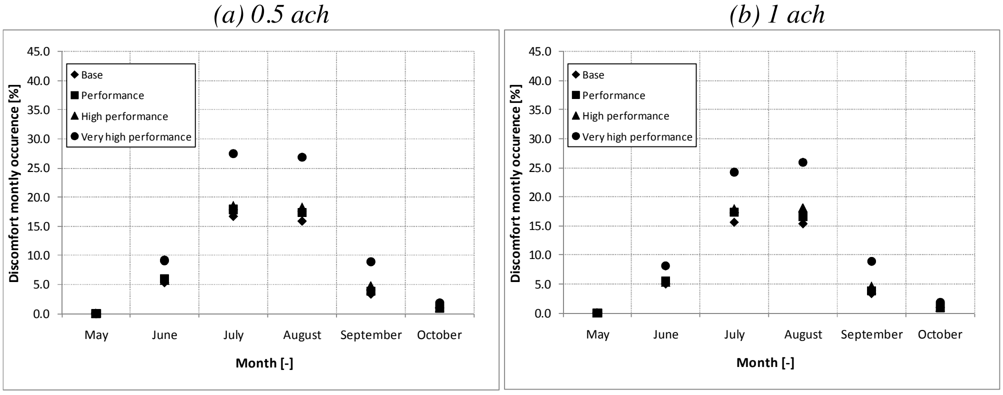
Comparing the results for the night and daytime periods allows to observe that the duration of thermal discomfort is important. Simulations indicate between 20% and 30% of the annual uncomfortable period arriving during the nighttime if no ventilation strategy is applied.

Applying a nighttime ventilation strategy instead, the thermal discomfort is reduced and up to 33% of gain is observed for three ach compared to 0.5 ach. Between 2 ach and 3 ach the reduction of discomfort is relatively insignificant situation, which can be favourable if the site natural ventilation potential is small. Even with this gain, the discomfort is not sufficiently reduced and other measures must be applied.

From these results another type of analysis can be done. The monthly occurrence of the thermal discomfort can give information about how the annual discomfort is distributed (Figure 6).



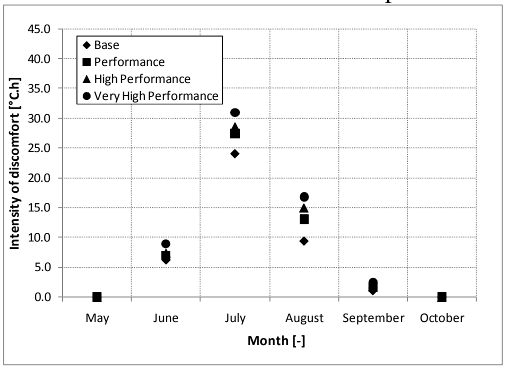
(a) 0.5 ach *(b) 1 ach*



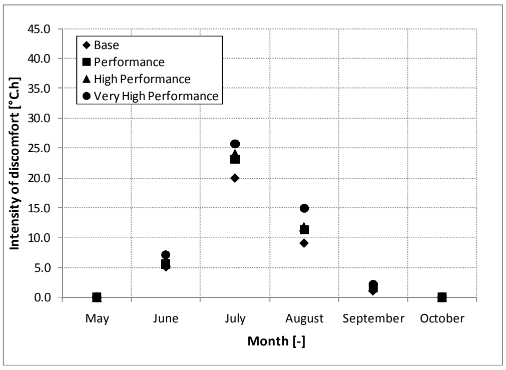
(a) 2 ach *(b) 3 ach*

Figure 6. Monthly thermal discomfort occurrences for the SFH typology function of envelope type.

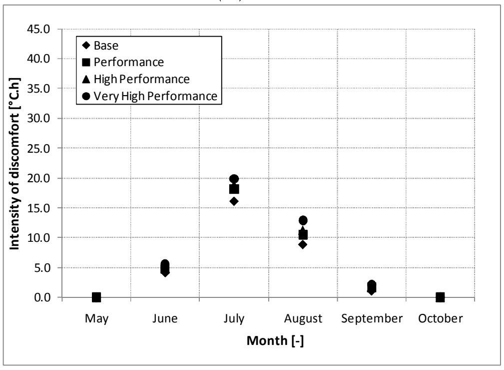
We can observe the first occurrences of thermal discomfort in June, while the last ones are observed in October. For the SFH typology, the thermal discomfort is mainly concentrated during July and August when for 30 to 45% of time the temperature is above the comfort threshold for the two building typologies. The nighttime ventilation strategy can bring a reduction of discomfort of up to 20 points for the SFH.



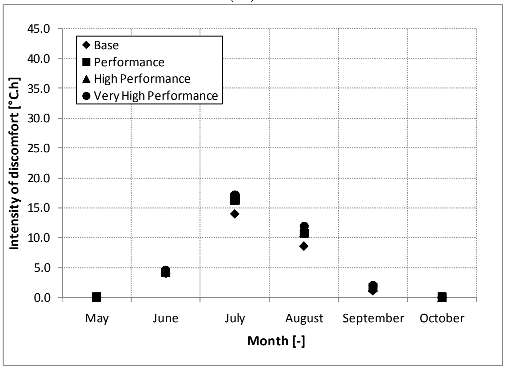
(a) 0.5 ach



(b) 1 ach



(a) 2 ach



(b) 3 ach

Figure 7. Monthly thermal discomfort occurrences for the TFH typology function of envelope type.

Similar behaviour is observed for the TFH typology (Figure 7) where the lower levels of discomfort observed in Figure 5 are confirmed. In this case, the nighttime ventilation strategy can lead to a reduction of discomfort of up to 13 points.

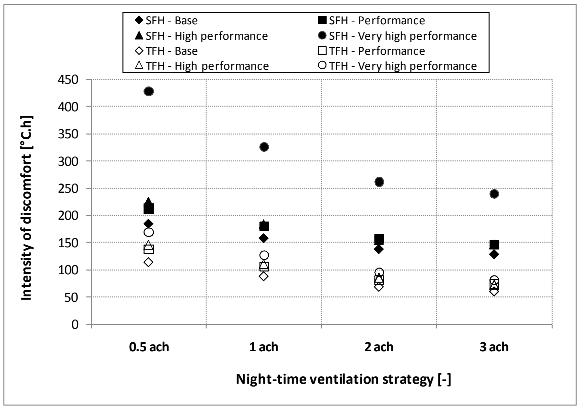


Figure 8. Intensity of thermal discomfort.

Another approach to analyse the thermal discomfort consists to evaluate its intensity during occupation period. Figure 8 shows the annual thermal discomfort intensity calculated according to the methods illustrated in Figure 3 and Figure 4. Increased values of intensity are observed simultaneous with the enhancement of the envelope. These values are reduced significantly for the Very High Performance type of envelope if nighttime ventilation airflow is increased. For the other tested envelope the trend is observed but the reduction is smaller.

CONCLUSION

The aim of this article consisted in understanding the relative influence of various parameters on the thermal comfort in highly insulated residential buildings.

In this article the thermal behaviour of typical French residential building was modelled using the simulation software TRNSYS. A parametric study was conducted based on representative French weather data, occupation, internal loads, heating and ventilation scenarios.

Different standard construction modes and their influence on the thermal comfort were analyzed: from minimal insulation requirements to very high insulated envelope according to French thermal regulation specifications. Moreover, controlled solar protection and increased nighttime ventilation were also considered as passive elements in order to take into account strategies that could be used in new buildings and that can produce a favourable effect on the thermal comfort.

This study has pointed out that the summer thermal discomfort is increasing quasi-linearly with the building envelope insulation enhancement. For example, a highly insulated SFH will be uncomfortable for up to 43% of the time in July compared to 23% of the time for the same building with the minimal insulation requirements envelope. The analysis has shown that 20% of the cumulative annual hours of discomfort are during nighttime.

The next steps of this research are:

- to evaluate if the nature of the insulation material impacts the results,
- to search, evaluate and then promote bioclimatic scenarios and envelope optimization that can favourably impact the summer thermal comfort,
- to continue the development of the comfort indicators introducing comfort limits and information about the number of dissatisfied persons during occupation.

For the recycled material insulation, wood wool or insulation brick preliminary results on the SFH typology have shown no significant reduction of the thermal discomfort. Instead, using insulation with a slightly higher thermal capacity (wood wool) can favourably influence the discomfort intensity.

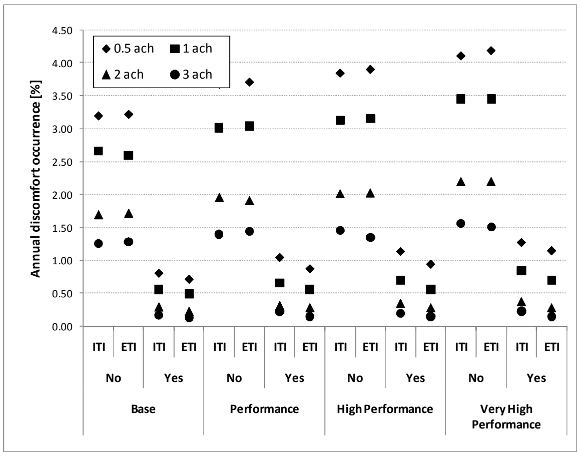


Figure 9. Overview of simple envelope improvement for the SFH typology.

Preliminary results concerning the presence of the solar protection system, described earlier in this article, have shown an important reduction of the thermal discomfort (Figure 9). Concerning the insulation position, it was concluded that an ETI could be more interested than ITI in terms of summer thermal comfort with an appropriate nightime ventilation strategy.

NOMENCLATURE

λ = thermal conductivity [W/mK]

U = surface heat transfer coefficient [W/m²K]

ach = air changes per hour

PVC = polyvinyl chloride

g = solar factor [-]

SFH = single floor house

TFH = two floor house

ITI = internal thermal insulation

ETI = external thermal insulation

TL = luminous transmission of the glass [%]

T_op = operative temperature [°C]

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