# Chapitre 1

## Contraintes physiques de confort limitant l'usage de la ventilation naturelle

*Ce chapitre fournit des informations de base sur les différentes contraintes qui limite la ventilation naturelle.*

*Dans un premier temps, quelques exemples extraits de l'état de l'art concernant l'inconfort d'été créé par l'ouverture vitrée sont présentés. En particulier, la contrainte acoustique empêche les occupants d'ouvrir la fenêtre; cet aspect est peu évoqué dans la bibliographie.*

*Un premier exemple de couplage aéraulique-thermique avec prise en compte de l'éclairage est d'abord traité pour appréhender comment l'ouverture des fenêtres modifie les apports solaires et simultanément l'éclairement naturel.*

*La dernière partie décrit deux approches pour gérer les différents inconforts. L'une consiste à développer un outil de gestion complexe pour traiter simultanément les différents aspects physiques, l'autre propose d'utiliser les équipements spécifiques pour diminuer le bruit lors des ouvertures. Deux scenarios de gestion du système d'ouvertures vitrées combinés avec des équipements anti-bruit sont présentés pour deux situations contrastées : la ventilation diurne dans un bâtiment tertiaire et la ventilation nocturne dans une maison résidentielle.*

## 1.1. Nécessité de l'analyse des ouvertures vitrées en prenant en compte les différents aspects physiques.

De nombreuses études ont été réalisées pour comprendre l'influence du comportement des occupants sur la performance de ventilation.

Calasiu et Veitch[Calasiu et Veitch, 2006] ont synthétisé des recherches sur la rétroaction des occupants sur les conditions lumineuses et le contrôle d'éclairage combiné aux manœuvres des protections solaires. Ils notent que par manque de modèle réaliste, le contrôle de l'éclairage et des protections solaires donne lieu à une estimation incorrecte de la consommation d'énergie et du niveau de confort des occupants.

Dans une enquête portant sur 58 bureaux suivis plusieurs semaines, Rea et al.[Rea et al., 1996] ont trouvé que les stores sont généralement descendus lorsque l'éblouissement ou l'inconfort thermique est détecté, et qu'ils ils restent ensuite en place même après que les inconforts aient disparu. Ils remarquent que les occupants ajustent les stores plus fréquemment sur les façades ouest et sud du bâtiment que sur les façades est et nord.

Inoue et al. [Inoue et al. 1988] ont surveillé plus de 1000 fenêtres orientées dans les directions est, ouest, sud-est et sud-ouest en été, automne et hiver. Leurs résultats indiquent que pour un rayonnement solaire de plus de $60W/m^2$, le pourcentage de fermeture des stores est directement proportionnel à la profondeur de la pénétration de la tâche solaire dans la pièce. Ils ont aussi trouvé que les occupants tendent à fermer les stores quand ils sont éblouis ou qu'il fait trop chaud. Eux aussi remarquent qu'une fois fermés, les stores le restent souvent pendant toute la journée. Cette tendance à oublier de ré-ouvrir les stores a aussi été remarquée par les études de Farber Associates [Farber Associates, 1992] et de Escuyer et Fontoynont [Escuyer et Fontoynont, 2001]. Dans la partie 1.2, un exemple de couplage thermo-aéraulique avec prise en compte de l'éclairage est traité pour appréhender comment l'ouverture des fenêtres modifie les apports solaires et simultanément l'éclairement naturel.

L'interaction entre ventilation naturelle et bruit extérieur est un autre sujet important pour les bâtiments urbains. Les recherches portant sur le contrôle des systèmes de ventilation sont relativement récentes. Il faut noter que l'acoustique n'a pas d'impact direct sur le transfert d'énergie entre le bâtiment et son environnement. L'étude acoustique exige une expertise spécifique bien différente de l'énergétique. Les études existantes sont concentrées sur le niveau de confort sonore et le développement des dispositifs qui réduisent la transmission du bruit. Des exemples incluent des systèmes passifs tels que vitrages spécifiques, couche absorbante, persiennes ainsi que des appareils actifs sophistiqués [Wang, 2014].

Les premières études ont été réalisées en vue de réduire certains types de bruit, tel que celui d'un ventilateur dans un conduit [de Lima, 2011], [Bibby, 2013]. En revanche, pour les ouvertures donnant sur l'extérieur, le bruit varie sur une grande plage de fréquences, ce qui peut difficilement être compensé par les dispositifs actifs.

On remarque que l'environnement intérieur est aussi bruyant que l’extérieur dès que l'ouverture de la façade dépasse une certaine taille, même si la transmission acoustique du bâtiment (fenêtres fermées) est faible. Or, les ouvertures vitrées sont beaucoup plus grandes que ce seuil.

Barclay et al.[Barclay et al., 2012] ont montré le potentiel d'économie d'énergie grâce à la ventilation naturelle en lien avec la cartographie du bruit extérieur. Il a été constaté que quand le niveau de tolérance est fixé à 35dbA, la consommation d'énergie pour refroidir les bâtiments dans un environnement tranquille est inférieure de plus de 20% comparée à un environnement bruyant. C’est pourquoi la contrainte acoustique ne doit pas être négligée dans l’évaluation de la performance énergétique en situation réelle.

## 1.2. Impact sur l'éclairage de l'ouverture des fenêtres

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# Influence of natural ventilation on solar gains and natural lighting by opening windows

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### Abstract

Natural ventilation generally implies a complete or partial opening of windows which modifies the solar gains and the natural lighting, changing the solar and daylight factors. This “secondary” effect is generally neglected in building energy simulation. This study analyzes the impact on the modification of optical characteristics of glazed surfaces on thermal condition and natural lighting due to opening windows. The results focus on the impact of window opening on visual and thermal performance including not only the air change rate but also the negative effect of solar gains which arrive directly in the room through the opening. The parametric study leads to conclude when this effect can be neglected or not.

### Introduction

As an effective solution to reduce summer cooling energy use, natural ventilation has been frequently studied. In the latest years, analytical and numeric modeling methods have made considerable progress [Costola et al., 2009] [Caciolo et al., 2012]. Especially for single sided natural ventilation, how the way of window opening affects ventilation efficiency has attracted many attentions[Dascalaki et al., 1996] [Alloca et al., 2003] [Caciolo et al., 2011). However, there is an unignorable gap between theoretical prediction and real energy performance of buildings [Fabi et al., 2012] [Roetzel., 2010]. The building ventilation stands in complex physics phenomena while most studies concentrate on the thermal-air related mechanism in energy simulation. In practice, the behavior of opening a window to acquire air change would also result in changes of received solar gains and daylight by indoor environment. This effect due to the modification of the building shell is called hereafter secondary effect.

Though the secondary effect is usually neglected in most building energy simulations, it should be demonstrated how it would influence the expected natural ventilation efficiency.

In particular, different types of windows are expected not only to provide different air change rate, but also to have different radiative effects. This article is dedicated to assessing how the thermal and luminous performances are affected in two common opening configurations.

## Methodology and approach

In this section, a series of hypothesis, as well as the necessary simplification of physical phenomena, is made to model the window system. The double glazing horizontal sash opening and top-hung opening shown in Figure 1 are dominant on the French construction market, and deserve therefore close inspection. For a parametric study, all the windows are fixed in the position of complete opening. The horizontal sash window has two sashes totally overlapped when opened thus the opening area is half of the window area, and the half glazed window area has the shading factor of a quadruple glazed window. The top-hung window could be opened with an angle of 30°. If the effective opening area can be defined without ambiguity for horizontal sash window, it is less obvious for top-hung windows. A definition of the effective opening area in natural ventilation simulation for these two configurations is proposed in [Caciolo et al., 2011].

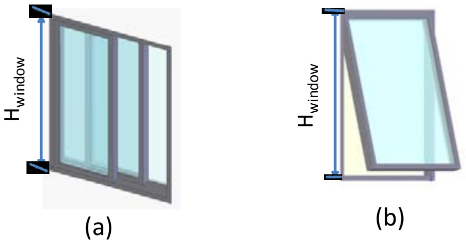


Figure 1. Windows typology
(a) Horizontal sash (b) Top-hung

### Simulation schema

To take into account the solar gains and daylight when the windows are opened, a model has been developed using the variables that mutually influence on each other. The logic employed in the following simulation is shown in Figure 2, regarding TRNSYS environment, we used validated models for air change rate, radiance on the facade and transmittance into the room [Caciolo et al., 2012][CIE, 2011]. The global model incorporates some inputs such as ventilation and artificial lighting strategy, and returns hourly values illustrating thermal and visual performance, indoor comfort and energy costs. In this article, the analysis is mainly focused on cooling needs compared with or without secondary effect.

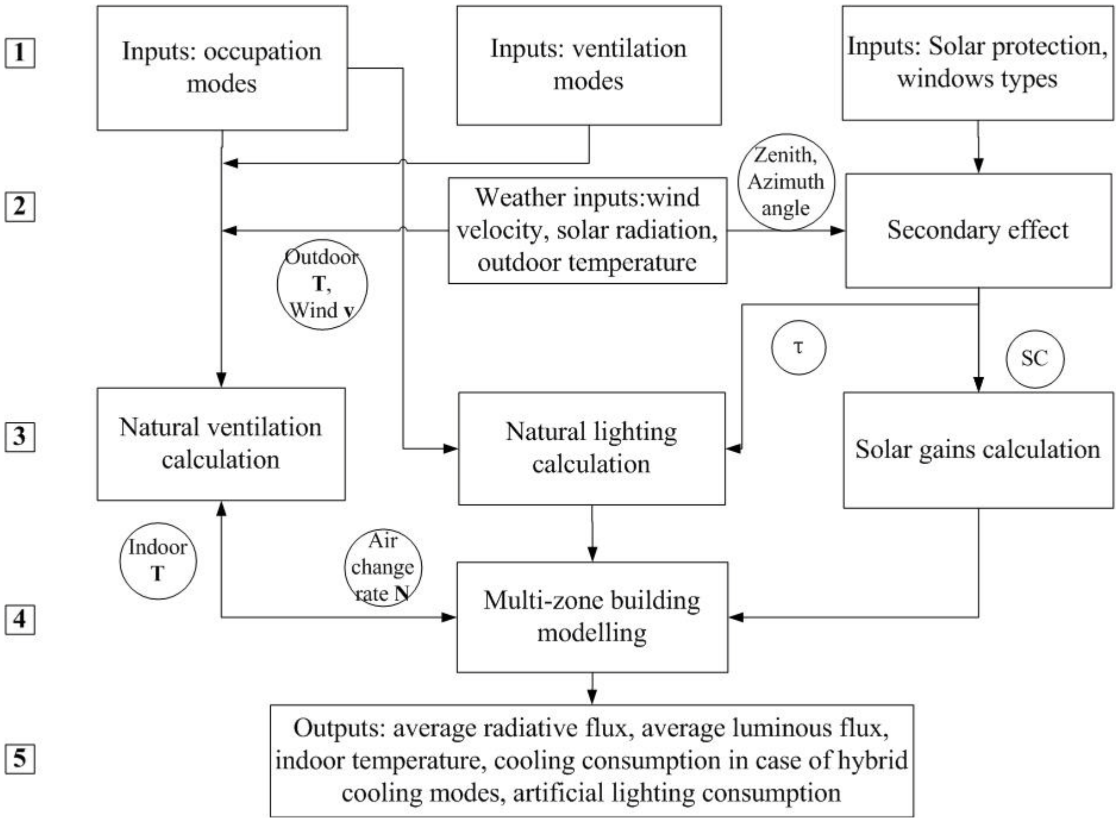


Figure 2. Proposed steps for the determination of thermal and visual performance

### Thermo-air model description

The window model encapsulating ventilation, solar and daylight transmission in the commercial building simulation tool TRNSYS 16 is connected to the Type 56, which is a dynamic multi-zone building model. The building is split into homogeneous thermal zones. Each zone is written as a node of air with uniform temperature, surrounded by walls characterized by a thermal resistance and a mass. The model carries out a balance sheet of energy including air and walls. The equations are resolved by the method of transfer functions [TRNSYS, 2007].

The calculation of air flow rate by natural ventilation is achieved by applying the correlations summarized in [Caciolo et al., 2013]. If mechanical ventilation system exists, it is considered that it doesn’t interact with the natural ventilation. In addition, the infiltration flow is hold to be constant. These hypotheses are righteous under the condition that the air change flow of mechanical ventilation and infiltration is largely inferior to the one of natural ventilation, which is the typical case. Compared to the incertitude generated by natural ventilation, the modification on air change rates by infiltration and mechanical ventilation can be regarded as negligible in the energy balance sheet.

### Secondary effect of solar gains

The study considers two basic window configurations in order to assess how the glass openings influence the heat and luminous transmission.

An aperture without window can be seen as a "virtual wall" having no conductive exchange but with the solar factor and the light transmission coefficient equal to 1. This "wall" is also modeled outside the Type 56 to issue the incident radiative contribution to the room, which is equal to incident direct and diffuse radiation flux on the opening times its surface.

In particular, for a horizontal sash window, the overlapped double panes reduce partially the transmittance. It is assumed that overlapped double panes are equivalent to quadruple panes window. The ratio of transmittance can be roughly thought as the square of double panes. Together with the other half open surface that the transmission factors equal to 1, we obtain

$$\tau_l = \frac{{\tau_l}_o^2 + 1}{2} \tag{1}$$

$$\mathrm{SC} = \frac{\mathrm{SC}_o^2 + 1}{2} \tag{2}$$

where $\tau_l$ is the luminous transmittance and SC is the shading coefficient according to [ASHRAE, 2001]. The foot indices "o" means the original value.

A top-hung window has a more complex geometry. The opening plane is divided into the unprotected part, $A_{open}$, represented by the equivalent opening surface, and the projection of inclined window. Because the top-hung windows open with a relative small angle, typically less than 30°, the optical properties $\tau_{lo}$ and $SC_o$ are considered as constants. Thus the modification of transmittance can be written within the same principle.

$$\tau_l = \left(1 - \frac{A_{open}}{A_{window}}\right){\tau_l}_o + \frac{A_{open}}{A_{window}} \tag{3}$$

$$\mathrm{SC} = \left(1 - \frac{A_{open}}{A_{window}}\right)\mathrm{SC}_o + \frac{A_{open}}{A_{window}} \tag{4}$$

where $A_{open}$ is the opened surface and $A_{window}$ is the window surface.

**Lighting, occupation and ventilation scenarios**

Energy consumption is inherently linked to the occupation scenario and ventilation strategy. The internal gains come from occupation and electrical equipments contribution. In the simulation, the internal heat gains from occupants and office electrical equipments are modulated during the day according to the schedule. (Figure 3a)

The natural lighting rate is calculated by means of a simplified method based on a daylight factor [CSTB, 2005]. The rate of artificial lighting use is on average for multiple offices determined in function of the natural lighting in the room according to [Alessandrini et al., 2006]. (Figure 3b)

Only when the office room is occupied, a mechanical ventilation system is active to assure the hygienic air change, namely 25 $m^3$/ (h·person). Window opening is allowed if outdoor temperature is below the indoor temperature and if the outdoor temperature is higher than the threshold temperature, $T_{out,close,thres}$, in order to avoid cold draft during occupancy hours or under-cooling of the room during non-occupancy hours. Then, the opening of the window is controlled by comparing the indoor temperature with two set-point values: $T_{in,min}$ and $T_{in,max}$ as presented on Figure 4. When the indoor temperature rises up to a cooling set point temperature $T_{set\text{-}point,cooling}$, the window is closed and the active cooling starts.

**Building typology**

A one person office room representing a whole building located in two climate zones is examined in the simulations: Paris (temperate) and Nice (Mediterranean). Several glazing surface ratios on the facade which affect luminous and radiant transmission are chosen as 30%, 50% and 70%. [Reiter and De Herde, 2001] The internal contributions are due to the following electrical equipments: a computer and an inkjet printer, for a total average power of 100 W (8 W/m²) in accordance with “EnergyStar” label. The sensible heat gains from occupants are 75 W per person.

The thermal characteristics of the rooms reach the requirements of French Thermal Regulation [RT2012]. The office has medium thermal inertia, as defined by [CEN, 2008], which is the most widespread in Europe. The floor consists of concrete plate and partition walls are plasterboards. The windows have an aluminum frame and low-e double glazing panes 4/16/4 filled with 85% argon: $U_w$=1.4 W/(m$^2$K), solar factor SC=0.59 and luminous transmittance τ = 0.71. The reflectivity of all internal walls is set to be 0.5.

According to the works of [Pernodet, 2009], the following fixed values have been set as

- daytime ventilation: $T_{in,min}$= 22 °C, $T_{in,max}$= 23 °C, $T_{out,close,thres}$= 15 °C
- nighttime ventilation: $T_{in,min}$= 21 °C, $T_{in,max}$= 23 °C, $T_{out,close,thres}$= 12 °C

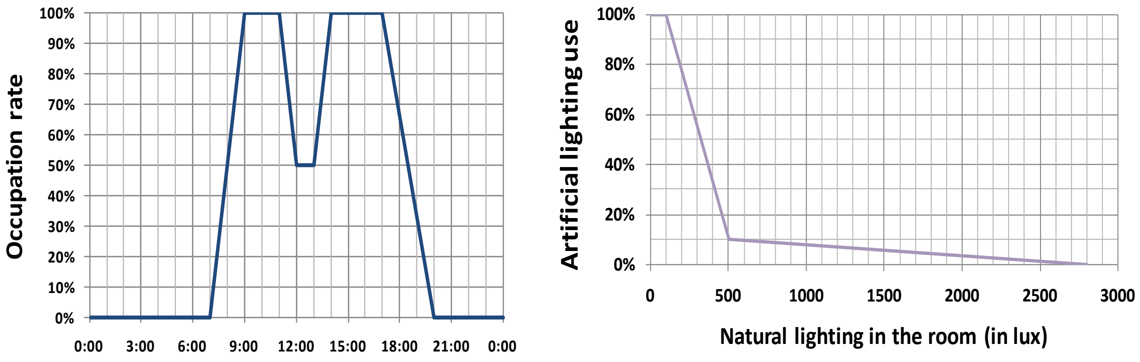


Figure 3 a. Occupants schedule during weekdays. [Filfli, 2006]
b. Use of artificial lighting regarding to natural lighting in a room estimated from outdoor irradiation. [Alessandrini et al., 2006]

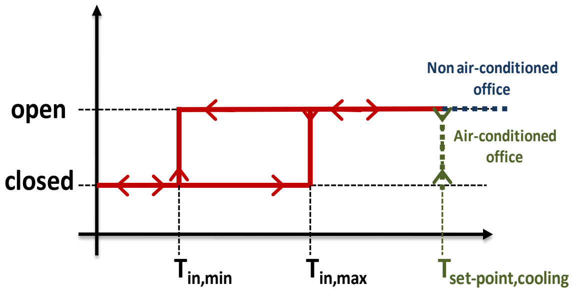


Figure 4. Chart showing window opening control[Pernodet, 2009]

The overhangs, if present as solar protection, have a width of 0.75m, 0.85m and 1m for the opening ratio of 30%, 50% and 70%, respectively, and are located 0.5 m above the window. The far away obstacles are neglected in this work.

## Results

A series of simulation drawn in this study covers several typical building configurations in France, mainly in two climate regions, Nice and Paris; two extreme days in hot seasons, summer solstice and autumnal equinox; with or without an overhang as solar protection. Within these configurations, the outdoor temperature and solar zenith angle vary significantly, which could provide a comprehensive samples for comparison and help understand the effect of natural ventilation on solar gains and natural

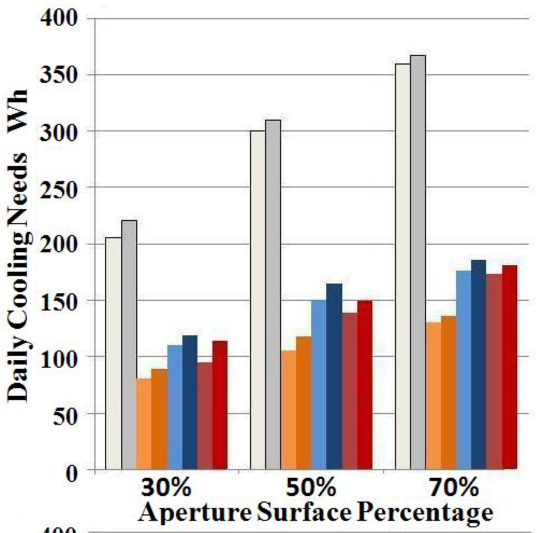
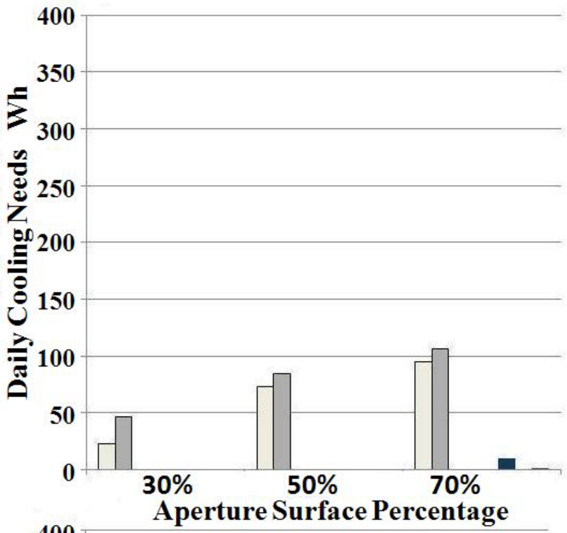
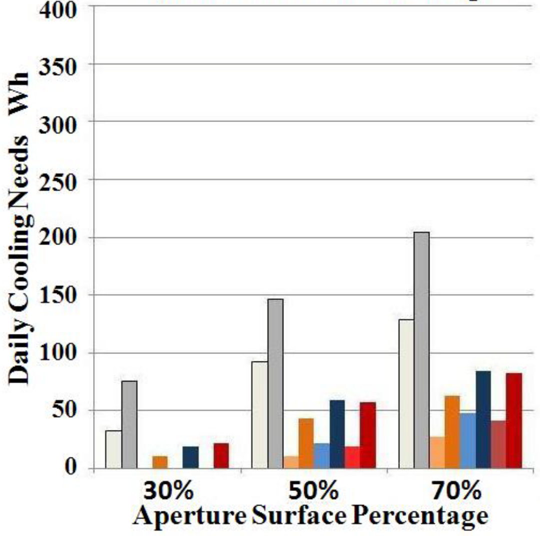
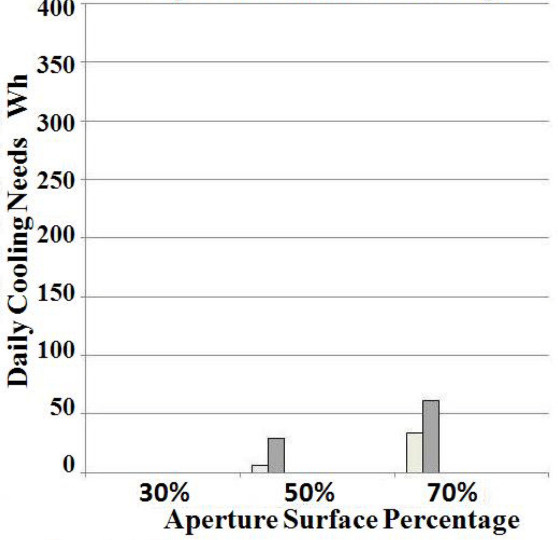
| | Solstice | Equinox |
|---|---|---|
| Nice |  |  |
| Paris |  |  |

Figure 5. Cooling needs of office with sash window calculated by the methods with or without consideration of secondary effect

lighting received by the rooms. For the sake of simplicity in the analysis of the secondary effect, all configurations use a hybrid cooling strategy (natural ventilation and active cooling). When the outdoor temperature is too high in summer, the efficiency of natural ventilation decreasing sharply, the indoor mechanical cooling system will then be active. By comparing the energy consumption between different configurations under the same cooling scenario, one could conclude how the secondary effect influences the calculation. Thus one can identify under which conditions the simplified calculation without secondary effect is robust and efficient.

**Horizontal sash windows**

Figure 5 presents the average daily cooling needs of office rooms with sash windows, without overhang, during the week around summer solstice and the week around autumnal equinox. The extreme situation corresponds here to the maximum opening surfaces facing to the south. The opening reduces partially the mechanical cooling loads, for instance, south-oriented by 20% and other orientations by 40% of the energy consumption of offices in the same situations but with windows all closed. The figure shows the difference between the cooling needs modeled neglecting secondary effect ($CN_0$) and the cooling needs modeled with secondary effect ($CN_{se}$). Generally the cooling needs considering secondary effect are larger.

This discrepancy can be explained by two reasons with contrary effects.

- On the one hand, after opening the window, the office room receives more solar gains, augmenting the indoor temperature.
- On the other hand, higher natural lighting passes into the room, reducing the artificial lighting demands, so as the indoor temperature.

The faster the indoor temperature increases, the faster the window is closed and the active cooling is used, increasing so the cooling demands. The final result is a compromise of the two effects.

According to this analysis, the configuration of Paris in summer solstice, involving the most significant difference due to the secondary effect, hereafter is picked out to inspect the details of the energy consumption (Figure 6).

For this goal, the total cooling needs difference is separated into two parts. One is the cooling needs increasing caused by the solar gains ($\Delta_1$) and the other one is the reduction of the artificial lighting ($\Delta_2$).

The grey column in Figure 6 is the cooling needs difference calculated results of Figure 5,

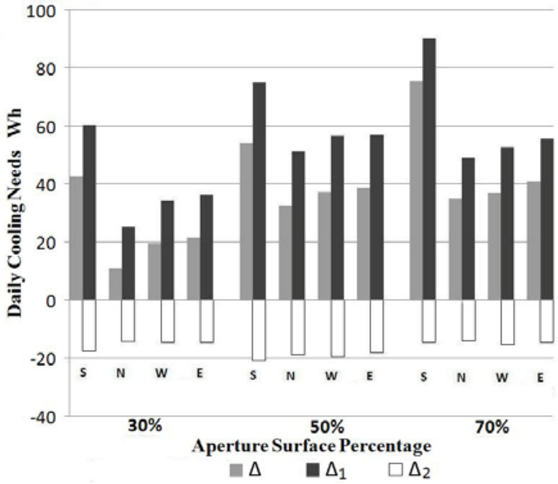


Figure 6. Cooling needs difference separating the solar gains effect and artificial lighting effect, Paris, summer solstice

$$\Delta = \mathrm{CN}_{\mathrm{se}} - \mathrm{CN}_0 \qquad (5)$$

One can check that the global difference is the sum of $\Delta_1$ and $\Delta_2$,

$$\Delta = \Delta_1 + \Delta_2 \qquad (6)$$

The largest black columns represent the contribution of solar gains by opening window to the increase of the cooling needs. The white columns with negative values represent the artificial lighting contribution to the difference of cooling needs.

**Analysis of horizontal sash window simulations**

Figure 7 exhibits the simulation results of daily cooling needs by resetting the points on an energy consumption map, including the configurations of offices facing to 4 directions, with or without an overhang as solar protection device, for the 3 aperture ratios, in Nice and in Paris, on summer solstice and on autumn equinox.

Any element that limits the sun influence on the window such as season, climate zones and solar protection devices reduce the impact of the secondary effect. The results are categorized into 4 groups:

- In Group I in blue, most of the cases are on autumnal equinox. The outdoor temperature is low enough: the original cooling needs is between 50 to 100Wh/m$^2$ in Nice and is almost zero in Paris. The natural ventilation could cover all cooling needs so that the calculation of secondary effect is unnecessary.
- In Group II in violet, the secondary effect has a slight influence on cooling needs simulation. These cases with relative low original cooling needs are the offices not oriented to the south with small opening surface. As the natural ventilation efficiency is limited, the secondary

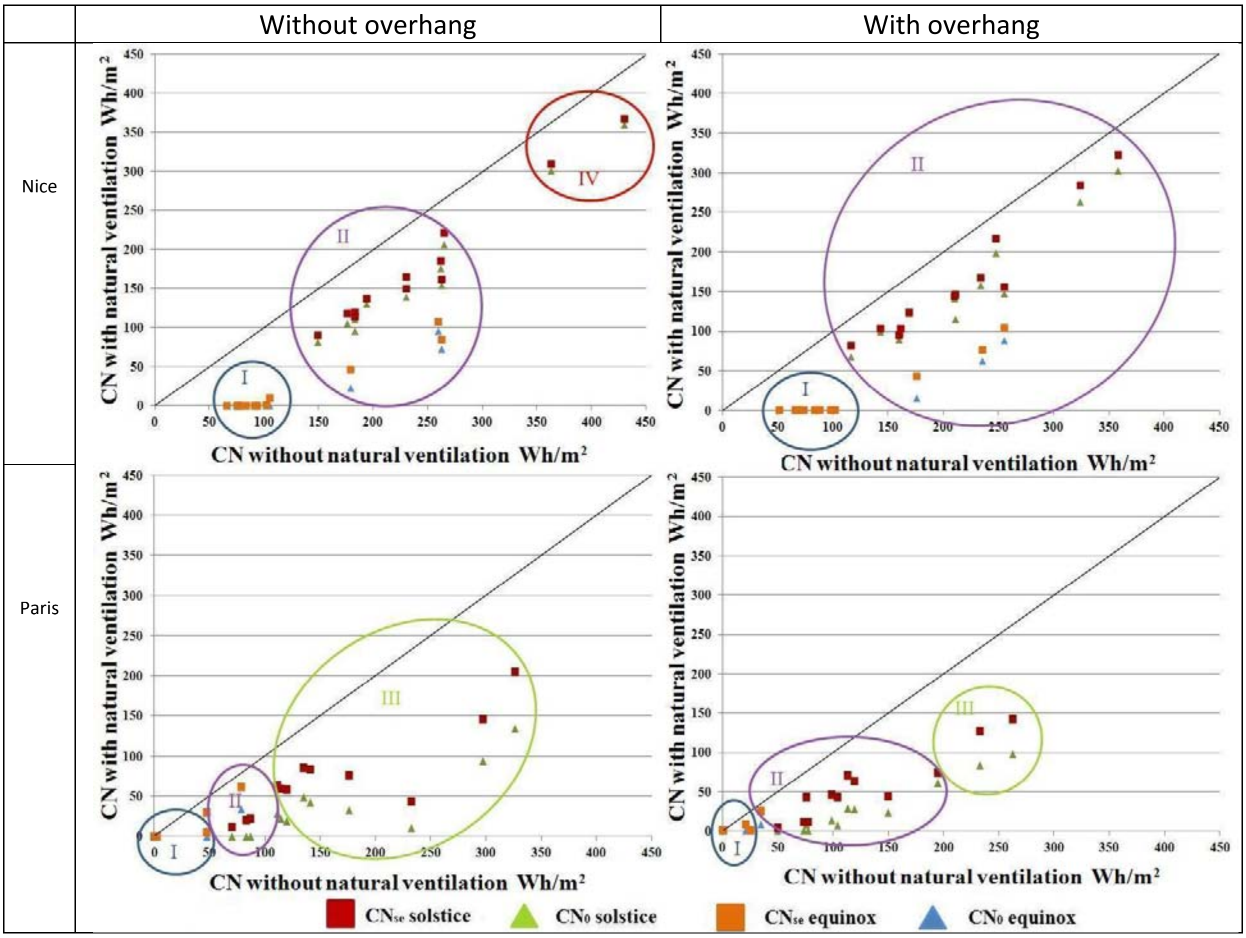


**Figure 7. Comparative results between original cooling needs and cases with natural ventilation**

effect doesn't have considerable influence on the calculation.

- In Group IV in red, the cases located in the highest original cooling needs region are south-oriented offices with 50% and 70% glazed surface in summer Nice. The reason why the difference of secondary effect in these cases is insignificant is that the outdoor temperature is so high that the natural ventilation is barely used.

In the Group I, II and IV, the calculation by neglecting secondary effect could be considered as consistent.

- The Group III in lawn green, where stands the maximum of difference, represents most of the offices with 50% and 70% glazed surface in summer Paris. In the temperate climate, the outdoor temperature is neither too high nor toolow, consequently the natural ventilation works effectively in most of the time. Larger glazed surface amplifying the effect of sunlight, its secondary effect is then more significant. For instance, for the Paris office with 70% opening surface oriented to south without overhang, the 74Wh/m$^2$ of difference of cooling needs on a day is equal to 25% of the total energy consumption.

For the calculation of natural ventilation in similar situations of Group III, the secondary effect should be inspected more carefully by the designers and researchers.

The two graphs on the right column show the corresponding simulation of office with solar protection devices. The presence of an overhang drives down both the cooling needs with and without natural ventilation, thus the points move downward and to the left. In addition, the difference between each pair of points is reduced, meaning that the impact of the secondary effect is lower with the adding of overhangs. It should be noted that the points in Group IV in offices without overhang in Nice are replaced into Group II in the cases with the overhang. When the overhang impairs the direct solar incident flux, the offices tend to open the window taking more profit of the natural ventilation. As a result, the secondary effect recurs more obviously. However, compared to the total cooling needs around 300Wh/m$^2$, this difference of 30Wh/m$^2$ is not important.

**Analysis of top-hung windows simulations**

Concerning the top-hung window, a series of simulations is done following the same principle. Similar to the horizontal sash window, the configurations consist of two climate regions, three aperture ratios, two typical seasonal days and with/without an overhang as solar protection.

The results reveal less difference than horizontal sash window across the comparative calculation. Figure 8 represents the extreme situation that is in summer Paris, corresponding to the worst case in sash window simulation. The difference between calculation with or without secondary effect varies only slightly, in general is less than 10Wh/m$^2$. In other situations, on account of climates or the presence of solar protection, this value is weakened even more therefore is not necessary to be presented here. In sum, for the top-hung window, the calculation of secondary effect could be simplified.

The reason why the secondary effect of top-hung windows is negligible could also be simply explained in a schematic way. According to an analysis of the typical frontal view in Figure 9, a small opening angle accounts for a small unprotected opening surface.

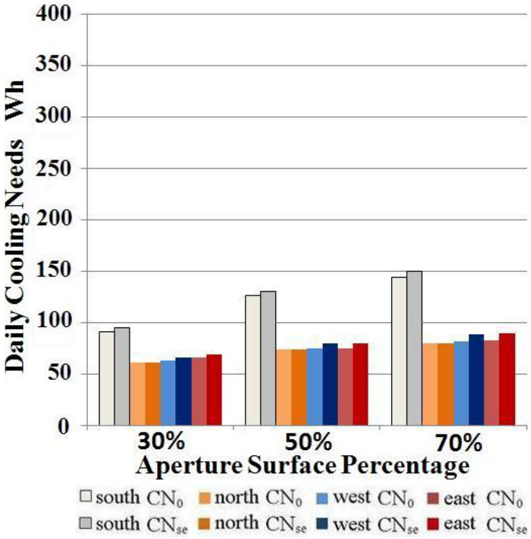


Figure 8. Cooling needs of office with top-hung window calculatedby the methods with or without consideration of secondary effect, Paris, summer solstice

In a 30° angle case, the unprotected opening surface, for instance, stays between 0 to 15% while the incident radiation zenith angle varying from 90° to 30° for an inclined angle equal to zero. Though the entered direct solar radiation is slightly larger when the sun light arrives by an inclined angle, the errors of simplified calculations, in average, are less than 10% compared to the simulations with secondary effect.

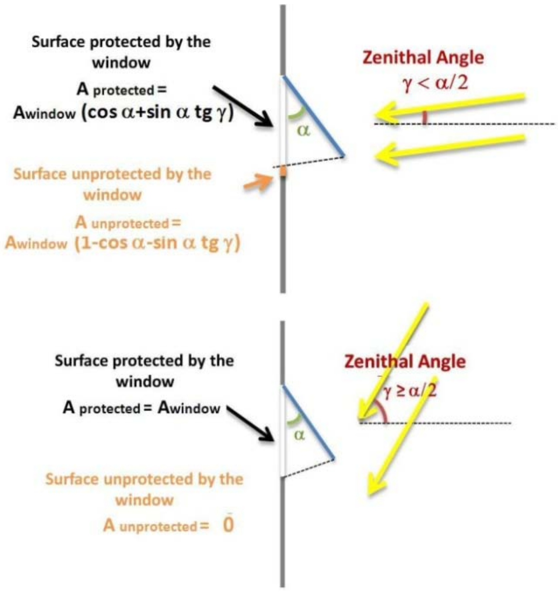


Figure 9. Frontal view of the top-hung window

## Conclusion

This work started with a statement establishing the problem of window opening effect on solar gains and natural lighting. Regarding natural ventilation, the thermal and visual performance of two common windows, horizontal sash and top-hung, are evaluated. Contribution is made to the understanding of the role of window opening in reducing the energy consumption and in compensating natural lighting across Paris and Nice on summer solstice and autumnal equinox.

Specifically, the results suggest that the secondary effect that occurred during the overlapping or inclining of windows alters the cooling effect of the natural ventilation. This adverse effect on natural ventilation efficiency of opening window depends on conditions. The more the natural ventilation is used, the more the secondary effect increases. The largest differences appear for the offices in temperate climates, where the natural ventilation can be dominant. Moreover, high level of glazed surface and south-oriented facade increase the secondary effect substantially.

## Nomenclature

$\tau_l$ = luminous transmittance
$SC$ = shading coefficient
$\tau_{lo}$ = original luminous transmittance
$SC_0$ = original shading coefficient
$A_{open}$ = opened surface
$A_{window}$ = window surface
$T_{out,close,thres}$ = threshold outdoor temperature,
$T_{in,min}$ = low set-point temperature
$T_{in,max}$ = high set-point temperature
$U_w$ = heat transfer coefficient
$CN$ = cooling needs
$CN_0$ = cooling needs without secondary effect
$CN_{se}$ = cooling needs with secondary effect
$\Delta$ = cooling needs difference caused by secondary effect
$\Delta_1$ = cooling needs difference caused by the solar gains
$\Delta_2$ = cooling needs difference caused by the artificial lighting

## 1.3. Enjeux en contrôle de système d'ouvertures vitrées

L'analyse des situations de demande de ventilation fait apparaitre deux classes de cas :

- Un premier où l'assemblage de produits existants : ouverture vitrée, protection solaire mobile ou fixe associés à des capteurs d'éclairement de bruit et de température peut permettre de gérer les surchauffes, l'éclairage et le niveau sonore. Les modèles de calcul simplifié du renouvellement d'air par ventilation mono façade ou traversante, d'éclairement naturel, de transmission sonore d'une source externe et enfin de transmission du rayonnement thermique sont disponibles.

- Un second, où il est impossible de concilier rafraichissement par ouverture de fenêtre et contrainte acoustique. il faut alors concevoir des produits nouveaux. L'effort doit alors porter sur une protection acoustique compatible avec la ventilation naturelle et pour laquelle une modélisation avec protection est nécessaire assortie d'essais expérimentaux en vue de l'obtention de modèles simplifiés utilisables.

Pour bâtir l'organigramme des contraintes, nous distinguons tout d'abord les bâtiments à usage résidentiel et les bureaux.

Dans les premiers, l'occupation apparaît majoritairement la nuit. La ventilation diurne, si elle présente des problèmes de sécurisation de l'habitation en inoccupation évite les contraintes acoustiques. En revanche, imaginer une ventilation nocturne (la plus efficace thermiquement) suppose de régler la question acoustique. On notera cependant que la protection sonore à imaginer peut être opaque puisqu'il n'y a plus à respecter une contrainte de transmission lumineuse. Le jeu complet des contraintes est reporté sur la Figure 1-3. Pour ce cas résidentiel, on s'intéressera à la ventilation traversante plus efficace.

Dans les bâtiments tertiaires, la situation est inverse. Les locaux sont inoccupés la nuit ce qui permet une ventilation nocturne sans contrainte acoustique. Seule la question de sécurité anti intrusion doit être traitée. En revanche, durant la journée une ventilation diurne pose la question du bruit bien entendu mais aussi celle de la transmission lumineuse. Une protection acoustique opaque obligerait à mettre en fonctionnement l'éclairage artificiel, générant à la fois des consommations électriques « inutiles », l'inconfort des occupants dans un espace fermé « permanant », et une contribution supplémentaire aux surchauffes contre lesquelles on lutte. Le jeu complet des contraintes en bâtiment tertiaire est reporté sur la Figure 1-4.

Sur ces deux figures, des ordres de grandeurs de renouvellements d'air supposés sont indiqués. En noir il s'agit d'estimation en ventilation traversante (cas favorable) et en rouge en mono façade. L'objectif de la modélisation CFD et des essais aura pour but de mesurer les taux de renouvellement d'air effectifs pour un rafraichissement correct des locaux.

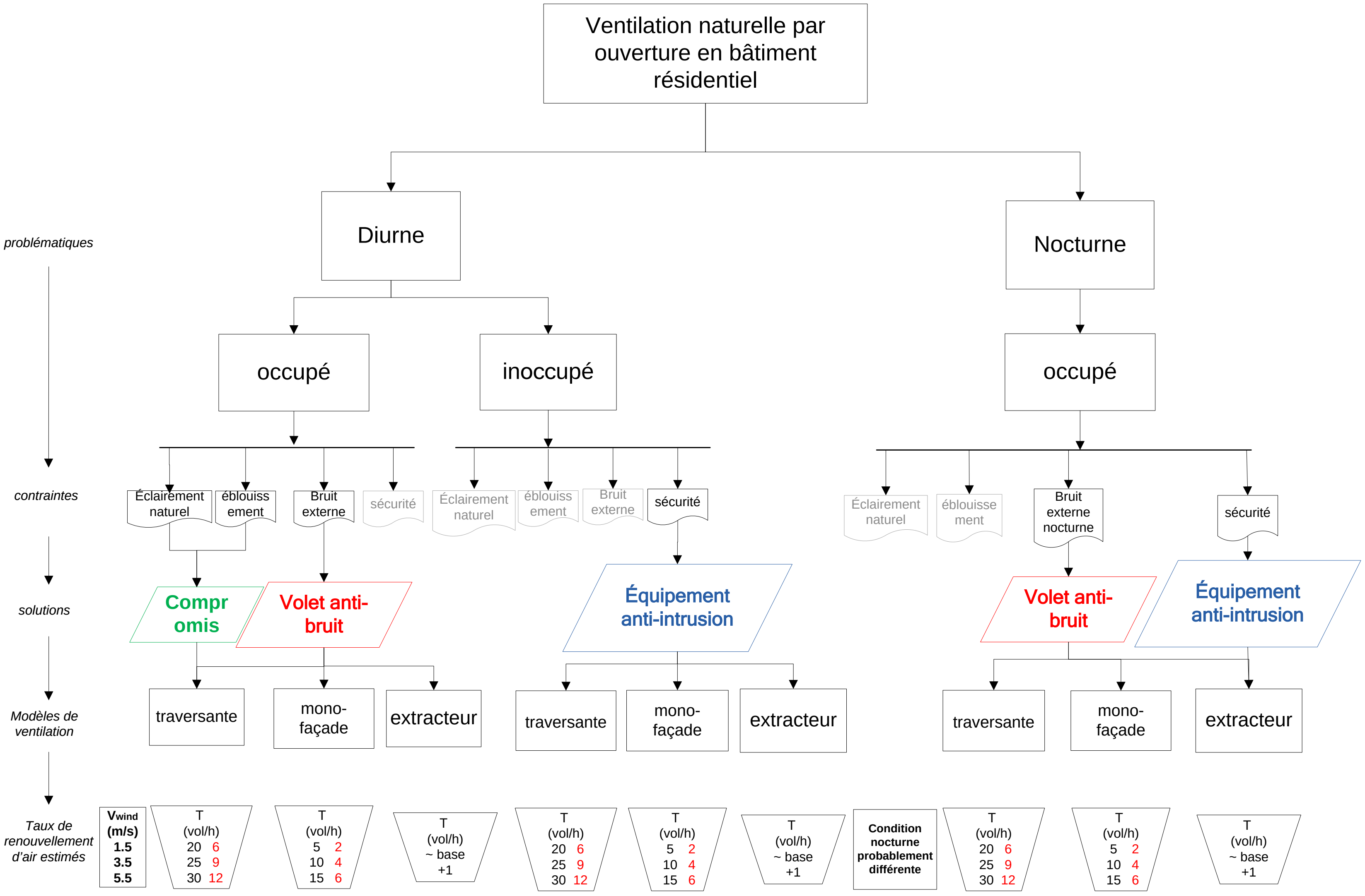


Figure 1-3. Arbre des possibilités dans le résidentiel

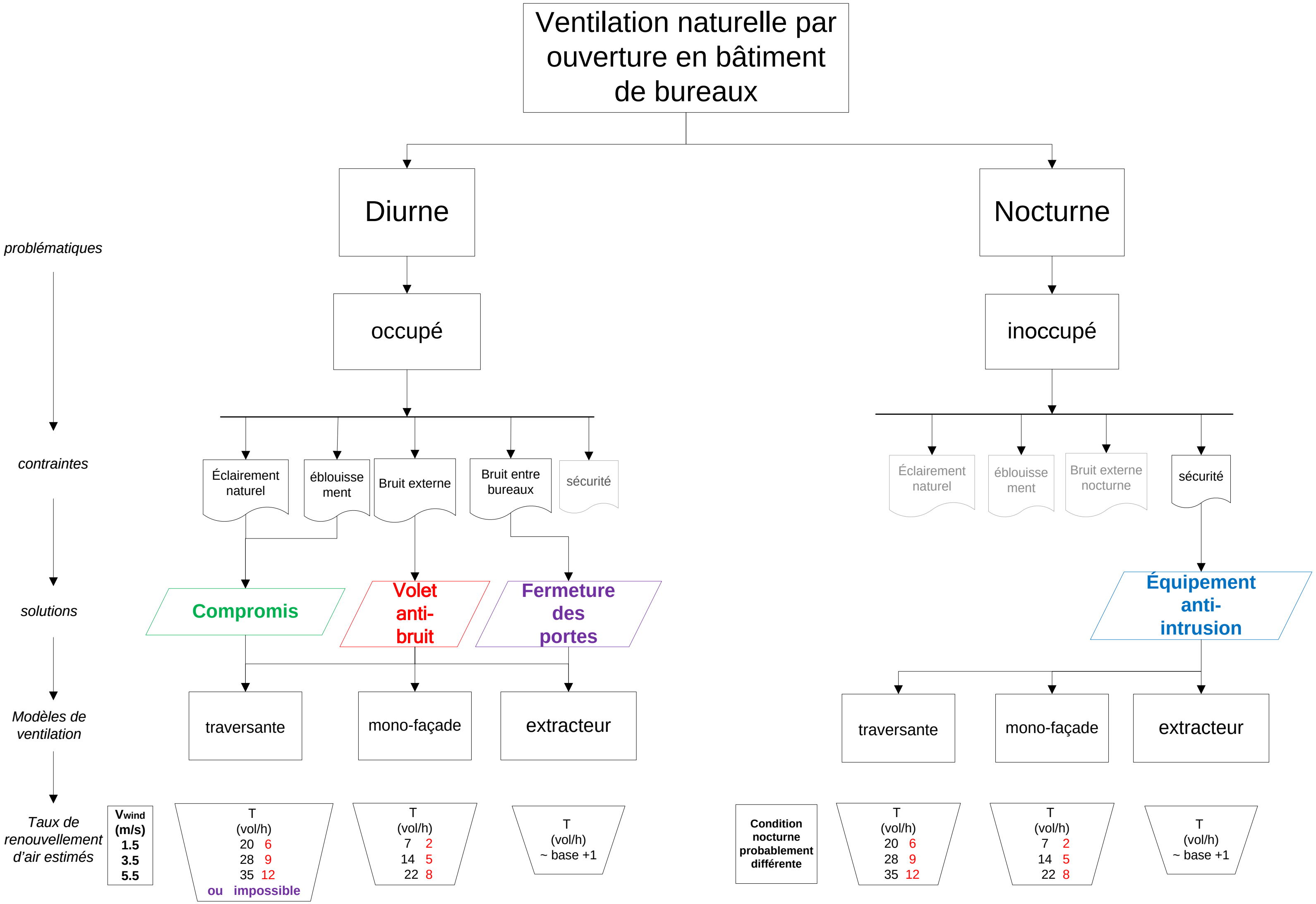


Figure 1-4. Arbre des possibilités dans le résidentiel