VENTILATIVE COOLING IN NATIONAL ENERGY PERFORMANCE REGULATIONS: REQUIREMENTS AND SENSITIVITY ANALYSIS

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ABSTRACT

Higher insulation and air tightness levels of buildings, increase the risk on overheating. Ventilative cooling as passive technique can limit overheating and decrease cooling energy consumption. The national energy performance regulations (EPBD) determine whether, how and under which requirements ventilative cooling can assist to reduce cooling demand and overheating. Therefore, those regulations are a key factor in the market uptake of ventilative cooling. Without a realistic and achievable approach, ventilative cooling will marginally be applied in buildings.

In this study, actual and possible requirements imposed on devices or systems for ventilative cooling are described. Besides, a sensitivity analysis is performed to assess the impact of parameter variation on the ventilative cooling effect. One reference dwelling is selected and introduced into the EP software of Belgium, The Netherlands and France. In that way, differences in buildings characteristics between countries on the output are ignored. Of course, the presented results are only valid for the selected reference dwelling.

In the three countries ventilative cooling by means of openable windows can be taken into account, in Belgium and France as a percentage of openable windows, in The Netherlands as present or not. Burglary resistance and water tightness of ventilative cooling devices are requirements (for The Netherlands) or have an impact on the performance of the ventilative cooling device (for Belgium). In France, openable windows are not allowed in case of active cooling. When there are openable windows in France, they are supposed to be opened during the heating season as well, resulting in an increased heating demand due to ventilative cooling.

As can be expected, ventilative cooling always decreases the cooling demand (26 to 96% in Belgium, 10 to 35% in The Netherlands), especially in combination with mobile solar shading.

Similar to the cooling demand, the risk on overheating in Belgium decreases by applying ventilative cooling. In France, summer indoor temperature can be strongly reduced by using openable windows, although the fraction openable windows has no effect. Next to ventilative cooling, thermal capacity as well as solar shading can have a considerable impact on summer comfort and should be considered as complementary means.

The overall primary energy consumption of the reference dwelling is lower when ventilative cooling is applied (5 to 12% in Belgium, up to 4% in The Netherlands) except for France where openable windows remarkably increase the heating demand (up to 38%). The lowest primary energy consumption is achieved by applying ventilative cooling in combination with sun shading.

KEYWORDS

Energy performance regulation, Overheating, Sensitivity analysis, Ventilative cooling

1 INTRODUCTION

Higher insulation and air tightness levels of buildings reduce the energy demand of dwellings, but increase the risk of overheating due to lower heat losses even in intermediate season. This has been highlighted in a number of Northern, Central and Southern European reports as listed by McLeod [1]. Experience shows that active cooling is too often considered to resolve these overheating problems, while other options should be prioritized in building design when relevant [2]. Possible design strategies affecting the heat balance (heat gains = heat losses + cooling demand) are:

heat gains: - solar gains: window surface, solar protection
- internal heat gains (if variable)
heat losses: - transmission losses: U-value
- controlled ventilation losses: air flow rate
- uncontrolled ventilation losses: air tightness level n_{50}
- ventilative cooling: air flow rate
thermal mass

The impact of some of the afore mentioned design strategies is studied before (f.i. [1], [3], [4]) and are also integrated in the national Energy Performance (EP) calculation procedures. Although ventilative cooling is a known technique since ancient times, this passive cooling technique is only included in a few national EP calculations, such as Belgium, France and The Netherlands. Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces with air flow rates higher than hygienic ones. This effective use of outside air reduces or cancels the energy consumption of cooling systems, while increasing thermal comfort. Ventilative cooling is relevant in a wide range of buildings and may even be necessary to realize renovated or new NZEB [5].

The national energy performance regulations (EPBD) determine whether, how and under which requirements ventilative cooling can assist to reduce cooling demand and overheating. Therefore, those regulations are a key factor in the market uptake of ventilative cooling. Without a realistic and achievable approach, ventilative cooling will marginally be applied in buildings.

In this study, actual and possible requirements imposed on devices or systems for ventilative cooling were described in three countries: Belgium, France and The Netherlands. Besides, a sensitivity analysis was performed to assess the impact of ventilative cooling (simulated by a openable windows), while varying other building characteristics, on net yearly heating demand, net yearly cooling demand, summer comfort and yearly primary energy consumption. To this end, one reference house was selected and modelled with the Energy Performance (EP) software of Belgium, France and The Netherlands. In this way, the effect of different building characteristics between countries on the output was ignored.

2 EP CALCULATION METHOD

In the three countries studied in this paper, Belgium, France and The Netherlands, heating demand, cooling demand as well as summer comfort is expressed in a different way (Table 1):

- Heating as well as cooling set points are different in each country (Table 2), and even function of occupation. In that way, differences in absolute energy demands between countries are enhanced.
- A (fictive) cooling demand cannot be determined within the French calculation procedure.
- In The Netherlands, no summer comfort parameter is used.
- The overall energy performance of the dwelling (the primary energy consumption) is in Belgium and The Netherlands expressed as a relative value, in France an absolute value is used.

The way cooling demand and summer comfort is treated in the national methodologies is described hereafter.

Table 1: Output of different national EP calculations

Output	**Belgium**	**France**	**The Netherlands**
Heating demand	Net yearly heating demand [MJ]	Net yearly heating demand [MJ]	Net yearly heating demand [MJ]
Cooling demand	Fictive net yearly cooling demand [MJ]	---	Fictive net yearly cooling demand [MJ]
Summer comfort	Overheating indicator [Kh]	Indoor temperature exceed T_{ic} [K]	---
Primary energy consumption	E-level [-] $PEF_{el} = 2.5$ $PEF_{fuel} = 1.0$	C_{ep} [kWh/m²] $PEF_{el} = 2.58$ $PEF_{fuel} = 1.0$	EPC [-] $PEF_{el} = 2.56$ $PEF_{fuel} = 1.0$

Table 2: National boundary conditions for heating and cooling demand calculations

Country	**Heating set point**	**Cooling set point**
Belgium	18°C	23°C
France	19°C / 16°C (non occ.)	28°C / 30°C (non occ.)
The Netherlands	20°C	24°C

2.1 Belgium

The Belgian procedure to calculate the so-called “overheating indicator” for dwellings is described in annex V of the EPB regulation [6]. The risk on overheating depends on the overheating indicator ($I_{overheat}$) which is determined by the normalized excessive heat gains (Eq. 1). When the overheating indicator does not exceed the maximum allowed value, chances of overheating are limited, but not impossible.

$$I_{overheat} = Q_{excessnorm,a} = \sum_{m=1}^{12} Q_{excessnorm,m} \tag{1}$$

$$Q_{excessnorm,m} \frac{(1-\eta_{util,overh,m}) \cdot Q_{g,overh,m}}{H_{T,overh} + H_{V,overh,m}} \cdot \frac{1000}{3.6} \tag{2}$$

With:

$I_{overheat}$	Overheating indicator	[Kh]
$Q_{excessnorm,m}$	Monthly normalized unwanted heat gains	[Kh]
$\eta_{util,overh,m}$	Utilization factor of the monthly heat gains	[-]
$Q_{g,overh,m}$	Monthly heat gains by insolation and internal heat production	[MJ]
$H_{T,overh}$	Heat transfer coefficient by transmission	[W/K]
$H_{V,overh,m}$	Monthly heat transfer coefficient by ventilation	[W/K]

In accordance with the overheating indicator, a conventional probability of placing an active cooling installation (p_{cool}) in a later stage, is defined (Eq. 3). This probability augments linearly with the overheating indicator (1 in case of active cooling).

$$p_{cool} = max\left\{0, min\left(\frac{I_{overheat} - I_{overheat,thresh}}{I_{overheat,max} - I_{overheat,thresh}}, 1\right)\right\} \qquad (3)$$

With:

$I_{overheat,thresh}$	Threshold value overheating indicator (above this value the risk on placing active cooling afterwards grows)	[1000 Kh]
$I_{overheat,max}$	Maximum allowed value overheating indicator (when the overheating indicator exceeds this value, a fine is imposed)	[6500 Kh]

When a risk on overheating occurs, without installing an active cooling system, a fictive cooling demand is calculated to take into account a possible installation of an active cooling installation afterwards. The fictive cooling demand equals the conventional probability multiplied with the net energy demand for cooling ($Q_{cool,net,princ}$) (Eq. 4):

$$Q_{cool,net,m} = p_{cool} \cdot Q_{cool,net,princ,m} \qquad (4)$$

With:

$Q_{cool,net,m}$	Monthly fictive net energy cooling demand	[MJ]
$Q_{cool,net,princ,m}$	Monthly net energy need for cooling per month	[MJ]

In case of no active cooling, a fixed system efficiency of 90% and a fixed EER of 2.5 is taken into account to determine the secondary and primary energy consumption.

2.2 France

The French procedure to calculate the so-called “T_{ic}” parameter is described in [7]. T_{ic} has to be lower than a reference value $T_{ic,ref}$. T_{ic} is the conventional indoor room temperature reached during a reference hot day in summer. The value of T_{ic} depends on the climate zone, the building type and the characteristics of the building envelope.

$T_{ic,ref}$ is determined by substituting the actual building characteristics by reference characteristics, such as:

- close obstacles are ignored;
- all sun screens and windows are supposed to be opened manually;
- the solar factor of the windows are fixed according to the region and altitude;
- …

In contrast with Belgium and The Netherlands, it seems that in France no fictive cooling is taken into account when no active cooling is installed.

2.3 The Netherlands

The Dutch procedure to calculate and evaluate the overheating risk in buildings is described in [8].

For buildings without active cooling, the fictive net cooling demand ($Q_{C;nd}$) is calculated:

$$Q_{C;nd} = a_{C;red} \cdot \left(Q_{C;gn} - \eta_{C;ls} \cdot Q_{C;ht}\right) \quad (5)$$

With:

$Q_{C;nd}$	Cooling demand	[MJ]
$Q_{C;gn}$	Total heat gains	[MJ]
$Q_{C;ht}$	Total heat losses	[MJ]
$\eta_{C;ls}$	Utilization factor for heat losses	[-]
$a_{C;red}$	Reduction factor for non-continuous cooling (= 1 in case of residential function)	[-]

In case of no active cooling, a fixed EER of 3.0 is taken into account.

3 DEVICES AND REQUIREMENTS

A lot of ventilative cooling means can be thought of, but besides openable windows (and vents in The Netherlands) none of them is integrated in the EP calculation procedure for residential buildings (Table 3). Additional properties of ventilative cooling devices are, in case of natural devices: burglary resistance, insect proof, water tightness and acoustic attenuation. In case of mechanical devices power consumption and noise production are important properties to take into account. These properties improve the potential of ventilative cooling and guarantee that the devices will be used. As shown in Table 4 almost none of these parameters are integrated in the current calculation procedure. Only in Belgium burglary proof is integrated in the EP calculation procedure. For burglary proof devices the ventilative cooling impact is 100% considered. When a device is not burglary resistance, it is considered as not having a cooling impact. When it is moderate burglary proof, it is considered as having 1/3 of its cooling potential. The definition of (moderate) burglary proof is not defined yet but will be determining the potential of ventilative cooling.

Table 3: Ventilative cooling means for dwellings in Belgian, French and Dutch EPBD regulation

Ventilative cooling means	Belgium	France	The Netherlands
Openable windows			
Turn windows	Net area (m²)	Max. opening ratio (%)	Yes / no
Tilt windows	Net area (m²)	Max. opening ratio (%)	Yes / no
Sliding windows	---	Max. opening ratio (%)	Yes / no
Roof windows	Net area (m²)	Max. opening ratio (%)	Yes / no
Vents integrated in/around windows (~ window grills)	---	---	Yes / no
Wall louvres	---	---	---
Natural extract chimney	---	---	---
Mechanical extract and/or supply fans	---	---	---

Table 4: Parameters regarding natural ventilative cooling integrated in current residential EP calculation procedure (yes / no) and current requirements (Req) and recommendations (Rec) in national EPBD regulation

	Belgium	**France**	**The Netherlands**
Burglary proof	Yes / ---	---	No / Rec
Insect proof	---	---	---
Water tightness	---	---	No / Rec
Acoustic attenuation	---	---	---

4 SENSITIVITY ANALYSIS

In this study, the effect of ventilative cooling is investigated by means of openable windows. The objective of the sensitivity analysis is to check how openable windows in combination with other building characteristics are assessed in Belgium, France and The Netherlands since these countries have a similar climate (in France, simulations are performed for the most northern climate zone, namely H1a). Therefore, net yearly heating demand, net yearly cooling demand, summer comfort and yearly primary energy consumption are determined and analysed.

4.1 Methodology

Different parameters are varied in the EP software of the three considered countries (Table 5). Each time the simulations are run on the same reference dwelling (Figure 1). The characteristics of the reference dwelling are listed in Table 6, which is also the reference to check the influence of the parameters listed in Table 7 on the ventilative cooling performance of the dwelling in the different countries. Actually there are two reference situations depending on the fraction openable windows. The first reference situation (REF 1) has no openable windows, referring to a dwelling without ventilative cooling techniques. The second reference situation (REF 2) has 50% openable windows, referring to a dwelling with ventilative cooling devices (namely openable windows).

As stated in Table 1 there are different output parameters to evaluate the building performance. Each of the output parameters of Table 1 is determined within the national EP software to be able to perform an overall comparison of the effect of the parameters listed in Table 7.

Table 5: Used EP software

Country	**EP software**	**Version**
Belgium	3G-Software	5.0.5
France	Clima-Win	2.0
The Netherlands	Enorm	1.5

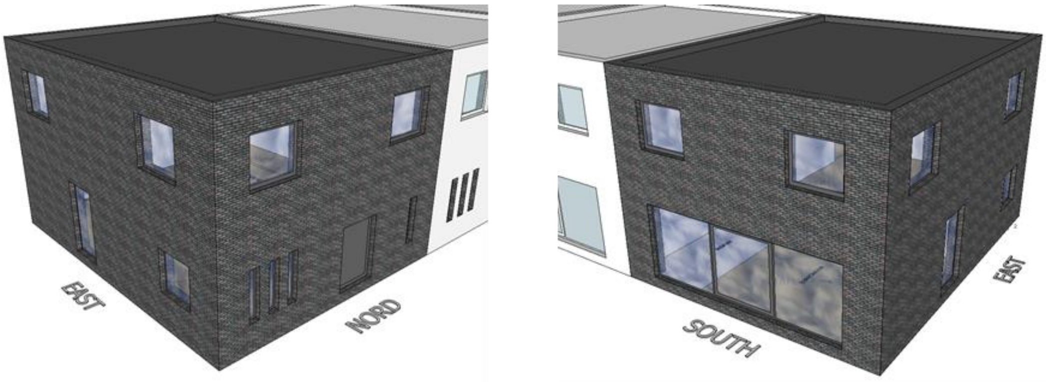

Figure 1: Reference dwelling used in the simulations: a semi-detached two story building

Table 6: Characteristics reference dwelling

Geometric characteristics		
External volume	472	m³
External heat loss surface	313	m²
Compactness (external volume/external heat loss surface)	1,51	m
Total floor surface	160	m²
Window surface (south window living room = 13,2 m²)	30,7	m²
Net floor surface	137	m²
Insulation of building envelope		
Average U-value of building envelope	0,39	W/m²K
Average U-value of the windows	1,60	W/m²K
Air tightness of the building envelope		
Belgium:	2,00	m³/hm²
France:	0,37	m³/hm²
The Netherlands:	0,19	dm³/sm²
Space heating and hot water		
Heat generation system	Condensing boiler (107%)	
Heat delivery system	Floor heating	
Mobile external sun protection		
Belgium:	No sun protection	
France:	No sun protection	
The Netherlands:	No sun protection	
Thermal mass		
Belgium:	Moderate heavy	
France:	Moderate heavy	
The Netherlands:	Average inertia	
Openable window fraction		
Belgium:	0% - 50%	
France:	0% - 50%	
The Netherlands:	Fixed windows – openable windows	
Active cooling		
Belgium:	No active cooling	
France:	No active cooling	
The Netherlands:	No active cooling	

Table 7: Parameters and variations (default (reference dwelling) values bold) and how it is simulated in the national EP software

n°	Parameter	Variations	
1	Fraction openable windows	**0** / 25 / **50** / 75 / 100%	
		Belgium:	0 / 25 / 50 / 75 / 100%
		France:	0 / 25 / 50 / 75 / 100%
		The Netherlands:	Openable windows
2	Thermal mass	**moderate heavy** / light	
		Belgium:	Light construction
		France:	Very light
		The Netherlands:	Timber framed
3	Solar shading and solar control	**no sun shading** / manual operated on South / automatically operated on South and East	
		Belgium:	τ_B = 3,9% ; ρ_B = 8,1%
		France:	τ_B = 3,9% ; ρ_B = 8,1%
		The Netherlands:	lump value of g_{tot}
4	Window-to-floor area ratio	15 / **22%**	(= 20,7 / 30,7 m^2 window surface)
5	Building air tightness	**2** / 10 $m^3/(h.m^2)$	
		Belgium:	2 / 10 $m^3/(h.m^2)$
		France:	0,57 / 2,83 $m^3/(h.m^2)$
		The Netherlands:	0,25 / 1,24 $dm^3/(s.m^2)$
6	Active cooling	Yes (EER = 2.5) / **no**	

4.2 Results

The output mentioned in Table 1 is shown for each parameter variation for Belgium (Be, red columns), France (Fr, blew columns) and The Netherlands (Nl, orange columns) in Figure 2 to Figure 13. In Figure 14 to Figure 17, the results are expressed relatively to REF 1. For visibility reasons the Dutch output of primary energy consumption (EPC) is multiplied by 100 in the plotted results.

4.2.1 Fraction openable windows

For the three countries, the effect of the fraction openable windows on heating and cooling demand, summer comfort and primary energy consumption is illustrated in Figure 2 to Figure 5. In Belgium and The Netherlands, openable windows are supposed to be closed during the heating season in contrast to France. As can be deduced from Figure 2, in France, the heating demand can differ considerably depending on the fraction openable windows. In this case, the heating demand increased with 30% between no and all openable windows (100%). This increasing heating demand is a serious disadvantage for ventilative cooling in France.

It is remarkable that the heating demand in The Netherlands is 40% lower compared to Belgium, although the setpoint for heating is 2°C higher in The Netherlands and the outdoor climate is slightly colder. Heating demands in France are situated in between (even though the windows are opened during heating season).

As illustrated in Figure 3, openable windows have a great effect on the fictive cooling demand in Belgium and The Netherlands. Unfortunately, the effect on the cooling demand is not known in France. In for dwelling considered, a fraction of 100% openable windows can nearly eliminate the cooling demand in Belgium. In The Netherlands, a reduction in cooling demand of about 30% is observed independent of the fraction openable windows since this cannot be varied in the software.

The risk on overheating in Belgium (Figure 4) follows a similar trend as the cooling demand (Figure 3). When no openable windows are present, the risk on overheating is one. In France, the summer indoor temperature exceed is strongly reduced by placing openable windows. The fraction openable windows, however, has no effect.

Figure 5 illustrates the yearly primary energy consumption in the three countries. In Belgium, ventilative cooling by means of openable windows can have a big impact on the total energy consumption. In this case, a reduction of up to 15% is found when the fraction openable windows is increased to 100%. In The Netherlands, the maximum reduction is 3%, which is much smaller than in Belgium due to a smaller effect on the cooling demand (Figure 3). However, with 25% openable windows, the reduction in primary energy consumption is similar as in Belgium.

In France, it is remarkable that an increased fraction openable windows leads to an increased primary energy consumption. This means that the increased heating demand (Figure 2) is not compensated by the decreased cooling demand (not shown, but can be deduced from the reduced indoor temperature exceed, Figure 4). Is seems that in the French EPBD, the air flow rate through openable windows is similar in winter as in summer time. In practice, however, windows are less opened in cold periods.
Furthermore, it is not allowed to compare the primary energy consumption for the reference dwelling between the three countries due to difference in its determination.

4.2.2 Thermal mass

For the three considered countries, the effect of the building thermal mass is illustrated by comparing the reference situations with the situations marked with “Light” on Figure 10 to Figure 13.

In Belgium and France, less thermal mass leads to an increased heating demand, whereas in The Netherlands, the heating demand decreases with decreasing thermal mass (Figure 10). According to building physics, however, heating demand increases with decreasing thermal mass. In France, the light building with openable windows (Light 50% OW, Figure 10) shows a significant increase in heating demand in comparison with the other presented cases. This can be explained by the fact that windows are also opened during winter period, causing high energy losses due to lack of thermal capacity.

The cooling demand clearly increases when there is less thermal capacity available (Figure 11). Again, the effect is logically higher with an increased fraction openable windows. With openable windows, cooling demands can be more than doubled in a light construction compared with moderate one. Especially in The Netherlands, a major impact is found.

As can be observed in Figure 12, the risk on overheating in Belgium clearly increases with decreasing thermal capacity, similarly to the cooling demand. A similar trend is observed for the French summer indoor temperature exceed. Logically, the temperature increase due to less thermal mass is much smaller in the dwelling with 50% openable windows.

For the three countries, primary energy consumption increases with reduced thermal mass (Figure 13). In The Netherlands, the relative impact of thermal mass on the total energy consumption seems to be independent of the fraction openable windows. In Belgium and France, however, the effect of thermal mass is more or strongly pronounced with an increased fraction openable windows. In The Netherlands, for lower thermal capacities, the decreased heating demand is compensated by the strongly increased cooling demand.

4.2.3 Solar shading and control strategy

Effects of solar shading and solar control is illustrated by comparing the reference situations with the situations marked with “SS” (solar shading). In Belgium and The Netherlands, mobile solar shading (Autom. SS, Figure 10) is supposed to be permanently open during the heating season, causing no increase in heating demand. In France, however, especially automated solar shading increases the net heating demand due to the supposed use of solar shading during the heating season. Without openable windows (0% OW), the heating demand is 50% higher when placing automated solar shading.

In Belgium, the effect of manual south oriented shading (Manual SS-S, Figure 11) on the cooling demand is similar to the effect of 25% openable windows (Figure 3). With automated solar shading on the south and east façades (Autom. SS on S & E), the reduction in cooling demand is similar to nearly 50% openable windows. In case of ventilative cooling (50% OW), the relative effect of solar shading on the cooling need is similar as when there were no openable windows, as long as a cooling demand exists.

In The Netherlands, the effect of solar shading on the cooling demand is similar. Since the effect of openable windows is limited, absolute effects of mobile solar shading can be significantly higher than ventilative cooling.

Figure 12 illustrates how the overheating risk decreases with more advanced solar shading control strategies, in Belgium and France. In contrast to the other parameters studied, adjustable solar protection devices give rise to maximum indoor temperatures lower than the reference value for France (negative indoor temperature exceed, Figure 12).

In Belgium and The Netherlands, the primary energy consumption (Figure 13) follows the same trend as the cooling demand (Figure 11). This means less energy consumption with increasing control of solar shading. Oppositely, in France, the primary energy consumption follows the course of the heating demand (Figure 10). This means, higher energy consumptions with more advanced solar shading. This illogical effect is similar to the impact of an increasing number of openable windows and can only be explained by a cooling demand which doesn’t decrease by using solar shading (although the indoor temperature exceed becomes negative, Figure 12).

4.2.4 Window-to-floor area ratio

Windows have an impact on the heating and cooling demand via the solar gains and the transmission losses. Traditionally a major part of the windows are south-oriented to have maximal solar gains during heating season. In this study, the window area of the south oriented window is lowered, marked with “A_w/A_{fl} = 15%” on Figure 10 to Figure 13.

For the reference dwelling, the heating demand increases and the cooling demand decreases with reduced window area, due to a reduction in solar gains which is higher than the reduction in heat losses (Figure 10 and Figure 11). The effect is similar for different fractions of openable windows.

The risk on overheating or indoor temperature exceed decreases logically with lower window surface (Figure 12).

The primary energy consumption in Belgium and The Netherlands decreases with lower window surface (Figure 13), due to a stronger effect on the cooling demand than on the heating demand. In France, depending on the fraction openable windows, the primary energy consumption increases or stays constant. Similar to what is observed for other parameters, the impact on the cooling demand is much smaller.

4.2.5 Building air tightness

On Figure 10 to Figure 13 the simulations marked with “h_{50} = 10” show the influence of a worse building airtightness on the reference dwelling. As can be expected, the tighter the building envelope, the smaller the heating demand and a the higher the cooling demand (Figure 10 and Figure 13). Regarding ventilative cooling performance, the dwelling doesn’t need to be very air tight. Although, for this case, in Belgium, the building air tightness, has no influence on the overheating risk (Figure 12).

In Belgium and The Netherlands, the heating demand augments by 20 to 35% when the air tightness (n_{50}) changes from 2 to 10 $m^3/(h.m^2)$ (Figure 10). Openable windows don’t influence the heating demand. Whereas in France the openable windows have a large influence (as stated before). When there are no openable windows an augmentation of the heating demand of 100% occurs, with 50% openable windows an augmentation of only 40% occurs.

Regarding primary energy consumption (Figure 13), the effect of the higher heating demand is larger than the effect of the decreased cooling demand. This effect is greater in Belgium than in The Netherlands. In France, when the air tightness is bad (n_{50} = 10 $m^3/(h.m^2)$), the influence of openable windows becomes negligible.

4.2.6 Active cooling

The main purpose of applying ventilative cooling techniques in a dwelling is to avoid the installation of an active cooling system. On Figure 6 to Figure 9 the influence of applying an active cooling installation is shown. In France the combination of an active cooling installation and openable windows is impossible.

Logically, active cooling has no influence on the heating demand (Figure 6). The cooling demand in Belgium can only be lowered by applying openable windows since the risk on overheating is one when there are no openable windows (Figure 7 and Figure 8). When applying active cooling, the risk on overheating is always one (= chance active cooling is used), resulting in a higher cooling demand in case of openable windows.

In The Netherlands, applying an active cooling system gives rise to an increased cooling demand (Figure 7), meaning that active cooling is also penalized. Remarking on Figure 8 is the fact that when there are no openable windows in France, the indoor temperature exceed stays the same, despite the active cooling system.

Of course applying an active cooling systems leads to a higher primary energy consumption (Figure 9). Because REF 1 has an overheating risk of one in Belgium and a same EER for fictive and active cooling of 2.5 is used in the calculations, this augmentation of primary energy consumption does not appear. In the Netherlands, the increase in primary energy consumption due to active cooling is enlarged by the smaller efficiency of 2.5 for active cooling instead of 3.0 for fictive cooling.

4.3 Conclusion

As stated before the goal of the sensitivity analysis is to check for which building characteristics ventilative cooling can be applied so the cooling demand and risk on overheating can be sufficiently reduced without influencing the heating demand. To this end, the effect of the parameters studied, is shown relatively to REF 1 on Figure 14 to Figure 17.

In Belgium and The Netherlands, applying ventilative cooling does not result in a modified heating demand (Figure 14). In France this is not the case, since the windows are also opened during the heating season. A less air tight building, leads in all considered countries to the highest heating demand. With the exception of a lightweight dwelling with 50% openable windows in France.

Regarding cooling demand (Figure 15), each calculated variation with ventilative cooling results in a significant reduction of the cooling demand (26 to 96% in Belgium, 10 to 35% in The Netherlands). When ventilative cooling is applied, the cooling demand increases when there is less thermal mass available. For all other varied parameters, the cooling demand is decreased compared to the reference situation with ventilative cooling (REF 2). The lowest cooling demand is achieved by combining ventilative cooling with sun shading.

The risk on overheating can clearly be significantly lowered by applying ventilative cooling (Figure 16). Yet again, a lightweight dwelling performs worse than the reference situation. Applying sun shading in combination with ventilative cooling results in the lowest risk on overheating and temperature exceed. For this case, in Belgium, without applying ventilative cooling, the calculated risk on overheating is only lower than one when automated sun shading is applied.

An overall assessment of the performance of the dwelling is obtained by considering the primary energy consumption (Figure 17). Except for France where openable windows increase the heating demand, the primary energy consumption, is lower when ventilative cooling is applied. The lowest primary energy consumption is achieved by applying ventilative cooling in combination with sun shading.

5 CONCLUSIONS

In the three countries ventilative cooling by means of openable windows can be taken into account, in Belgium and France as a percentage of openable windows, in The Netherlands as present or not. Burglary resistance and water tightness of ventilative cooling devices are requirements (for The Netherlands) or have an impact on the performance of the ventilative cooling device (for Belgium). In France, no cooling demand could be determined, whereas in The Netherlands no summer comfort criterion is defined. In Belgium and The Netherlands, a kind of fictive cooling is calculated when no active cooling is present. In France, openable windows are not allowed in case of active cooling.

With respect to the heating demand, openable windows have a negative effect in France due to supposed openable windows during heating season. It is also remarkable that in contrast to Belgium and France, less thermal mass decreases the heating demand in The Netherlands.

As can be expected, ventilative cooling always decreases the cooling demand (26 to 96% in Belgium, 10 to 35% in The Netherlands), especially in combination with mobile solar shading. The effect is more pronounced with increasing thermal mass.

Similar to the cooling demand, the risk on overheating in Belgium is decreased by applying ventilative cooling. Also in France, summer indoor temperature can be strongly reduced by using openable windows, although the fraction of openable windows has no effect. Next to ventilative cooling, thermal capacity as well as solar shading can have a considerable impact on summer comfort and should be considered as complementary means.

Except for France, where openable windows remarkably increase the heating demand (up to 38%), the primary energy consumption, is lower when ventilative cooling is applied (5 to 12% in Belgium, up to 4% in The Netherlands). The lowest primary energy consumption is achieved by applying ventilative cooling in combination with sun shading.

Although the building simulated was the same for the three countries and the outdoor climate quite similar, huge differences in output values can be found for the same set of parameter values. It is important to realize that these specific conclusions are based on simulations run on one building type. Further research on different buildings types should be carried out, to have more general conclusions.

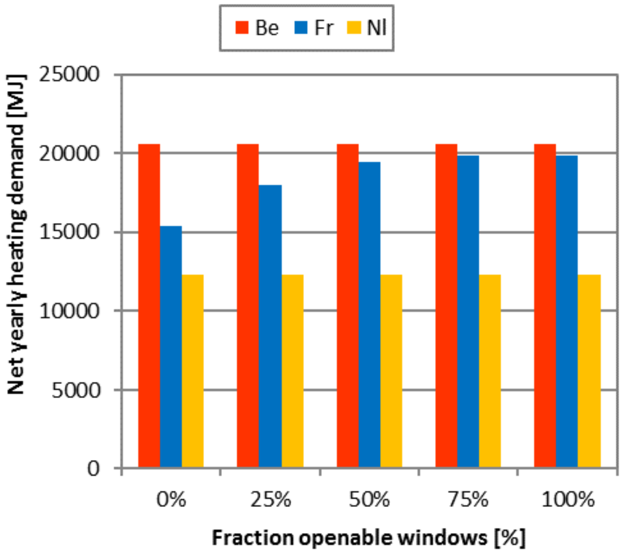

Figure 2: Net yearly heating demand [MJ] as a function of the fraction openable windows for Be, Fr and Nl

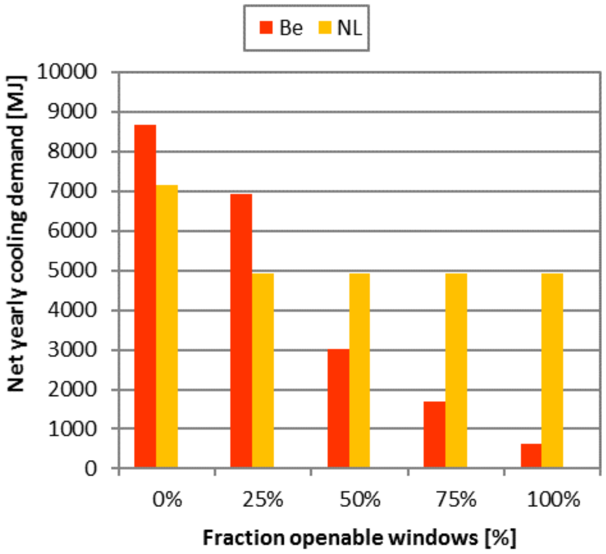

Figure 3: Fictive net yearly cooling demand [MJ] as a function of the fraction openable windows for Be and Nl

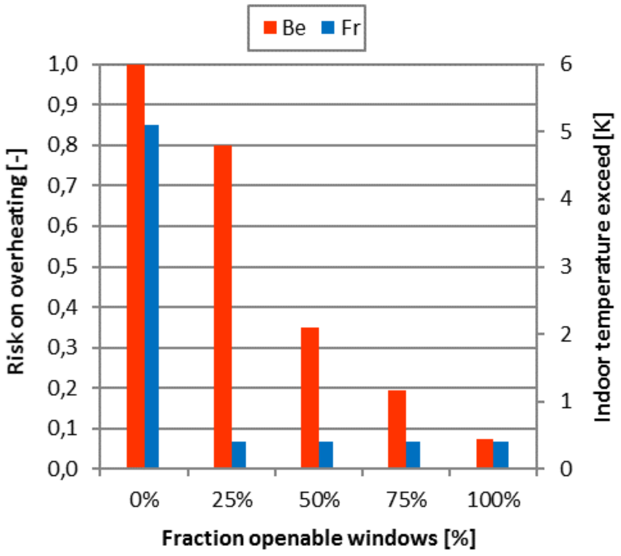

Figure 4: Risk on overheating (Be, left axis) and indoor temperature exceed (Fr, right axis) as a function of the fraction openable windows

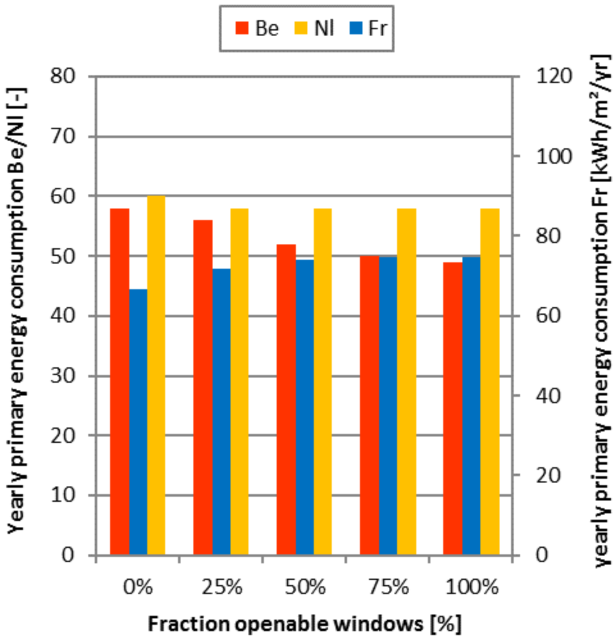

Figure 5: Yearly primary energy consumption [-] or [kWh/m²/yr] as a function of the fraction openable windows for Be, Fr and Nl

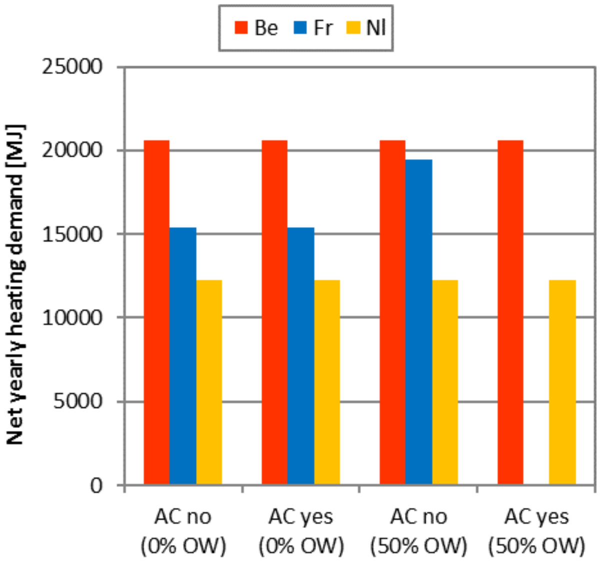

Figure 6: Net yearly heating demand [MJ] as a function of presence of active cooling (AC) for Be, Fr and Nl

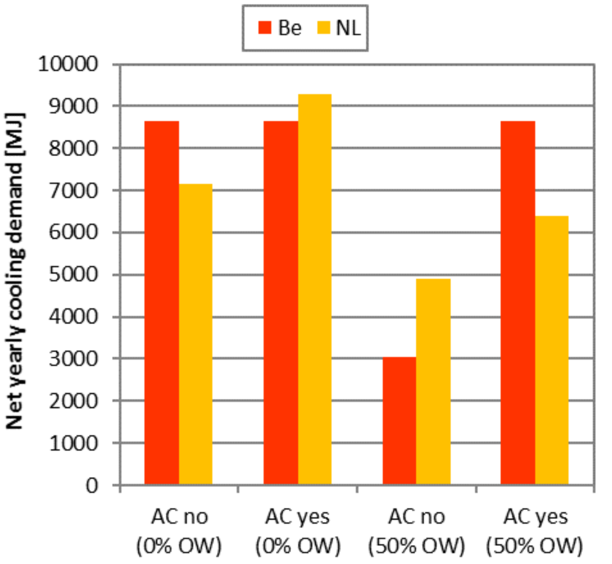

Figure 7: Fictive net yearly cooling demand [MJ] as a function of presence of active cooling (AC) for Be and Nl

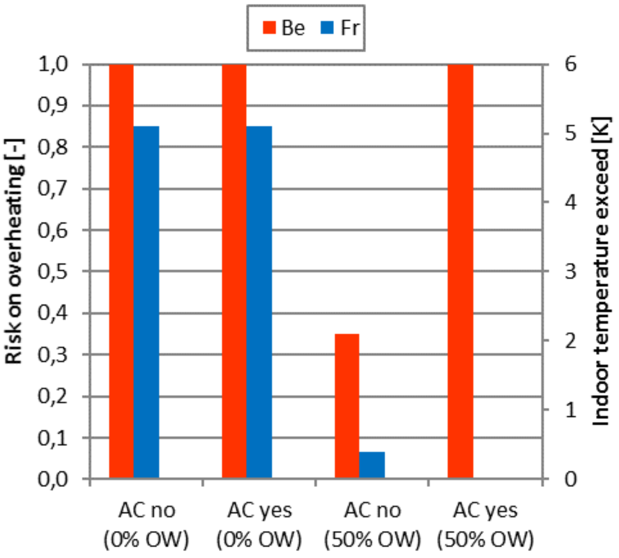

Figure 8: Risk on overheating (Be, left axis) and indoor temperature exceed (Fr, right axis) as a function of presence of active cooling (AC)

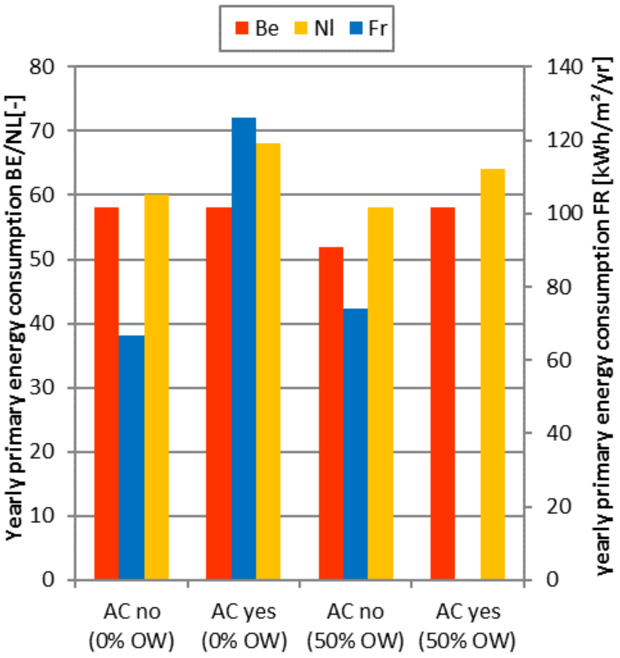

Figure 9: Yearly primary energy consumption [-] or [kWh/m²/yr] as a function of presence of active cooling (AC)

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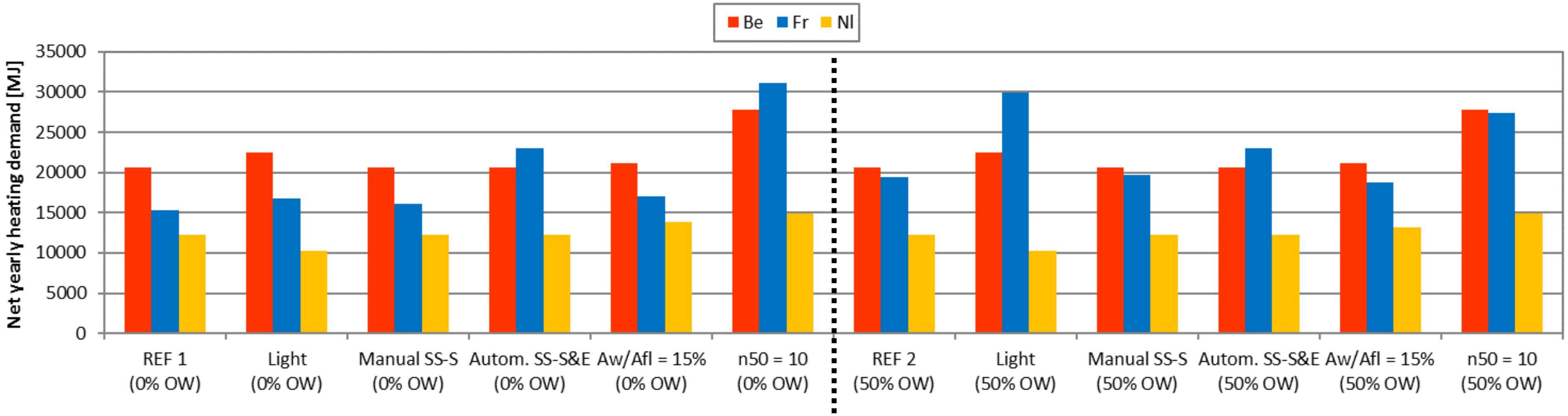

Figure 10: Net yearly heating demand [MJ] for Be, Fr and Nl. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

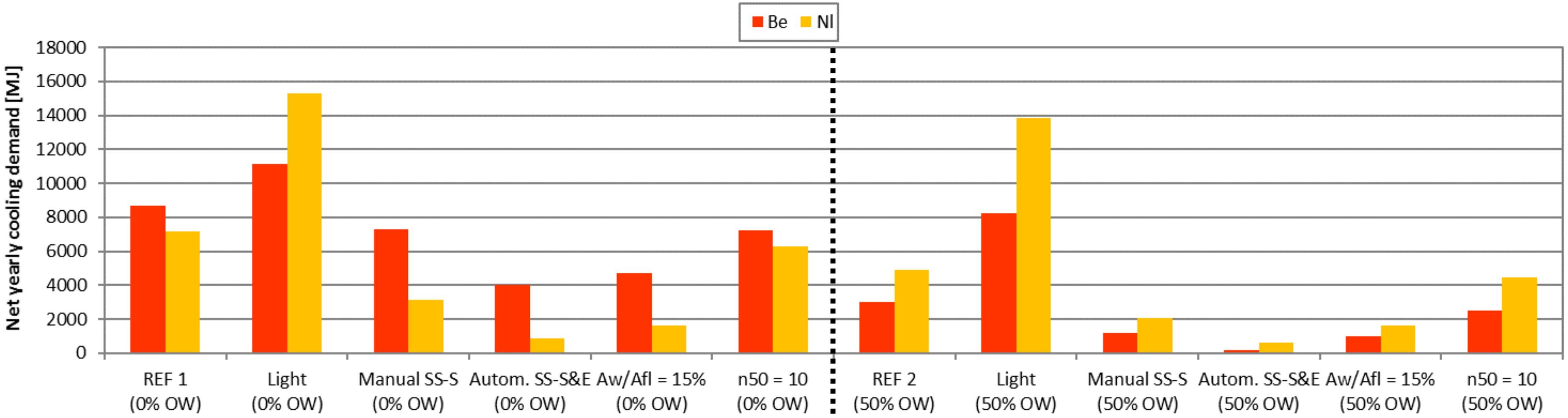

Figure 11: Fictive net yearly cooling demand [MJ] for Be and Nl. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

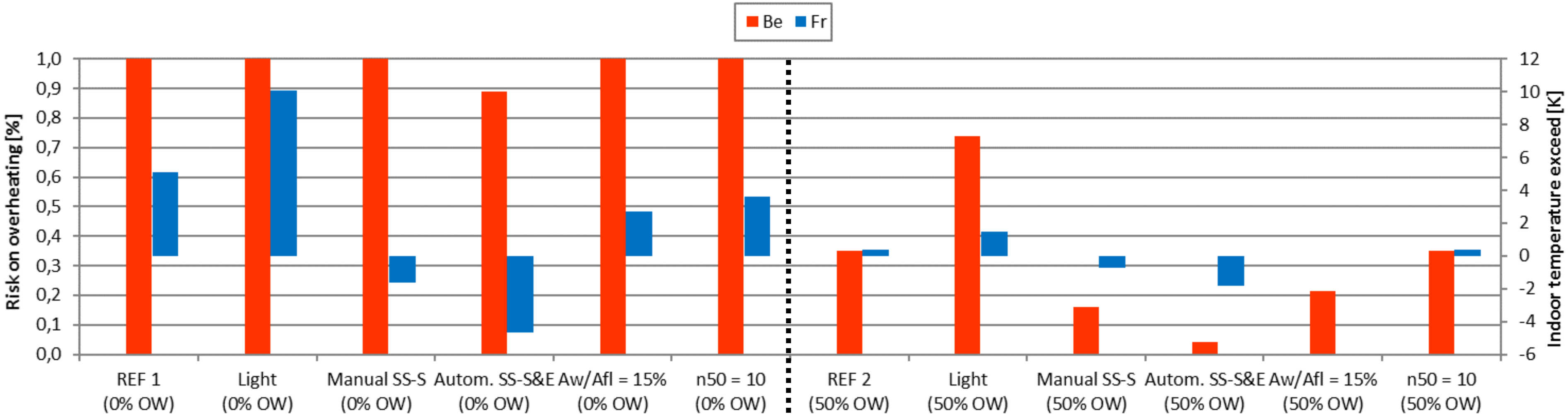

Figure 12: Risk on overheating (Be, left axis) and indoor temperature exceed (Fr, right axis). At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

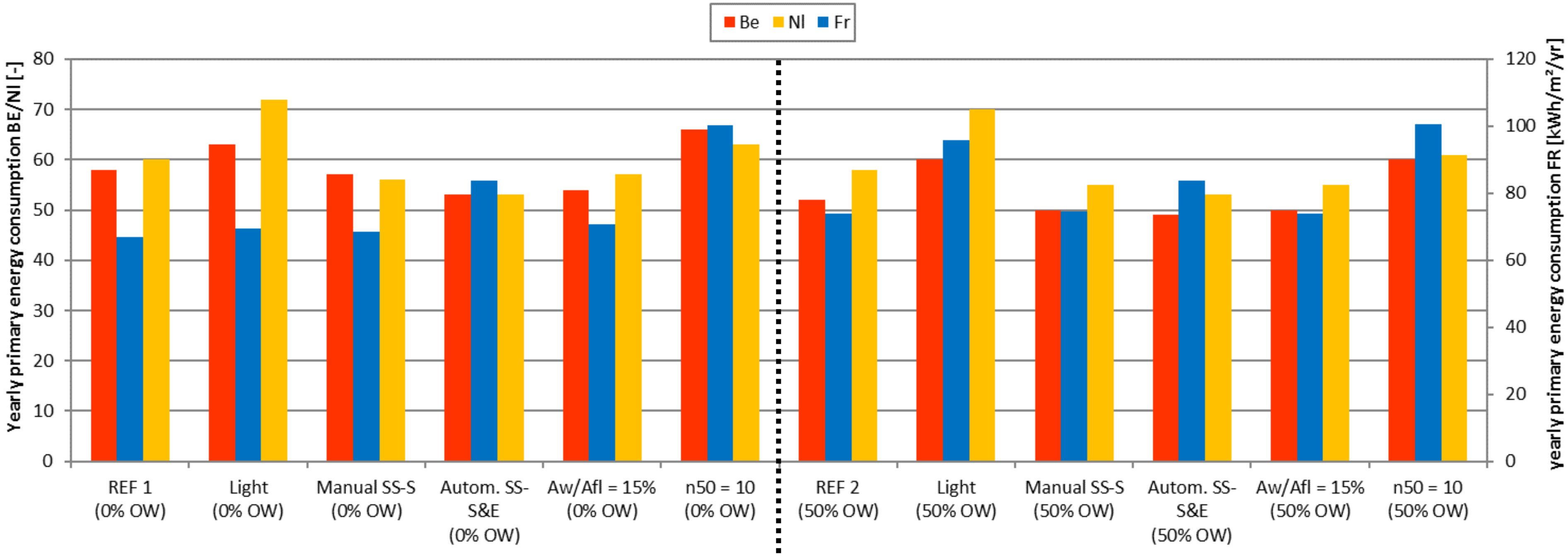

Figure 13: Yearly primary energy consumption [-] or [kWh/m²/yr] for Be, Fr and Nl. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

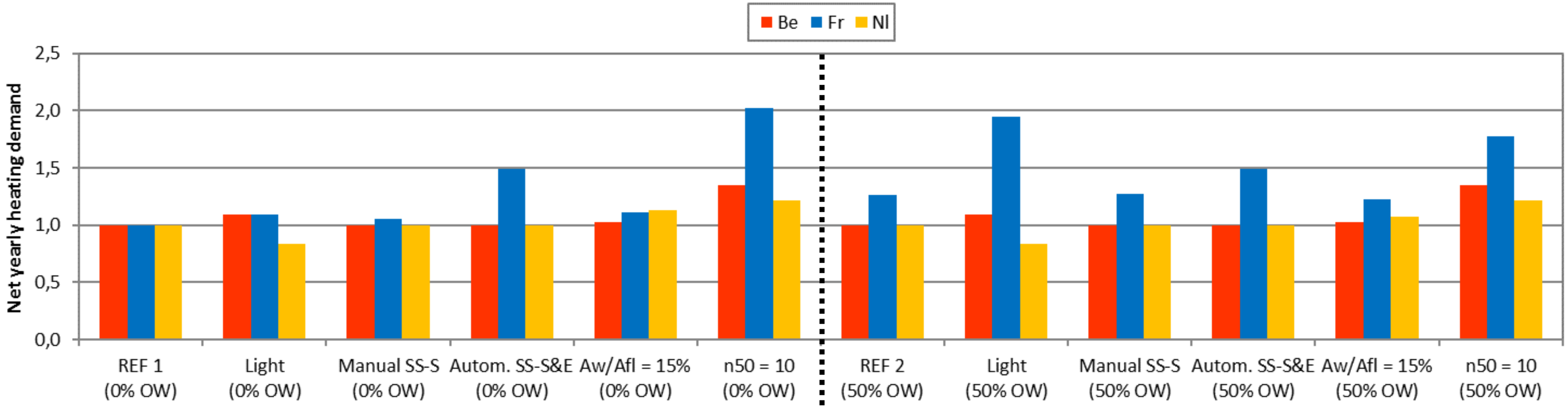

Figure 14: Relative net yearly heating demand with respect to REF 1 for Be, Fr and Nl. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

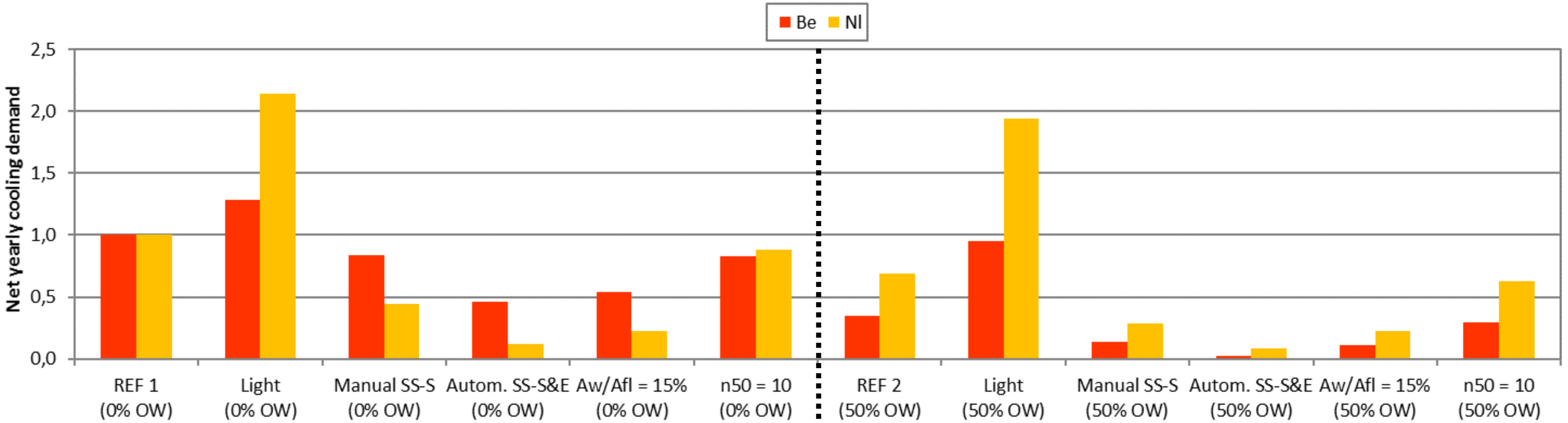

Figure 15: Relative fictive net yearly cooling demand with respect to REF 1 for Be and Nl. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

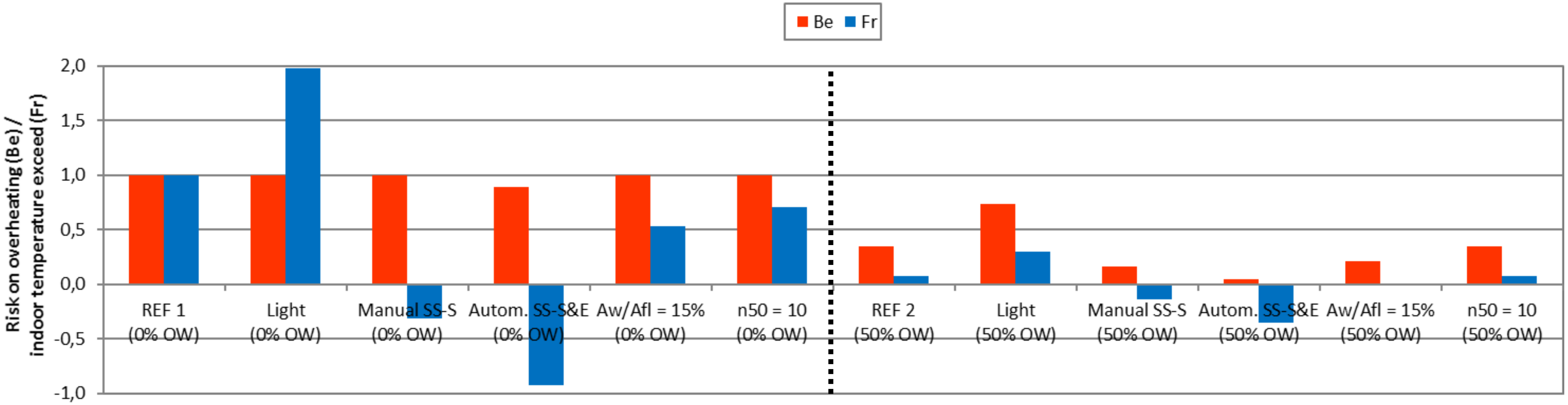

Figure 16: Relative risk on overheating (Be) and relative indoor temperature exceed (Fr) with respect to REF 1. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.

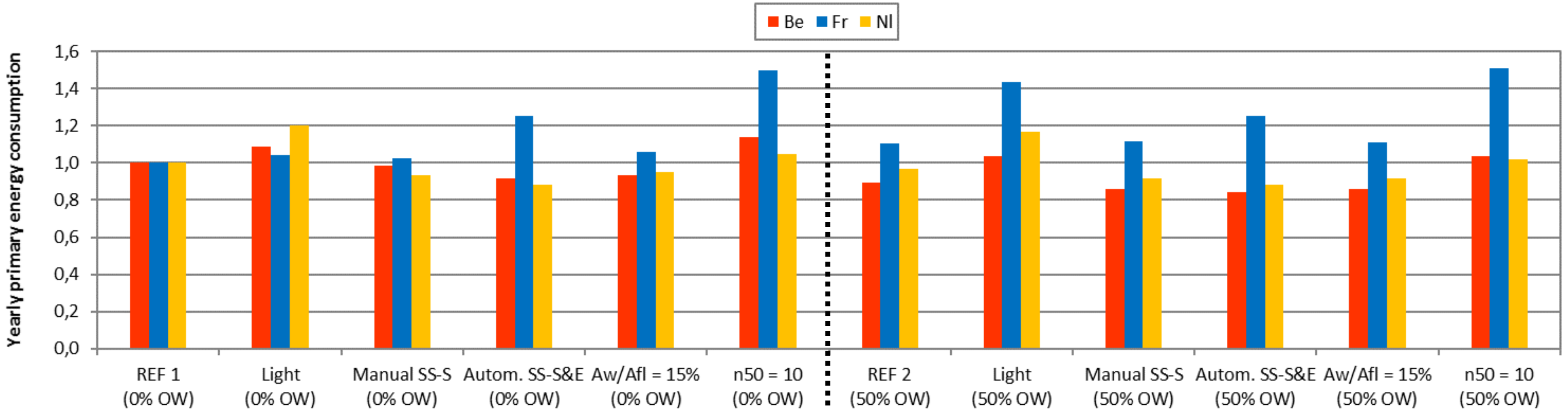

Figure 17: Relative yearly primary energy consumption with respect to REF 1 for Be, Fr and Nl. At the left side of the dotted line the reference dwelling without ventilative cooling (0% OW) and its variations, at the right side of the dotted line the reference dwelling with ventilative cooling (50% OW) and its variations.