The impact of climate updates on the energy performance assessment in a legislative framework

Kjartan Van den Brande[a], Geoffrey Van Moeseke[b], Nicolas Heijmans[c], Wolf Bracke[a], Marc Delghust[a], Arnold Janssens[a]

[a]*Research Group of Building Physics, Construction and Services, Department of Architecture and Urban Planning, Ghent University (UGent), Jozef Plateaustraat 22 EA1, B-9000 Gent, Belgium*
[b]*Louvain research institute for Landscape, Architecture, Built environment, Place du Levant 1/L5.05.04, 1348 Louvain-la-Neuve*
[c]*BBRI, Energy Aspects of Buildings Laboratory, 1342 Limelette, Belgium*

Abstract

In North-West Europe the legislative focus to reduce ta building's energy consumption has historically grown to mainly concentrate on limiting the heat losses. However, due to global warming, this strategy has caused buildings to increasingly endure overheating problems. In Flanders, Belgium, the energy performance framework uses climate data from 1958 until 1975. This outdated assumption could result in wrong incentives towards building owners regarding heating and cooling strategies. In this research, five alternative climate scenarios were constructed accounting for global warming and micro-climates. These scenarios were simulated on a sample of the Flemish building stock, taking into account different typologies and building performance levels. We discuss the impact of the alternative scenarios on the energy performance, the shift from heating loads towards cooling loads and on overheating. The analysis shows that warmer climate scenarios are most problematic for compact buildings and buildings which are thoroughly insulated. Also, it becomes difficult to tackle overheating with passive measures and thus the need for active cooling will become more difficult to avoid. There is a need for policy makers to re-evaluate their legislative framework to account for the changing climate. Future research could aid in assessing different adaptation

strategies for the framework.

Keywords: buildings, energy performance calculation, global warming, micro-climate

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Contents

1. Introduction

In order to lower building energy use in Europe the European Union has established a legislative framework including the Energy Performance of Buildings Directive (EPBD) (European Union, 2002). Through this legislative framework the EU member states are obliged to set up a national or regional framework.

This framework includes a comparative methodology for the calculation and the evaluation of the energy performance of buildings. Through this methodology the legislative framework defines which aspects should be taken into account to achieve an energy performant building and the weight of each aspect in the evaluation process. These aspects include **boundary conditions** (e.g. weather patterns, topography, build environment, ...), **building measures** (insulation level, air tightness, solar shading, ...), **systems** (heating, cooling, ventilation, ...), **internal conditions** (e.g. user behaviour, interior temperatures, air quality, ...) and **cost efficiency**.

In order to transition the European building stock towards (nearly) zero energy buildings by 2030 (European Commision, 2020), the frameworks applied by the EU member states, have been adjusted over the years. Firstly to follow a tightening path (Concerted Action, 2008, 2012, 2016, 2018), making sure that the building market has the time to adapt to the more stringent requirements. Secondly to ameliorate the functionality of the framework in terms of accuracy and usability, for instance by incorporating new research and technologies into the framework. In recent years there has been a growing awareness that the changing climate itself, in comparison to the fixed climate assumed in the calculation method, impact the accuracy. (S. Bakaloglou, D. Charlier, 2021, T. Frank, 2005, 2020, A. Fonseca, Jimeno et al., 2020, A. Moazami, 2019, I. Alhindawi,C. Jimenez-Bescos, 2020). Due to global warming, the climate data used in the energy performance calculations becomes increasingly outdated. This discrepancy will only further increase as the future climate models (see section 2) predict a further increase of the global warming.

In Belgium the energy performance of buildings (EPB) framework has been part of the legislation since 2006. Each of the three regions (Brussels, Flanders, Wallonia) has its own tailored framework, eventhough the calculation process is mostly the same. For these three frameworks, a monthly quasi-steady-state calculation method is used to perform the energy performance calculations. The climate, used in the calculations, is represented by three monthly parameters: the average exterior temperature, the total global solar irradiation and the total diffuse solar irradiation. These values are based on the Belgian climate between 1958 and 1975 (R. Dogniaux, M. Lemoine, 1980, W. Palz, 1984) and can be found in table 1 and in table 2 under the EPBcl tag. Since the establishment of the Belgian EPB frameworks these values have not been changed.

Recent climate data for Belgium (1980 - 2020) shows that climate has gradually become warmer in Belgium as a result of climate change, and that the number of heat waves per year has increased (Royal Meteorological Institute, klimaat.be). The impact of this discrepancy on the calculated energy performance is unclear as climate influences both the energy needs for heating and for cooling, and the first and latter have an opposite influence on the overall energy consumption. Consequently the wrong incentives could be given to the Belgian building stock, leading to suboptimal and non-robust design decisions.

Furthermore, the use of a single reference climate (EPBcl) neglects the local variations due to micro-climates in Belgium. These local variations are caused by different effects. In the south-eastern part of Belgium the topography is defined by a western extension of the Eifel, a low mountain range, part of the Rhenish Massif. The higher elevation results in lower average exterior temperatures. In the largest cities, the heat island effect causes the temperatures to be higher on average.

To update the current building energy regulations, a study looking into the influence of alternative climate scenarios was commissioned by the three Belgian Regions (N. Heymans et al., 2021, G. Van Moeseke et al., 2021, K. Van den Brande et al., 2021). The development of the calculation method is executed by the EPB-consortium, a collaboration between policy makers, researchers from academia, private consulting companies and stake holders in the building industry. This paper reports the results of that study extended with additional analyses. Three aspects are analysed. First the building's overall energy performance under alternative climate scenarios. Secondly, a deeper focus on the shift of the heating and cooling loads seperately. And thirdly an analysis of the overheating problem which will become increasingly important in a global warming context.

For this study five alternative climate scenarios were defined. One is based on climate data from recent years (2009-2019), which provides insight on the effect of applying the currently used but outdated climate scenario. Two climate scenarios are based on local climate data, which shows the differentiation between climate in central Belgium opposed to the climate at higher altitude (eastern Belgium) and the heat island effect (Brussels) (see section 3). The last two climate scenarios are based on future predictions taking global warming into account (see section 2). Subsequently, the climate scenario currently embedded in the official calculation method is replaced by one of the five alternative scenarios. Next, the calculations are performed on a sample of the Flemish building stock (see section 4.1). This ensures that the spectrum of different building geometries from the Flemish building stock are taken into account. Furthermore the influence of the energy performance level of the buildings is taken into account by applying different series of energy saving measures to the building sample (see section 4.3). In this study the building measures comprise the characteristics of the envelope (insulation level and infiltration through air leakage and open windows) and the properties of the systems (heating, cooling and ventilation). The chosen climate scenarios, the building sample and the building measures series are further explained in the following chapters.

2. Establishing alternative climate scenarios: global warming

2.1. Exterior temperatures

2.1.1. Future climate projections

At the time the study was performed, the most recent IPCC assessment report (IPCC, 2013) contains future scenarios defined by the anthropogenic radiative forcing. The prescribed radiative forcing is then used to calculate corresponding CO2 concentrations. These future scenarios are called Representative Concentration Pathways (RCPs) and are followed by a number that indicates the radiative forcing around the year 2100. Scenario RCP2.6 implies strong reductions in carbon emissions after about the year 2020, whereas the business-as-usual scenario RCP8.5 assumes continued increases in emissions until the year 2100. These CO2 concentration pathways are used as input to comprehensive climate models, which project a range of global temperature responses (see Figure 1). For scenario RCP2.6 the models project further warming of less than 1°C above current levels by year 2050 and subsequent slow cooling. Scenarios RCP4.5 and RCP6.0 result in additional warming of about 1.5 to 2°C until the year 2100, whereas for the business-as-usual scenario RCP8.5 temperatures increase by 4°C by the year 2100 and by 8°C by the year 2300.

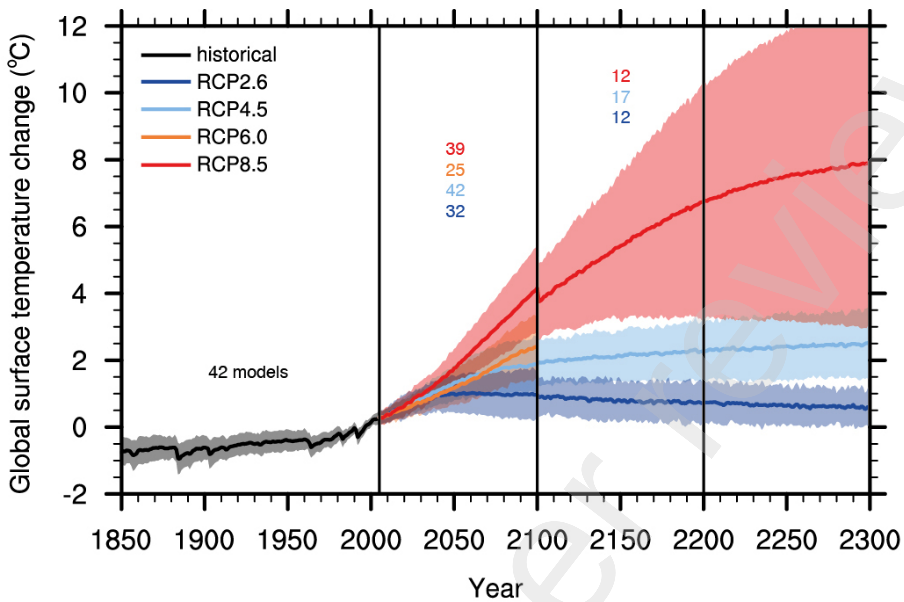


Figure 1: Global average surface temperature projections relative to 1986-2005. Shading indicates the 5 and 95% range and the line is the multi model mean. The number of climate models used is indicated. Not all models have simulated the full period until year 2300, which leads to a jump in the red line at year 2100 (IPCC, 2013)

As Figure 1 shows, forecasts vary depending on the global emission scenarios and climate models used.

2.1.2. Climate change predictions for Belgium

The Royal Meteorologic Institute (RMI) of Belgium summarizes future climate change in Belgium as follows (KMI, 2020):

- A warmer climate: In 2100, the average warming would be between +0.7°C and +5°C (according to RCP 2.6 and RCP 8.5 scenarios respectively).
- The number of heat waves would also increase: from the second half of the 21st century, at least one heat wave is expected per summer, regardless of the environment (rural and urban). In Brussels in particular, as a result of urbanization, heat waves would triple in amount by 2100, their intensity would double and their duration would increase by half.

- The number of droughts would also be higher throughout the country according to the RCP 8.5 scenario.

- Increased precipitation: In 2100, winters would become much wetter (according to the RCP 8.5 scenario) and summers would experience only a slight or no decrease in precipitation. The number of days of heavy rainfall (more than 10 mm of precipitation) would also increase.

The National Adaptation Plan for Belgium 2017-2020 (Federal Public Service Healt, Food Chain Safety and Environment, 2016) is more detailed in the description of the expected impacts. However, the references they use are relatively old (2009), which may explain discrepancies with the above summary:

- A warmer climate: all forecasts indicate an increase in temperatures in all seasons (from 1.5°C to 4.4°C in the winter and from 2.4°C to 7.2°C in the summer by 2100).

- A more pronounced seasonality of precipitation: precipitation is expected to decrease in summer (to -25% by 2100) and increase in winter (to +22% by 2100). The results are mixed for annual precipitation, which increases or decreases depending on the model used.

- More extreme events: heavy rains in winter and heavy thunderstorms in summer are expected to become more frequent and/or more intense, as well as more frequent heat waves are expected in summer.

- The decrease in average precipitation in summer, combined with greater evaporation, is expected to lead to a decrease of more than 50% in the minimum flow of rivers by the end of the 21st century. This results in an increased risk of water shortages.

- The sea level on the Belgian coast could rise by 60 to 90 cm by 2100, or even by 200 cm depending on the most pessimistic scenario.

- Expected increase in the phenomenon of heat islands in urban areas

The integration of climate change into the current Flemish calculation method requires consideration of both the impact on average temperatures and on the frequency and magnitude of external events.

2.1.3. Time Horizon

If future climate change would be integrated, it is important to first establish the reference period that is taken into account. In this paper two logics are combined:

- the period is linked to an estimate of the average life of buildings. Deadlines of 30 to 60 years are often encountered for life-cycle cost studies, for elements related to energy performance.
- the period is linked to political objectives. Both the Paris Agreement and the regional renovation strategies aim for 2050 as a deadline.

At the time of writing this study, both logics correspond to a horizon at 2050.

The Flemish calculation method is a monthly quasi-steady-state method where the climate scenario is defined by one characteristic value per month for the outside temperature and the global and diffuse solar irradiation. Consequently it is necessary to construct characteristic values representing the future reference period. This can be done by taking the climate data at the deadline or by taking an average over the reference period. Climate models make it possible to generate continuous climate profiles between today and a future deadline. It is therefore technically possible, with access to these profiles, to construct typical years for the future, as is done in the past. In this paper, the choice was made to simplify the actual profiles to a linear interpolation between the current data and the 2050 deadline and consequently the average between these two extremes was taken.

2.1.4. Monthly average values for future predictions

Table 1 provides the monthly average exterior temperatures that were assumed for the three future climate scenarios (in yellow), used in this paper. The values for the period 2000-2019 are based on data from RMI (G. Van Moeseke et al., 2021). For climate scenario RCP2.6 the average deviation considered is 1.5°C in the winter months and 4°C in the summer months by 2100 compared to the current average RMI data. For climate scenario RCP8.5 the average deviation considered is 4.4°C in the winter months and 7.2°C in the summer months by 2100 compared to the current average RMI data. The deviations for summer are applied to the months April to September. The deviations for the winter are applied to the months October to March.

Table 1: Monthly average temperatures for Belgium for different climate scenarios

	EPBcl	RMI	RCP2.6			RCP8.5		
T_{ext} [°C]	1958 - 1975	2000 - 2019	2019 - 2050	2050	2100	2019 - 2050	2050	2100
Jan	3.2	3.6	3.8	4.1	5.1	4.7	5.5	8.0
Feb	3.9	4.3	4.5	4.8	5.8	5.4	6.2	8.7
Mar	5.9	7.0	7.3	7.6	8.5	8.1	8.9	11.4
Apr	9.2	10.6	11.1	11.5	13.0	12.4	13.7	17.8
May	13.3	14.0	14.4	14.9	16.4	15.8	17.1	21.2
Jun	16.2	17.1	17.5	18.0	19.5	18.9	20.2	24.3
Jul	17.6	18.7	19.2	19.6	21.1	20.5	21.8	25.9
Aug	17.6	18.3	18.7	19.2	20.7	20.1	21.4	25.5
Sep	15.2	15.3	15.7	16.2	17.7	17.1	18.4	22.5
Oct	11.	11.7	12.0	12.3	13.2	12.8	13.6	16.1
Nov	6.3	7.5	7.8	8.1	9.0	8.6	9.4	11.9
Dec	3.5	4.5	4.8	5.0	6.0	5.6	6.4	8.9

2.2. Global and diffuse irradiation

The values for global and diffuse irradiation were gathered from RMI climate data for the period 2000-2019 and are shown in Table 2.

Table 2: Monthly average global and diffuse irradiation for Belgium for different climate scenarios

(MJ/m²)	I_{global}		$I_{diffuse}$	
	EPBcl	RMI	PEB	RMI
	1958 - 1975	2000 - 2019	1958 - 1975	2000 - 2019
Jan	71.4	79.1	51.3	52.9
Feb	127.0	137.7	82.7	82.9
Mar	245.5	281.4	155.1	160.9
Apr	371.5	435.4	219.2	230.1
May	510.0	542.2	293.5	282.2
Jun	532.4	543.4	298.1	294.7
Jul	517.8	559.8	305.8	288.3
Aug	456.4	478.3	266.7	247.8
Sep	326.2	343.3	183.6	177.7
Oct	194.2	207.5	118.3	117.2
Nov	89.6	97.4	60.5	63.6
Dec	547.7	63.6	40.2	42.5

Because solar irradiation values are hard to predict for the future. The same values for the period 2000-2019 were assumed for the future scenarios (RCP2.6 & RCP8.5).

3. Establishing alternative climate scenarios: local climates

3.1. Exterior temperatures

3.1.1. South-Eastern Belgium

Data from the Belgium Royal Meteorological Institute (RMI) is used to identify geographical gradients for temperatures and solar irradiation for particular periods (G. Van Moeseke et al., 2021). Based on climate maps, comparisons were established between sub-regions on a monthly basis, for the normalized values over the period 1981-2010. As mentioned before the sout-eastern part of Belgium, located in the region of Wallonia, has the highest elevation and consequently the lowest average exterior temperatures. This is visible in Table 3, which shows the temperature ranges for Flanders and Wallonia and the values used to represent a colder climate are highlighted in yellow. Note that the climate scenario adapted in the current calculation method is based on climate data from Uccle, which has temperatures closer to the ones in Flanders.

Table 3: Range monthly average temperatures for Flanders and Wallonia

	EPBcl	Flanders		Wallonia	
T_{ext}		min.	max.	min.	max.
Jan	3.2	2.5	4.0	-0.5	3.5
Feb	3.9	3.0	4.0	0.0	4.0
Mar	5.9	6.0	7.0	3.0	7.0
Apr	9.2	9.0	10.0	6.0	9.0
May	13.3	12.5	14.0	10.5	13.0
Jun	16.2	15.0	16.5	13.0	16.5
Jul	17.6	17.5	19.0	15.5	18.0
Aug	17.6	17.5	18.5	15.0	18.0
Sep	15.2	14.5	15.5	11.5	15.0
Oct	11.	10.5	11.5	8.0	11.5
Nov	6.3	6.5	7.5	3.5	6.5
Dec	3.5	3.5	4.5	0.5	3.5

3.1.2. Urban heat island effect

A study by R. Hamdi et al. on the Belgian region of Brussels using data from 1961 till 1990 (R. Hamdi et al., 2009) shows that the urban heat island (UHI) effect in the center of Brussels can raise temperatures between 2.2°C and 2.9°C (see Figure 2). This study also shows that the UHI also affects Uccle, which is located within and close to the border of the Brussels-Capital Region. This indicates that the climate data used in the official calculation method (which is based on climate data from Uccle) also takes into account the UHI. However, the effect is smaller in comparison to the capital's center. Figure 2 shows that the UHI effect can raise temperatures in Uccle to 1.6°C above the rural mean.

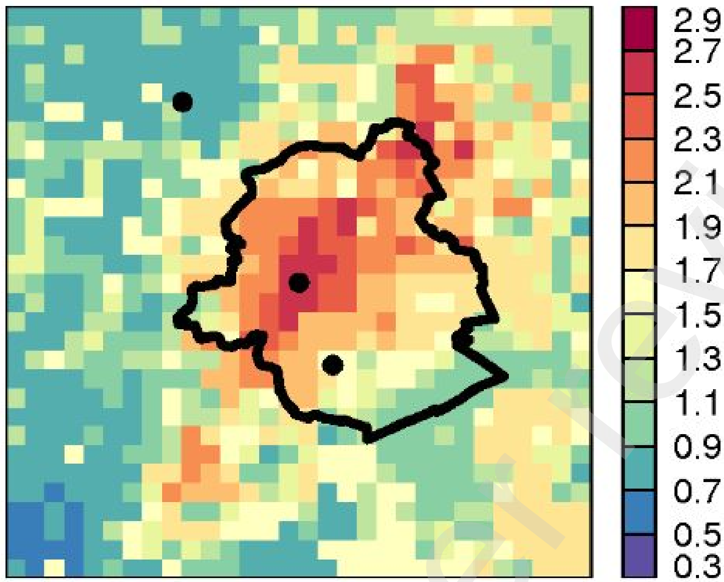


Figure 2: Heat map of the region of Brussels. The scale of the value is in °C difference with resprect to the minimum temperature simulated on the rural values (outside the city). The black dots represent the center of the capital, the Uccle weather station (bottom) and the Brussegem weather station (top) (R. Hamdi et al., 2009)

For this study, a conservative UHI effect of 2.2°C is taken into account resulting in a temperature addition of 0.6°C (2.2°C-1.6°C). This addition is applied to the future climate scenario RCP2.6, which results in the monthly temperature values for the local climate scenario in the center of Brussels. The values are shown in Table 4.

3.2. Global and diffuse irradiation

The values for global and diffuse irradiation for the two local climate scenarios were also gathered from RMI climate data for the period 2000-2019 and are shown in Table 2.

Table 4: Correction of reference climate data and addition of UHI of 2.2°C

T_{ext} [°C]	EPBcl UHI_{Uccle}	RCP2.6 UHI_{Uccle}	$RCP2.6_{UHI}$ $UHI_{Br.center}$
Jan	3.2	3.8	4.4
Feb	3.9	4.5	5.1
Mar	5.9	7.3	7.9
Apr	9.2	11.1	11.7
May	13.3	14.4	15.0
Jun	16.2	17.5	18.1
Jul	17.6	19.2	19.8
Aug	17.6	18.7	19.2
Sep	15.2	15.7	16.3
Oct	11.2	12.0	12.6
Nov	6.3	7.8	8.4
Dec	3.5	4.8	5.4

4. Method

4.1. building geometry data

The aim in this study is to evaluate the impact of different climate scenarios on the building stock of Flanders. Since the establishment of the legal framework in 2006, the Flemish Energy and Climate Agency (VEKA) has gathered data from each submitted energy performance certificate. This open-source database (Vlaams Open Data Portaal) contains building stock data for more than 400 000 building units. The cases include both residential and non-residential buildings and both new constructions and renovations.

For this research a sample has been drawn from the new residential buildings, based on the four common typologies:

- apartments 2 bedrooms 32%
- terraced houses 3 bedrooms 5%
- semi-detached houses 3 bedrooms 14%
- detached houses 3 bedrooms 12%

These four typologies represent ± 63% of the new residential buildings in Flanders and, more importantly, make sure that a broad spread of the building typologies is assured in order to get a good image of the impact of alternative climate scenarios. Since some detailed data, mostly on orientation and shading, was missing, an in-house simulation tool, built by Delghust and Strobbe (M. Delghust, T. Strobbe, 2015) was used to generate the corresponding detailed geometry (area of different faces and orientations) necessary for the energy calculations. For every cluster, a detailed parametric building information model was built in Revit. This base model is then adjusted to correspond to the overall geometry of each house.

The results generated in this study show a clear difference between the impact of alternative climate scenarios on the apartments and on the other three typologies. For the last three typologies,the impact is similar. For this reason this paper will focus on the results for the apartments and the detached houses, two extremes in terms of compactness. The results for all typologies will be provided in the appendix.

4.2. energy simulation tool

Based on the detailed geometry and the defined set of measures, the simulation tool calculates the primary energy use according to Flemish building regulations, which are based on the monthly quasi-steady state method as described in ISO 13790 (ISO/TC 163/SC 2, 2008). The Flemish building energy calculation methodology takes into account the energy use for space heating, space cooling and domestic hot water as well as the auxiliary energy use and renewable energy generation(Flemisch Energy and Climate Agency, 2015). The energy use for space heating and space cooling is calculated on a monthly basis. For space heating, by subtracting the useful heat gains (solar gains and internal heat gains) from the heat losses (transmission, infiltration and ventilation) and vice versa for space cooling. For the calculation of the overheating indicator an extra heat loss is taken into account: ventilation through window opening behaviour during hot periods.

4.3. building measures packages

To evaluate the influence of climate change on the whole spectrum of building geometries and building properties, three building measures packages (MP) were defined. MP1 was chosen to represent the older part of the building stock in Flanders. This will provide insight on the impact of climate change on the residential buildings which are not yet renovated and thus have a low energy performance level. MP2 is based on the current building practice. The building characteristics of MP2 meet the current legislative requirements. However, the strictness of the current requirement for the overall energy performance of the building makes sure that a more exhaustive effort is required for individual measures (e.g. insulation thickness, photovoltaic panels, ventilation system, ...). This provides a certain freedom of choice for the building owner to choose specific focus points. MP3 is based on the current guidelines for passive houses.

Table 5: building measures packages

MP1	based on 70's practice
MP2	based on current EPB requirements and criteria
MP3	based on passive house guidelines

The following tables show the insulation level and system properties values used for the 3 MPs. More information on the specific parameters can be found in annex V of the Energy Decree (Flemisch Energy and Climate Agency, 2015);

4.3.1. Building envelope properties

Table 6: building envelope properties

	U_{roof} (W/m².K)	U_{wall} (W/m².K)	U_{floor} (W/m².K)	U_{window} (W/m².K)	$U_{partyw.}$ (W/m².K)	$U_{partyfl.}$ (W/m².K)	air-permeability @50Pa (m³/h.m²)	g value windows (-)	exterior solar shading
MP1	0.97	0.76	2.88	4.8	1.88	2.88	12	0.875	manual
MP2	0.24	0.24	0.24	1.4	0.6	0.8	3	0.5	manual
MP3	0.15	0.15	0.15	0.8	0.6	0.6	1	0.5	manual

4.3.2. Ventilation system properties

Table 7: Ventilation system properties

	Ventilation	demand control	f_{reduc} (-)	heat recovery	$r_{preh,heat}$ (-)
MP1	none	no	1	no	1
MP2	mechanical exhaust	yes	0.75	no	1
MP3	balanced	yes	0.75	yes	0.28

with:

f_{reduc} = correction factor taking demand control into account

r_{preh} = correction factor for preheating of the air flow

4.3.3. Heating & cooling system properties

Table 8: Heating & cooling system properties

	generation system (-)	emission system (-)	η_{gen} COP (-)	η_{distr} (-)	η_{emm} (-)	f_p (-)	η_{total} (-)
MP1	gas boiler	radiators	0.75	0.8	0.83	1	0.498
MP2	gas condensation boiler	radiators	0.92	0.8	0.83	1	0.61
MP3	heat pump (ground-water)	floor heating	4.58	1	0.87	2.5	1.33

4.3.4. window opening behaviour

As previously mentioned, the overheating indicator calculation takes an extra heat loss into account: ventilation through window opening behaviour (which assumes the occupant to open the windows at night on hot summer days). The heat transfer coefficient of this heat loss is calculated in a simplified manner by multiplying the volume of the building unit by a term for the heat capacity of air (=0.34) and a factor ($V_{free,nat,overh,seci}$) based on a fictive potential for intensive ventilation. This factor takes into account the following effects:

- sufficient openings for intensive ventilation → the openings have to account for more than 6.4% of the floor area of the living room and bedrooms.
- protection against burglary: openings accessible from the exterior have to be secured against burglary.
- adjustment possibilities of the openings: a positioning between fully opened and fully closed is possible.
- possibility of cross ventilation through the building or stack effect.
- manual or automatic control

The potential for intensive ventilation is determined by going through a decision tree, taking afore mentioned effects into account (Flemisch Energy and Climate Agency, 2015). Going through the decision tree, the value for this factor is obtained between 0 (no heat losses via window opening behaviour) and 1.1 (maximum potential). Three assumptions were made, based on common practice:

- All open windows, accessible from the outdoor environment, are secured against burglary and adjustment of the window positioning is possible.
- Exterior doors are considered unprotected and thus cannot be left partly opened without the risk of burglary.
- No automatic control has been applied.

Due to these assumptions, only five values for the potential of intensive ventilation parameter are possible:

• none	$\dot{V}_{free,nat,overh,seci}$	=	0	the 6.4% rule does not apply
• very weak	$\dot{V}_{free,nat,overh,seci}$	=	0.15	non secured exterior doors are necessary to achieve the 6.4% rule there is no cross ventilation or stack effect possible
• weak	$\dot{V}_{free,nat,overh,seci}$	=	0.20	all openings are secured there is no cross ventilation or stack effect possible
• high	$\dot{V}_{free,nat,overh,seci}$	=	0.55	non secured exterior doors are necessary to achieve the 6.4% rule cross ventilation or stack effect is possible
• very high	$\dot{V}_{free,nat,overh,seci}$	=	0.70	all openings are secured cross ventilation or stack effect is possible

4.3.5. Photovoltaic panels

The applied area of the photovoltaic panels are based on the gross floor area of the case buildings. In the Flemish legislation, a minimum share of renewable energy is required per m^2 of gross floor area (currently (in 2022) at 15 kWh/m^2).

Table 9: photovoltaic panels

	generated energy per m^2 of gross floor area (kWh)
MP1	0
MP2	10
MP3	15

5. Analysis

The analysis of the alternative climate scenarios will be done in three steps. First the overall energy performance of the building sample under different climate scenarios is analysed. In the second step the shift of the heating and cooling loads is looked at in more depth. And in the third step the influence of a warmer climate scenario on the overheating problem is investigated.

5.1. overall energy performance

In this study there will only be focused on the Flemish energy performance calculation method. In the official calculation method used in the region of Flanders, the overall energy performance is denoted by the indicator named E-level. The E-level denotes the ratio between the calculated energy performance of the building and a variable reference value, which is calculated as a function of the volume and the heat loss area of the building. The formula to calculate the reference value was defined at the start of the legislative EPB framework (2006) and is based on a statistical regression analysis. The analysis was preformed on a building sample of 200 buildings with a fixed building measures package, representative for that period. To obtain the E-level, the ratio is multiplied by 100. This makes it possible to compare the overall energy performance of a specific building to a building with the same volume and heat loss surface area and the building requirements of 2006. For example, the E-level requirement in 2016 was E50, denoting a building with an energy performance twice as good as opposed to the same building in 2006. The current requirement in 2021 is E30, denoting a nearly zero energy building.

5.1.1. shift E-level distribution

In this section the shift of the E-level distribution is compared for the different climate scenarios. Figure 3 and 4 provide the E-levels for building measures package 1 (unrenovated buildings). For climate scenarios with a warmer climate (global warming or heat island effect) the results show a decline of the E-levels for all typologies. For the most severe climate scenario

(RCP8.5), the calculated energy performance improves up to 25%. Thus, a warmer climate scenario has a positive influence on the calculated energy performance (E-level) of unrenovated houses. For the colder climate scenario (Wall: Wallonia), the effect is reversed and the E-level of unrenovated houses is reduced up to 40%. When comparing apartments to detached houses, it seems that the maximum effect an alternative climate scenario can have does not differ that much between the two typologies.

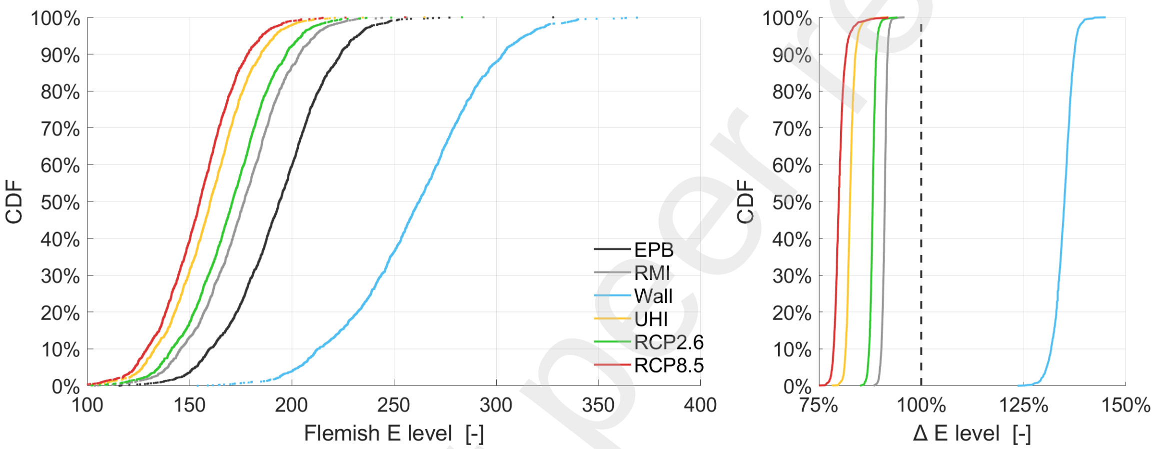


Figure 3: E-levels for apartments: comparison of different climate scenarios for MP1

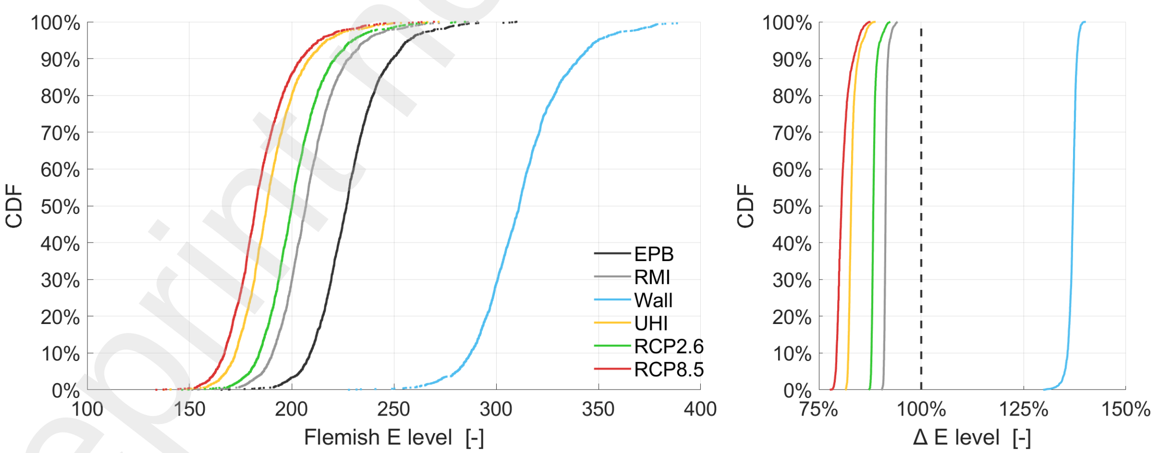


Figure 4: E-levels for detached houses: comparison of different climate scenarios for MP1

When the same comparison is made while applying the highest performing building measures package (MP3: passive house), an opposite shift of the E-level distributions is observed (see Figures 5 and 6). The warmer climate scenarios result in a higher E-level and thus the calculated energy performance of the buildings goes down. For this building measures package (MP3) a difference is observed between typologies: the E-level worsens for all apartments, while a small share of the detached houses maintains the same E-level.

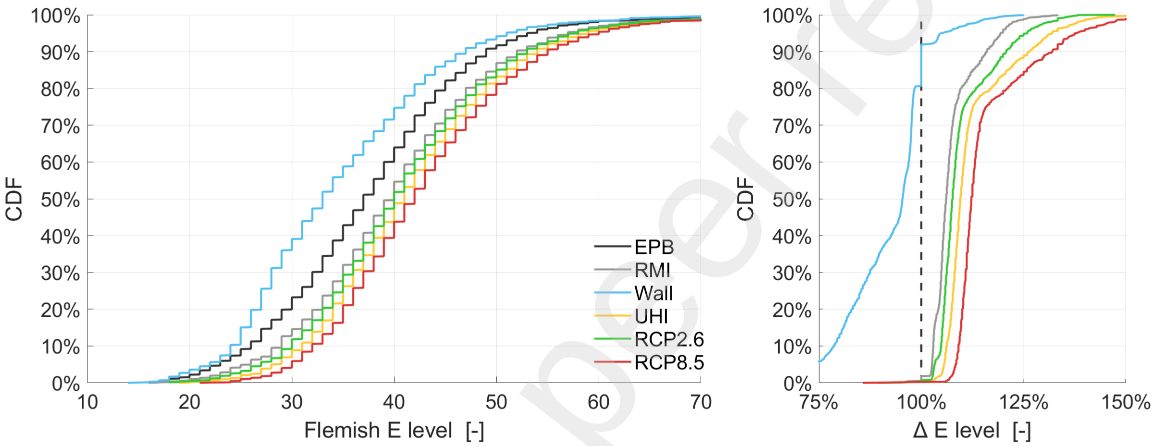


Figure 5: E-levels for apartments: comparison of different climate scenarios for MP3

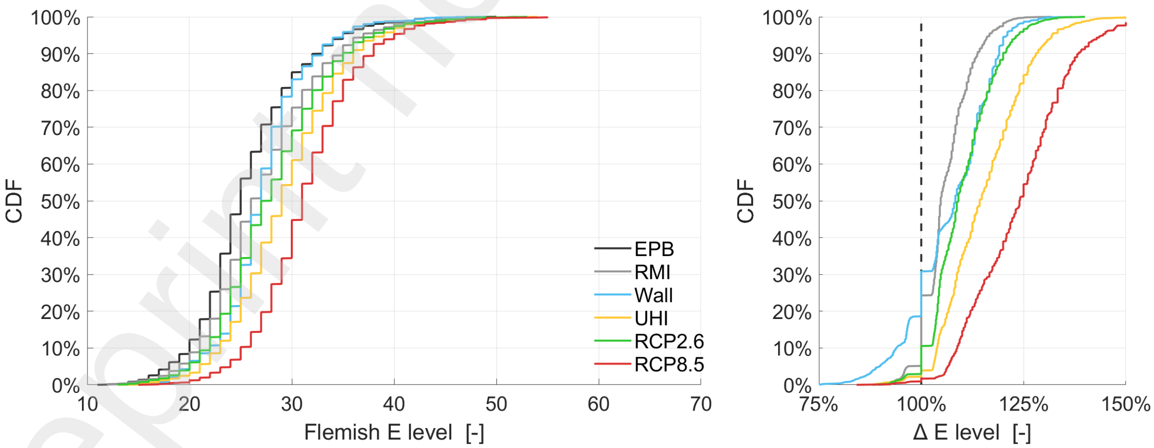


Figure 6: E-levels for detached houses: comparison of different climate scenarios for MP3

Figure 6 shows that 55% of the detached houses under the historic climate and 25% of the detached houses under the global warming RCP2.6 scenario maintain the same or a lower E-level. For the warmer climate scenarios (UHI and RCP8.5) most of the houses receive a higher E-level with an average increase of 20% and up to 50%. For the colder climate scenario (Wall) there is a clear difference between apartments and detached houses. While for detached houses 18% will result in a better calculated energy performance and 70% in a worse calculated energy performance, for the apartments this is reversed with 80% of the apartments resulting in a beter calculated energy performance and 9% resulting in a worse calculated energy performance.

The impact of alternative climate scenarios under building measures package 2 (MP2: current requirements) will be situated between the results for MP1 and MP3. For MP2 the same conclusions can be drawn as for MP1, however, the shift is smaller with an improvement of the calculated energy performance (E-level) of up to 10% for the warmest climate scenario (RCP8.5).

5.1.2. Shift heating and cooling needs

In this section the reason for improvement or decline of the energy performance under alternative climate scenarios is further investigated. This is done by comparing the shift of the primary energy consumption for heating (ΔEp,heat) against the shift of the primary energy consumption for cooling (ΔEp,cool). The shifts under the colder climate scenario (Wall) are distinct from the shifts under the other warmer climate scenarios:

- warmer scenarios: heating loads decrease and cooling loads increase.
- colder scenarios: heating loads increase and cooling loads decrease.

First the results for the apartments are shown. For warmer climate scenarios in combination with building measures package 1 (MP1: unrenovated houses), the decrease of the heating loads is substantially larger than the increase of the cooling loads. For this reason, all cases will obtain a higher calculated energy performance (lower E-level).

Under building measures package 2 (MP2: current requirements) most apartments will also have a larger decrease of the heating loads opposed to an increase of the cooling loads (see Figure 7). However, the average ratio between the shifts is closer to one. Under the historic scenario, the decrease of the heating loads is almost twice as large as the increase in cooling loads (ratio = 0.47). Under the global warming scenario RCP8.5, the ratio is close to 1 (ratio =0.74). For this reason some of the apartment cases under MP2 have a decrease of energy performance (higher E-level). This occurs for the apartments with the lowest compactness and occurs more when the climate scenario gets warmer. Share of apartments with a higher E-level:

- historic scenario: 5%
- heat island effect: 8%
- global warming RCP2.6: 8%
- global warming RCP8.5: 15%

For the colder climate scenario (Wall), all apartments under MP1 and MP2 have a larger increase in heating loads opposed to a lower decrease in cooling loads and thus the calculated energy performance will be lower for all cases.

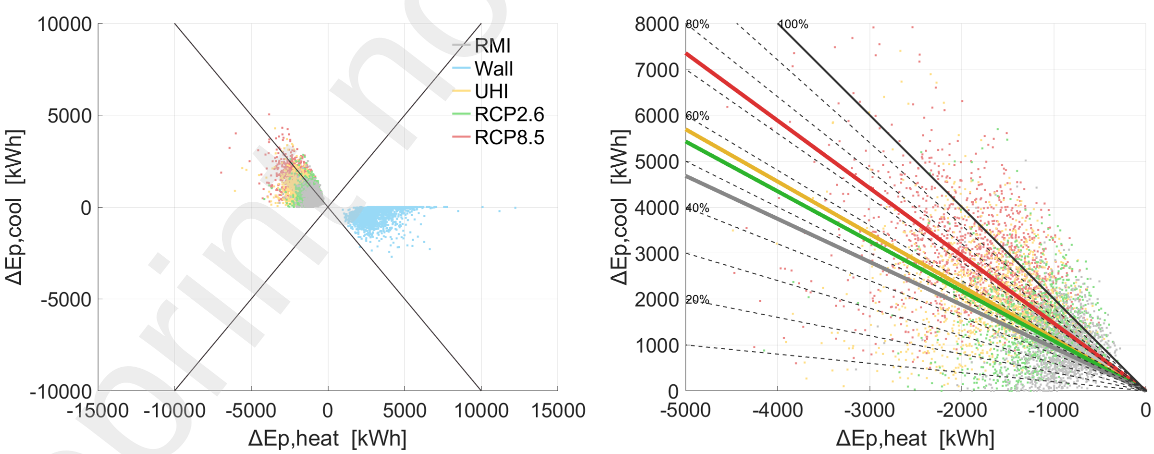


Figure 7: Comparison of shift in heating loads against shift in cooling loads for MP2, apartments

When building measures package 3 (MP3: passive house) is applied to the apartments, the balance tips over and the shifts reverse. For the warmer climate scenarios, the increase of the cooling loads will be much larger than the decrease in heating loads (see Figure 8). For all warmer scenarios the ratio will be around 4. As a consequence, the E-level will rise and the calculated energy performance will worsen.

For the colder climate scenario (Wall), on average the decrease of the cooling loads is larger than the increase of the heating loads and thus the E-level will decline (see Figure 8). However, for a fifth of the apartments the E-level will rise slightly (8%) or stay equal (12%).

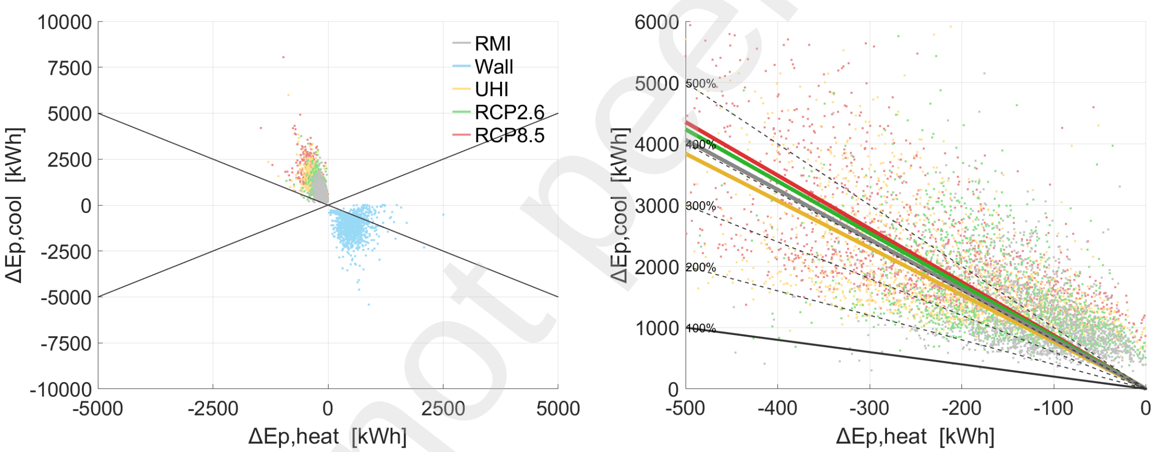


Figure 8: Comparison of shift in heating loads against shift in cooling loads for MP3, apartments

For the detached, semi-detached and terraced houses the heating and cooling loads are larger compared to those for the apartments and thus the shift under alternative climate scenarios will be twice as large.

For the warmer climate scenarios under building measures packages 1 and 2 (MP1: unrenovated houses, MP2: current requirements), the decrease of the heating loads are again the prevailing factors with a higher energy performance as a consequence. Due to their larger heat loss surface area, the effect is larger for detached houses opposed to the apartments, with average ratios from 0.25 for the historic scenario to 0.4 for the global warming RCP8.5 scenario (see Figure 9). Again, under MP2, some detached houses still obtain a larger E-level, although only for the global warming scenarios and the shares are a lot smaller in comparison to the apartments (3% under scenario RCP2.6 and 8% under scenario RCP8.5).

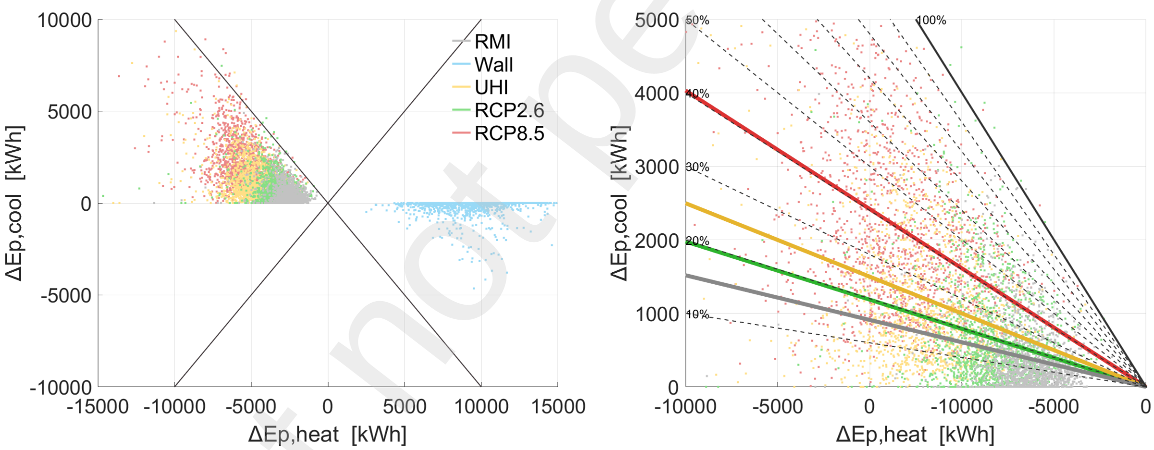


Figure 9: Comparison of shift in heating loads against shift in cooling loads for MP2, detached housess

When MP3 is applied the balance tips over, as was the case for the apartments. For the warmer climate scenarios, the increase of the cooling loads are much larger than the decrease of the heating loads. This will result in a decline of the calculated energy performance (see Figure 10). For the detached buildings there is some difference under different climate scenarios with average ratios from 2.3 for the historic scenario up to 3.5 for the global warming RCP8.5 scenario.

For the colder climate scenario (Wall), on average the increase of the heating loads is larger than the decrease of the cooling loads and thus the E-level will increase. However, for about a third of the detached houses the E-level will decrease slightly (5%) or stay equal (26%).

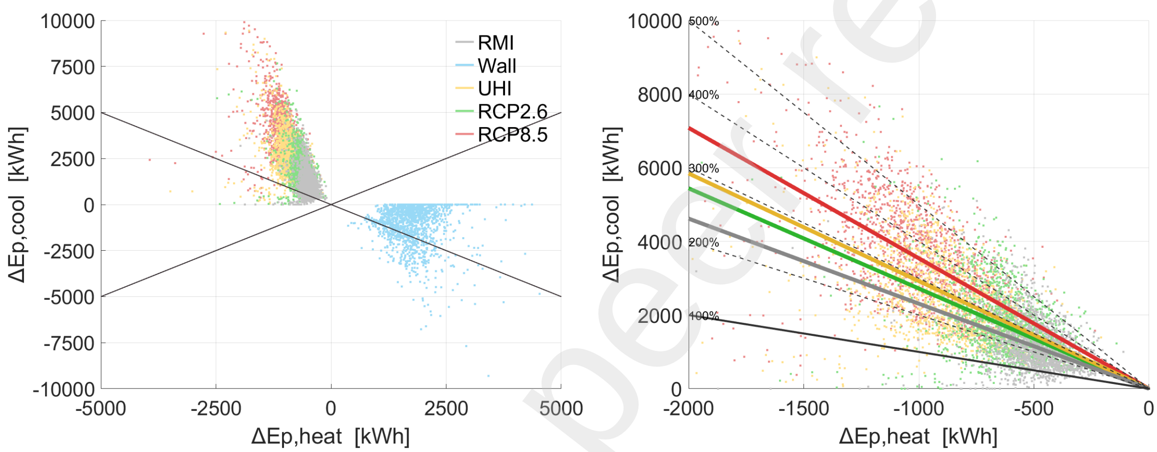
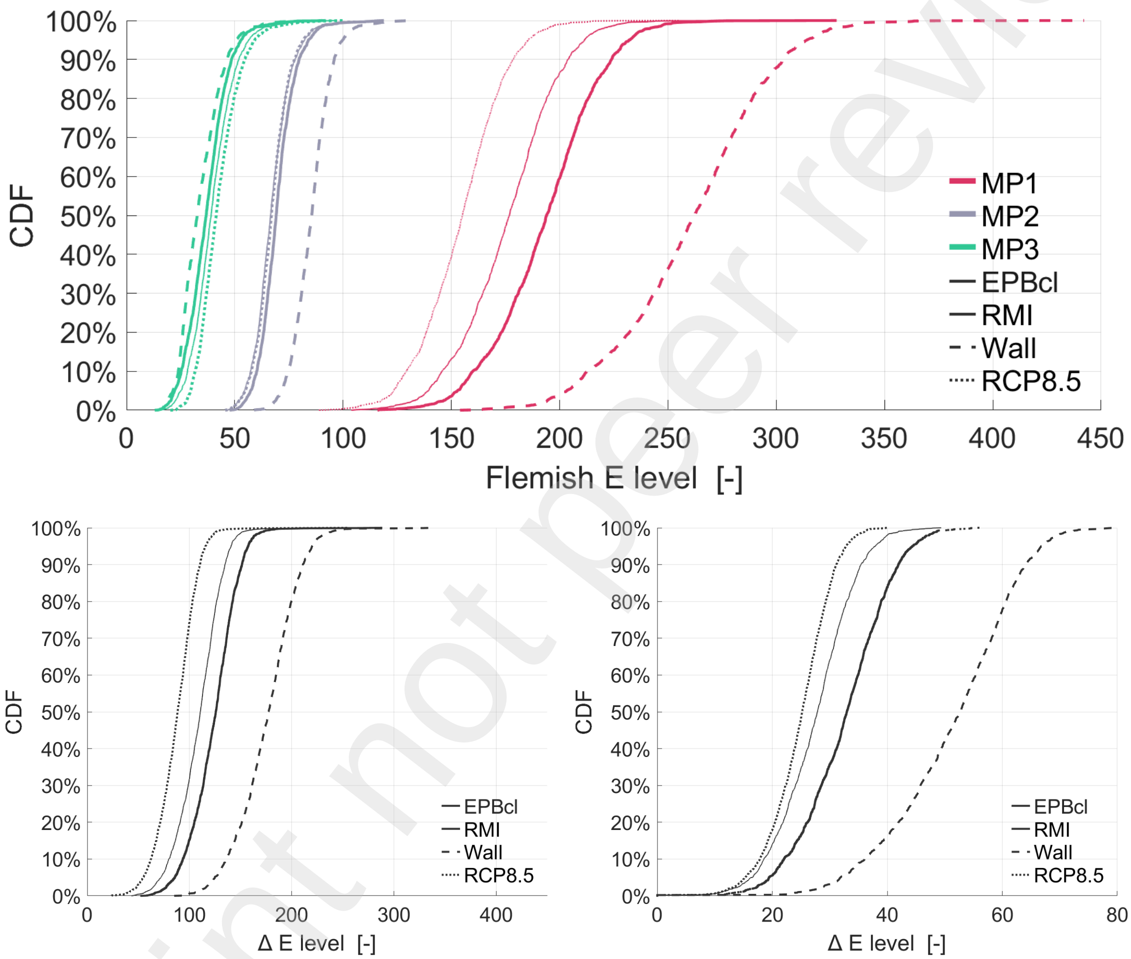


Figure 10: Comparison of shift in heating loads against shift in cooling loads for MP3, detached housess

5.1.3. Energy efficiency gains between building measures packages

In this section the three different building measures packages are shown in relation to each other. Only the current climate scenario (EPBcl), the historic scenario (RMI), the colder climate scenario (Wall) and the most severe warmer climate scenario (RCP8.5) are shown.

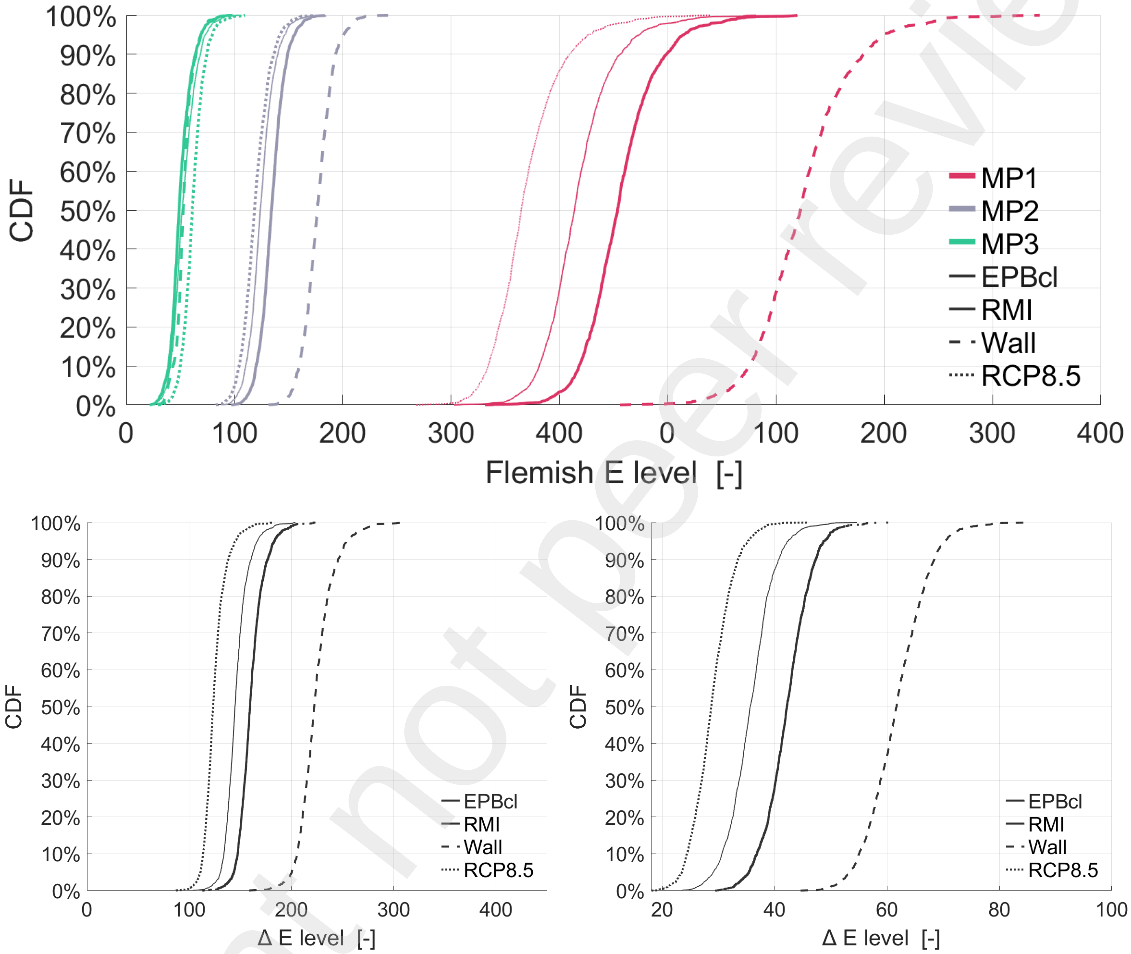
Figure 11 and 12 show that the E-level distributions for the three MP's are closer to one another when a warmer climate scenario is applied. Especially a switch from MP1 to MP2 is far less influential when one of the warmer climate scenarios is considered.Under the current legislative framework, renovating an apartment (from MP1 to MP2) would lead to a reduction of, on average, 125 E-level points. However, when the same renovation effort is applied under the global warming scenario RCP8.5, this average reduction drops to 80. Going for an extensive energy performance (from MP2 to MP3) would yield a reduction of 42 E-level points under the current legislative framework. This average reduction drops to 28 E-level points under scenario RCP8.5.



(a) E-level distribution (upper) and E-level reduction going from MP3 to MP2 (left) and from MP2 to MP1 (right)

Figure 11: Comparison building measures packages for differenct climate scenarios: apartments

For detached houses the average reduction when renovating the building (from MP1 to MP2) drops from 160 under the current scenario to 123 under the global warming scenario RCP8.5. When going for passive house standards (from MP2 to MP3) the average reduction drops from 32 E-level points to 25 E-level points.



(a) E-level distribution (upper) and E-level reduction going from MP3 to MP2 (left) and from MP2 to MP1 (right)

Figure 12: Comparison building measures packages for differenct climate scenarios: detached houses

These results show that the benefits of applying better building measures are overestimated in the current framework if we take global warming into account. This overestimation is larger (in absolute values) when going from MP1 to MP2 in comparison to going from MP2 to MP3. However, the lower the E-level, the harder it is to reduce the value further, which makes the overestimation of de reduction when going to passive house standards more severe.

5.1.4. conclusion regarding aggregated E-level and share of heating and cooling loads

- The energy performance of more compact the housing typology, is less influenced by alternative climate scenarios.

- The energy performance of houses which have a more controled energy balance (e.g. MP3) is less influenced by climate change, although the E-level worsens.

- The less compact the housing typology, the less favourable a warmer climate scenario will be for achieving better energy performance evaluation.

- The lower the compactness of a home, the more favorable a colder climate scenario will be for achieving better energy performance evalution.

- The higher the insulation level of the building, the less favourable a warmer climate scenario will be for achieving better energy prformance evauation.

- For the warmer climate scenarios, the warmest scenario (RCP8.5) will yield the largest increase (or slightest decrease) in E-level values compared to current values.

- When warmer climate scenarios are applied, the gains of switching to a more energy performant building measures package is reduced. Not considering global warming could increase the performance gap, as the savings associated with a more efficient package of measures are overestimated.

5.2. overheating

In this section, the influence of alternative climate scenarios on the overheating of the building is investigated. The analysis is based on the calculation of the overheating indicator (in Kelvin hours) as described in the official energy performance calculation method (Flemisch Energy and Climate Agency, 2015, K. Goethals et al., 2013). As mentioned in section 4 this indicator takes into account the heat losses via transmission, ventilation and window opening (= potential for intensive ventilation) and the internal and solar heat gains. The indicator, in Kelvin hour, represents the excess heat gains which are not used to reduce the heating loads and by consequence heat up the building beyond the comfort temperature. The overheating indicator itself is used as a benchmark to estimate the probability that the building owner will install an active cooling system. Below 1000Kh the probability is presumed to be 0%. Above 6500Kh the probability is presumed to be 100%, with a linear increase of the probability between these two values. 6500Kh is the maximum allowed value for the overheating indicator.

This section will be divided into two phases. In phase 1, manual solar shading is considered and the potential for intensive ventilation is based on data from the EPB-database related to each case. In phase 2, different measures for controlling the overheating are applied to MP3.

The results in this section show that the potential for intensive ventilation has a large influence on the overheating indicator. The following table provides the division of the potential (defined by a factor) for intensive ventilation in the as-built situation. The ventilation flow rates via the opening of windows ($\dot{V}_{free,nat}$) is based on the product of this factor and the volume of the building (V_{bld}).

Table 10: shares of potential for intensive ventilation per typology

	no potential $\dot{V}_{free,nat}$ $= 0 \cdot V_{bld}$	very weak pot. $\dot{V}_{free,nat}$ $= 0.15 \cdot \dot{V}_{bld}$	weak potential $\dot{V}_{free,nati}$ $= 0.20 \cdot \dot{V}_{bld}$	high potential $V_{free,nat}$ $= 0.55 \cdot \dot{V}_{bld}$	very high pot. $\dot{V}_{free,nat}$ $= 0.70 \cdot \dot{V}_{bld}$
App	10%	12%	21%	27%	30%
Terr	5%	6%	15%	32%	40%
sDet	4%	5%	16%	37%	38%
Det	3%	4%	15%	32%	48%

Figure 13 and 14 provide the overheating indicator distributions for MP2. When applying the current climate scenario (EPBcl) 78% of the apartments achieve the overheating requirement of 6500Kh. When applying the historic scenario (RMI) this number decreases to 63% for the apartments. For the warmest climate scenario only 23% of the apartments achieve the requirement.

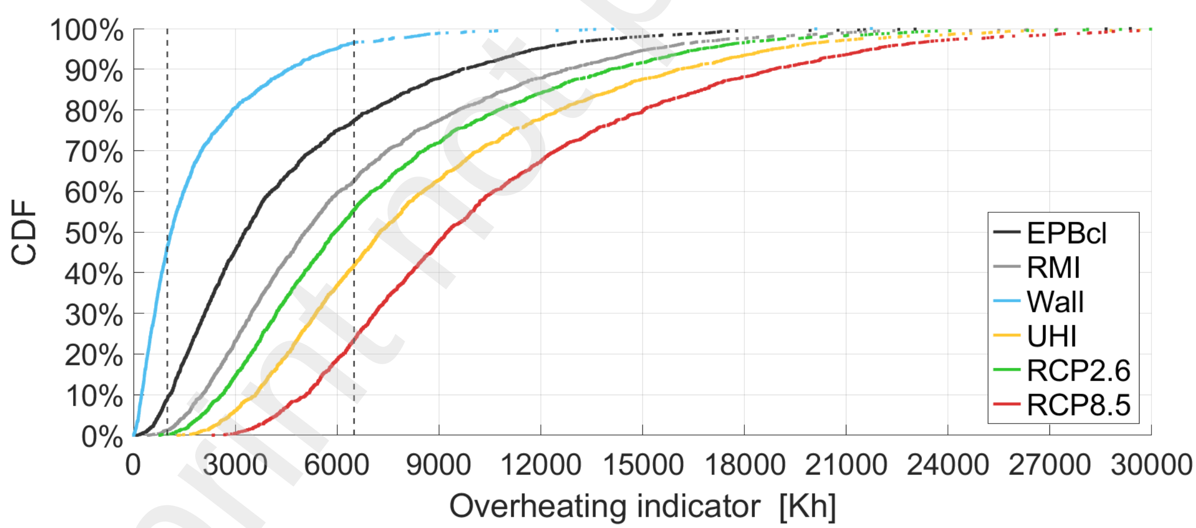


Figure 13: Comparison overheating indicator shift for different climate scenarios under MP2: apartments

For the detached houses the situation is less problematic as this typology is less compact and thus has relatively more heat loss surface area to remove excess heat. For all scenarios, the majority of the cases achieve the overheating requirement. However, when applying the global warming scenarios (RCP2.6 & RCP8.5), 10% and 20% respectively of the detached houses have an overheating indicator value of above 6500Kh.

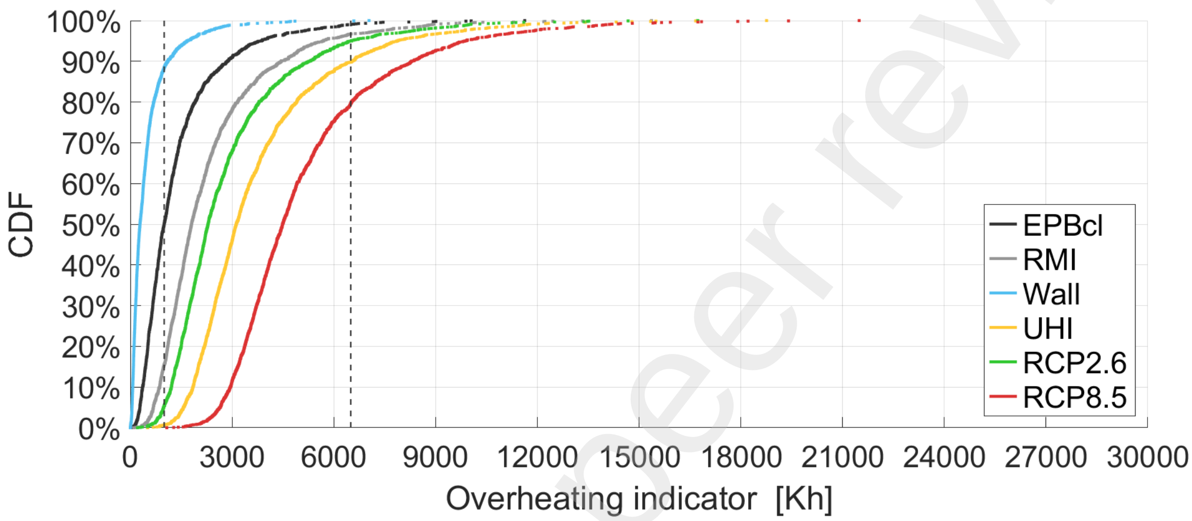


Figure 14: Comparison overheating indicator shift for different climate scenarios under MP2: detached houses

Figure 15 and 16 provide the overheating indicator distributions for MP3. This building measures package is based on passive houses and is adapted to reduce the heat losses as well as possible. Consequently, overheating will be more problematic under this measures package. Under the current climate scenario (EPBcl) 72% of the apartments buildings do not reach the requirement. When applying the historic scenario this share rises to 84%. For the global warming scenario RCP8.5 only 2% of the apartments achieve the requirement.

When applying MP3, the situation is less problematic for the detached houses as opposed to the apartments. 16% of the detached houses under the current climate scenario (EPBcl) do not reach the requirement. For the warmest climate scenario only 26% of the detached houses manage to stay under 6500Kh.

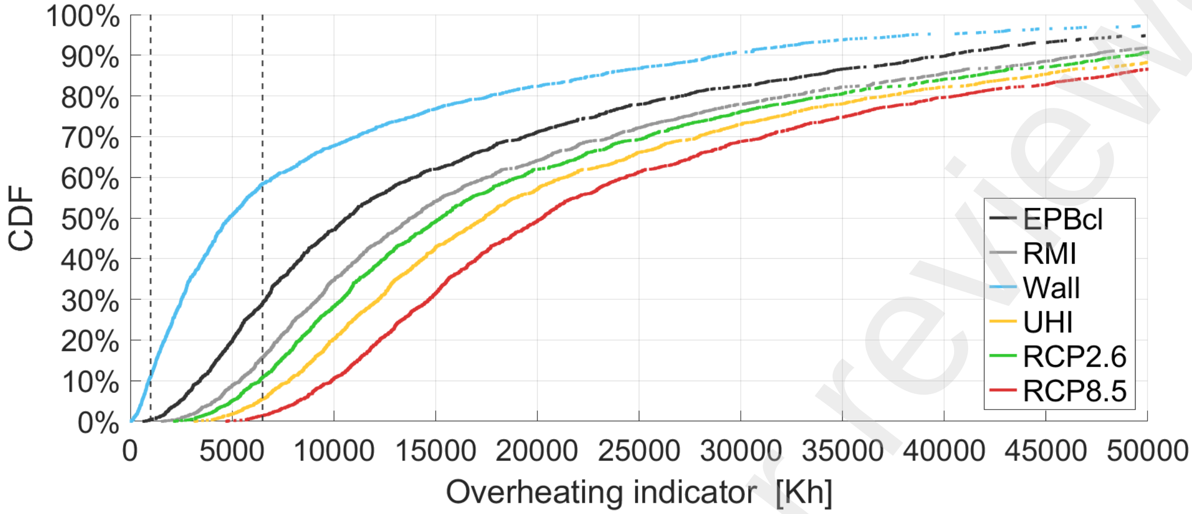


Figure 15: Comparison overheating indicator shift for different climate scenarios under MP3: apartments

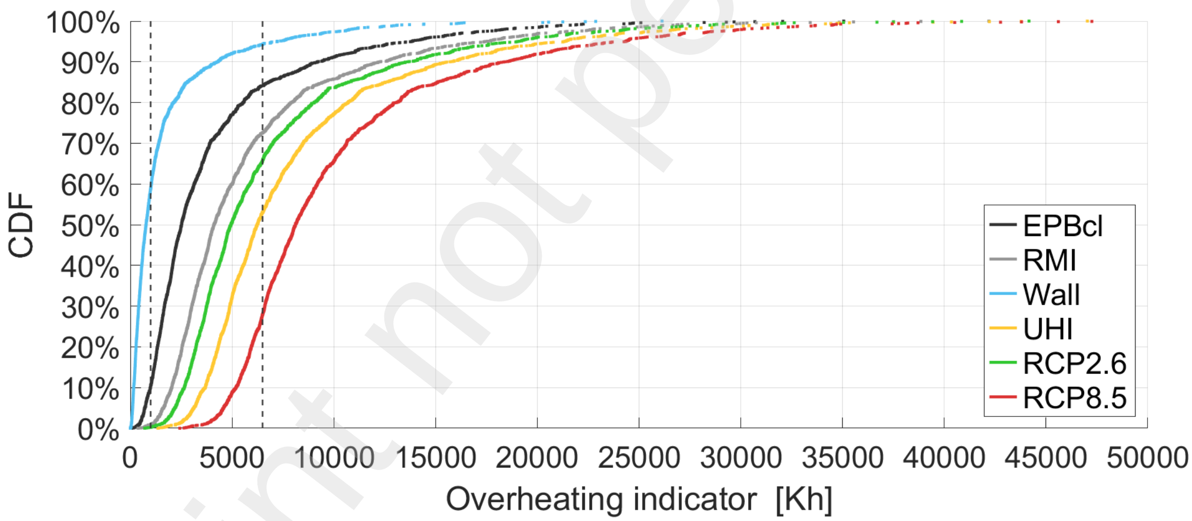


Figure 16: Comparison overheating indicator shift for different climate scenarios under MP3: detached houses

As shown in the previous part, it is very hard to reduce overheating when an increased insulation level and airtightness (equal to MP3) is pursued. The official calculation method allows some strategies to further reduce overheating. In following part, a combination of two of these strategies is applied:

- application of automated solar shading opposed to manual solar shading
- increasing the potential for intensive ventilation:
  - to a very high potential ($V_{free,nat} = 0.7 \cdot V_{bld}$)
    → no automatic control
  - to a maximum potential ($V_{free,nat} = 1.1 \cdot V_{bld}$)
    → automatic control
- a combination of automated solar shading and a very high potential

For apartments, it is very hard to reach the overheating requirement of 6500Kh when MP3 is applied (see Figure 17). Only 29% of the apartments reach this requirement. Only when applying a maximum potential for intensive ventilation this value can be improved to 94%.

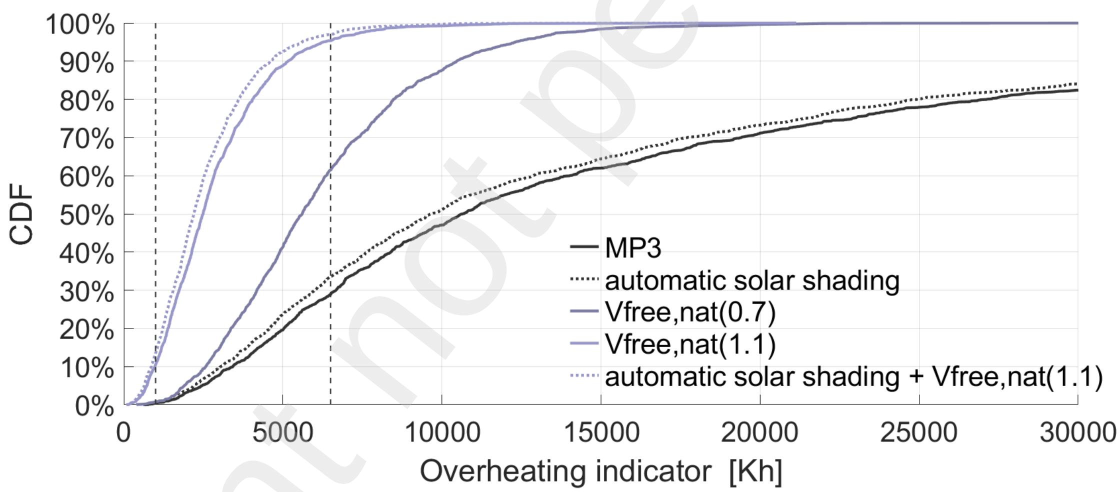


Figure 17: Comparison overheating indicator shift for different overheating protection measures under MP3: apartments, current climate

For detached houses, 85% reach the requirement under MP3 and only a very high potential for intensive ventilation is needed for 97% of the detached houses to reach the requirement (see Figure 18).

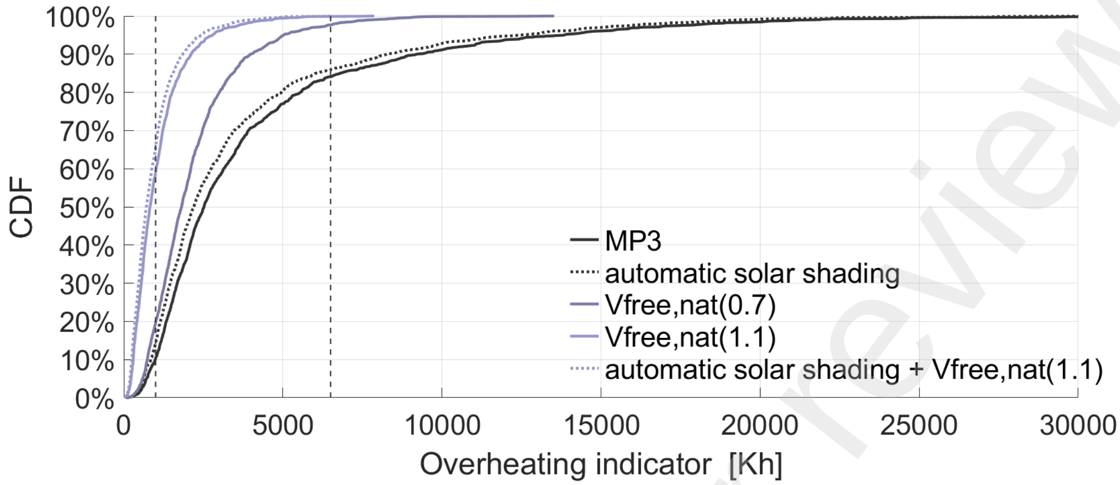


Figure 18: Comparison overheating indicator shift for different overheating protection measures under MP3: detached houses, current climate

When the global warming RCP2.6 climate scenario and MP3 are applied, only 12% of the apartments and 66% of the detached houses reach the overheating requiremen (see Figures 19 and 20). When applying the maximum potential for intensive ventilation these values rise to 82% and 98% respectively.

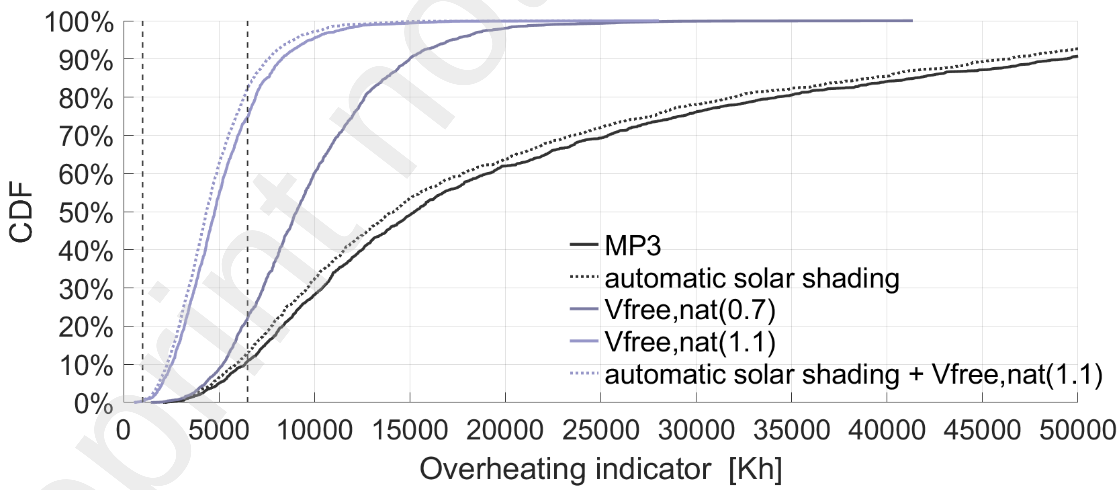


Figure 19: Comparison overheating indicator shift for different overheating protection measures under MP3: detached houses, RCP2.6

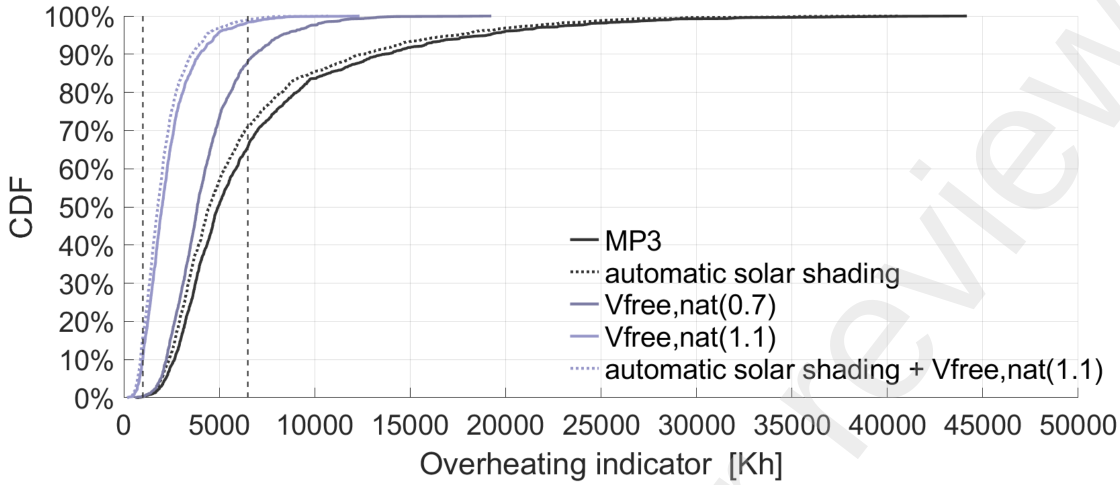


Figure 20: Comparison overheating indicator shift for different overheating protection measures under MP3: detached houses, RCP2.6

When the global warming RCP8.5 climate scenario and MP3 are applied, only 25% of the detached houses reach the requirement (see Figure 22). This share can be improved by applying a maximum potential for intensive ventilation to 92%. However, even with the maximum potential, only 30% of the apartments manage to stay below 6500Kh (see Figure 21).

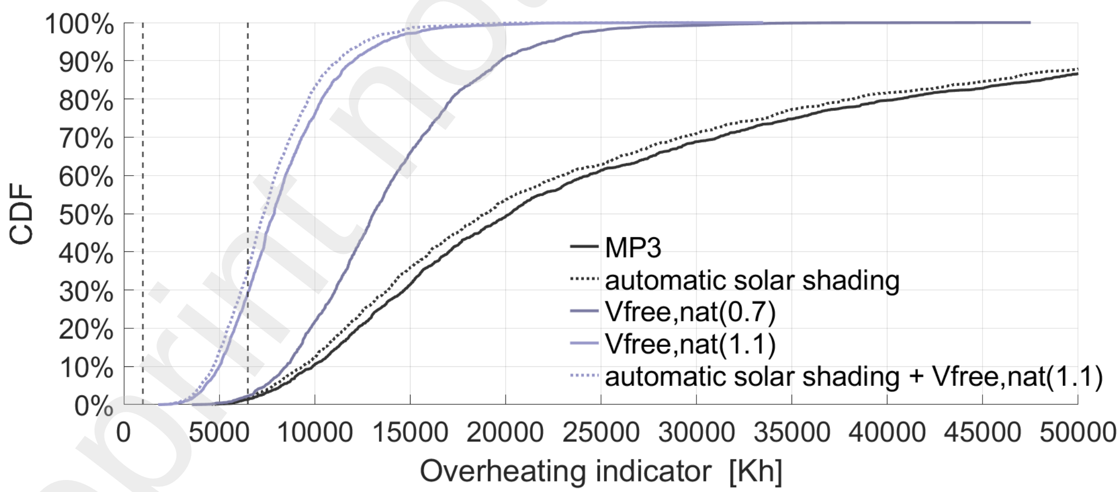


Figure 21: Comparison overheating indicator shift for different overheating protection measures under MP3: detached houses, RCP8.5

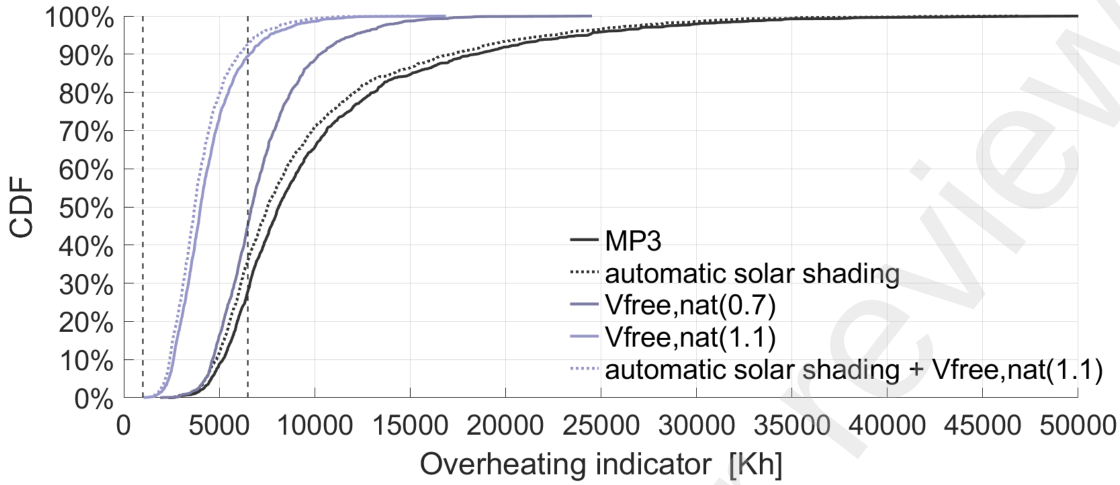


Figure 22: Comparison overheating indicator shift for different overheating protection measures under MP3: detached houses, RCP8.5

5.2.1. conclusion regarding overheating

For apartments, it is very difficult to achieve the current overheating requirement under a warmer climate scenario and with the application of MP3. When the optimistic global warming forecast (RCP2.6) is assumed, 82% of the apartments will meet the requirement if they can have a maximum potential for intensive ventilation. For apartments, this is not an obvious goal as the possibility of cross ventilation or stack effect is less easy to achieve here. When the most pessimistic climate scenario (RCP8.5) is adopted, only 30% of apartments will be able to meet, even when applying a maximum of intensive ventilation. For detached houses, the requirement is easier to meet. It is also easier for this typology to create cross ventilation and a stack effect. However, under the most pessimistic climate scenario (RCP8.5), 8% of detached houses will not meet the requirement, even with a maximum of intensive ventilation. It should be borne in mind that the dataset contains a variety of dwellings and therefore even some dwellings that are prone to overheating (e.g. large glazing surface facing south).

6. Conclusion and Policy Implications

Energy performance calculation methods in a legislative context are country or region-specific because they need to account for their legislative and environmental context. As this context is changing constantly, the legislative framework for building energy performance is growing organically to adapt to new insights and growing awareness. The required developments for these updates (from research to implementation) take time, thus creating a temporal discrepancy between the calculated energy performance and the reality and, consequently, enlarging the performance gap. This is especially so for parameters that are hard or impossible to predict.

In this paper, the focus lies on one of those parameters: the climate scenario. As the main goal of the legislative framework is to guide a building team towards energy efficient decisions, the performance gap, maintained by applying an outdated climate scenario, could bias the decision-making process. The results in this paper indicate that the influence of renovating the building or aiming for passive house/energy neutral standards is overestimated by not considering a climate scenario involving global warming. This is especially so for less compact buildings. Under the assumption of a warmer climate, maintaining the current nearly zero energy building standard will result in less buildings reaching the current requirements. Furthermore, this paper shows that it will become increasingly harder to protect the building against overheating issues. With growing temperatures, the focus shifts from heating needs towards cooling needs, leading to more buildings with an active cooling system.

If the climate scenario would be updated to a global warming scenario, the average E-level of buildings would rise, when current nearly zero energy standards are maintained (MP3). In consequence, more effort is needed to reach the same requirements (max. E30, max. overheating of 6500Kh). This could become problematic as the current requirements are already very strict. With this knowledge, it is up to the policy maker to find a balance between calculation accuracy, setting requirements and safeguarding a cost-optimal solution. If the current legislative framework is no longer viable, there are different strategies or a combination of those strategies to consider.

A first strategy could be loosening the current requirement. The advantage is that the evolution of the overall energy performance of the building stock is still traceable. The disadvantage is that E30 has been defined to represent a nearly zero energy building for a long time and is already well known to the common public.

A second strategy could be by updating the evaluation process, specifically the way the reference energy consumption is calculated. As mentioned in this paper, the E-level is the ratio between the calculated energy consumption and a reference consumption representative for a building measures package from representative for 2006 (with on average E100). In this study, the latter has not been adjusted to the alternative climate scenarios. Subsequently the impact of the alternative climate scenarios is embedded in the generated E-level values. If the alternative climates would also be implemented in the calculated reference consumption, the E value again compares building measures packages, without the influence of the changing climate. Consequently, the E30 requirement is still representative for a nearly zero energy building.

A third strategy is providing more measures to the building team, to reach a better energy efficiency. For instance, currently a standard efficiency for the cooling system is presumed for each building. Allowing for more energy efficient cooling systems to have an influence on the E-level and the overheating indicator could make it more manageable to reach the current requirement.

A last strategy focusses on the overheating indicator as results in this study show that the requirement of 6500Kh is unreachable for most buildings under the global warming scenario RCP8.5. The legislative framework could step away from the current assumption that not all buildings have a cooling system, resulting in the calculation of a fictive cooling load, which is based on the overheating indicator. Instead the energy loads for cooling could be treated in the same way as the energy loads for heating. Namely, defining a fixed comfort temperature and calculating the energy needed to reach this comfort level.

These different strategies provide different solutions with their own advantages and disadvantages which ask for further research with a deeper focus on the whole range of possible applications for different building measures.

Acknowledgements

This research was funded by the three Belgian regional authorities (Flemish, Walloon and Brussels) in the framework of the contract 'Scientific and technical support of the EPB platform for the further development and refinement of the EPB calculation methods, and for their project management.

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