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Potential contribution to BIPV systems to nearly Zero Energy Buildings and methodology for project outputs assessment

BIPV system and energy system requirements for nearly Zero-Energy Buildings and assessment methodology

Version Number: v1.0

BIPVBOOST

"Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation"

Start date: October 2018. Duration: 4 Years

Executive Summary

The Energy Performance of Buildings Directive (EPBD) specifies that all “Member States shall ensure that by 31 December 2020, all new buildings are nearly zero energy buildings”. The objectives of this report are to evaluate the potential contribution of BIPV solutions in meeting nZEB requirements and the impact of the innovations developed in the project.

The main step towards nZEB buildings can be first made through improvements in terms of thermal insulation of the envelope of buildings. Once the limits of thermal performance improvements start to be reached, another lever to reduce the primary energy balance of a building is to add on-site renewable energy systems. Depending on the local regulation, their production can be taken into account at a lower Primary Energy Factor (PEF) and at best can be partially or completely considered to reduce the primary energy balance. Such difference in the accounting of the production imposes to analyse in detail the nZEB regulation defined in each Member States. Indeed, the definition of what a nZEB building is highly varies from one country to another so that not one or two different tendencies among regulations can be put forward. Some definitions are more restrictive, in terms of primary energy balance allowed, in terms of integration of renewable systems or other aspects such as the CO_2 footprint, of LCA. Thus, an inventory and an analysis of the nZEB regulations of the 7 selected countries has been conducted. It allowed to identify four types of potential contribution of BIPV systems in complying with nZEB requirements. These have been defined as follows:

- Type 1: Passive properties, i.e. reducing primary energy consumption through reduced need
- Type 2: Reducing primary energy balance by deducing primary energy avoided thanks to renewable energy production
- Type 3: Reaching renewable energy (absolute or relative) contribution targets
- Type 4: Additional country-specific potential contributions of BIPV (CO_2 footprint, LCA, …)

Due to type 1 and type 4 contributions complexity and the lack of robust and exploitable sources, these potentials were not analysed in more details in this deliverable. As far as type 2 and type 3 contributions are concerned, the potential of competing distributed renewable technologies such as BAPV and solar thermal (ST) were also assessed and put in perspective with results of BIPV systems. The potential contribution of BIPV and competing systems was assessed by comparing the compliance with nZEB regulations of reference buildings without any renewable energy system and then of the same reference building with one of the three studied renewable energy systems (BIPV, BAPV and ST). In line with previously conducted assessments in BIPVBOOST Deliverable 1.1 and 1.2, four building types were selected: single-family houses, multi-family houses, educational buildings and office buildings.

When comparing the results of different studied renewable systems, focus was put on:

- The primary energy balance scoring of the building after considering the renewable system’s contribution compared to the legal threshold.
- To what extent the renewable system contributes to reduce the primary energy balance, expressed by a relative percentage.
- The cost-efficiency of the renewable system, i.e., the primary energy balance reduction that can be achieved with a 1000 € investment into this system.
- The validation or not of defined renewable energy integration targets.

Overall, the results obtained are encouraging and, except for a few cases, it can be said that BIPV systems can clearly contribute to reduce the primary energy balance of a building. When compared to BAPV solutions, the results vary depending on the reference cases.

In single-family houses, for instance, BIPV systems are more cost-efficient investments to improve the Primary Energy (PE) balance than BAPV systems.

Then, BIPV systems installed on the facades of multi-family houses can contribute to reduce the primary energy balance in the same range as BAPV on flat roofs (for an equivalent occupied area). This is possible thanks to the higher system surface power densities of the considered BIPV systems and in spite of less optimal irradiance conditions. Yet, from a cost-efficiency perspective, BAPV systems remain more advantageous.

On the contrary, for educational buildings, because of the architectural characteristics of the reference buildings considered in this report, leading to limited available surfaces on the facades and the important available surface on the roof, leads to BAPV enabling to reduce the primary energy balance more than BIPV. Nevertheless, the advantage of BAPV in terms of cost-efficiency is not straightforward, and in some countries BIPV appears as the most cost-efficient solution between both PV product.

Finally, the results for office buildings are less encouraging for BIPV as this renewable system only allows to reduce the primary energy balance marginally and this at lower cost-efficiencies than BAPV.

Table 1.1.1 and Table 1.1.2 below provide an overview of the results for all studied renewable systems and all building types in terms of relative PE balance reduction and cost-efficiency. The average best results provided in those tables support the above-presented analysis. Nevertheless, these tables cannot be a substitute for a detailed analysis. It can be observed that, even though BIPV has the potential to substantially reduce the primary energy balance of buildings, in some cases by a magnitude higher or equal to competing BAPV systems, it is not always the most cost-efficiency choice for this purpose, roofing installations of a single-family house being the only exception to this statement.

Table 1.1.1 Average best PE balance relative reduction for BIPV, BAPV and ST for all four studied building types.

Building Type	BIPV average best PE balance relative reduction	BAPV average best PE balance relative reduction	ST average best PE balance relative reduction
SFH	**-55%**	**-55%**	-37%
MFH	**-55%**	-50%	-25%
EB	-20%	**-40%**	-11%
OB	-25%	**-33%**	*NA*

Table 1.1.2 Average best cost-efficiencies (% relative PE balance variation/k€) for BIPV, BAPV and ST for all four studied building types

Building Type	BIPV average best cost-efficiency	BAPV average best cost-efficiency	ST average best cost-efficiency
SFH	**17**	8	9
MFH	0,60	**1,75**	0,96
EB	0,37	0,36	**0,51**
OB	0,05	**0,39**	*NA*

Some elements can be added to the above presented results to nuance the outcomes of the BIPV potential contribution's assessment. Indeed, from the study of the potential contribution of solar thermal systems, it can be considered, that they are not direct competitors to BIPV systems. Even though, solar thermal systems score rather good both in terms of primary energy balance reduction and cost-efficiency, multiple renewable energy integration targets are not suited to be met by solar thermal (because they concern a mandatory electrical capacity installed or because they refer to needs that are not covered by DHW). Therefore, the combination of BIPV systems on the facades and solar thermal on the consequently available surface on the roof appears as an interesting solution. Indeed, solar thermal systems are quite complementary to BIPV systems both in term of occupied area and covered needs.

Looking at BIPVBOOST's project innovations the analysis shows that they can highly improve the cost-efficiency of BIPV systems, in all cases and countries. Although, one should keep in mind that these BIPVBOOST improvements only enhance the added value of BIPV compared to competing renewable energy systems such as BAPV or solar thermal. But as such, if the regulation is not well suited (e.g. limited accounting of PV production, or unrestrictive legal primary energy balance threshold), these improvements will not change the status of BIPV, which could remain a subpar investment choice, especially compared to energy efficiency investments. This highlights the fact that the multifunctionality of BIPV products can be a key asset and should be used as a leverage to strengthen the attractiveness of BIPV. Adding an additional layer of thermal insulation can be evoked as one example. Nevertheless, this is encouraging and shows that BIPVBOOST will bring significant impact and clearly reinforce the potential contribution of BIPV in complying with nZEB requirements. In addition, the objective is met in the sense that all BIPVBOOST innovations substantially improve the cost-efficiency of BIPV solutions for the studied cases.

Finally, based on the analysis, remarks can be made with regards to how the nZEB regulations are designed. For instance, regulations imposing too stringent criteria for the deduction of renewable energy production from the primary energy consumption can lead to limited BIPV potential contribution in complying with nZEB regulations. The absence of any criteria with regards to renewable energy integration, or too unrestrictive legal threshold that can easily be achieved without the installation of any renewable systems are also neither encouraging the installation of renewable systems nor the choice of ambitious energy efficiency solutions.

Overall, a case by case analysis is highly required and few general conclusions, if any, are valid across all building typologies and countries. There is no "one fits all" solution and improving the primary energy balance of a building can be achieved in multiple ways, should it be with active or passive materials.

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Contents

1 ABOUT THIS REPORT

1.1 Description of the deliverable content and purpose

The Energy Performance of Buildings Directive (EPBD) specifies that all "Member States shall ensure that by 31 December 2020, all new buildings are nearly zero energy buildings". The objectives of this report are to evaluate the potential contribution of BIPV solutions in meeting nZEB requirements and the impact of the innovations developed in the project. The analysis has been conducted for different applications, building types and locations. Estimations are based on real cases, both renovations and new constructions. Quantified results are provided, considering the electricity production, and the multifunctional properties of BIPV systems. An inventory of existing nZEB requirements in key European countries (some still under development) is also presented. It permitted to identify the countries and cases in which BIPV can have the most impact. These findings can also serve as a support to market exploitation activities.

1.2 Relation with other activities in the project

Table 1.2.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within BIPVBOOST project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.2.1 Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
T1.1	Used to retrieve data on reference cases and methodology for competitiveness assessment
T1.2	Used to retrieve data on improvements planned in the frame of the BIPVBOOST project
All Tasks from WP2 to WP7	Used to obtain estimated impact of improvements to be developed in the frame of BIPVBOOST

1.3 Reference material

The deliverables published in the frame of the activities mentioned in the table above, i.e. D1.1 and D1.2.

1.4 Abbreviation list

BAPV – Building Applied Photovoltaics

BC – Base case

BE - Belgium

BIPV – Building Integrated Photovoltaics

CA – Conditioned Area

CB – Commercial Building

CE – Cost Efficiency

CH – Switzerland

CHP – Combined Heat and Power

COP – Coefficient of Performance

DE – Germany

DHW – Domestic Hot Water

EB – Educational Building

EPBD – Energy Performance of Buildings Directive

ERS – Energy Reference Surface

FE – Final Energy

FR – France

H - Hospital

$HP_{a/a}$ – Air/air heat pump

$HP_{a/w}$ – Air/water heat pump

IBC – Interdigitated back contact

IT – Italy

kWh_{EL} – kilowatt hour of electricity

kWh_{PE} – kilowatt hour of primary energy

LCA – Life-cycle assessment

MFH – Multi Family House

NEB – Net Energy Buildings

NGFA – Net Gross Floor Area

NL – Netherlands

NR – Non residential

nZEB – Nearly Zero Energy Buildings

OB – Office Building

PE – Primary Energy

PEF – Primary Energy Factor

PERC – Passivated Emitter Rear Cell

PV - Photovoltaics

R - Residential

RBC – Belgian region of Brussels

RW – Belgian region of Wallonia

SF – Sport Facility

SFH – Single Family House

SP – Spain

ST – Solar Thermal

TS – Thermal Surface

UA – Useful Area

VL – Belgian region of Flanders

2 INTRODUCTION

As stated in Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, the building sector is responsible for approximately 36% of CO2 emission in the EU. For comparison, the building sector represents almost 40% of all carbon emissions in the world [1]. Most of these emissions, (around 70%) are operational emissions (linked to heating, cooling and lighting). The remaining 30% are embodied carbon emissions related to materials and construction processes throughout the whole building lifecycle. [2] This demonstrates the relevance of regulatory measures aiming at improving the energy efficiency of buildings. In this regard, renovating the existing building stock has been put forward by the European Commission in its Green Deal as an important pillar to reach climate neutrality by 2050. Indeed, considering the extremely low renovation rates currently witnessed in most Member States, a stimulus is highly necessary, and ensuring that all buildings become more energy efficient would require, at least, a doubling of these rates.

3 INVENTORY AND ANALYSIS OF NZEB REGULATIONS IN SELECTED EUROPEAN COUNTRIES

3.1 The Directive

To boost energy performance of buildings, the EU has established a legislative framework that includes the Energy Performance of Buildings Directive EU (EPBD) and the Energy Efficiency Directive (EED). Note that both directives were amended, as part of the "Clean Energy for all Europeans" package presented in late 2016 and entered into force in 2018 and 2019. More precisely, article 9 of the Energy Performance of Buildings Directive 2010/31/EU (EPBD) specifies that all *"Member States shall ensure that:*

> *(a) by 31 December 2020, all new buildings are nearly zero energy buildings.*
>
> *(b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.*

Member States shall draw up national plans for increasing the number of nearly zero-energy buildings. These national plans may include targets differentiated according to the category of building." Moreover, the text adds that *"the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from "renewable sources produced on-site or nearby".* This last part represents an opportunity for distributed PV systems, among which BIPV. Especially as these latter solutions, thanks to their unique multifunctional characteristics, can potentially contribute both to improving the energy efficiency of the building and produce energy for the remaining demand.

It is worth noting that the text does not specify any threshold value that would define what a nZEB is. These values are defined at the national level and are presented in the following section.

3.2 Inventory of national regulations

In order to analyse the contribution of BIPV to complying with nZEB targets, an inventory of national nearly Zero Energy Building regulations in seven key European countries was conducted. For each country (and region if significant regional differences exist), the following elements of the regulations have been identified as relevant and have been examined:

- Building typology (new/existing)
- Category (residential/non-residential)

- Subcategory (single-family house, multifamily house, educational building, …)
- Included energy uses (heating, cooling, air-conditioning, ventilation, domestic hot water, lighting, appliances, central services, …)
- Physical boundary (building, building unit, …)
- System boundary for generation (in-situ, nearby, …)
- Share of renewables in energy demands
- Type and period of balance (monthly/seasonally/annually)
- Max value for different metrics (energy needs, primary energy consumption)
- Normalisation factor (useful area, gross area, net area, conditioned area, …)
- Conversion factors (static, dynamic, …)
- Other metrics and requirements

In the following Sections 3.2.1 to 3.2.7, for each country (and region in the case of Belgium), a summary of the national (regional) regulation's key content is provided. More detailed tables can be found in the Appendixes in sections 8.1 to 8.9.

Note that the presentation of the different national and regional nZEB regulations are representative of their state of advancement as of Q1 2020. As explained in the previous section, all new buildings shall be nearly zero energy buildings by the 31st of December 2020. Therefore, potential modifications can still be made to these regulations until the end of 2020, which could impact the results presented in this document.

3.2.1 Belgium

In all three Belgian regions (Brussels, Flanders and Wallonia), the renewable energy that is produced on-site can be converted into avoided primary energy and then subtracted from the primary energy need to give the final primary energy value. The balance between energy need and energy production is a monthly balance. The limit imposed in terms of kWh $_{PE}$/m^2.year varies in function of the building category and subcategory. Known values across all three regions range from 45 to 86 kWh $_{PE}$/m^2.year for residential buildings and from 90 to 108 kWh$_{PE}$/m^2.year for non-residential buildings.

In addition, in Flanders, the integration of renewables is compulsory. One possibility to achieve this requirement is to install a PV system producing at least 15 kWh/m$^2_{JA}$.year. Among the possible alternatives to meet this requirement are solar thermal, biomass heating, heat pumps, district heat network or financial participation in renewable energy production.

3.2.2 France

In France, self-produced electricity, from PV or cogeneration, is deducted from the energy consumption for the calculation of the Cep (maximum conventional consumption of primary energy). The primary energy balance is a seasonal balance (winter, summer, mid-season). Nevertheless, the primary energy consumption before deduction of self-produced energy is also limited by a certain value, determined by the Cep$_{max}$ for the given building type and category, location, altitude, average surface and GHG emissions' coefficient of used energies incremented by a value of 12 kWh/m^2.year. The limit imposed in terms of kWh$_{PE}$/m^2.year varies in function of the building category and subcategory. Known values range from 45 to 90 kWh $_{PE}$/m^2.year for residential buildings and from 70 to 110 kWh$_{PE}$/m^2.year for non-residential buildings.

As far as renewable energy is concerned, a requirement of 5 kWh$_{PE}$/m^2.year exists for new residential buildings. Among possible alternatives solutions to meet this requirement, solar thermal for DHW, heat network that have renewable source greater than 50%, heat pump with a COP greater than 2 or micro-cogeneration boilers with a yield greater than 0,9 can be mentioned.

3.2.3 Germany

In Germany, self-produced electricity can be deduced from the primary energy consumption if:

- The production is generated in the immediate spatial connection to the building.
- Priority is given to self-consumption and
- The electricity is not used for electricity-based heating using the Joule effect.

The amount of the deductible PV production depends, among others, on the installed capacity, the presence of an energy storage system, the primary energy consumption of a reference building defined in the law (building with identical geometry, useful area, orientation as the studied building and having a set of predefined parameters).

The limit imposed in terms of kWh$_{PE}$/m^2.year varies in function of the building category and subcategory. Known values range from 53 to 98 kWh $_{PE}$/m^2.year for residential buildings and from 90 to 189 kWh$_{PE}$/m^2.year for non-residential buildings. The upper value of each range corresponds to retrofitted buildings, thus explaining the higher values.

As far as the integration of renewables is concerned, a minimum of 15% of the cooling and heating needs must be covered by renewable energy. There are multiple alternative options to fulfil this requirement. For instance, covering at least 50% of heating and cooling needs by waste energy, by energy coming from a combined heat and power (CHP) plant, or installing a certain capacity of renewables on the building.

3.2.4 Italy

The produced PV electricity can be deducted from the primary energy consumption, but a certain number of rules must be followed to be able to do so. The compensation between renewable energy production and primary energy consumption is only allowed between same energy carriers, on a monthly basis, and only up to the self-consumed produced electricity. The exported electricity is then considered on a yearly basis to compensate annual primary energy needs. A further restriction specifies that electricity used to produce heat through Joule effect cannot be taken into account.

When it comes to the integration of renewables, three requirements exist. Firstly, 50% of DHW (domestic hot water) needs and, secondly, 50% of DHW, heating and cooling combined needs must be covered by renewable energy. Finally, it is compulsory to install at least 1 kW/50m^2 $_{UA}$ of renewable electrical power. The same restrictions with regards to how the electricity is used apply.

3.2.5 Netherlands

In the Netherlands, the primary energy consumption maximum value concerns the primary **fossil** energy consumption. Therefore, only the part of the renewable electricity produced on site that is used for uses that are excluded of the calculation of the total primary fossil energy consumption (such as plug loads, appliances, or lighting for the residential sector) can be deducted from the primary fossil energy consumption. Exported electricity to the grid is also deductible from the primary fossil energy consumption.

The limit imposed in terms of kWh$_{PE}$/m^2.year varies in function of the building category and subcategory. Known values range from 40 to 70 kWh $_{PE}$/m^2.year. This limit is defined for the primary fossil energy balance.

As far as the integration of renewables is concerned, the regulation defines a compulsory ratio of renewable energy production (self-consumed and exported) to the total primary fossil energy consumption after deduction. This ratio ranges from 30 to 40% depending on the considered building type.

It should also be mentioned that the Netherlands is the only country in which a requirement related to environmental performance of the building exists. Indeed, in other countries this aspect is often mentioned but not stated as compulsory.

3.2.6 Spain

In Spain, the produced renewable energy cannot be deducted from the total primary energy consumption. Nevertheless, because of an important difference between the primary energy factor used for electricity from the grid and renewable electricity, it is possible to reduce the primary energy consumption when a part of the produced electricity is self-consumed for the eligible uses.

The limit imposed in terms of kWh_{PE}/m^2.year varies in function of the building category and subcategory. For new buildings the limits lies at 76 kWh_{PE}/m^2.year, while for retrofitted buildings the range starts at 130 kWh_{PE}/m^2.year.

When it comes to the share of renewables, it is defined as the share of DHW (domestic hot water) and indoor swimming pool air-conditioning energy needs covered by renewable energy. In the Spanish regulation, the notion of renewable energy encompasses all on-site renewables, urban heating systems, heat pumps complying with a set of technical specifications, or residual energy. In addition, it is compulsory for non-residential buildings with a built surface greater than 3000 m² to install a specified capacity of renewable electricity generating system, while not exceeding 100 kW.

3.2.7 Switzerland

With the exception made of cogeneration installations, self-produced electricity is not taken into account in the calculation of weighted energy demand.

There is no requirement in terms of share of renewables, but a renewable electricity production capacity of at least 10 W/m^2_{ERS} is compulsory for new buildings. In addition, for multi storey building, an integrated renewable system on the façade must be foreseen.

3.2.8 nZEB regulations overview

Table 3.2.1 Summary of nZEB regulations

Country	Primary energy balance threshold	Possibility to deduced PV production	Balancing type	Eligible energy uses	Installation of on-site renewables producing electricity
Belgium – Brussels	Appendix 3	All but up to monthly consumption only	Monthly	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting for non-residential buildings)	Not compulsory
Belgium – Wallonia	Appendix 3	All but up to monthly consumption only	Monthly	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting for non-residential buildings)	Not compulsory
Belgium – Flanders	Appendix 3	All but up to monthly consumption only	Monthly	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting for non-residential buildings)	Not compulsory
France	Appendix 3	All but up to seasonal consumption only	Seasonally	Heating, DHW, Ventilation, Cooling, Auxiliary Energy and Lighting	Not compulsory
Germany	Appendix 3	Minimum between flat amount proportionate to installed capacity and other fixed amounts	Yearly	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting for non-residential buildings)	Not compulsory
Italy	Appendix 3	Self-consumed electricity for eligible uses and exported electricity	Monthly	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting and central services for non-residential buildings)	Compulsory
Netherlands	Appendix 3	Whole produced electricity	Monthly	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting and central services for non-residential buildings)	Not compulsory
Spain	Appendix 3	Self-consumed electricity for eligible uses	Monthly	Heating, DHW, Ventilation, Cooling (+lighting and central services for non-residential buildings)	Compulsory for buildings >3000 m²
Switzerland	Appendix 3	NA	NA	Heating, DHW, Ventilation, Cooling, Auxiliary Energy (+lighting and central services for non-residential buildings)	Compulsory + façade-integrated solution has to be systematically foreseen for multi-floor buildings

4 METHODOLOGY

4.1 POTENTIAL CONTRIBUTION OF BIPV IN COMPLYING WITH NZEB REGULATION

Based on the analysis of above-presented regulations, four potential contributions of BIPV to nZEB requirements have been identified. Three of them can be considered as generic potential contributions as they are applicable to most (but not all) countries and building types. The fourth potential is more specific and applies to a few cases only.

4.1.1 Type 1 – Passive properties: reducing primary energy consumption through reduced needs

A BIPV solution can contribute to reduce energy needs thanks to its thermal and optical characteristics. This potential contribution of BIPV is mostly relevant for curtain walls with semi-transparent BIPV or shading elements. Indeed, curtain walls with lower transparency rates or shading devices can limit overheating due to sun radiation during the summer and thus reduce cooling needs for example.

This contribution type should not be mistaken with the fact that the BIPV electricity production can cover to some extent the heating, DHW, lighting, …etc. needs (provided the related energetic systems are fuelled with electricity).

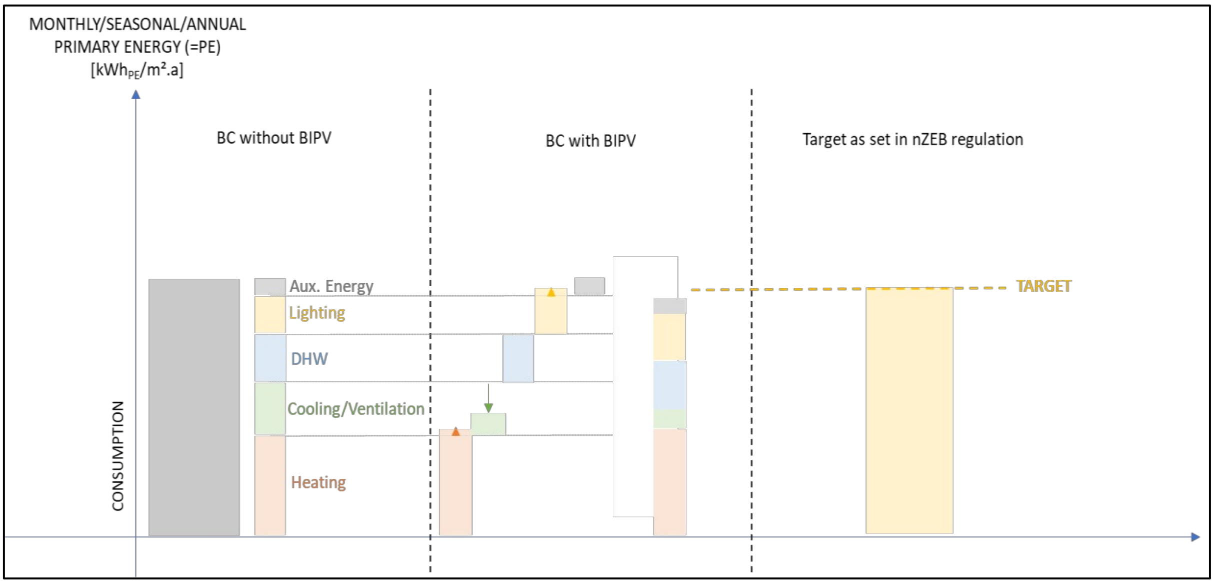


Figure 4.1.1 Schematic overview of Type 1 BIPV potential contribution

In the literature, some scientific papers address the impact of semi-transparent BIPV systems on the heating, cooling and lighting consumption of buildings [3] [4] [5]. Experiments are either conducted at the scale of a unique window connected to a box by measuring temperature and other relevant parameters, or at the scale of a whole building by using specialised software simulating building's energy performances.

Overall conclusions are that in geographical areas where cooling needs are predominant over heating needs, semi-transparent BIPV systems can contribute to reduce overall primary energy consumption.

Nevertheless, in areas where heating needs are not neglectable, the cooling needs' reduction does not compensate for the heating and lighting needs' increase. In addition, results are highly dependent on the transparency level of the semi-transparent BIPV systems, on the orientation, the number and the surface of glazed areas as well as on climatic conditions. In Italy, for example, the most important cooling needs' reduction (-60%) is achieved in Trento (North of Italy), with a semi-transparent BIPV system with a transparency rate of 20% and applied on the only glazed façade, oriented South. On the contrary, in Palermo (South of Italy), when a semi-transparent BIPV system with a transparency rate of 40% is applied on the only glazed façade, oriented East, a 11% reduction in cooling needs is achieved. As far as the lighting needs' variation is concerned, the relative increase ranges from 38% to 250% depending on the climatic zone in Italy, the transparency level and the orientation of the façade on which the BIPV system is applied. Finally, in central and southern Italy, there are no heating needs. In northern Italy, the impact of the installation of a semi-transparent BIPV system on a façade can increase heating needs from 10% to 300% depending on the transparency level and the orientation of the façade on which the BIPV system is applied [4].

Therefore, because of the limited number of available sources and the high dependency of results to an important number of architectural and geographical factors, this potential contribution of BIPV will not be assessed in the rest of this report.

4.1.2 Type 2 - Reducing primary energy balance by deducing primary energy avoided thanks to renewable electricity production

In most countries, a part or the whole renewable energy production can be considered as avoided primary energy and therefore, deduced from the total primary energy consumption.

The criteria for the determination of the deductible renewable energy production vary from one country to another. Less stringent criteria allow to deduce the whole production, while other regulations stipulate that the production can only be deduced up to the amount of consumed primary energy and this through a monthly, seasonal, or annual balance or up to a flat amount. In countries where a direct deduction of renewable production is not allowed, the renewable production can still indirectly contribute to reduce the primary energy consumption. Indeed, when converting the final energy consumption to primary energy consumption, energy vector-specific primary energy factors are used. Primary energy factors associated to electricity coming from the grid range from 1,45 to 3 depending on the country. In some national regulation a different PEF is given for electricity generated by renewable systems such as PV systems. This PEF for renewable electricity is typically lower, thus mathematically reducing the primary energy consumption.

Note that competing technologies, such as BAPV or ST, will also be investigated. The electricity produced with a BAPV system can be deducted from the primary energy consumption following the same conditions and criteria as BIPV.

It is assumed in the rest of this report that all solar thermal systems installed only provide heat for domestic hot water. Therefore, the considered solar thermal systems cover only a limited roof surface. In the case of solar thermal systems (partially) covering both DHW and heating needs, e.g. when coupled with a heat pump, the required surface for the system would be more consequent. In addition, the considered surface for solar thermal systems is based on the typical required surface for the given application (covering DHW needs only), and the given country, knowing that higher irradiations in southern locations allow to reduce the covered surface. In terms of primary energy balance reduction, the heat produced by a solar thermal system can contribute to reduce the need for the initial energy vector (gas or electricity for example) used to produce domestic hot water. In the case of a building where domestic hot water is heated with a heat pump, the solar thermal technology is not tested. The hybrid association of a solar thermal system with a geothermal or air/water heat pump is possible. Nevertheless, in the case of a retrofit, the addition of a solar thermal system to such a heat pump requires some technical adjustments (potential intermediary water tank addition or replacement of the existing water tank with a new one, with adapted type and size, additional pipework, …) which are associated to hardly quantifiable extra costs. In the case of new building and of a geothermal heat pump, the installation of solar thermal system can allow savings in terms of drilling length, but those savings are highly case dependent, thus hardly quantifiable. In addition, the contribution of the solar thermal system to the reduction of primary energy consumption is also difficult to estimate as it can impact the COP's value (Coefficient of Performance) of the heat pump, which itself depends on numerous factors.

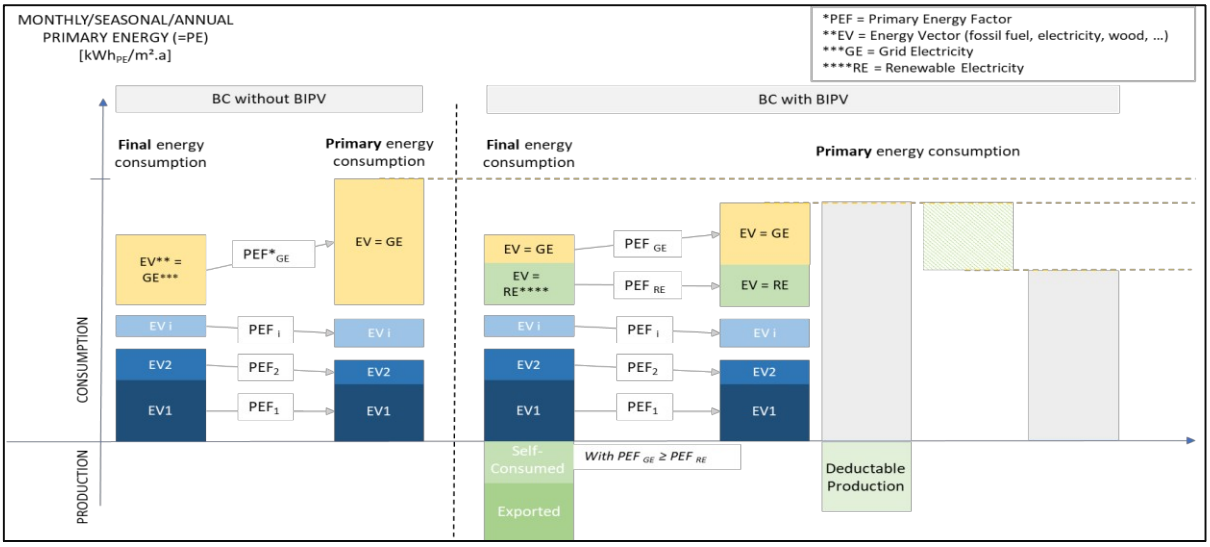


Figure 4.1.2 Schematic overview of Type 2 BIPV potential contribution

4.1.3 Type 3 - Reaching renewable energy (absolute or relative) contribution targets

In most countries, a requirement concerning the usage of renewable energy exists.

This requirement can consist of a relative share of renewable energy in the total energy consumption (or in the energy consumption for certain uses) or an absolute quantity that must be produced. In this latter case, the renewable energy that can be considered to determine the renewable share can correspond to the whole renewable production (self-consumed and exported) or only to a part of it depending on the national nZEB regulation.

These targets can in some cases be achieved without the presence, on or integrated to the envelope of the building, of a renewable system such as BIPV, BAPV or ST. Indeed, a heat pump, a connection to

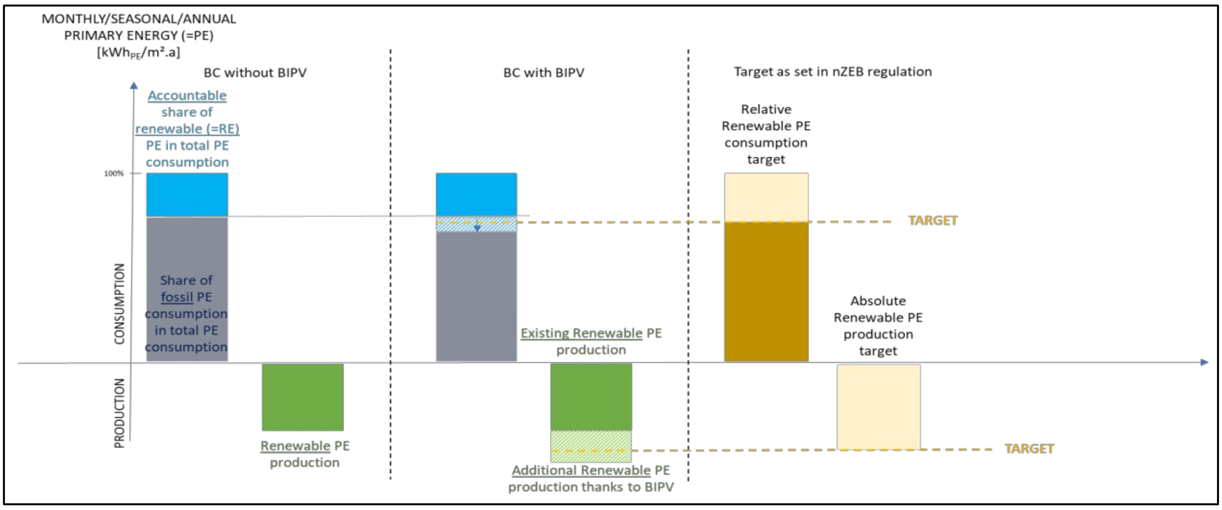


Figure 4.1.3 Schematic overview of Type 3 BIPV potential contribution

a district heat network or the financing of a renewable project can also lead to the achievement of the renewable energy integration target. Therefore, in the following section, if the target is not already achieved in the base case, it will be calculated to what extent the installation of a BIPV system or of a competing technology (BAPV or ST) can contribute to meet the target.

4.1.4 Type 4 – Additional country-specific potential contributions of BIPV (CO_2 footprint, LCA, …)

The environmental footprint of a building over its entire lifecycle (from the production of its construction materials to its use) is not systematically taken into account in nZEB regulations. In Spain, the calculation of the CO_2 footprint of a building is part of the energy certification process but is not stated as a compulsory requirement. In the Netherlands, however, an indicator considers the environmental impact of a building through its entire lifecycle.

Although, assessing to which extent a building equipped with BIPV would perform in environmental terms compared to the same building equipped with conventional building’s envelope solution, or equipped with BAPV, is out of the scope of this report. Indeed, the complete and thorough evaluation of this fourth type of potential contribution of BIPV would require conducting comparative or consequential LCAs, which is highly specific and is out the boundaries of the present deliverable. Nevertheless, as the assessment of the environmental performances of renewable energy systems, for example based on LCA methodology or PEF (Product Environmental Footprint) guidelines, have gained more importance (e.g. CO_2 footprint of PV panels are now a criterion in the evaluation of PV tenders in France), this aspect cannot be overlooked. Thus, it is investigated in the frame of Task 1.5 of BIPVBOOST’s WP1.

Therefore, there will be not specific calculations conducted for this fourth type.

4.1.5 Potential contributions of BIPV overview

Here below in Figure 4.1.4 is a summarising representation of the various types of BIPV potential contributions to complying with nZEB requirements presented in Sections 4.1.1 to 4.1.4.

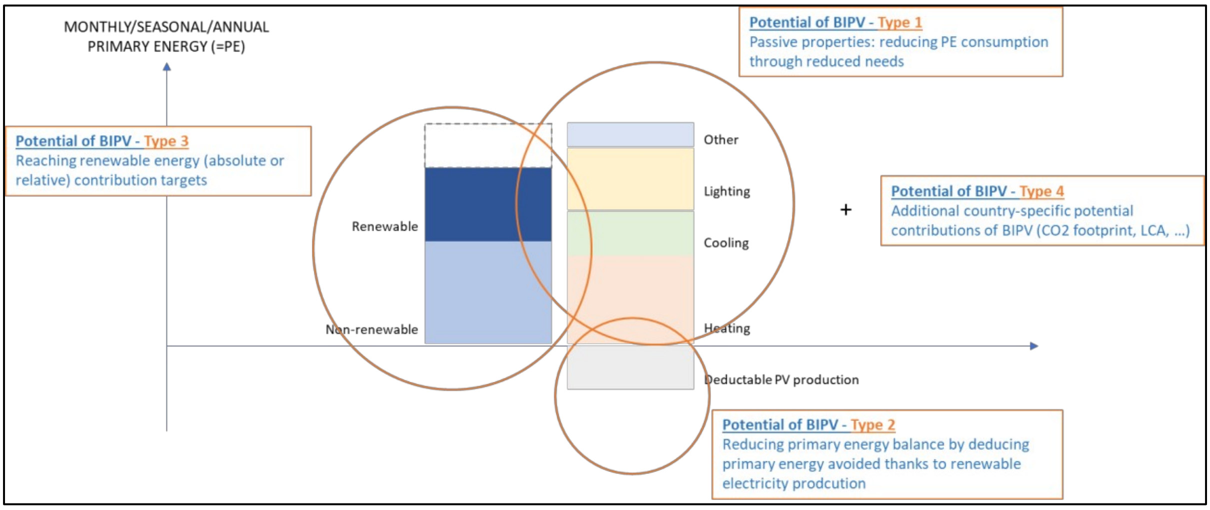


Figure 4.1.4 Schematic overview of different types of BIPV potential contribution

4.2 Reference cases

In order to evaluate the contribution of a BIPV system, or competing renewable systems, to the performances of a building with regards to nZEB requirements, reference cases have been defined. They consist of buildings with thermal performances currently achievable in the construction industry, and without on-site renewable energy system (with the exception of heat pumps in few cases). Most reference buildings are based on sources which present examples of nZEB (or equivalent) buildings [6] [7] [8] [9] [4] [3] [5]. These have been chosen to make sure that studied cases are representative of what can be achieved today in the selected countries, using mainstream techniques and materials available on the market. These buildings' main architectural and energetic characteristics are provided in Appendix 3, and an overview of studied reference cases is provided in Table 4.2.1.

Some total primary energy consumption values of reference buildings, as presented in abovementioned tables, might appear as high, given the fact that they are based on nZEB building examples. This is explained by the fact that, in multiple nZEB building examples, the building had one or multiple renewable energy system(s) installed, thus influencing the primary energy consumption value. Yet, in order to define coherent base cases, i.e. without pre-existing renewable energy system(s), the contribution and impact of those renewable systems was removed, thus increasing the primary energy consumption value.

In addition, it should be kept in mind that the ratio between primary energy factors for fossil fuels and primary energy factors used for electricity lies on average around 2. Thus, explaining why there can be significant differences in terms of primary energy consumption for two same building types based on energy systems using different vectors for the same energy use.

At least one reference building was defined for each studied combination *{Country (BE/FR/DE/IT/NL/SP/CH); Building type (SFH/MFH/EB/OB)}*. When enough data was available, two reference buildings have been used for one studied combination: one building with an electricity-based energy consumption, and the other one based on another energy vector, such as gas. This will allow to determine whether the type of system covering heating, cooling, ventilation and DHW needs of a building influences the potential contribution of BIPV.

Table 4.2.1 Number of cases studied per country and type of building

	Single-family House (SFH)	Multi-family house (MFH)	Educational Building (EB)	Office Building (OB)
Belgium	1	2	1	2
France	1	2	1	2
Germany	2	2	1	2
Italy	2	1	1	2
Netherlands	1	2	1	2
Spain	2	1	1	2
Switzerland	2	1	1	2

5 QUANTIFIED CONTRIBUTION OF BIPV TO NZEB REQUIREMENTS

5.1 Characteristics of studied BIPV systems and other renewable energy systems

The studied BIPV, BAPV and ST systems for which the potential contribution to complying with nZEB regulations will be assessed are respectively gathered inTable 5.1.1, Table 5.1.2 and Table 5.1.3. [10] [11] [12]

PV tiles | In-roof mounting system | Full roof solution

Ventilated facade | Curtain wall

Figure 5.1.1 Illustrations of studied BIPV systems

Table 5.1.1 Description of BIPV systems

Product type		BIPV								
Building type		*SFH*	*SFH*	*SFH*	*MFH*	*MFH*	*EB*	*EB*	*OB*	*OB*
Cladding typology		Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed opaque solution with thermal properties (insulation layer)	Glazed opaque solution with thermal properties (insulation layer)	Glazed opaque solution without thermal properties	Glazed opaque solution without thermal properties	Glazed semi-transparent solution without thermal protection	Glazed semi-transparent solution without thermal protection
Technological system		PV tiles	In-roof mounting system	Full roof solution	ventilated façade	ventilated façade	ventilated façade	ventilated façade	Curtain wall	Curtain wall
PV technology		mono cSi (PERC)	mono cSi (PERC)	CIGS	mono cSi IBC	multi cSi	mono cSi (PERC)	CIGS	aSi	mono cSi (PERC)
Degradation rate year 1	[%/year]	1,80%	1,80%	0,70%	1,00%	1,80%	1,80%	0,70%	1,00%	1,80%
Degradation rate year >1	[%/year]	0,45%	0,45%	0,70%	0,25%	0,50%	0,45%	0,70%	1,00%	0,45%
System power density	[Wp/m²]	106	179	132	175	153	161	134	25	100
Application area		Tilted roof	Tilted roof	Tilted roof	Facade	Facade	Facade	Facade	Facade	Facade
End-user cost	[€/m²]	332	208	249	684	650	462	412	652	797
Extra-cost	[€/m²]	172	91	118	388	369	236	202	347	446

Table 5.1.2 Description of BAPV systems

Product type		BAPV	BAPV	BAPV	BAPV	BAPV
Building type		SFH	SFH	SFH	MFH, EB, OB	MFH, EB, OB
PV technology		mono cSi (PERC)	mono cSi IBC	multi cSi	mono cSi (PERC)	multi cSi
Degradation rate year 1	[%/year]	1,80%	1,00%	1,80%	1,80%	1,80%
Degradation rate year >1	[%/year]	0,45%	0,25%	0,50%	0,45%	0,50%
System power density	[Wp/m²]	179	198	157	110	98
Application area		Tilted roof	Tilted roof	Tilted roof	Flat roof, mounted on tilted structure	Flat roof, mounted on tilted structure
End-user cost	[€/m²]	298	395	199	119	84

A few elements of explanation can be brought as to how the system power area density in determined based on the module efficiency for the different considered BIPV and BAPV systems. These can explain why for a same PV technology, very different system power area densities can be obtained. This is summarised in Figure 5.1.2.

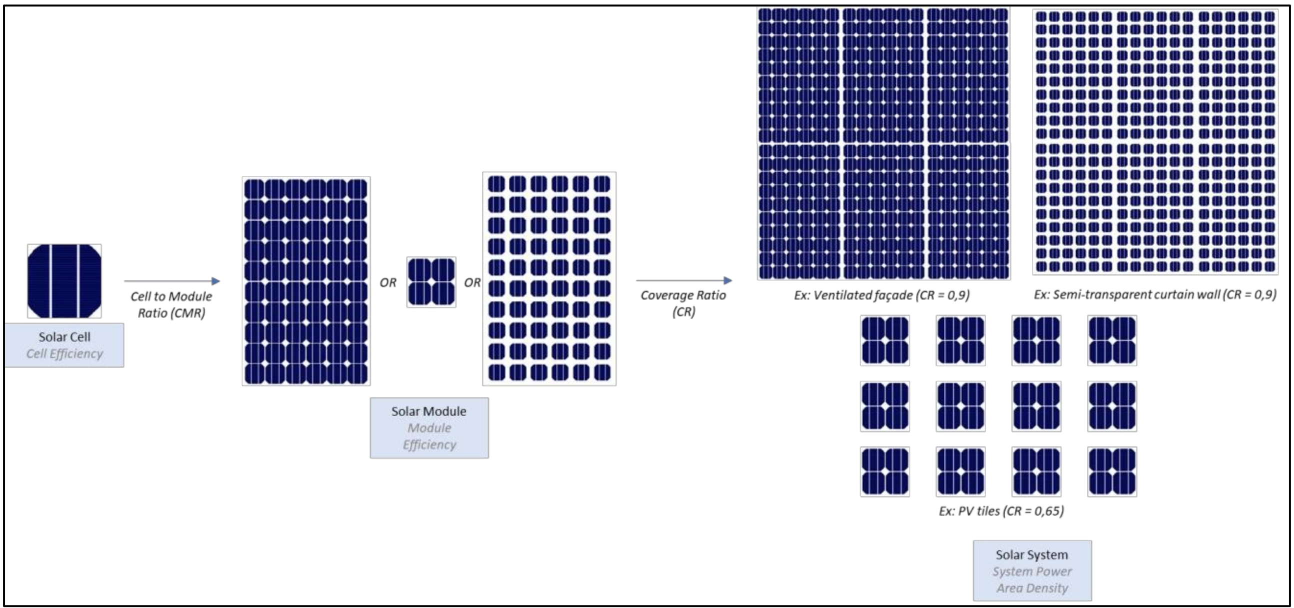


Figure 5.1.2 Summarising the methodology applied to obtain system power area densities calculations

Table 5.1.3 Description of ST systems

Product type		ST			
Building type		SFH	MFH	EB	OB
ST technology		Flat plate collector	Flat plate collector	Flat plate collector	NA
Application area		Tilted roof	Flat roof, mounted on tilted structure	Flat roof, mounted on tilted structure	NA
End-user cost	[€/m²]	940	700	650	NA

Solar thermal systems are not studied in the cases of office buildings, because in the reference cases office buildings do not typically have any DHW needs.

5.2 How to read the results

The results are presented per country (or per region when relevant) and per type of building. The results are visually presented and analysed based on the visual support of two different charts (Chart1, Chart2) and four different matrix tables (Table1, Table2, Table3 and Table4). In each case, the presentation will follow the same logic, which is presented here below, along with keys to read and understand the presented data.

First a mock-up of the considered building is provided. It aims at giving an idea to the reader of the building's typology in terms of roof tilt, general wall to window ratio, ….

Table1:

The first table presents the configuration of the studied renewable energy systems, such as the occupied areas, the installed capacity, the system area to building floor area ratio, as well as the different technologies and orientations tested. The occupied areas are consistent with available surfaces but are not defined as an optimum based on the building's energy needs nor on the national nZEB regulation. All the available and suitable (the notion of suitable area excludes the space occupied by windows in the case of ventilated BIPV facades, or the area occupied by chimneys in the case of BIPV roofing, for example) surface of a given building element (eastern and/or western and/or southern facade or roof) are completely covered. An exception to this rule was made for:

- single-family houses, where installed capacity was in some cases curtailed to be consistent with the maximum allowed capacity for residential PV systems, as defined in the local regulation.
- solar thermal systems as they require limited surfaces.

Chart1:

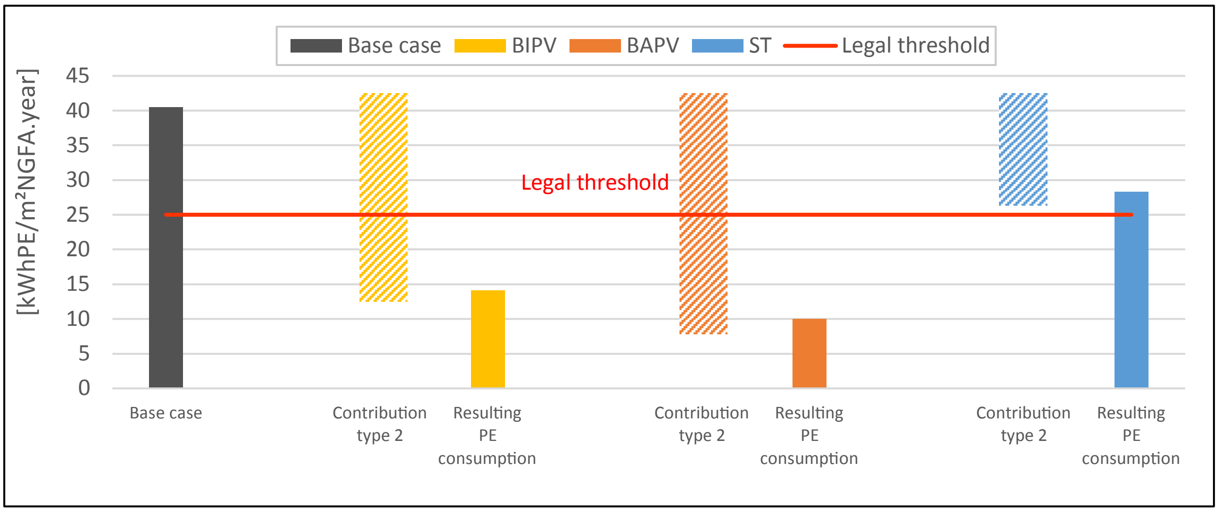


Figure 5.2.1 Chart1 example

Chart1 shows the type 2 contribution for the three studied renewable energy systems. On this chart, the results of only one orientation and one technology is represented for each renewable system (BIPV, BAPV, ST). The BIPV and BAPV systems tested per building type are presented respectively in Table 5.2.1 and Table 5.2.2. There is only one type of ST system studied in this deliverable which is the one represented on Chart1.

Table 5.2.1 Selected BIPV system per building type for Chart1 representation

Product type		BIPV			
Building type		SFH	MFH	EB	OB
Cladding typology		Glazed opaque solution without thermal properties	Glazed opaque solution with thermal properties (insulation layer)	Glazed opaque solution without thermal properties	Glazed semi-transparent solution without thermal protection
Technological system		In roof mounting system	Ventilated façade	Ventilated façade	Curtain wall
PV technology		mono cSi (PERC)	mono cSi IBC	mono cSi (PERC)	mono cSi (PERC)
Degradation rate year 1	[%/year]	1,80%	1,00%	1,80%	1,80%
Degradation rate year >1	[%/year]	0,45%	0,25%	0,45%	0,45%
System power density	[Wp/m²]	179	175	161	100
Application area		Tilted roof	Facade	Facade	Facade

Table 5.2.2 Selected BAPV system per building type for Chart1 representation

Product type		BAPV	BAPV
Building type		SFH	MFH, EB, OB
PV technology		mono cSi (PERC)	mono cSi (PERC)
Degradation rate year 1	[%/year]	1,80%	1,80%
Degradation rate year >1	[%/year]	0,45%	0,45%
System power density	[Wp/m²]	179	110

Results for all combinations of *{orientation; technology}* are presented in Table1 (content of table explained on page 24). In Chart1, the hatched area corresponds to the avoided primary energy thanks to the installation of the renewable energy system. When known, the legal threshold for the studied building type is represented, yet the absence of a legal threshold on the chart does not mean that the national nZEB regulation does not define one, but that the threshold's value or the values required to calculate were not available at the time of writing. An overview of the different legal thresholds defined for the seven studied countries can be found in Appendix 2.

Table2:

Table2 represents the relative primary energy consumption variation thanks to the installation of the considered renewable energy system at a given orientation. This relative variation, noted (α), is calculated as follows and is written as a percentage:

$$\propto_{\substack{Renewable\ system\ j\\ Orientation\ i}} = -\frac{(E0-E2)}{E0} * 100\%$$

Where:

- E0 is the primary energy consumption of the reference building without any installation of an additional renewable system, i.e. the base case
- E2 is the primary energy consumption of the reference building after having taken into account type 2 contribution of the given renewable energy system (BIPV, BAPV or ST), at a given orientation

Table 5.2.3 Table2 example

	BIPV System 1	BIPV System 2	…	BIPV System j	BAPV System 1	BAPV System 2	…	BAPV System k	Solar Thermal
Orientation 1	-65%	-50%		-72%	-75%	-73%		-78%	-34%
Orientation 2	-60%	-45%		-67%	-70%	-68%		-73%	*NA*
…									
Orientation i	-71%	-65%		-77%	-81%	-78%		-84%	*NA*

Table3:

Table3 represents the cost efficiency of the different tested renewable energy systems in different orientations. It informs on the relative improvement in PE consumption for each slide of 1000€ invested in CAPEX for the tested renewable energy system. Thus, the higher, the better. This cost efficiency (CE) is expressed in %/k€ and is calculated as follows:

$$CE = \frac{\frac{(E0-E2)}{E0} * 100\%}{\frac{EUC}{1000}} = \frac{-\propto}{\frac{EUC}{1000}}$$

Where:

- E0 is the primary energy consumption of the reference building without any additional renewable energy system
- E2 is the primary energy consumption of the reference building after having taken into account type 2 contribution of the given renewable energy system (BIPV, BAPV or ST), at a given orientation
- EUC is the end-user cost considered for the installed renewable energy system. It should be noted that for BIPV systems, only the part of the end-user cost which is attributable to BIPV (the extra cost of BIPV compared to a conventional building envelope solution) is considered in the different calculations. Indeed, it was concluded from the analysis conducted in previous deliverable "Cost competitiveness status of BIPV solutions in Europe" that adopting an extra-cost approach was the most appropriate method to evaluate the cost of BIPV.

Table 5.2.4 Table3 example

	BIPV System 1	BIPV System 2	…	BIPV System j	BAPV System 1	BAPV System 2	…	BAPV System k	Solar Thermal
Orientation 1	8	9		6	10	11		8	17
Orientation 2	6	7		3	8	9		5	NA
…									
Orientation i	11	14		10	14	16		12	*NA*

Taking as an example value at the top left corner, a cost efficiency of 8 for BIPV system 1 in orientation 1 means that a 1000€ investment to install BIPV system 1 in orientation 1 will lead to a 8% decrease of the primary energy consumption compared to the reference building with no BIPV, BAPV or ST.

Chart2:

Chart2 is another way to represent the cost efficiency of the tested renewable energy systems. On this chart, one can see the position of each combination *{renewable system; orientation; installed capacity}* based on the primary energy consumption it allows to achieve and on system's end-user cost. On the background of the chart, areas of different colours are depicted, each representing a different level of end-user cost per kWh_{PE} per m² (of normalised area) reduction achieved. Renewable energy systems, in their studied configuration (orientation and installed capacity), located in the green area allow to improve the primary energy consumption scorings at a reduced cost compared to systems located in dark orange areas.

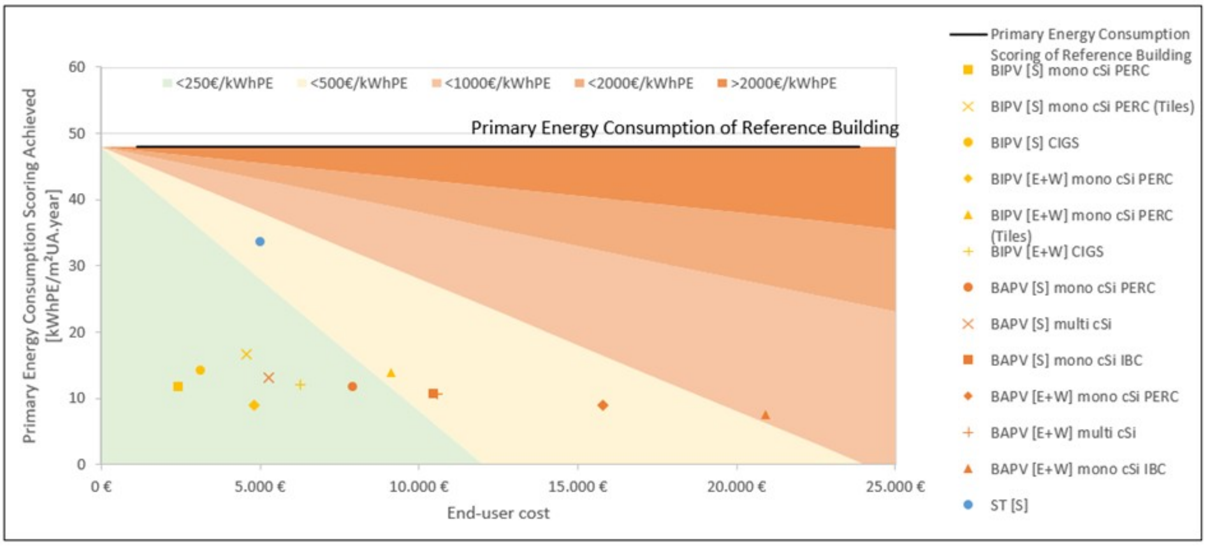


Figure 5.2.2 Chart2 example

Table4:

Finally, Table4 indicates whether the renewable integration target is achieved thanks to the different configurations tested. Depending on the country and the type of building, the renewable integration target can be met by respecting one condition, multiple conditions or one condition among multiple possible conditions. Renewable energy integration targets presented in those tables are always mandatory targets.

Table 5.2.5 Table4 example

	BIPV System 1	BIPV System 2	…	BIPV System j	BAPV System 1	BAPV System 2	…	BAPV System k	Solar Thermal
Orientation 1	Y	Y		Y	Y	N		N	N
Orientation 2	Y	Y		Y	N	N		N	*NA*
…									
Orientation i	N	N		N	N	N		N	*NA*

5.3 Belgium (RBC, RW, VL)

5.3.1 Single-family house

This single-family house’s heating and DHW needs are covered by gas. There is no cooling system.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.3.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Belgium

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	25	25	25	25	25	25	5
South	Installed capacity [kWp]	4	3	3	4	4	5	*NA*
South	RE system surface to net floor area [-]	0,16	0,16	0,16	0,16	0,16	0,16	0,03
East & West	Occupied area [m²]	50	50	50	50	50	50	*NA*
East & West	Installed capacity [kWp]	9	5	7	9	8	10	*NA*
East & West	RE system surface to net floor area [-]	0,31	0,31	0,31	0,31	0,31	0,31	*NA*

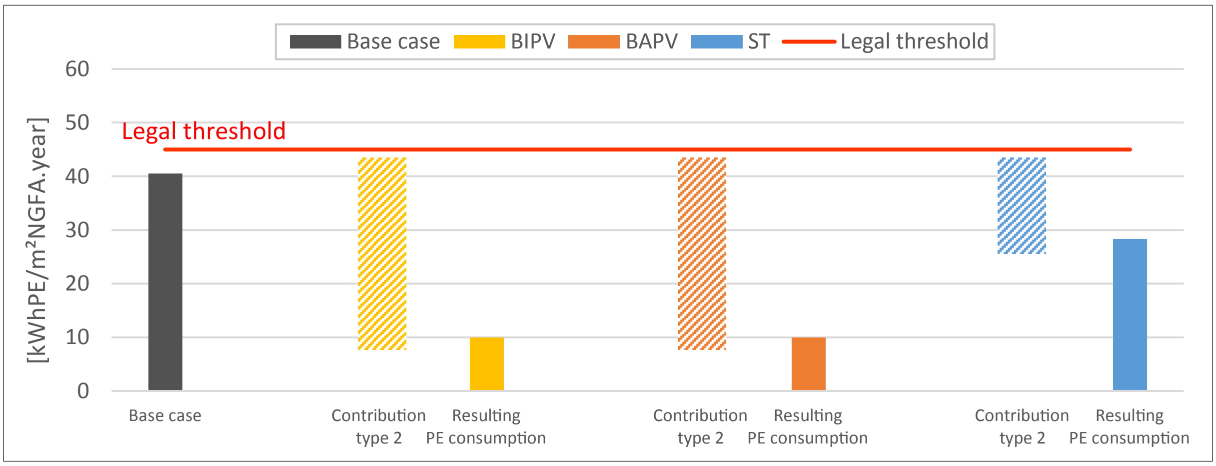


Figure 5.3.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Region of Brussels (Belgium)

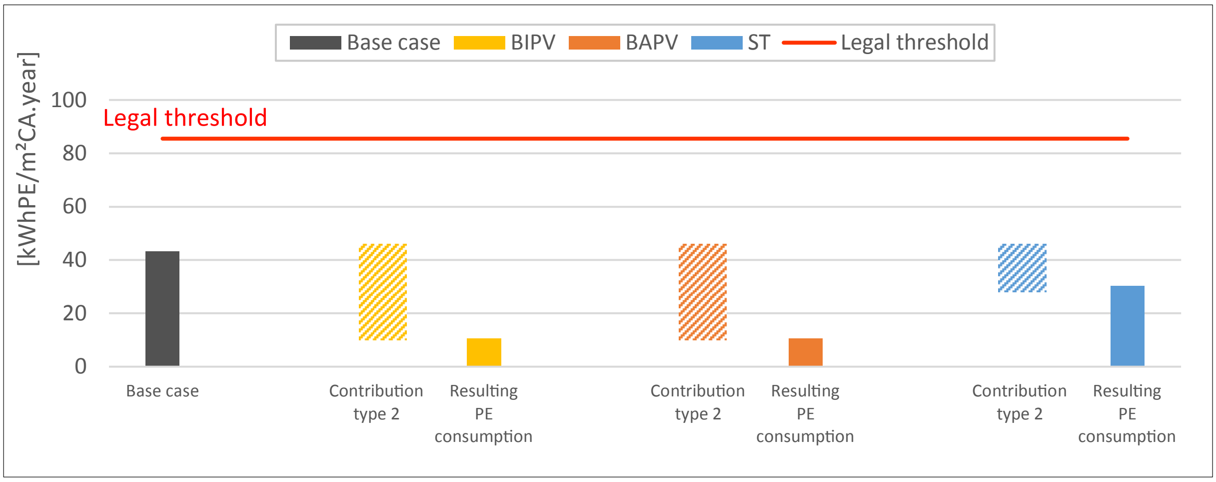


Figure 5.3.2Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Region of Wallonia (Belgium)

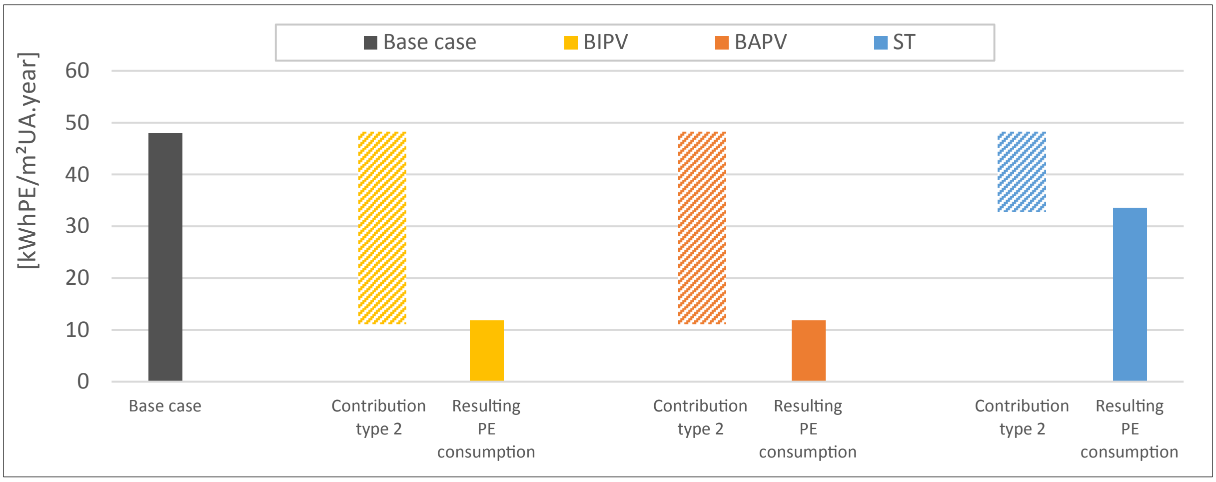


Figure 5.3.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in the Region of Flanders (Belgium)

Table 5.3.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Belgium

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-75%	-65%	-70%	-75%	-73%	-78%	-30%
East & West	-81%	-71%	-75%	-81%	-78%	-84%	NA

Table 5.3.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Belgium

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	31	14	23	10	14	7	6
East & West	17	8	12	5	7	4	*NA*

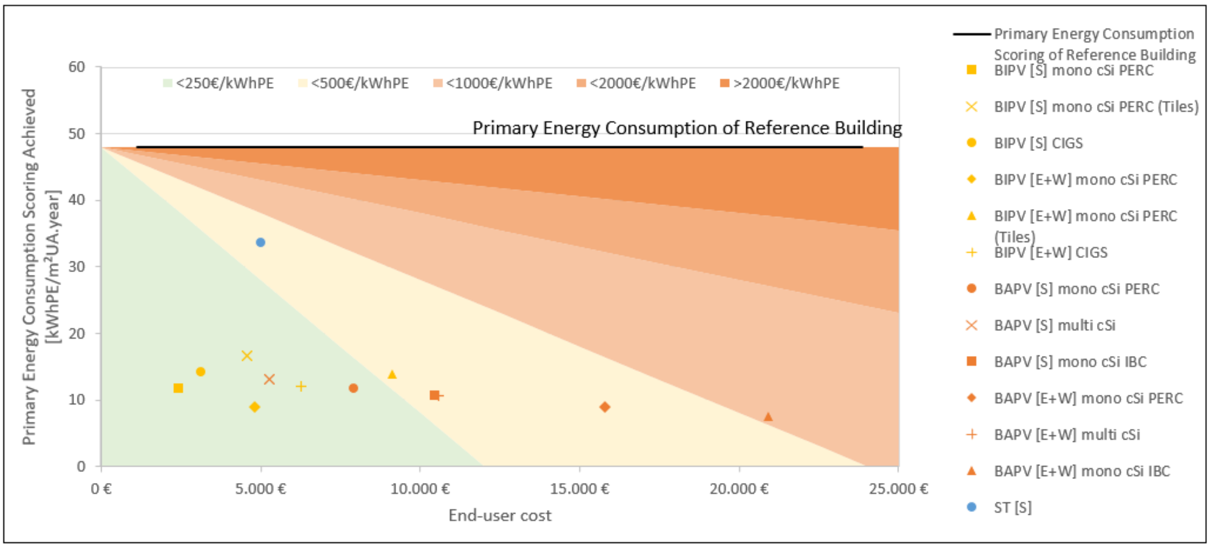


Figure 5.3.4 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Belgium

Table 5.3.4 Validation of renewable energy integration target as set by national regulation for a SFH in Flanders (Belgium)

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	Y
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

The deduction of the renewable electricity production from the total primary energy consumption is only limited by the monthly primary energy consumption. During the winter months, and to some extent during the mid-season, the monthly primary energy consumption exceeds the monthly primary energy avoided thanks to the production of renewable electricity. Type 2 contributions of BIPV and BAPV systems represented in Figure 5.3.1, Figure 5.3.2 and Figure 5.3.3 are similar. This can be explained by the fact that both considered systems have the same characteristics in terms of system power density and yield. Nevertheless, when **looking at the cost efficiency results for the different systems in Table 5.3.3 ,as the extra cost of BIPV is lower than the cost of BAPV, BIPV systems perform better**. The best cost efficiencies are reached with the mono cSi PERC-based BIPV system and the multi cSi-based BAPV system. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 250€ for most BIPV systems. Eventually allowing to, respectively, for BIPV and BAPV, improve this kWh_{PE}/m^2 scoring by 31% for each 1000€ invested and 14% per each 1000€ invested, compared to the reference building. It can also be noted that the installation of a system twice as big on the east and west orientations of the roof, compared to the south orientation only, does not result in an important additional primary energy balance decrease.

In Brussels and in the region of Wallonia, there are no renewable energy targets defined. In Flanders, the renewable energy target of 15 kWh_{EL}/m^2.year is always achieved for BIPV and BAPV with all studied technologies and all orientations. As far as solar thermal is concerned, the target of 0,025 $m^2_{solar\ thermal\ installed}/m^2_{normalisation\ area}$ is also achieved with the studied configuration.

5.3.2 Multi-family house: Case 1/2

In this first MFH case, the heating is based on heat pump, while an electric heater is used for the domestic hot water. The central ventilation system is also based on electricity.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

A further multi-family house case with different heating, cooling, ventilation and DHW equipment is presented in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.3.5 Occupied areas (m²) of studied renewable system with different technologies and orientations on a MFH in Belgium (1/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	**Occupied area [m²]**	250	250	257	257	35
South	**Installed capacity [kWp]**	44	38	28	25	NA
South	**RE system surface to net floor area [-]**	0,19	0,19	0,19	0,19	0,03
East	**Occupied area [m²]**	114	114	NA	NA	NA
East	**Installed capacity [kWp]**	20	17	NA	NA	NA
East	**RE system surface to net floor area [-]**	0,08	0,08	NA	NA	NA
West	**Occupied area [m²]**	132	132	NA	NA	NA
West	**Installed capacity [kWp]**	23	20	NA	NA	NA
West	**RE system surface to net floor area [-]**	0,10	0,10	NA	NA	NA
East & West	**Occupied area [m²]**	246	246	NA	NA	NA
East & West	**Installed capacity [kWp]**	43	38	NA	NA	NA
East & West	**RE system surface to net floor area [-]**	0,18	0,18	NA	NA	NA

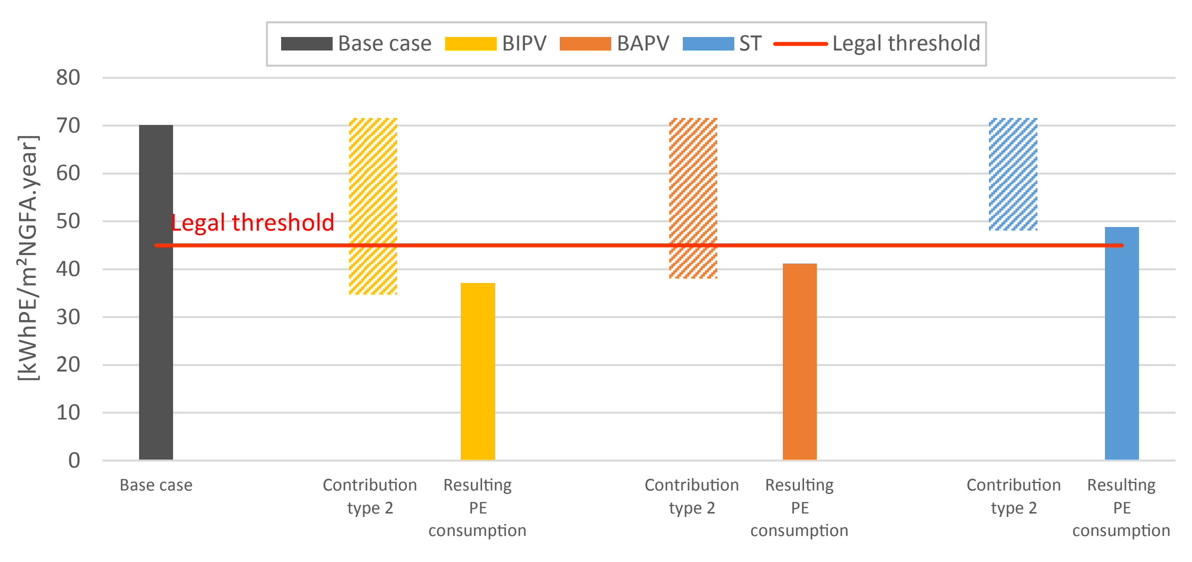


Figure 5.3.6 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in the Region of Brussels (Belgium)

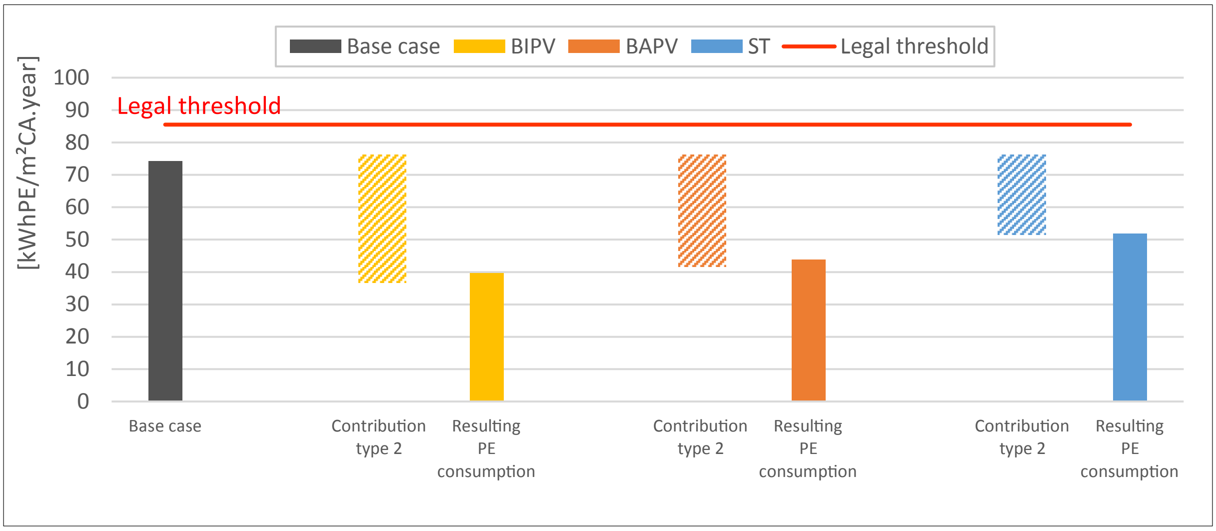


Figure 5.3.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in the Region of Wallonia (Belgium)

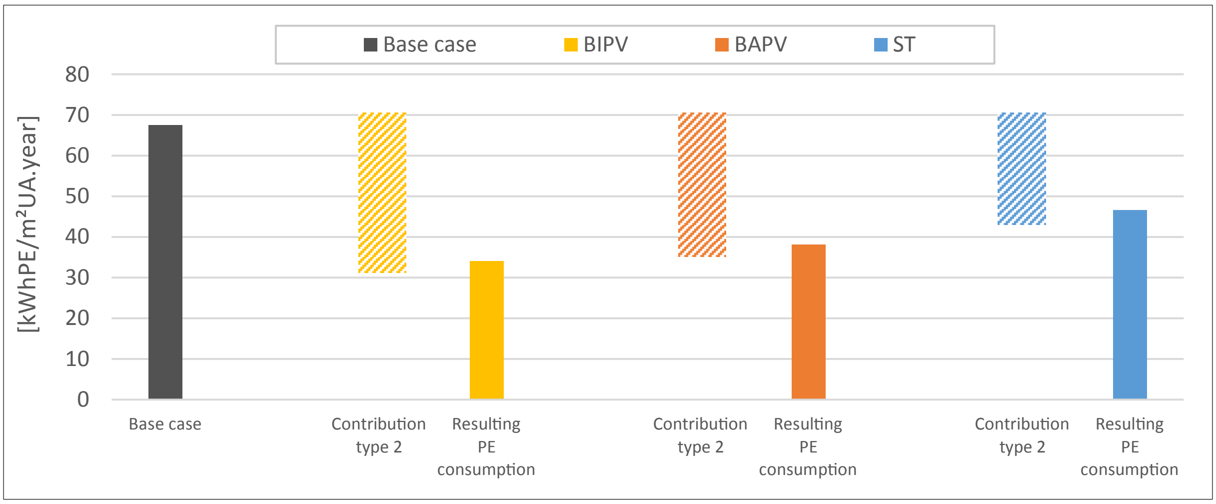


Figure 5.3.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in the Region of Flanders (Belgium)

Table 5.3.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Belgium

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-49%	-47%	-44%	-41%	-31%
East	-29%	-26%	NA	NA	NA
West	-30%	-27%	NA	NA	NA
East & West	-39%	-37%	NA	NA	NA

Table 5.3.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Belgium

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,48	0,48	1,34	1,81	1,19
East	0,61	0,59	NA	NA	NA
West	0,54	0,52	NA	NA	NA
East & West	0,38	0,38	NA	NA	NA

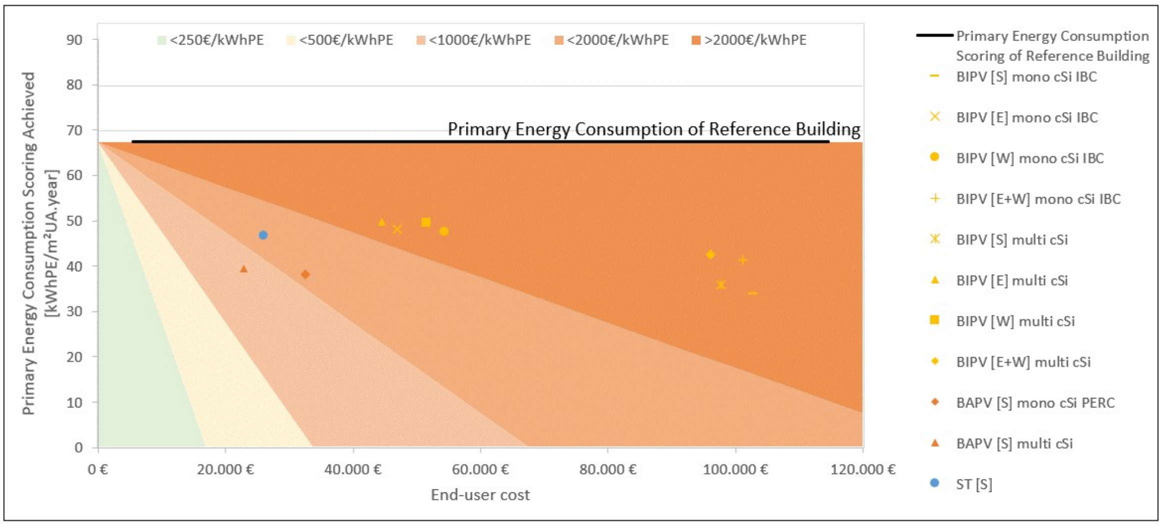


Figure 5.3.8 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Belgium

Table 5.3.8 Validation of renewable energy integration target as set by national regulation for a MFH in Flanders (Belgium)

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y
East	N	N	NA	NA	NA
West	N	N	NA	NA	NA
East & West	Y	N	NA	NA	NA

Key findings:

In Figure 5.3.5, Figure 5.3.6, Figure 5.3.7, it can be observed that the primary energy consumption reduction thanks to BIPV and BAPV are roughly comparable. This can be explained by the fact that even though the BIPV installed on the façade benefits from non-optimal irradiance conditions, the mono IBC technology allows a more important power surface density at the module level than the mono PERC-based BAPV system represented in the charts. In addition, the system power surface density is also more important for the BIPV system, since on the flat roof, the BAPV modules are installed on tilted racks, which, to avoid shadow, are installed at a certain distance from each other. This is supported by the installed capacity values in Table 5.3.5. Therefore, for an equivalent system surface, the two BIPV and BAPV technologies represented in the chart result in an equivalent primary energy balance reduction.

Yet, BAPV systems' cost efficiencies are almost up to 4 times higher than with BIPV systems, with 1,81% primary energy balance reduction per 1000€ invested reached in the case of a multi cSi-based, south-oriented BAPV system. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at around 1000€ for BAPV systems and above 2000€ for all BIPV systems. Both south-oriented BAPV and BIPV systems allow to go below the known legal thresholds.

The target of 15 kWh_{EL}/m^2.year is reached for both BIPV and BAPV systems oriented south. For BIPV oriented east, west or both, the target is not reached, mostly because the available surface on these orientations are smaller. As far as solar thermal is concerned, there are no specific requirements and the installation of this system allows by itself to reach the renewable energy integration target.

5.3.3 Educational building

This educational building’s heating is based on a connection to the district heat network, while DHW, ventilation and lighting needs are covered by electricity.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.3.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in Belgium

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	255	255	1770	1770	70
South	Installed capacity [kWp]	41	34	194	173	*NA*
South	RE system surface to net floor area [-]	0,04	0,04	0,25	0,25	0,01
East	Occupied area [m²]	316	316	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	51	42	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*
West	Occupied area [m²]	316	316	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	51	42	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	632	632	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	101	85	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*	*NA*

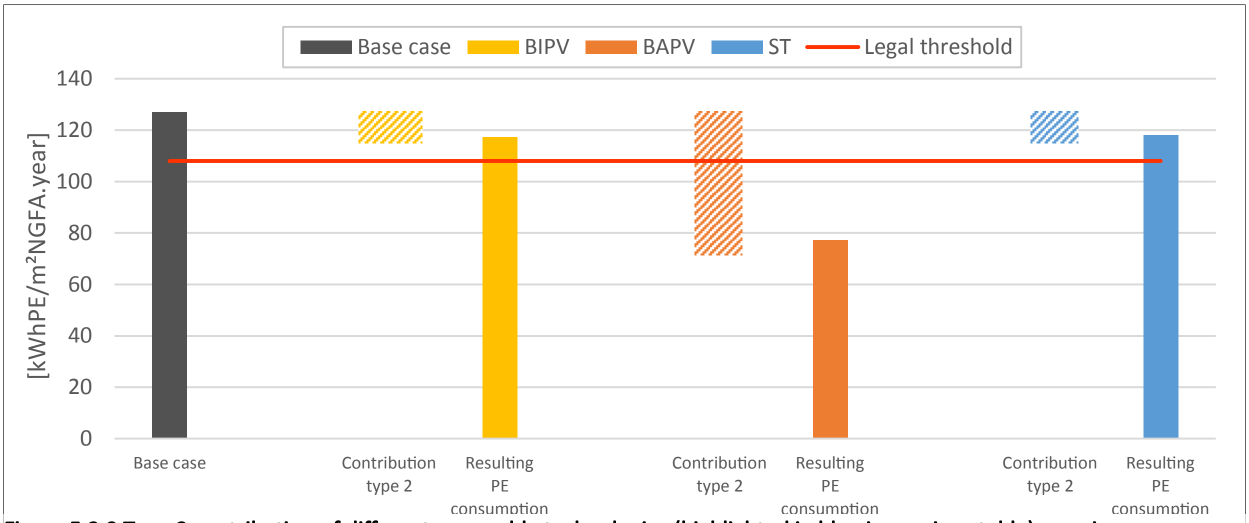


Figure 5.3.9 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in the Region of Brussels (Belgium)

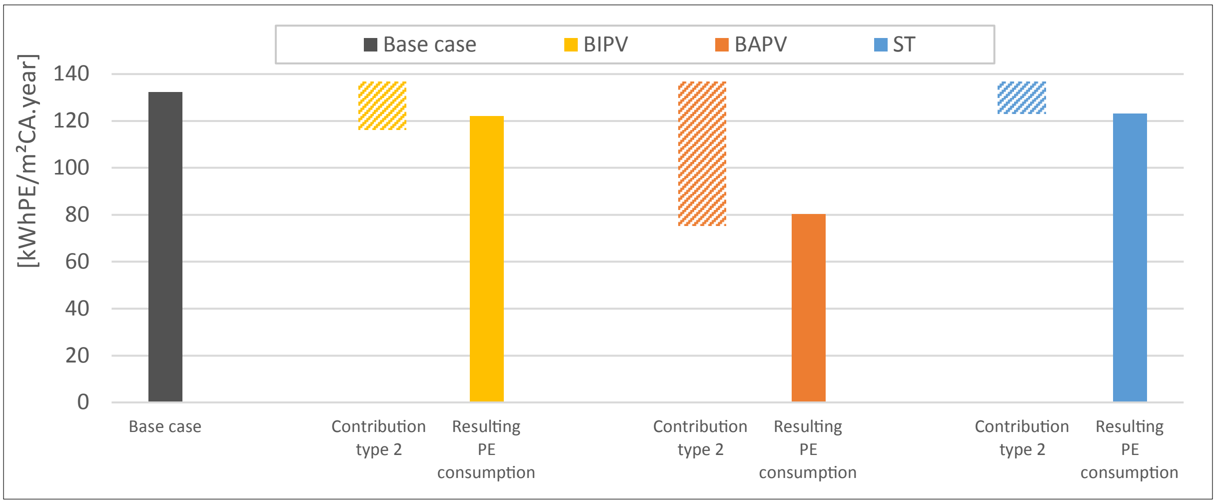


Figure 5.3.11 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in the Region of Wallonia (Belgium)

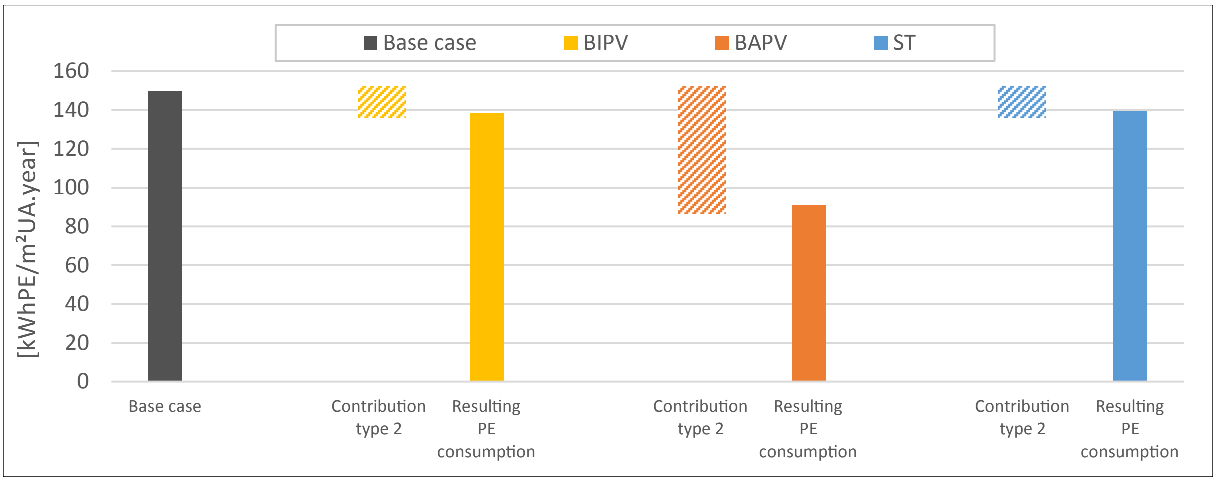


Figure 5.3.10 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in the Region of Flanders (Belgium)

Table 5.3.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in Belgium

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-8%	-6%	-39%	-36%	-7%
East	-9%	-6%	*NA*	*NA*	*NA*
West	-7%	-5%	*NA*	*NA*	*NA*
East & West	-16%	-11%	*NA*	*NA*	*NA*

Table 5.3.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in Belgium

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,13	0,11	0,19	0,24	0,15
East	0,11	0,10	*NA*	*NA*	*NA*
West	0,10	0,08	*NA*	*NA*	*NA*
East & West	0,11	0,09	*NA*	*NA*	*NA*

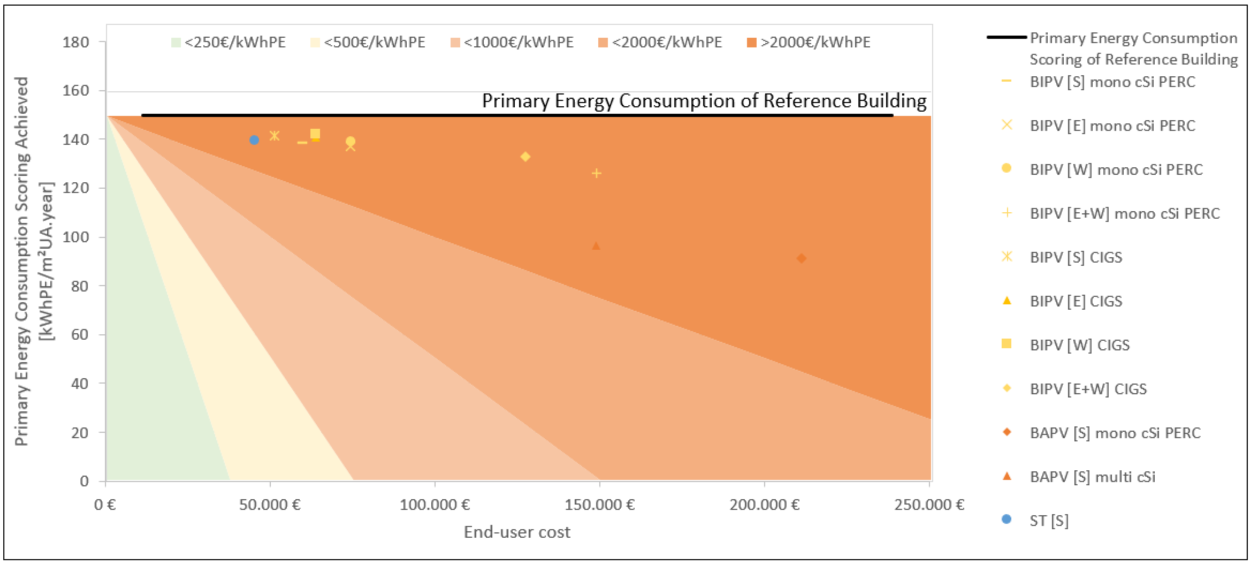


Figure 5.3.12 PE consumption scorings achieved with different renewable systems and associated cost for a EB in Belgium

Table 5.3.12 Validation of renewable energy integration target as set by national regulation for a EB in Belgium

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	N	N	Y	Y	N
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	N	N	*NA*	*NA*	*NA*

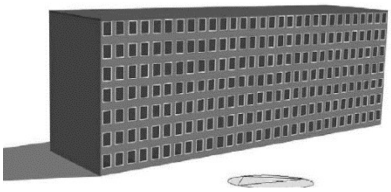
Key findings:

In the case of this educational building in Belgium, a wider gap between BIPV and BAPV can be observed. This is due both to the less favourable irradiance conditions on the façade where BIPV is installed and to the more important available surface on the educational building's roof.

Still, the gap in terms of cost efficiency between these two types of renewable energy systems is not as wide as one could have thought. The most cost-efficient BAPV system is the multi cSi-based system with a cost efficiency of 0,24% primary energy balance reduction per 1000€ invested compared to the reference building, approximately the double than for the BIPV systems. But this is mainly due to the massive gap in occupied areas. All in all, in such case, the architectural characteristics of the building naturally limit the potential of BIPV and favour BAPV.

Renewable integration target of 15 kWh/m^2 $_{\text{normalisation area}}$. is never achieved for BIPV because of poor irradiance conditions on the façade, limited available space and an important total building surface.

5.3.4 Office building: Case 1/2



This office building's heating needs are covered by a gas boiler. The remaining eligible uses (cooling, ventilation and lighting) are fuelled by electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

A further office building case with different heating, cooling and ventilation equipment is presented in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.3.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Belgium

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	NA	NA
East	Installed capacity [kWp]	67	16	NA	NA
East	RE system surface to net floor area [-]	0,11	0,11	NA	NA
West	Occupied area [m²]	666	666	NA	NA
West	Installed capacity [kWp]	67	16	NA	NA
West	RE system surface to net floor area [-]	0,11	0,11	NA	NA
East & West	Occupied area [m²]	1331	1331	NA	NA
East & West	Installed capacity [kWp]	133	33	NA	NA
East & West	RE system surface to net floor area [-]	0,22	0,22	NA	NA

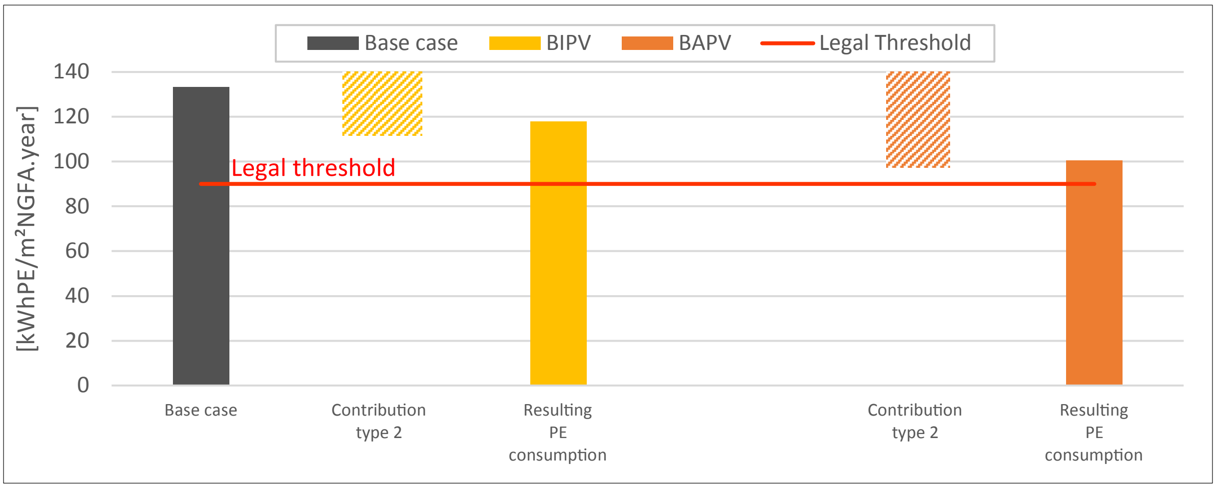


Figure 5.3.15 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in the Region of Brussels (Belgium)

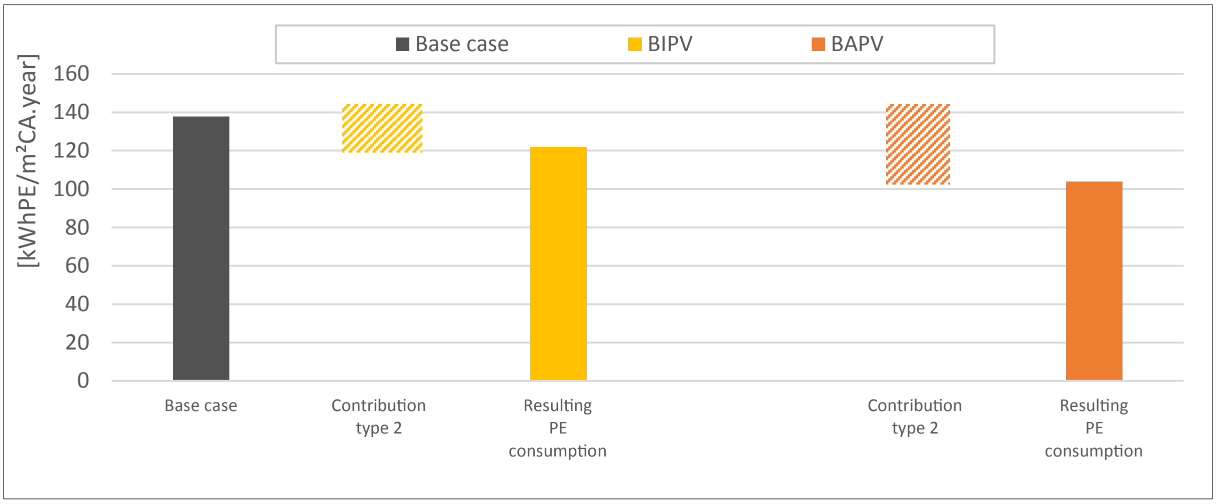


Figure 5.3.14 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in the Region of Wallonia (Belgium)

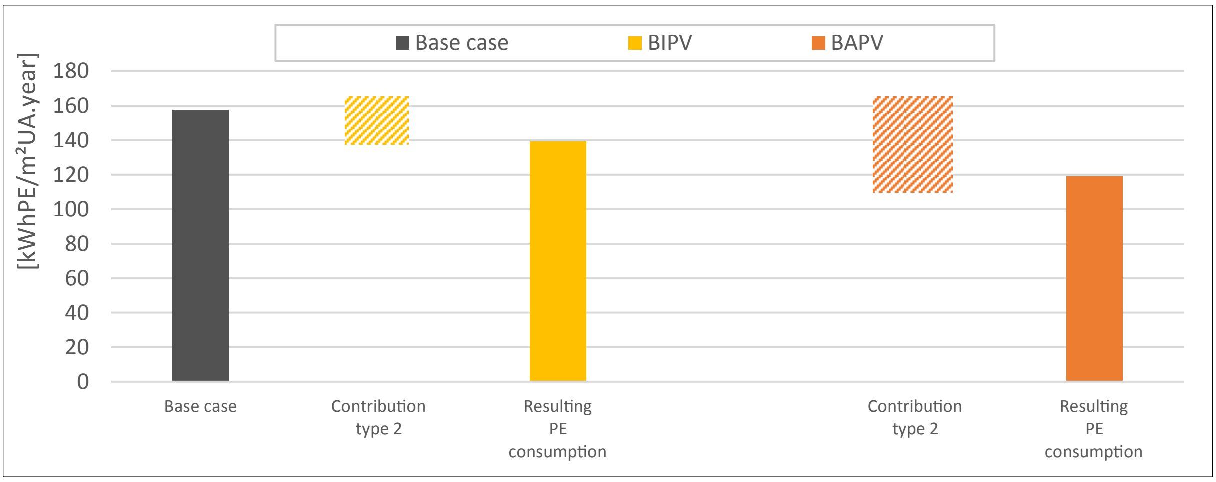


Figure 5.3.13 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in the Region of Flanders (Belgium)

Table 5.3.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Belgium

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-12%	-3%	-25%	-22%
East	-10%	-3%	NA	NA
West	-9%	-2%	NA	NA
East & West	-19%	-5%	NA	NA

Table 5.3.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Belgium

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,04	0,01	0,23	0,29
East	0,03	0,01	NA	NA
West	0,03	0,01	NA	NA
East & West	0,03	0,01	NA	NA

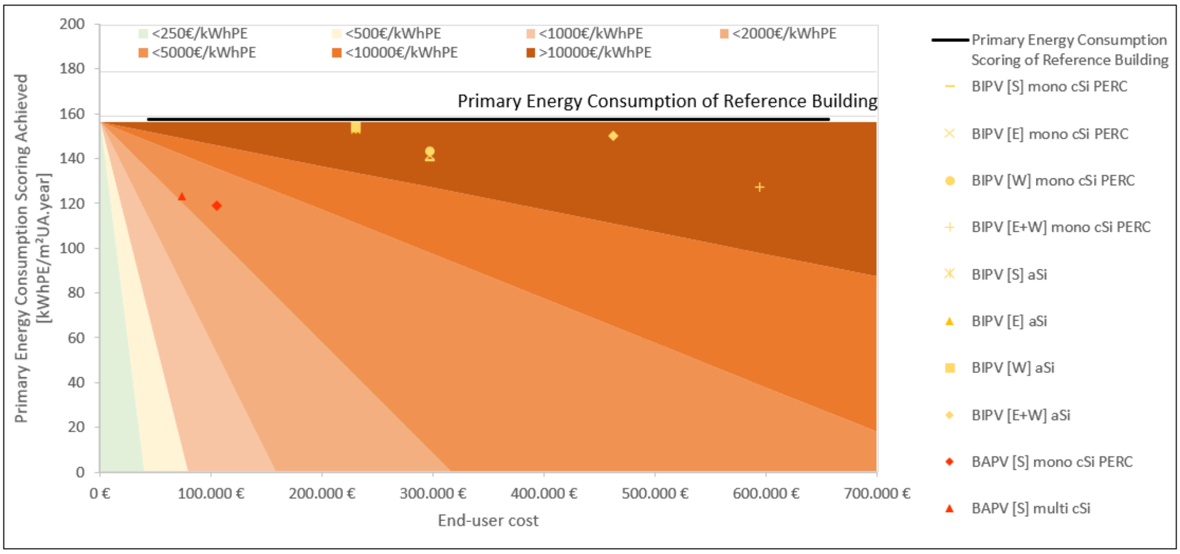


Figure 5.3.16 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Belgium

Table 5.3.16 Validation of renewable energy integration target as set by national regulation for a OB in Belgium

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	Y	N
East	N	N	NA	NA
West	N	N	NA	NA
East & West	N	N	NA	NA

Key findings:

Compared to the educational building, the available surface on the roof for the BAPV and available surface on the façade for the BIPV system are more comparable. By installing the mono PERC semi-transparent BIPV curtain wall on east and west façade, an equivalent primary energy consumption reduction can be achieved to the one reached with the BAPV system on the roof.

Nevertheless, the BAPV system is a significantly more cost-efficient solution. Indeed, BAPV cost efficiencies are 5 to 30 times more important than the ones for BIPV systems. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at around 2000€. Again, it is mainly caused by its advantageous electricity generation.

It is also the only renewable system which enable to reach the renewable energy integration target.

5.4 France

5.4.1 Single family house

This single-family house's heating and DHW needs are covered by gas. There is no cooling system.

The three tested BIPV systems (mono cSi PERC-based PV tiles, multi cSi-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.4.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in France

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	30	30	30	30	30	30	4
South	Installed capacity [kWp]	5	3	4	5	5	6	*NA*
South	RE system surface to net floor area [-]	0,16	0,16	0,16	0,16	0,16	0,16	0,02
East & West	Occupied area [m²]	60	60	60	60	60	60	*NA*
East & West	Installed capacity [kWp]	11	6	8	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,32	0,32	0,32	0,32	0,32	0,32	*NA*

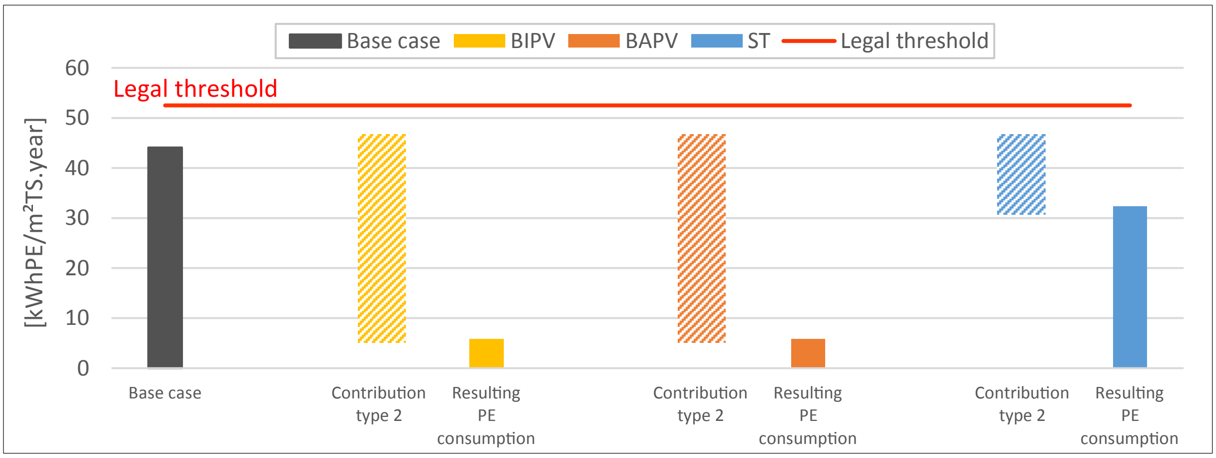


Figure 5.4.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in France

Table 5.4.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in France

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-87%	-77%	-80%	-87%	-83%	-82%	-26%
East & West	-95%	-81%	-86%	-95%	-90%	-98%	NA

Table 5.4.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in France

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	26	12	19	8	12	6	6
East & West	14	7	10	4	6	3	NA

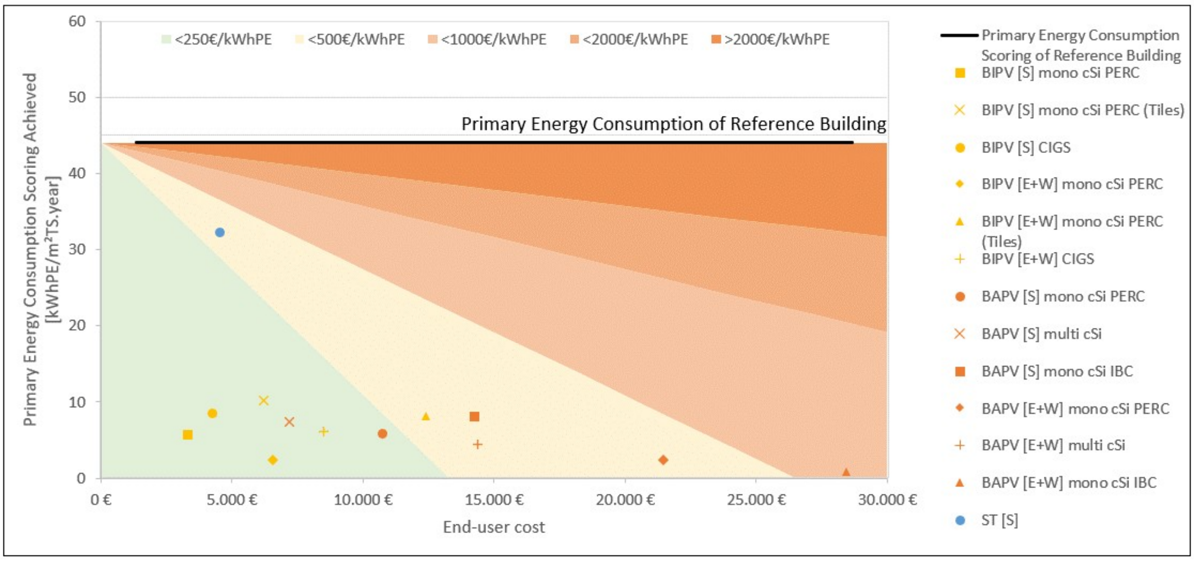


Figure 5.4.2 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in France

Table 5.4.4 Validation of renewable energy integration target as set by national regulation for a SFH in France

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	Y
East & West	Y	Y	Y	Y	Y	Y	NA

Key findings:

The deduction of the renewable electricity production from the total primary energy consumption is only limited by the seasonal primary energy consumption. During the winter months, and to some extent during the mid-season, the monthly primary energy consumption exceeds the monthly primary energy avoided thanks to the production of renewable electricity. Type 2 contributions of BIPV and BAPV systems represented in Figure 5.4.1 and Table 5.4.2 are similar. This can be explained by the fact that both considered systems have the same characteristics in terms of system power density and yield. Table 5.3.2Nevertheless, when looking at the cost efficiency results for the different systems in

Table 5.4.3, as the extra cost of BIPV is lower than the cost of BAPV, BIPV systems perform better with regards to this indicator.

The best cost efficiencies are reached with the multi cSi-based BIPV and BAPV systems. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 250€ for most BIPV systems. Eventually allowing to, respectively, for BIPV and BAPV, improve this kWh_{PE}/m^2 scoring by 26% for each 1000€ invested and 12% per each 1000€ invested, compared to the reference building.

It can also be noted that the installation of a system twice as big on the east and west orientations of the roof, compared to the south orientation only, does not result in an important additional primary energy consumption decrease.

The renewable integration target consists in producing 5 kWh_{PE}/m^2 of normalised area. This target is reached for both BIPV and BAPV systems for the different orientations and technologies studied. When a solar thermal system is installed, a specific target is defined, which is that the solar thermal system should be at least 2m². This condition is also validated in the studied configuration.

5.4.2 Multi-family house: Case ½

In this first MFH case, the heating is based on heat pump, while an electric heater is used for the domestic hot water. The central ventilation system is also based on electricity.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

A further multi-family house case with different heating, cooling, ventilation and DHW equipment is presented in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.4.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in France (1/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	**Occupied area [m²]**	250	250	257	257	30
South	**Installed capacity [kWp]**	44	38	28	25	*NA*
South	**RE system surface to net floor area [-]**	0,19	0,19	0,19	0,19	0,02
East	**Occupied area [m²]**	114	114	*NA*	*NA*	*NA*
East	**Installed capacity [kWp]**	20	17	*NA*	*NA*	*NA*
East	**RE system surface to net floor area [-]**	0,08	0,08	*NA*	*NA*	*NA*
West	**Occupied area [m²]**	132	132	*NA*	*NA*	*NA*
West	**Installed capacity [kWp]**	23	20	*NA*	*NA*	*NA*
West	**RE system surface to net floor area [-]**	0,10	0,10	*NA*	*NA*	*NA*
East & West	**Occupied area [m²]**	246	246	*NA*	*NA*	*NA*
East & West	**Installed capacity [kWp]**	43	38	*NA*	*NA*	*NA*
East & West	**RE system surface to net floor area [-]**	0,18	0,18	*NA*	*NA*	*NA*

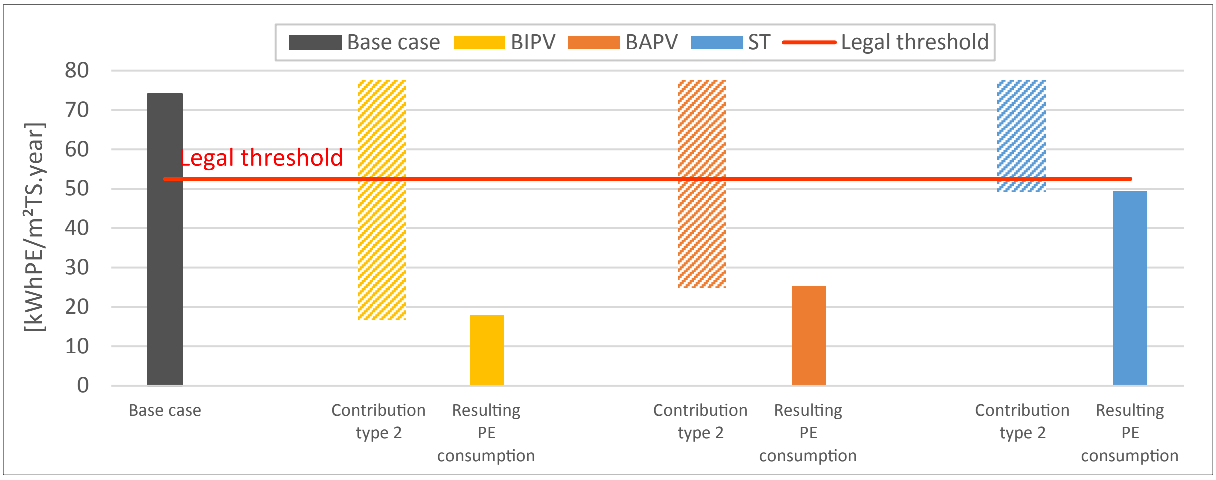


Figure 5.4.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in France

Table 5.4.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in France

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-76%	-67%	-66%	-60%	-33%
East	-33%	-30%	*NA*	*NA*	*NA*
West	-33%	-31%	*NA*	*NA*	*NA*
East & West	-54%	-49%	*NA*	*NA*	*NA*

Table 5.4.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in France

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,65	0,61	1,78	2,30	1,32
East	0,63	0,60	*NA*	*NA*	*NA*
West	0,54	0,52	*NA*	*NA*	*NA*
East & West	0,47	0,45	*NA*	*NA*	*NA*

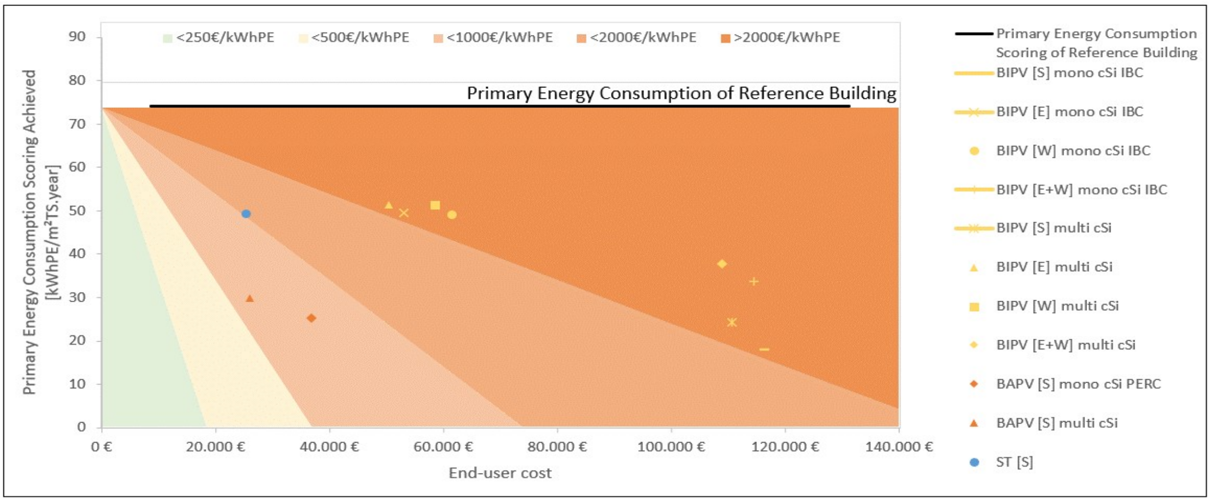


Figure 5.4.4 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in France

Table 5.4.8 Validation of renewable energy integration target as set by national regulation for a MFH in France

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	*No target*	*No target*	*No target*	*No target*	*No target*
East	*No target*	*No target*	*NA*	*NA*	*NA*
West	*No target*	*No target*	*NA*	*NA*	*NA*
East & West	*No target*	*No target*	*NA*	*NA*	*NA*

Key findings:

In Figure 5.4.3, it can be observed that the primary energy consumption reduction thanks to BIPV and BAPV are roughly comparable, with a slight advantage for the former. This can be explained by the fact that, even though the BIPV installed on the façade benefits from non-optimal irradiance conditions, the mono IBC technology allows a more important surface power density at the module level than the mono PERC-based BAPV system represented in the charts. In addition, the system surface power density is also more important for the BIPV system, since on the flat roof, the BAPV modules are installed on tilted racks, which, to avoid shadow, are installed at a certain distance from each other. This is supported by the installed capacity values presented in Table 5.4.5. Therefore, for an equivalent occupied area, the two BIPV and BAPV technologies represented in the chart result in an equivalent primary energy balance reduction.

In terms of cost efficiency, the values reached with BAPV systems are 3 to 4 times better than with BIPV systems, when oriented south. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 1000€ for BAPV systems.

For all three studied systems, the primary energy balance lies below the legal threshold once their contribution has been taken into account.

There are no renewable energy integration targets defined for multi-family houses.

5.4.3 Educational building

This educational building in France is a kindergarten thus explaining the particularly low primary energy consumption of the reference building.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.4.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in France

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	130	130	800	800	20
South	Installed capacity [kWp]	21	17	88	78	*NA*
South	RE system surface to net floor area [-]	0,04	0,04	0,22	0,22	0,01
East	Occupied area [m²]	80	80	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	13	11	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,02	0,02	*NA*	*NA*	*NA*
West	Occupied area [m²]	80	80	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	13	11	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,02	0,02	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	160	160	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	26	21	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*

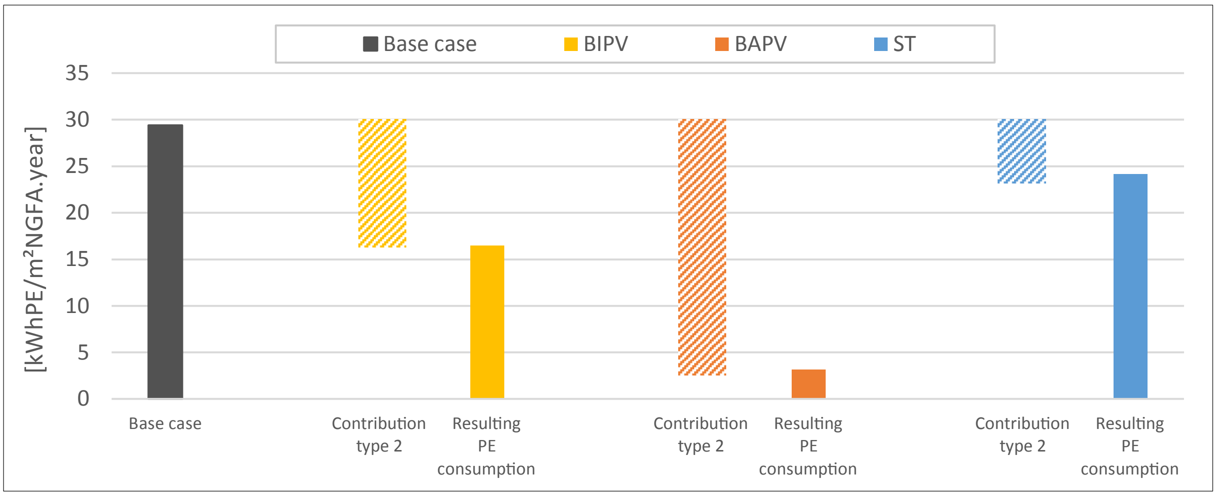


Figure 5.4.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in France

Table 5.4.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in France

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-44%	-32%	-89%	-87%	-18%
East	-24%	-17%	NA	NA	NA
West	-20%	-14%	NA	NA	NA
East & West	-39%	-31%	NA	NA	NA

Table 5.4.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in France

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	1,44	1,21	0,94	1,29	1,37
East	1,25	1,05	NA	NA	NA
West	1,07	0,90	NA	NA	NA
East & West	1,03	0,97	NA	NA	NA

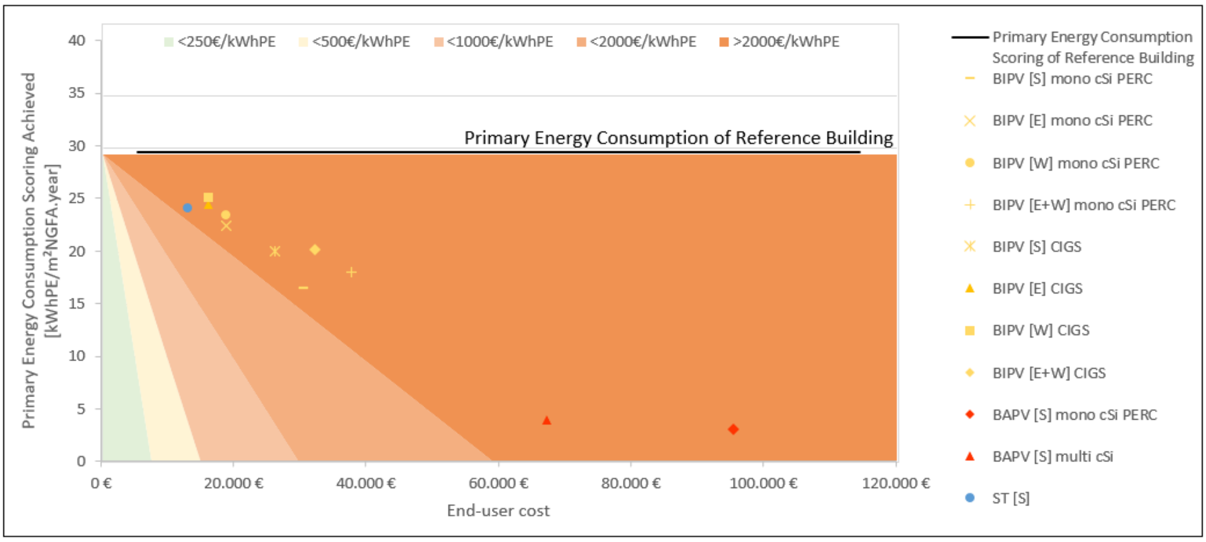


Figure 5.4.6 PE consumption scorings achieved with different renewable systems and associated cost for a EB in France

Table 5.4.12 Validation of renewable energy integration target as set by national regulation for a EB in France

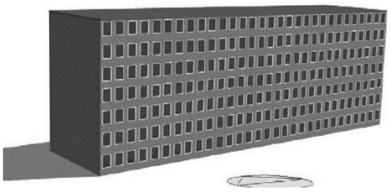
	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	*No target*	*No target*	*No target*	*No target*	*No target*
East	*No target*	*No target*	NA	NA	NA
West	*No target*	*No target*	NA	NA	NA
East & West	*No target*	*No target*	NA	NA	NA

Key findings:

The installation of a BAPV system on the flat roof of the building allows a significant reduction of the primary energy balance, but **BIPV systems remain the most efficient system to install, if placed on the southern façade,** closely followed by the solar thermal system.

There are no renewable energy integration targets defined for educational buildings in France.

5.4.4 Office building: Case 2/2



This office building’s heating needs are covered by a gas boiler. The remaining eligible uses (cooling, ventilation and lighting) are fuelled by electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

A further office building case with different heating, cooling and ventilation equipment is presented in in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.4.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in France

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

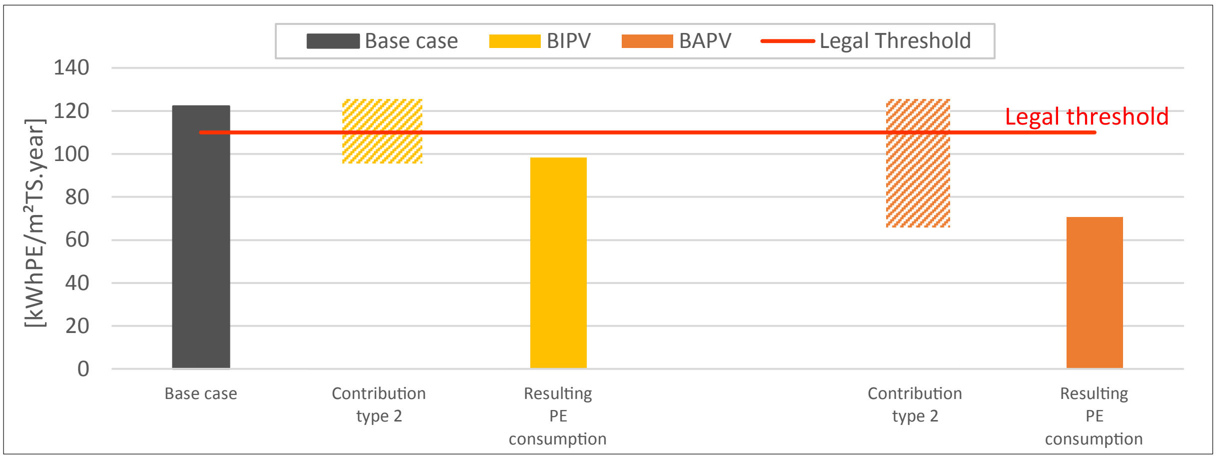


Figure 5.4.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in France

Table 5.4.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in France

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-20%	-5%	-42%	-37%
East	-17%	-4%	*NA*	*NA*
West	-15%	-4%	*NA*	*NA*
East & West	-31%	-8%	*NA*	*NA*

Table 5.4.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in France

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,07	0,02	0,40	0,51
East	0,06	0,02	*NA*	*NA*
West	0,05	0,02	*NA*	*NA*
East & West	0,05	0,02	*NA*	*NA*

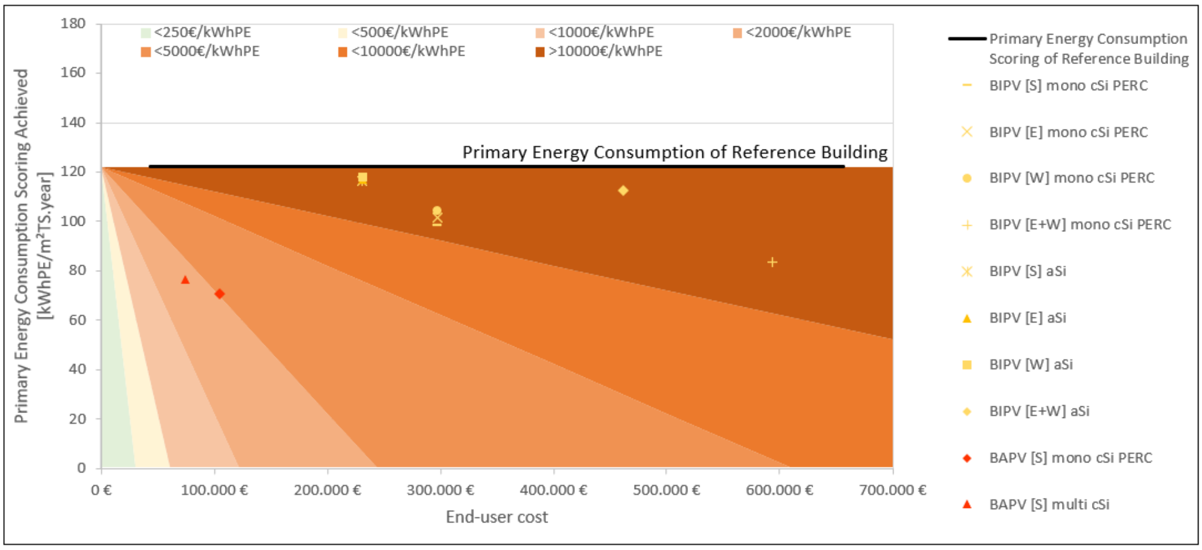


Figure 5.4.8 PE consumption scorings achieved with different renewable systems and associated cost for a OB in France

Table 5.4.16 Validation of renewable energy integration target as set by national regulation for a OB in France

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	*No target*	*No target*	No target	No target
East	*No target*	*No target*	*NA*	*NA*
West	*No target*	*No target*	*NA*	*NA*
East & West	*No target*	*No target*	*NA*	*NA*

Key findings:

The installation of a semi-transparent BIPV system only allows limited primary energy balance reduction, especially when an aSi-based solution is chosen. Yet, by installing the mono PERC semi-transparent BIPV curtain wall on east and west façade, an almost equivalent primary energy balance reduction can be achieved to the one reached with the BAPV system on the roof.

The advantage in terms of electricity production also leads the BAPV system to be a more cost-efficient solution than BIPV, in this particular case. Indeed, cost efficiencies reached with BIPV systems range from 0,02 to 0,07% primary energy balance reduction per 1000€ invested while, for BAPV systems they range from 0,40 to 0,51% primary energy balance reduction per 1000€ invested.

Nevertheless, the legal threshold defined for office buildings, can be reached with both the mono cSi PERC-based BIPV system and both studied BAPV systems.

There are no renewable energy integration targets for office buildings in France.

5.5 Germany

5.5.1 Single family house: Case 1/2

In this first single-family house, the heating, DHW and ventilation needs are covered by electricity. There is no cooling system.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.5.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Germany (1/2)

		BIPV mono cSi PERC (roof)	**BIPV mono cSi PERC (Tiles) (roof)**	**BIPV CIGS (roof)**	**BAPV mono cSi PERC (roof)**	**BAPV multi cSi (roof)**	**BAPV mono cSi IBC (roof)**	**Solar Thermal (roof)**
South	**Occupied area [m²]**	50	50	50	50	50	50	*NA*
South	**Installed capacity [kWp]**	9	5	7	9	8	10	*NA*
South	**RE system surface to net floor area [-]**	0,21	0,21	0,21	0,21	0,21	0,21	*NA*
East & West	**Occupied area [m²]**	100	100	100	60	60	60	*NA*
East & West	**Installed capacity [kWp]**	18	11	13	11	9	12	*NA*
East & West	**RE system surface to net floor area [-]**	0,42	0,42	0,42	0,25	0,25	0,25	*NA*

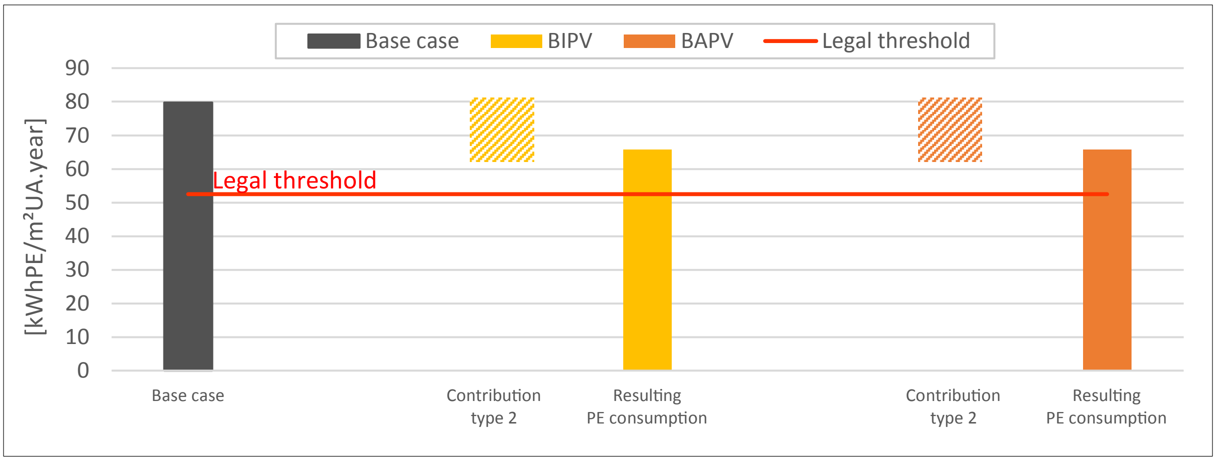


Figure 5.5.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Germany

Table 5.5.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Germany

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-18%	-18%	-18%	-18%	-18%	-18%	NA
East & West	-18%	-18%	-18%	-18%	-18%	-18%	NA

Table 5.5.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Germany

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	3	2	2	1	1	1	*NA*
East & West	2	1	1	1	1	1	*NA*

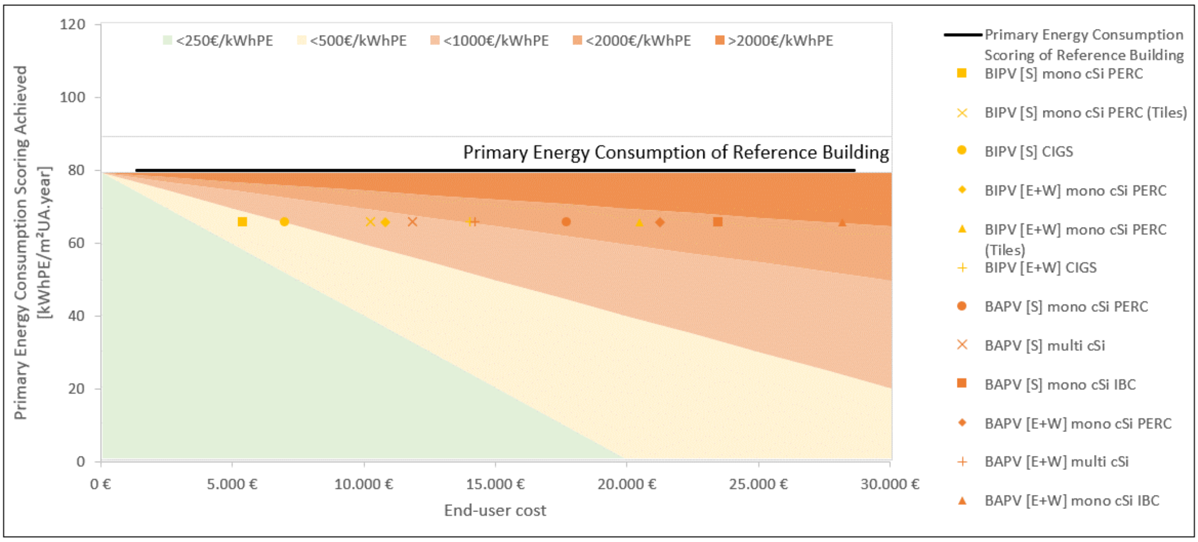


Figure 5.5.2 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Germany

Table 5.5.4 Validation of renewable energy integration target as set by national regulation for a SFH in Germany

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	*NA*
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

As it can be observed in Table 5.5.2, there is no difference in terms of primary energy consumption reduction between the BIPV and BAPV system. Indeed, in Germany, the deductible renewable energy production is calculated as the minimum of three values, one of them being 20% of the reference building primary energy consumption. In this case, those 20% are always the minimum value and therefore are determining the deductible renewable production. As a result, the cost efficiency indicator values gathered in Table 5.5.3 are rather low compared to SFH in France or Belgium, as an important part of the BIPV or BAPV system does not contribute to reduce the primary energy consumption. **Although, one can note that the BIPV options are the most cost efficient, considering their positions on the graph.**

The legal threshold is neither reached with BIPV systems nor with BAPV systems. This is due to the way the nZEB regulation limits the part of the renewable production that can contribute to reduce the primary energy balance.

The criterion to reach the renewable energy integration target for SFH in Germany is either to install 0,02 $Wp/m^2_{\text{normalisation area}}$ or to cover 15% of heating and cooling needs with renewable energy. As the first criterion is achieved, the target is reached.

5.5.2 Single family house: Case 2/2

In this single-family house, except for the ventilation needs which are covered by electricity, the remaining needs for heating and DHW are covered by a gas boiler.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.5.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Germany (2/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	25	25	25	25	25	25	5
South	Installed capacity [kWp]	4	3	3	4	4	5	0
South	RE system surface to net floor area [-]	0,16	0,16	0,16	0,16	0,16	0,16	*NA*
East & West	Occupied area [m²]	50	50	50	50	50	50	*NA*
East & West	Installed capacity [kWp]	9	5	7	9	8	10	*NA*
East & West	RE system surface to net floor area [-]	0,31	0,31	0,31	0,31	0,31	0,31	*NA*

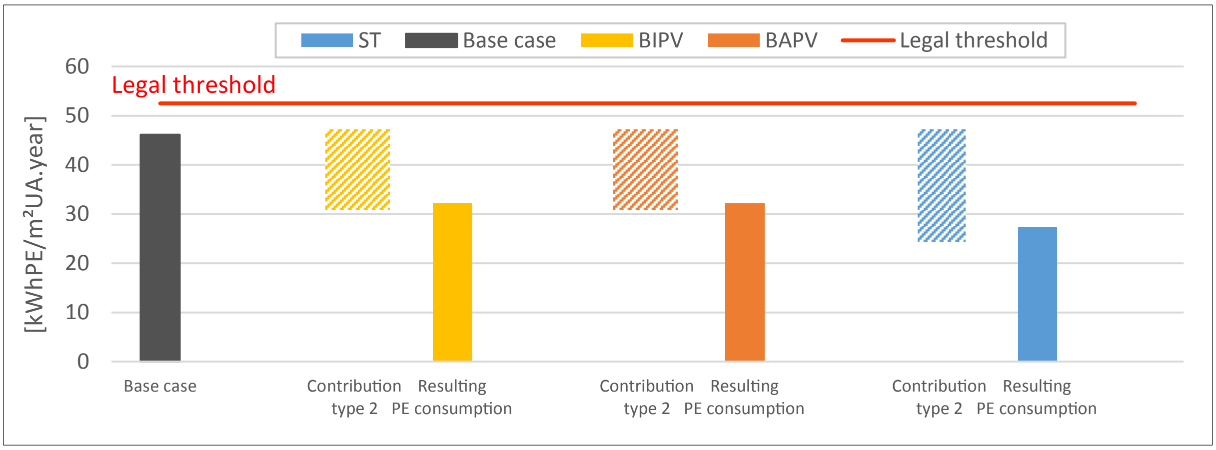


Figure 5.5.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Germany

Table 5.5.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Germany

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-30%	-30%	-30%	-30%	-30%	-30%	-41%
East & West	-30%	-30%	-30%	-30%	-30%	-30%	NA

Table 5.5.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Germany

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	11	6	9	3	5	3	7
East & West	6	3	4	2	3	1	*NA*

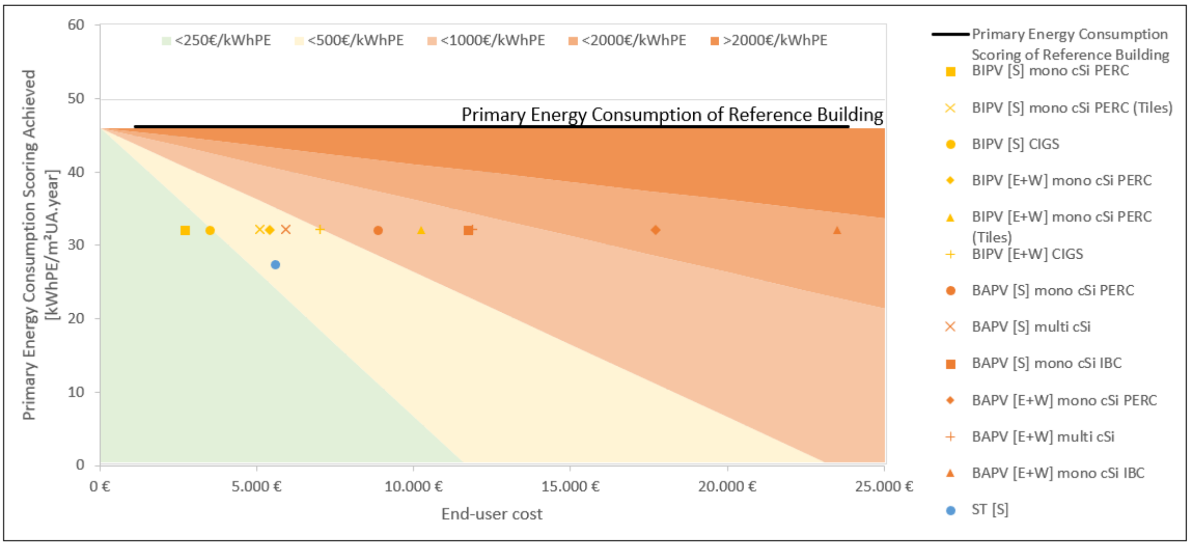


Figure 5.5.4 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Germany

Table 5.5.8 Validation of renewable energy integration target as set by national regulation for a SFH in Germany

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	N	Y	Y	Y	Y	N
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

As in the first SFH case, the deductible renewable production is the same for all PV systems and their different configurations. This limit in terms of deductible renewable electricity production is such that, in this case, a solar thermal system allows to achieve a better primary energy consumption scoring. Overall, as for the previous case, most BIPV systems are more cost-efficient solutions than BAPV systems. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 250€ for the mono cSi PERC-based, south-oriented in roof mounting BIPV systems. Eventually allowing to, improve this kWh_{PE}/m^2 scoring by 11% for each 1000€ invested.

The criterion to reach the renewable energy integration target for SFH in Germany is either to install 0,02 $Wp/m^2_{\text{normalised area}}$ or to cover 15% of heating and cooling needs with renewable energy. Except for the BIPV system based on mono PERC (PV tiles) installed on a south orientation, the first criterion is always achieved. Indeed, for this particular system, the coverage ratio is the least important of all three BIPV systems considered, which is confirmed by the installed capacities presented in Table 5.5.5. Then, considering solar thermal, as it only covers a part of the DHW needs, it cannot allow to comply with the second criterion.

5.5.3 Multi-family house: Case ½

In this MFH different eligible uses are all fuelled by electricity.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.5.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in Germany (1/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	**Occupied area [m²]**	250	250	257	257	35
South	**Installed capacity [kWp]**	44	38	28	25	*NA*
South	**RE system surface to net floor area [-]**	0,19	0,19	0,19	0,19	0,03
East	**Occupied area [m²]**	114	114	*NA*	*NA*	*NA*
East	**Installed capacity [kWp]**	20	17	*NA*	*NA*	*NA*
East	**RE system surface to net floor area [-]**	0,08	0,08	*NA*	*NA*	*NA*
West	**Occupied area [m²]**	132	132	*NA*	*NA*	*NA*
West	**Installed capacity [kWp]**	23	20	*NA*	*NA*	*NA*
West	**RE system surface to net floor area [-]**	0,10	0,10	*NA*	*NA*	*NA*
East & West	**Occupied area [m²]**	246	246	*NA*	*NA*	*NA*
East & West	**Installed capacity [kWp]**	43	38	*NA*	*NA*	*NA*
East & West	**RE system surface to net floor area [-]**	0,18	0,18	*NA*	*NA*	*NA*

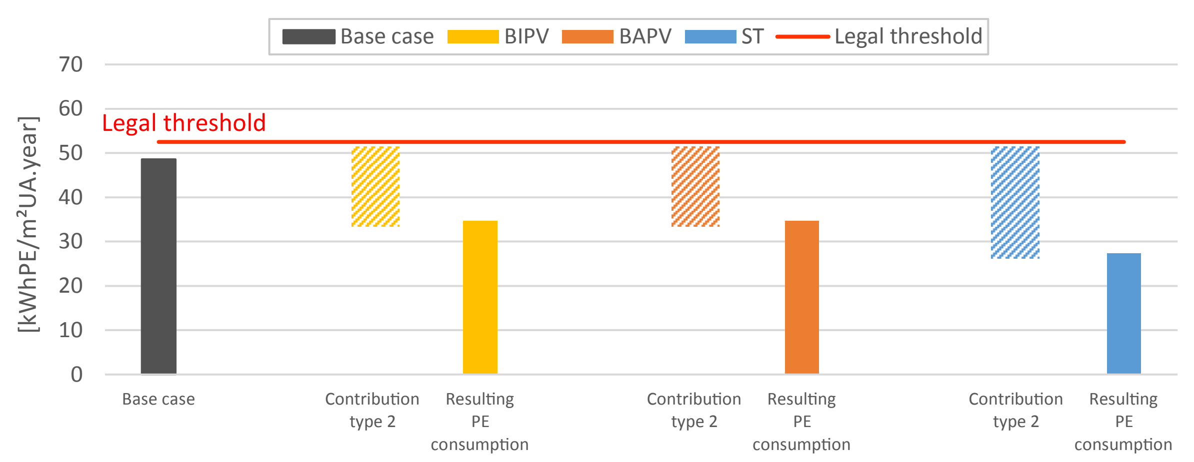


Figure 5.5.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in Germany

Table 5.5.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Germany

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-29%	-29%	-29%	-29%	-44%
East	-29%	-29%	*NA*	*NA*	*NA*
West	-29%	-29%	*NA*	*NA*	*NA*
East & West	-29%	-29%	*NA*	*NA*	*NA*

Table 5.5.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Germany

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,25	0,26	0,79	1,12	1,50
East	0,55	0,58	*NA*	*NA*	*NA*
West	0,47	0,50	*NA*	*NA*	*NA*
East & West	0,25	0,27	*NA*	*NA*	*NA*

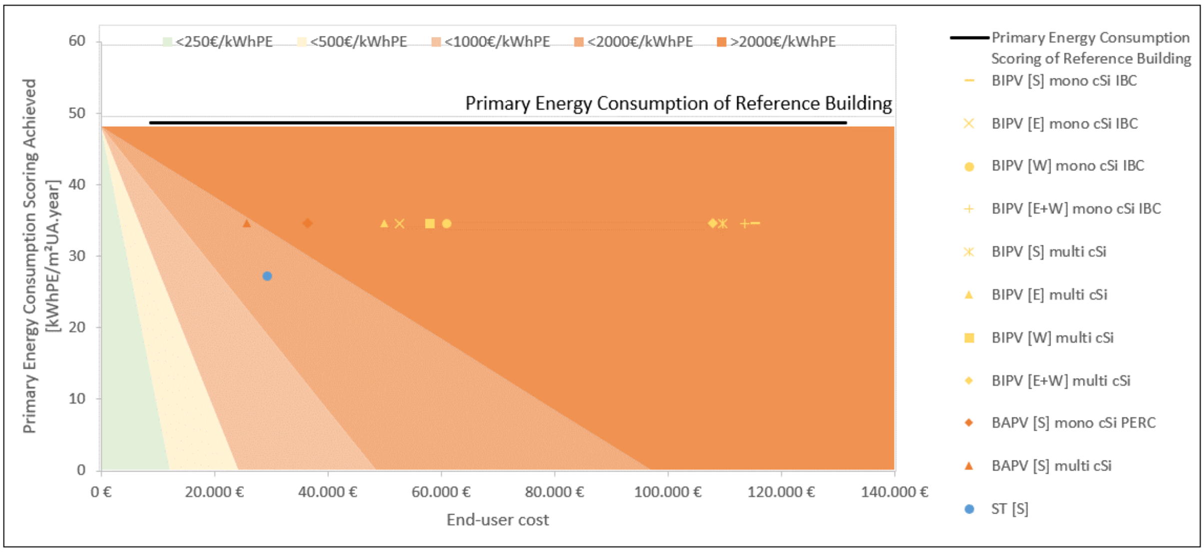


Figure 5.5.6 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Germany

Table 5.5.12 Validation of renewable energy integration target as set by national regulation for a MFH in Germany

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	N
East	Y	Y	*NA*	*NA*	*NA*
West	Y	Y	*NA*	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*	*NA*

Key findings:

As for the SFH cases, BIPV and BAPV systems with all studied orientations and technologies allow to reduce the primary energy balance by the same amount. Due to this limitation, in terms of cost efficiency, BAPV systems score better with 1,12% primary energy balance reduction per 1000€ invested achieved with the multi cSi-based BAPV system against 0,26% primary energy balance reduction per 1000€ invested for its equivalent BIPV system.

In terms of renewable energy integration target, both BIPV and BAPV system allow to meet the 0,02 Wp/m² criterion. The solar thermal system, by only covering a part of the DHW needs, does not allow to meet the 15% heating and cooling needs coverage target.

5.5.4 Multi-family house: Case 2/2

In this second MFH case, the heating and DHW needs are covered through a connection to the district heat network. As the primary energy factor used for this energy vector is 0,3 in Germany, this explains why the reference building's primary energy consumption is very low.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.5.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in Germany (2/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	250	250	257	257	35
South	Installed capacity [kWp]	44	38	28	25	*NA*
South	RE system surface to net floor area [-]	0,19	0,19	0,19	0,19	0,03
East	Occupied area [m²]	114	114	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	20	17	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,08	0,08	*NA*	*NA*	*NA*
West	Occupied area [m²]	132	132	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	23	20	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,10	0,10	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	246	246	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	43	38	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*	*NA*

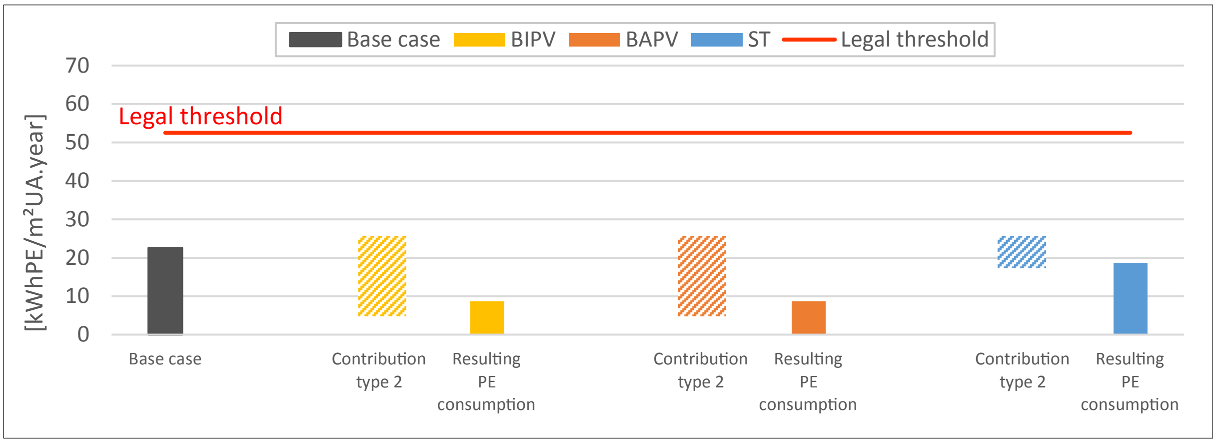


Figure 5.5.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in Germany

Table 5.5.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Germany

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-62%	-62%	-62%	-62%	-17%
East	-62%	-62%	*NA*	*NA*	*NA*
West	-62%	-62%	*NA*	*NA*	*NA*
East & West	-62%	-62%	*NA*	*NA*	*NA*

Table 5.5.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Germany

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,54	0,56	1,70	2,41	0,59
East	1,18	1,24	*NA*	*NA*	*NA*
West	1,02	1,07	*NA*	*NA*	*NA*
East & West	0,55	0,57	*NA*	*NA*	*NA*

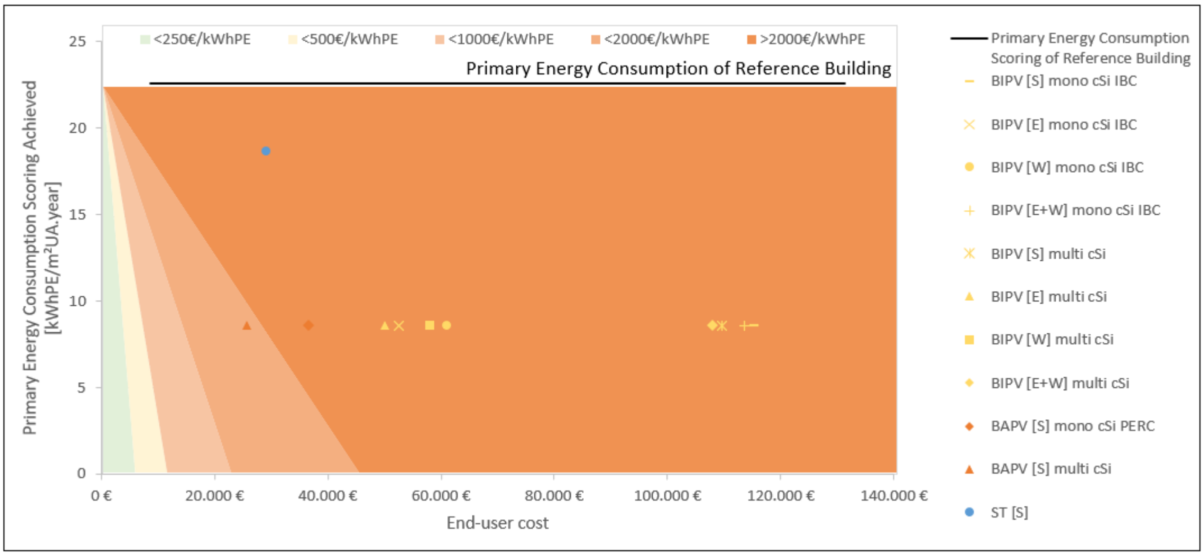


Figure 5.5.8 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Germany

Table 5.5.16 Validation of renewable energy integration target as set by national regulation for a MFH in Germany

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	N
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*	*NA*

Key findings:

As far as the potential contribution of BIPV and BAPV are concerned, same remarks as for the first case apply.

5.5.5 Educational building

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.5.17 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in Germany

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	255	255	1770	1770	70
South	Installed capacity [kWp]	41	34	194	173	NA
South	RE system surface to net floor area [-]	0,04	0,04	0,25	0,25	0,01
East	Occupied area [m²]	316	316	NA	NA	NA
East	Installed capacity [kWp]	51	42	NA	NA	NA
East	RE system surface to net floor area [-]	0,04	0,04	NA	NA	NA
West	Occupied area [m²]	316	316	NA	NA	NA
West	Installed capacity [kWp]	51	42	NA	NA	NA
West	RE system surface to net floor area [-]	0,04	0,04	NA	NA	NA
East & West	Occupied area [m²]	632	632	NA	NA	NA
East & West	Installed capacity [kWp]	101	85	NA	NA	NA
East & West	RE system surface to net floor area [-]	0,09	0,09	NA	NA	NA

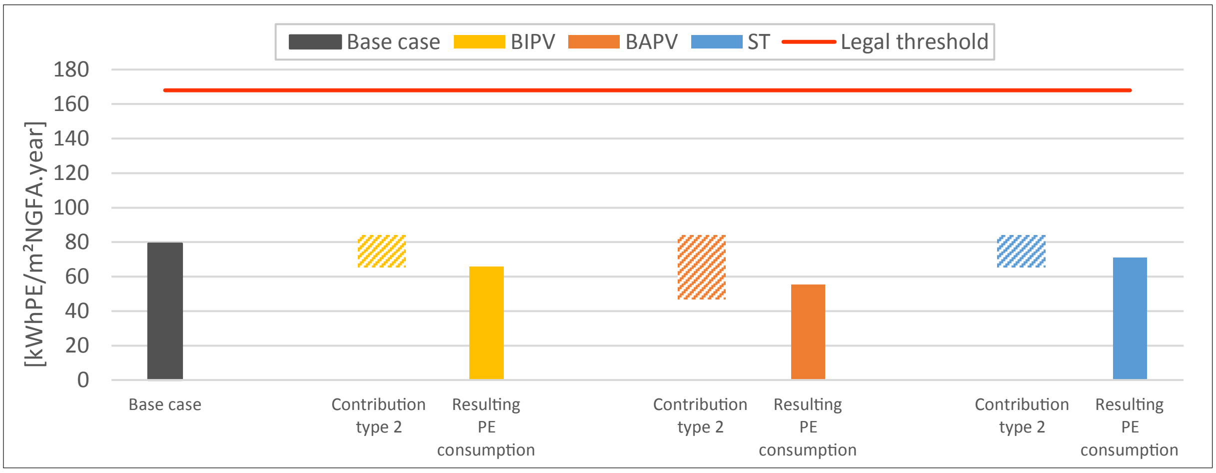


Figure 5.5.9 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in Germany

Table 5.5.18 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in Germany

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-17%	-12%	-30%	-30%	-10%
East	-17%	-12%	*NA*	*NA*	*NA*
West	-15%	-11%	*NA*	*NA*	*NA*
East & West	-30%	-23%	*NA*	*NA*	*NA*

Table 5.5.19 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in Germany

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,28	0,24	0,14	0,20	0,23
East	0,23	0,19	*NA*	*NA*	*NA*
West	0,20	0,17	*NA*	*NA*	*NA*
East & West	0,20	0,18	*NA*	*NA*	*NA*

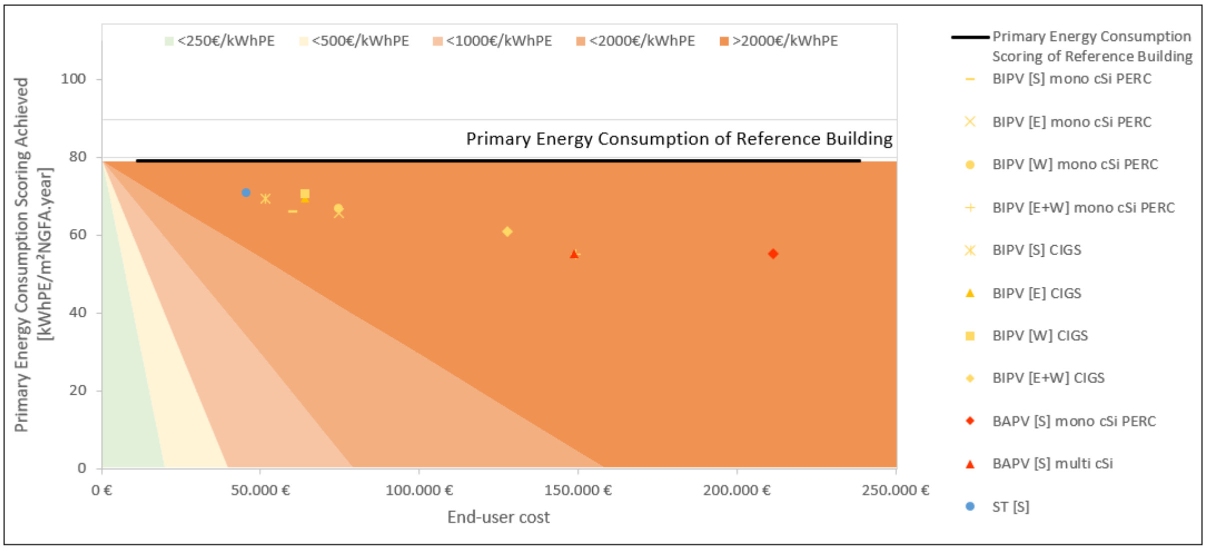


Figure 5.5.10 PE consumption scorings achieved with different renewable systems and associated cost for a EB in Germany

Table 5.5.20 Validation of renewable energy integration target as set by national regulation for a EB in Germany

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	*No target*	*No target*	*No target*	*No target*	*No target*
East	*No target*	*No target*	*NA*	*NA*	*NA*
West	*No target*	*No target*	*NA*	*NA*	*NA*
East & West	*No target*	*No target*	*NA*	*NA*	*NA*

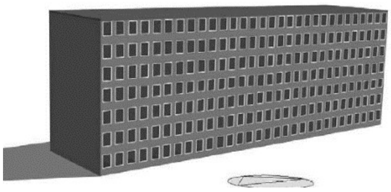
Key findings:

The method to determine the deductible renewable energy production is based on the same principle for residential and non-residential buildings. Yet, in this educational building case, the primary energy consumption reduction allowed thanks to the BIPV and the BAPV system are different. Indeed, the deductible renewable energy production is calculated as the minimum of three values. In this case, the minimum value is no longer the 20% of the primary energy consumption of the reference building but a fixed number of deductible kWh (150) multiplied by the renewable system's installed capacity.

Thus, a mono PERC BIPV system installed on both east and west orientation allows to reduce the primary energy consumption to the same extent as a mono PERC BAPV system installed on the roof and oriented south but with a better cost efficiency. **Overall, façade BIPV systems considered for educational buildings are more cost-efficient solutions than BAPV on roofs.** Eventually allowing to, improve the kWh_{PE}/m^2 scoring by 0,28% for each 1000€ invested for mono cSi PERC-based BIPV system. Solar thermal scores well and appears to be more cost efficient than 5 out of 8 tested BIPV façade configurations.

As this is retrofitted building, there are not renewable energy integration targets defined.

5.5.6 Office building: Case 1/2



This office building's heating is based on a gas boiler, while cooling, ventilation and lighting needs are based on electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.5.21 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Germany

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

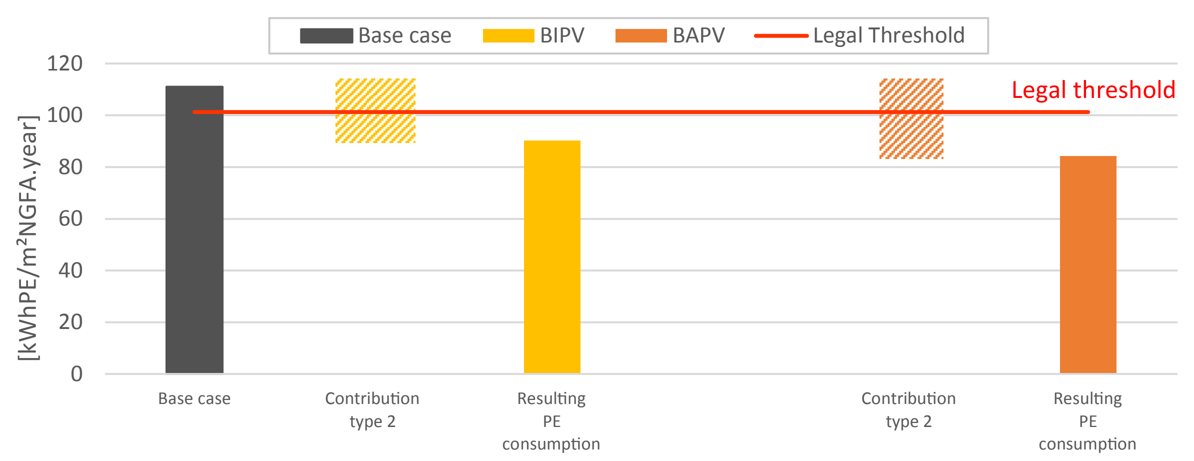


Figure 5.5.11 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Germany

Table 5.5.22 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Germany

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-19%	-5%	-24%	-24%
East	-16%	-4%	*NA*	*NA*
West	-14%	-3%	*NA*	*NA*
East & West	-24%	-7%	*NA*	*NA*

Table 5.5.23 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Germany

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,06	0,02	0,23	0,33
East	0,05	0,02	*NA*	*NA*
West	0,05	0,01	*NA*	*NA*
East & West	0,04	0,02	*NA*	*NA*

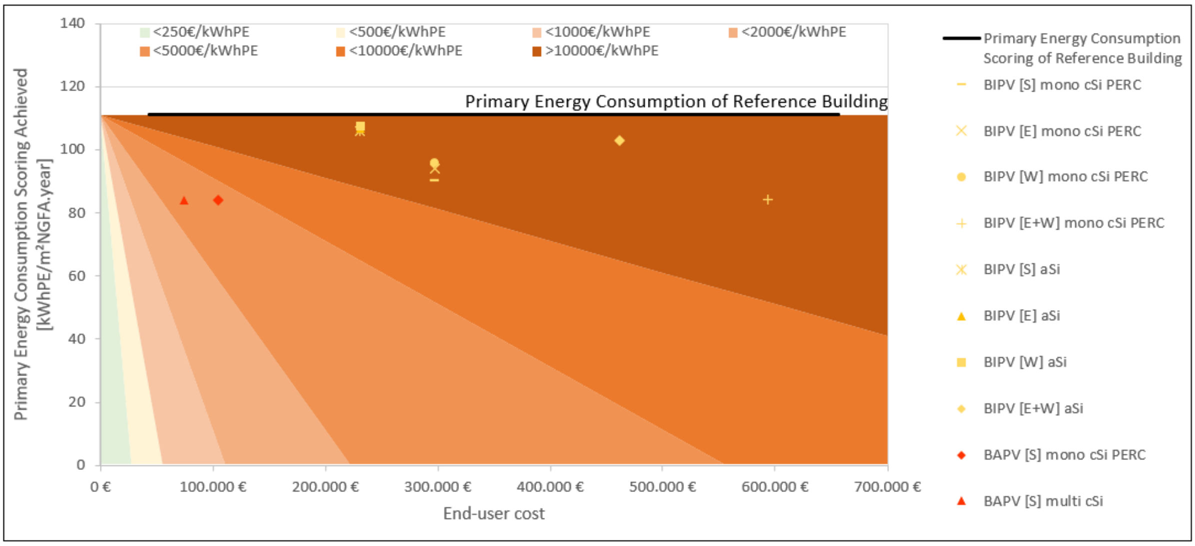


Figure 5.5.12 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Germany

Table 5.5.24 Validation of renewable energy integration target as set by national regulation for a OB in Germany

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Y	Y	Y	Y
East	Y	N	*NA*	*NA*
West	Y	N	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*

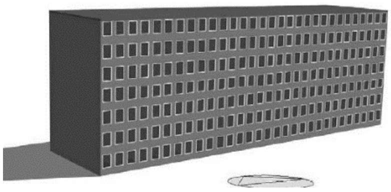
<u>Key findings:</u>

The same way as for the educational building, the deductible production is not based on the same constant value for both BIPV and BAPV system but depends on the systems' installed capacity. **With the mono PERC-based BIPV curtain wall installed on both east and west facades, the same primary energy balance reduction as for the mono PERC BAPV south-oriented system can be reached.**

Nevertheless, BAPV systems remain largely more cost efficient with cost-efficiency values up to 15 times higher.

Even though the heating system uses gas as energy vector, thanks to a cooling system based on electricity, the 15% coverage of combined heating and cooling needs is achieved in most BIPV systems configurations and for all studied BAPV systems.

5.5.7 Office building: Case 2/2



This office building's needs are all covered by electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.5.25 Occupied areas (m^2) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Germany

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

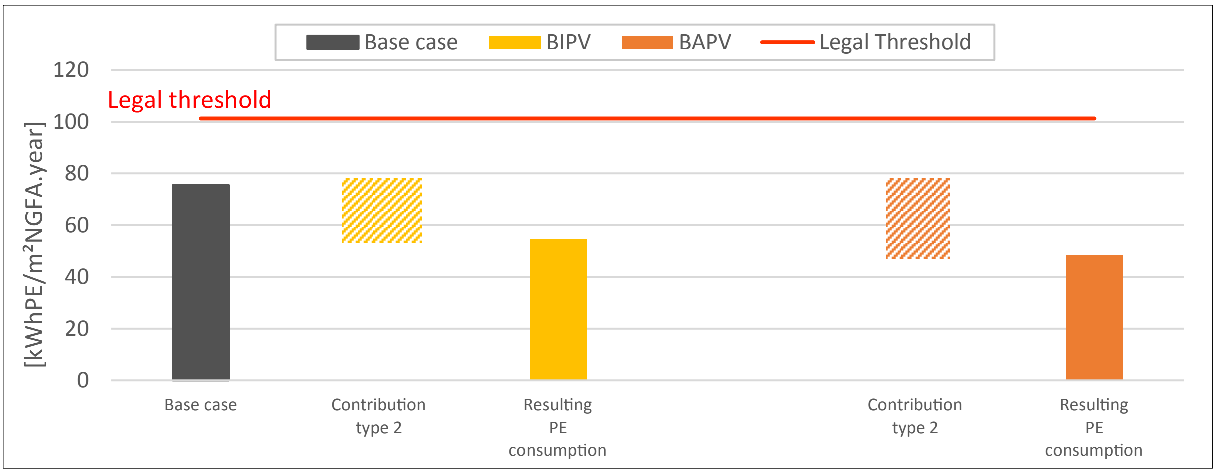


Figure 5.5.13 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Germany

Table 5.5.26 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Germany

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-28%	-7%	-36%	-36%
East	-23%	-6%	*NA*	*NA*
West	-20%	-5%	*NA*	*NA*
East & West	-36%	-11%	*NA*	*NA*

Table 5.5.27 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Germany

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,09	0,03	0,34	0,48
East	0,08	0,02	*NA*	*NA*
West	0,07	0,02	*NA*	*NA*
East & West	0,06	0,02	*NA*	*NA*

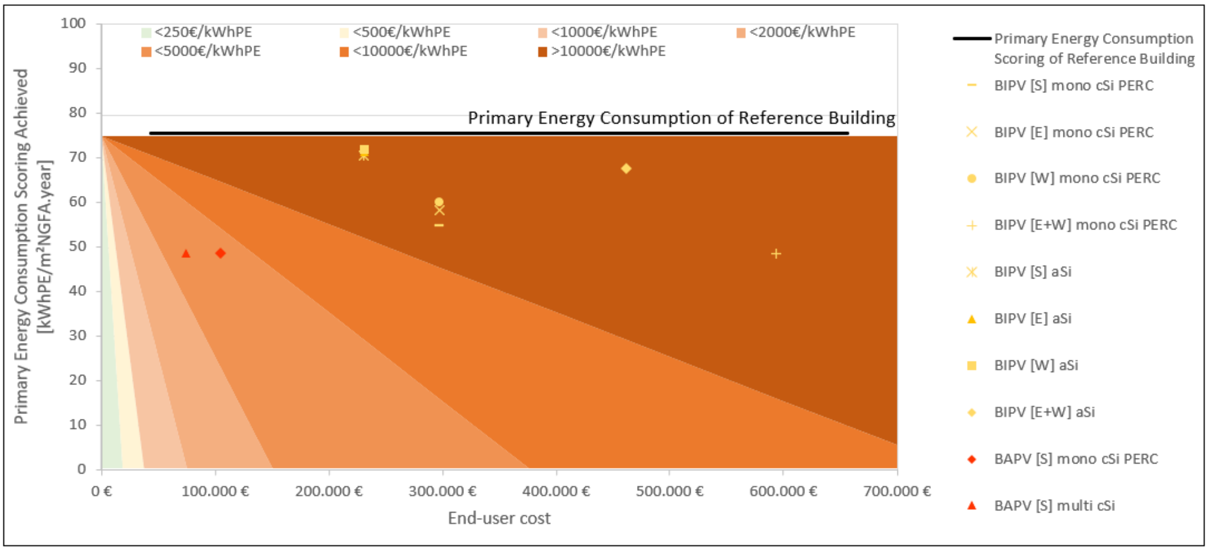


Figure 5.5.14 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Germany

Table 5.5.28 Validation of renewable energy integration target as set by national regulation for a OB in Germany

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Y	N	Y	Y
East	Y	N	*NA*	*NA*
West	Y	N	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*

<u>Key findings:</u>

Same remarks as for the office building case 1 apply. Namely, that with more covered surface, and using the mono PERC -based BIPV curtain wall, the same primary energy consumption scoring can be achieved as with a south oriented, mono PERC-based BAPV system. Nevertheless, from a cost perspective, BAPV systems remain largely more cost efficient.

5.6 Italy

5.6.1 Single family house: Case 1/2

This single-family house's equipment for heating and DHW consists in a heat pump, thus needs are covered by electricity. There are no ventilation or cooling needs.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.6.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Italy (1/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	40	40	40	40	40	40	*NA*
South	Installed capacity [kWp]	7	4	5	7	6	8	*NA*
South	RE system surface to net floor area [-]	0,21	0,21	0,21	0,21	0,21	0,21	*NA*
East & West	Occupied area [m²]	80	80	80	60	60	60	*NA*
East & West	Installed capacity [kWp]	14	8	11	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,42	0,42	0,42	0,31	0,31	0,31	*NA*

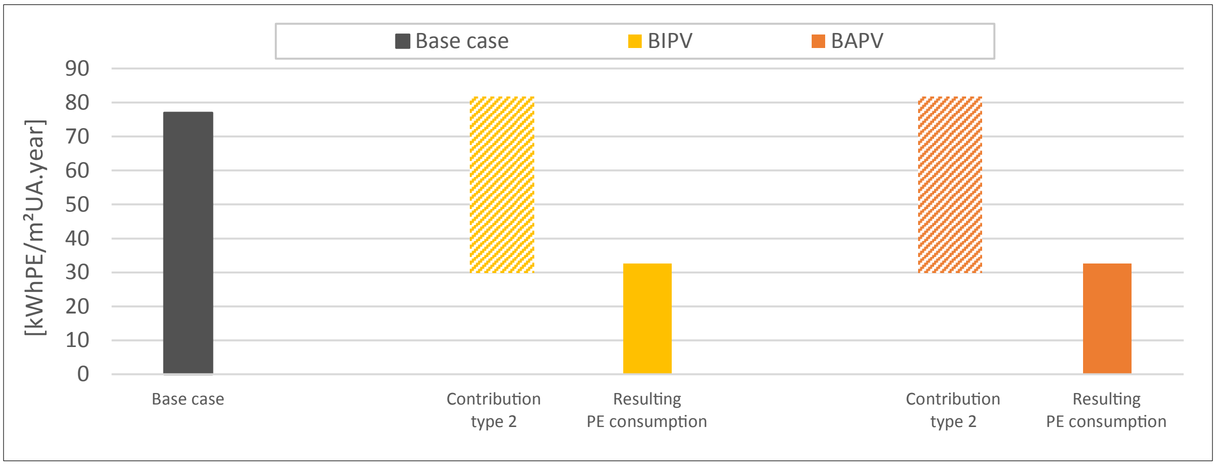


Figure 5.6.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Italy

Table 5.6.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Italy

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-58%	-44%	-50%	-58%	-53%	-61%	NA
East & West	-65%	-49%	-55%	-55%	-51%	-58%	NA

Table 5.6.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Italy

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	13	5	9	4	5	3	*NA*
East & West	7	3	5	3	3	2	*NA*

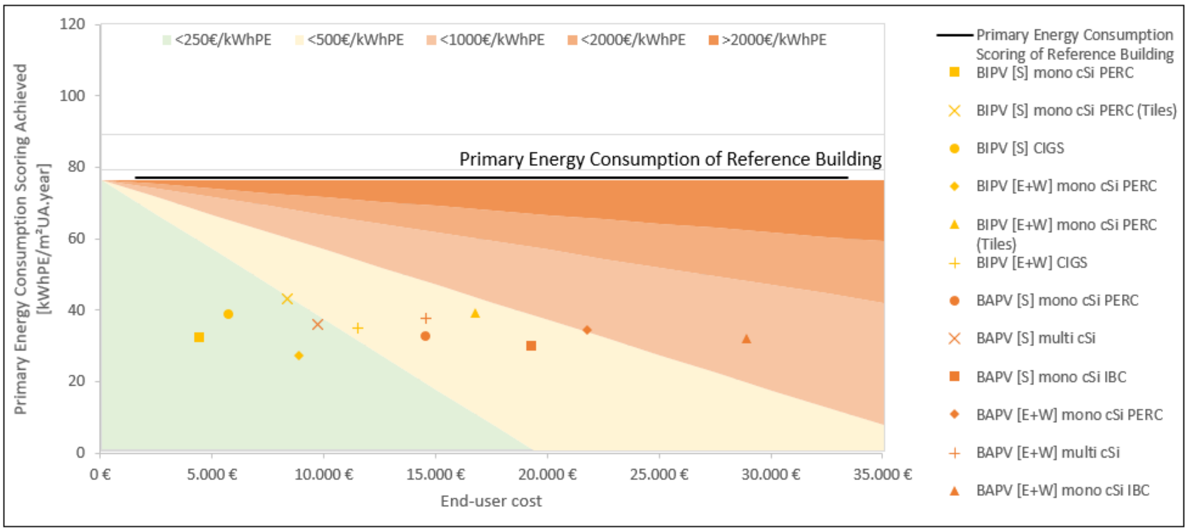


Figure 5.6.2 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Italy

Table 5.6.4 Validation of renewable energy integration target as set by national regulation for a SFH in Italy

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	*NA*
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

Both the BIPV and the BAPV systems allow to deduce an important part of the primary energy balance.

Cost-efficiency values lie around 4% primary energy balance reduction per 1000€ invested for the different BAPV systems' configurations while the highest cost-efficiency of 13% primary energy balance reduction per 1000€ invested is reached for the mono cSi PERC-based in roof mounting BIPV system in the south orientation. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 250€ for 4 out of 6 studied BIPV configurations.

There are three criteria to validate in Italy for SFH to achieve the renewable energy integration target. First, a renewable system producing electricity with a capacity of 0,02 Wp/m² of normalised area needs to be installed. Then, 50% of DHW needs as well as 50% of heating, DHW and cooling needs combined need to be covered by renewable energy. In this electricity-based SFH case, all three criteria are validated by both BIPV and BAPV systems.

5.6.2 Single family house: Case 2/2

This single-family house uses fossil fuels to cover its heating and DHW needs.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.6.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Italy (2/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	30	30	30	30	30	30	3
South	Installed capacity [kWp]	5	3	4	5	5	6	*NA*
South	RE system surface to net floor area [-]	0,21	0,21	0,21	0,21	0,21	0,21	0,02
East & West	Occupied area [m²]	60	60	60	60	60	60	*NA*
East & West	Installed capacity [kWp]	11	6	8	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,43	0,43	0,43	0,43	0,43	0,43	*NA*

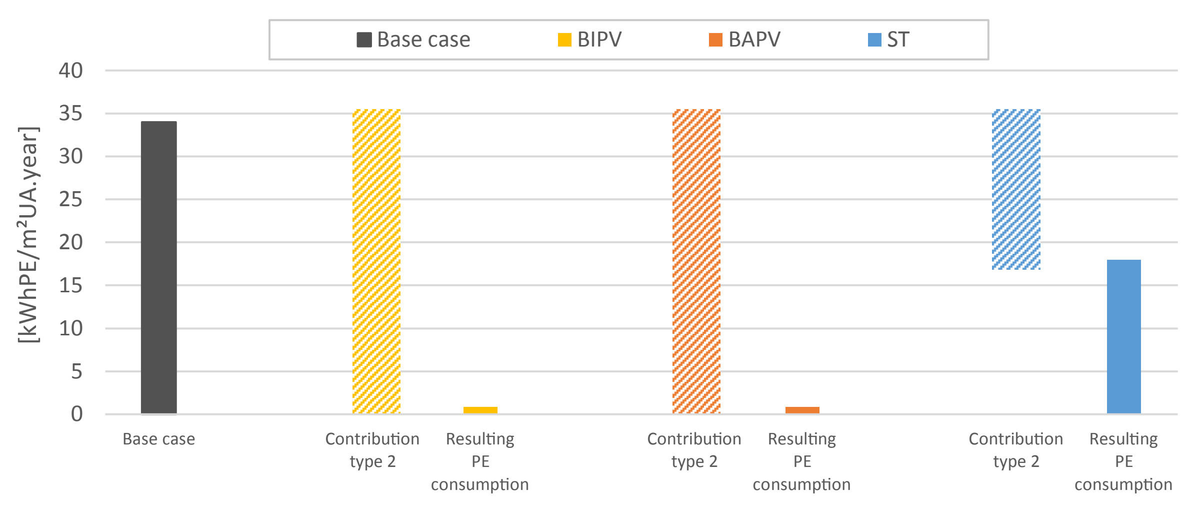


Figure 5.6.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Italy

Table 5.6.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Italy

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	29	12	20	9	13	7	14
East & West	15	7	11	5	7	3	*NA*

Table 5.6.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Italy

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	29	12	20	9	13	7	14
East & West	15	7	11	5	7	3	*NA*

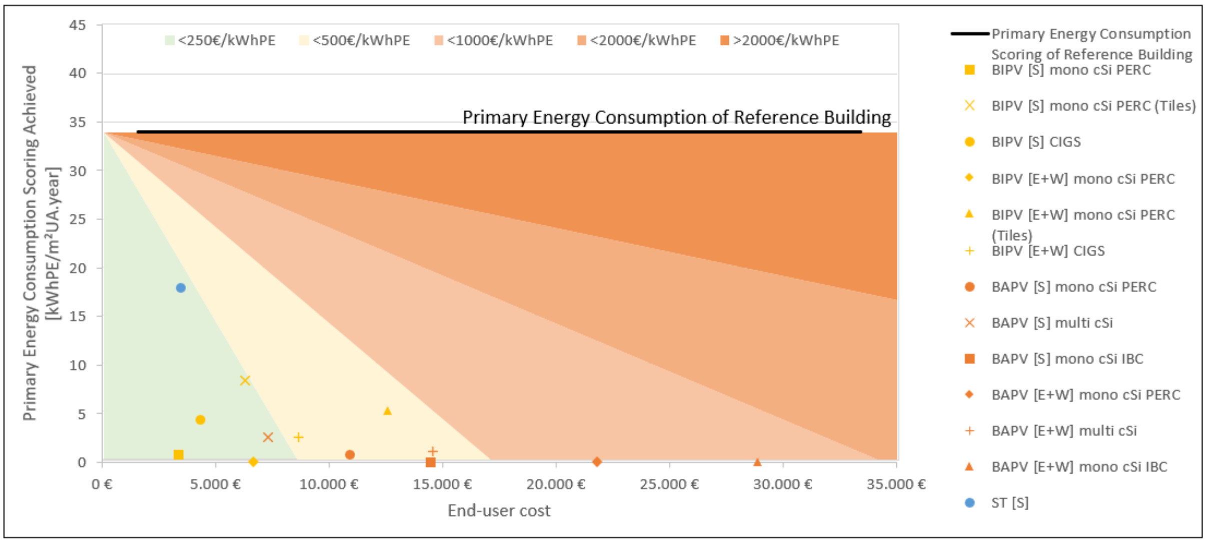


Figure 5.6.4 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Italy

Table 5.6.8 Validation of renewable energy integration target as set by national regulation for a SFH in Italy

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	N	N	N	N	N	N	N
East & West	N	N	N	N	N	N	*NA*

Key findings:

As there are no ventilation and cooling needs for this single-family house and as, in Italy, heating needs are limited, DHW needs represent a significant share in the total needs. In addition, irradiance conditions in Italy improve the relevance of solar thermal. Therefore, the contribution of solar thermal for this single-family house is important. BIPV and BAPV systems also allow to achieve important primary energy consumption reductions. In some cases, the whole primary energy consumption is compensated by the renewable electricity production (self-consumed for eligible uses and exported).

When putting in regard the primary energy consumption reduction and end user cost, BIPV systems have a better cost efficiency scoring, especially the in-roof mounting systems. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 250€ for the mono cSi PERC-based, south-oriented in-roof mounting BIPV systems and three other BIPV configurations Solar thermal also allows a significant primary energy consumption reduction compared to its installed surface and initial end-user cost.

Figure 5.6.9 shows that for this particular single-family house, the enhanced power density of BAPV compared to BIPV is not really taken advantage of. Indeed, some of the BIPV systems, with lower power densities, already allow to almost compensate for the whole primary energy consumption of the reference building.

There is a combination of three criteria to validate the renewable energy integration target. Since one of them is the installation of a certain on-site electric capacity, the target can never be achieved with solar thermal (except if there are local exceptions for solar thermal that we could not find trace of in regulations). As far as the BIPV and BAPV systems are concerned, the renewable integration target is not reached either. Indeed, as the heating and DHW needs rely on fossil fuels, the 50% renewable coverage of both heating needs and heating, cooling and DHW combined needs is not achievable with an electricity generating renewable system.

5.6.3 Multifamily house

This MFH case in Italy uses a heat pump to cover heating and DHW needs. There are no ventilation and cooling needs.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.6.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in Italy (1/1)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	**Occupied area [m²]**	450	450	500	500	*NA*
South	**Installed capacity [kWp]**	79	69	55	49	*NA*
South	**RE system surface to net floor area [-]**	0,19	0,19	0,21	0,21	*NA*
East	**Occupied area [m²]**	180	180	*NA*	*NA*	*NA*
East	**Installed capacity [kWp]**	32	28	*NA*	*NA*	*NA*
East	**RE system surface to net floor area [-]**	0,08	0,08	*NA*	*NA*	*NA*
West	**Occupied area [m²]**	150	150	*NA*	*NA*	*NA*
West	**Installed capacity [kWp]**	26	23	*NA*	*NA*	*NA*
West	**RE system surface to net floor area [-]**	0,06	0,06	*NA*	*NA*	*NA*
East & West	**Occupied area [m²]**	330	330	*NA*	*NA*	*NA*
East & West	**Installed capacity [kWp]**	58	50	*NA*	*NA*	*NA*
East & West	**RE system surface to net floor area [-]**	0,14	0,14	*NA*	*NA*	*NA*

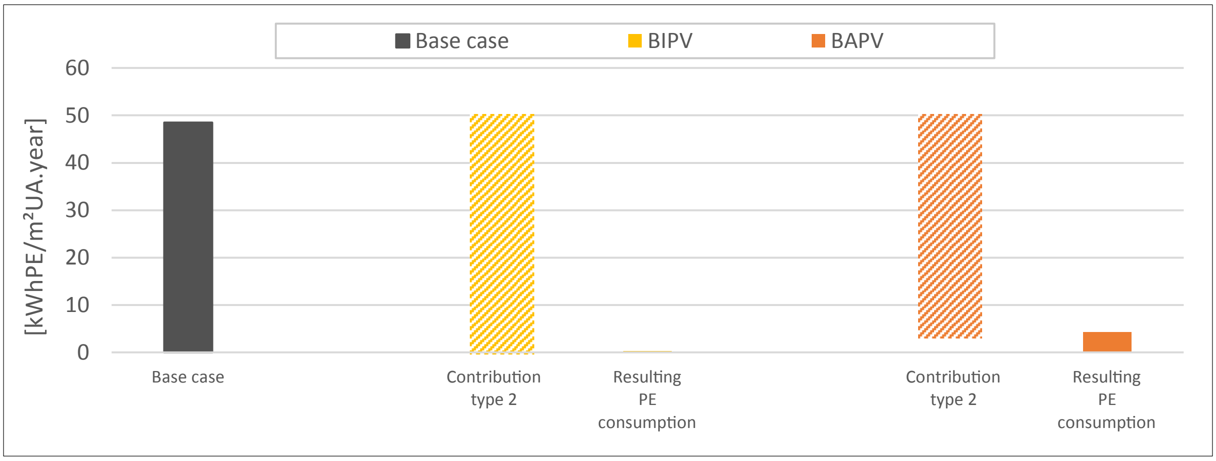


Figure 5.6.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in Italy

Table 5.6.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Italy

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-99%	-97%	-91%	-88%	*NA*
East	-57%	-51%	*NA*	*NA*	*NA*
West	-40%	-35%	*NA*	*NA*	*NA*
East & West	-72%	-68%	*NA*	*NA*	*NA*

Table 5.6.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Italy

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,47	0,48	1,25	1,72	*NA*
East	0,67	0,63	*NA*	*NA*	*NA*
West	0,57	0,51	*NA*	*NA*	*NA*
East & West	0,46	0,46	*NA*	*NA*	*NA*

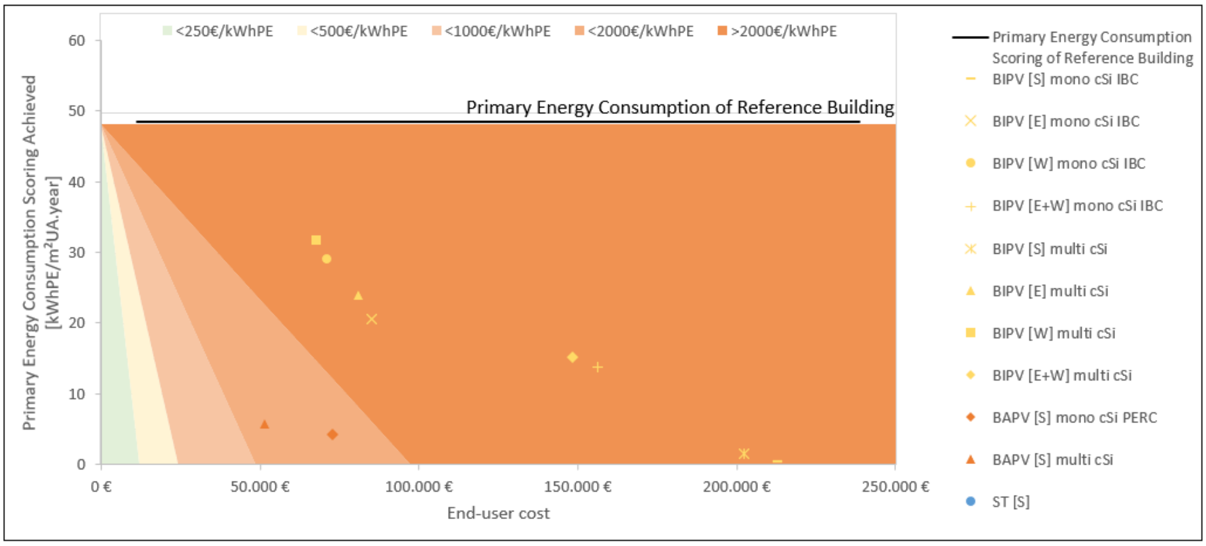


Figure 5.6.6 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Italy

Table 5.6.12 Validation of renewable energy integration target as set by national regulation for a MFH in Italy

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	*NA*
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*	*NA*

Key findings:

In Italy, both the generated renewable electricity that is self-consumed for eligible uses and that is exported can be deducted in the primary energy balance. In some of the BIPV systems configurations, almost the total primary energy consumption can be compensated. BAPV systems also allow primary energy balance reductions of the same magnitude, though at a lower cost. Indeed from a cost efficiency point of view, BAPV systems score better than the tested façade BIPV systems with respective cost-efficiency values of 1,25 to 1,7% primary energy balance reduction per 1000€ invested and 0,5% primary energy balance reduction per 1000€ invested. The reduction of each kW_{PE}/m^2 compared to reference building being achieved at less than 2000€ for BAPV systems only.

Renewable energy integration targets are reached for both BIPV and BAPV systems when oriented south. When the target is not reached, it is because the criterion of 0,02 $Wp/m^2_{\text{normalised area}}$ is not met.

5.6.4 Educational building

Except for the ventilation based on electricity, remaining needs (heating and DHW) are covered by a gas boiler.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.6.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in Italy

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	200	200	1400	1400	50
South	Installed capacity [kWp]	32	27	154	137	*NA*
South	RE system surface to net floor area [-]	0,03	0,03	0,20	0,20	0,01
East	Occupied area [m²]	300	300	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	48	40	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*
West	Occupied area [m²]	300	300	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	48	40	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	600	600	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	96	80	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*	*NA*

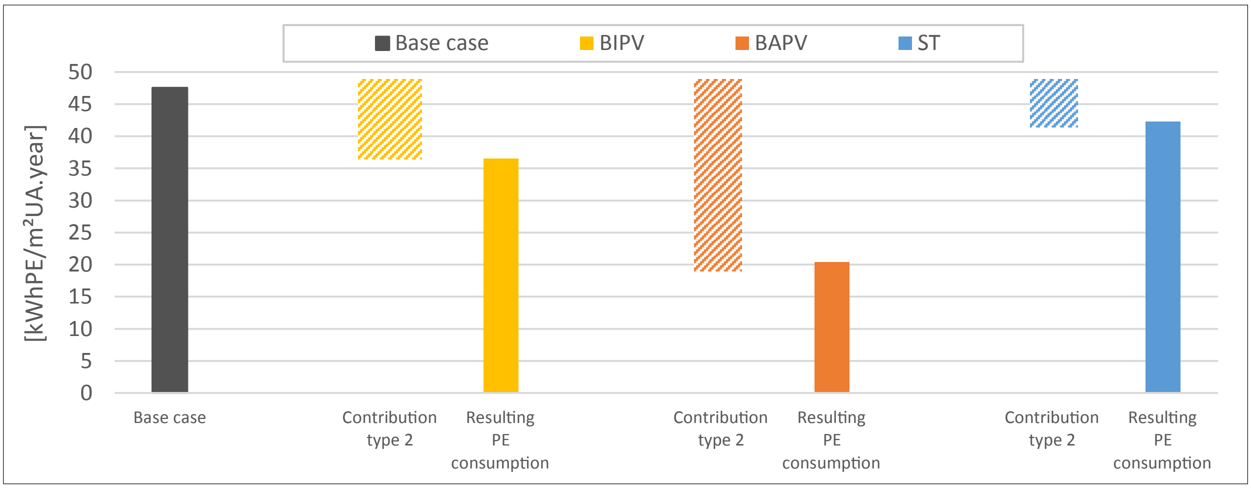


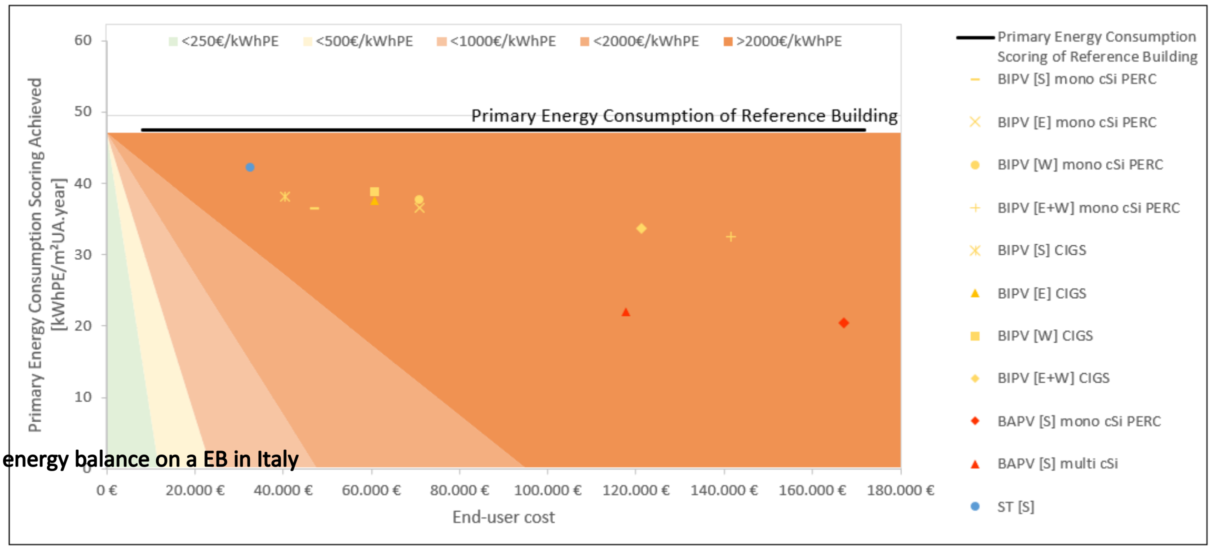
Figure 5.6.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in Italy

Table 5.6.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in Italy

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-23%	-20%	-57%	-54%	-11%
East	-23%	-21%	*NA*	*NA*	*NA*
West	-20%	-18%	*NA*	*NA*	*NA*
East & West	-32%	-29%	*NA*	*NA*	*NA*

Table 5.6.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in Italy

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,49	0,49	0,34	0,45	0,34
East	0,33	0,34	*NA*	*NA*	*NA*
West	0,29	0,30	*NA*	*NA*	*NA*
East & West	0,22	0,24	*NA*	*NA*	*NA*



energy balance on a EB in Italy

Figure 5.6.9 PE consumption scorings achieved with different renewable systems and associated cost for a EB in Italy

Table 5.6.16 Validation of renewable energy integration target as set by national regulation for a EB in Italy

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	N	N	N	N	N
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	N	N	*NA*	*NA*	*NA*

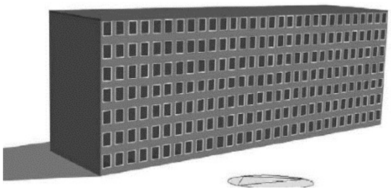
Key findings:

The produced electricity with the BIPV or BAPV system used for lighting and ventilation, as well as the exported electricity can be deduced from the primary energy balance. The BAPV system, thanks to a higher occupied area on the roof, allows to achieve a lower primary energy balance scoring than BIPV façade systems.

But it is worth highlighting that BIPV façade systems score better in terms of cost efficiency among the three studied renewable energy systems, even though values are quite similar. Indeed cost-efficiency values for the three systems range from 0,34% primary energy balance reduction per 1000€ invested for solar thermal and the mono cSi PERC-based BAPV systems, to 0,49% primary energy balance reduction per 1000€ invested for both south-oriented BIPV systems.

Because heating and DHW needs are based on fossil fuels, the 50% coverage of heating, cooling and DHW needs combined and of DHW needs, by renewable energy cannot be achieved. As far as solar thermal is concerned, the fact that no electrical power is installed hinders the validation of one the three mandatory criteria.

5.6.5 Office building: Case 1/2



There are no heating and DHW needs considered for this office building. Ventilation and cooling needs are covered by electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

A further office building case with different heating, cooling and ventilation equipment is presented in in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.6.17 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Italy

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	648	648	973	973
South	Installed capacity [kWp]	65	16	107	95
South	RE system surface to net floor area [-]	0,09	0,09	0,13	0,13
East	Occupied area [m²]	648	648	*NA*	*NA*
East	Installed capacity [kWp]	65	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
West	Occupied area [m²]	648	648	*NA*	*NA*
West	Installed capacity [kWp]	65	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
East & West	Occupied area [m²]	1296	1296	*NA*	*NA*
East & West	Installed capacity [kWp]	130	32	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*

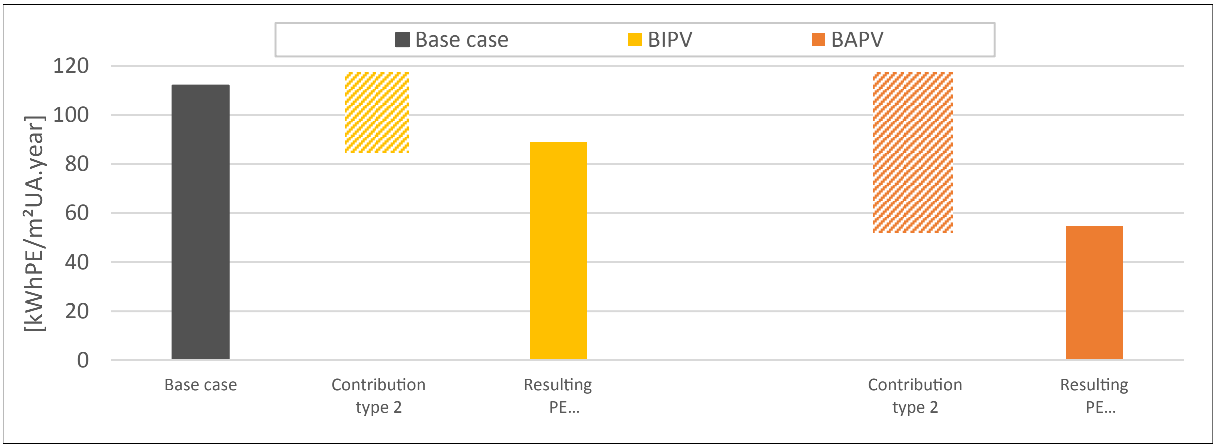


Figure 5.6.10 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Italy

Table 5.6.18 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Italy

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-20%	-5%	-51%	-45%
East	-18%	-4%	NA	NA
West	-15%	-4%	NA	NA
East & West	-32%	-8%	NA	NA

Table 5.6.19 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Italy

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,07	0,02	0,44	0,56
East	0,06	0,02	NA	NA
West	0,05	0,02	NA	NA
East & West	0,06	0,02	NA	NA

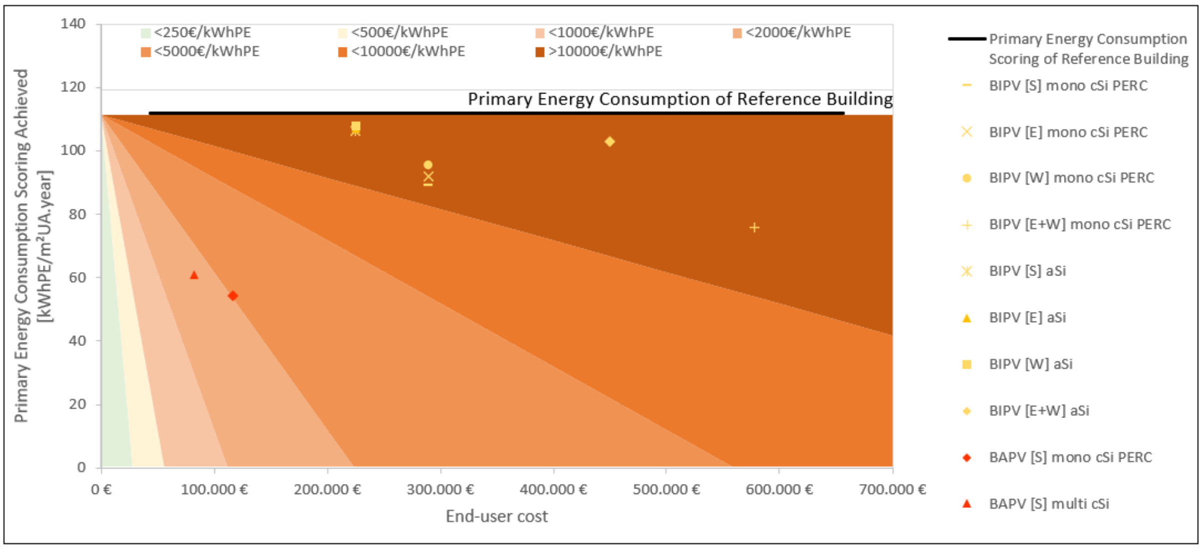


Figure 5.6.11 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Italy

Table 5.6.20 Validation of renewable energy integration target as set by national regulation for a OB in Italy

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	N	N
East	N	N	NA	NA
West	N	N	NA	NA
East & West	N	N	NA	NA

Key findings:

BAPV systems allow to reduce more significantly the primary energy consumption in this case of an office building, and this with a much better cost-efficiency than other tested renewable energy systems.

As far as the renewable energy integration targets are concern, aSi-based curtain wall (and to lesser extent, mono PERC-based BIPV curtain walls) with their limited production output cannot fulfil half of the cooling needs. On the contrary, BAPV, thank to better sun irradiance conditions, allow to cover 50% of the cooling needs, but in terms of installed capacity, they fall slightly short of the target of 0,02 $Wp/m^2_{\text{normalised area}}$.

5.7 Netherlands

5.7.1 Single-family house

In this single-family house, except for the ventilation needs which are covered by electricity, the remaining needs for heating and DHW are covered by a gas boiler.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.7.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in the Netherlands (1/1)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	25	25	25	25	25	25	5
South	Installed capacity [kWp]	4	3	3	4	4	5	*NA*
South	RE system surface to net floor area [-]	0,16	0,16	0,16	0,16	0,16	0,16	0,03
East & West	Occupied area [m²]	50	50	50	50	50	50	*NA*
East & West	Installed capacity [kWp]	9	5	7	9	8	10	*NA*
East & West	RE system surface to net floor area [-]	0,31	0,31	0,31	0,31	0,31	0,31	*NA*

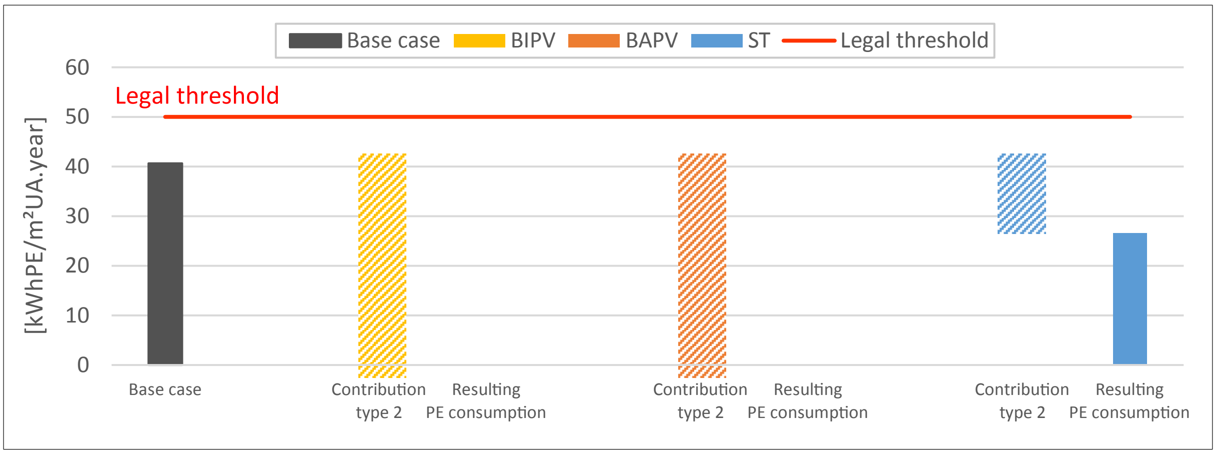


Figure 5.7.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in the Netherlands

Table 5.7.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in the Netherlands

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-100%	-60%	-75%	-100%	-86%	-100%	-35%
East & West	-100%	-100%	-100%	-100%	-100%	-100%	*NA*

Table 5.7.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in the Netherlands

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	44	14	25	13	17	10	7
East & West	22	12	17	7	10	5	*NA*

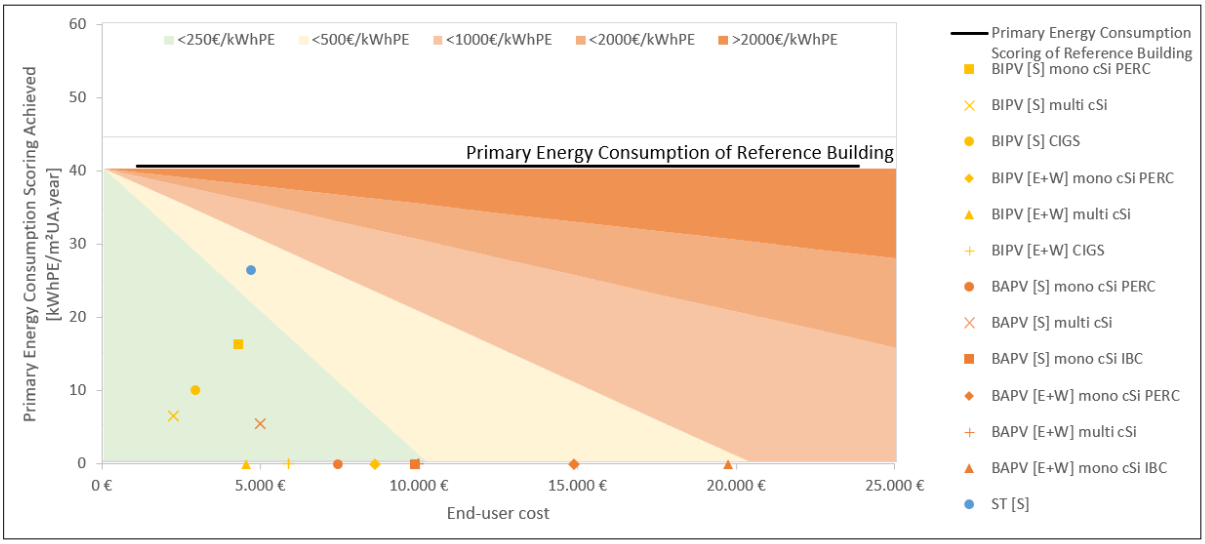


Figure 5.7.2 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in the Netherlands

Table 5.7.4 Validation of renewable energy integration target as set by national regulation for a SFH in the Netherlands

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	Y
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

The regulation in the Netherlands allows to deduce a large amount of the on-site produced renewable energy from the primary energy balance, in such a way that the resulting primary energy balance goes down to zero or almost zero in many cases. In multiple configurations, BIPV systems appear like the most cost-efficient investments among the three types of renewable energy systems that have been tested. The reduction of each kWh $_{PE}$/m^2 compared to reference building being achieved at less than 250€. Eventually allowing to improve this kWh$_{PE}$/m^2 scoring by 44% for each 1000€ invested, compared to the reference building.

In the Netherlands, the share between renewable energy production and the total primary fossil energy consumption (after potential deductions) has to be of at least 40% in the case of a SFH. This share is reached for all studied renewable systems.

5.7.2 Multifamily house: Case 1/2

In this MFH different eligible uses are all fuelled by electricity.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.7.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in the Netherlands (1/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	250	250	257	257	35
South	Installed capacity [kWp]	44	38	28	25	NA
South	RE system surface to net floor area [-]	0,19	0,19	0,19	0,19	0,03
East	Occupied area [m²]	114	114	NA	NA	NA
East	Installed capacity [kWp]	20	17	NA	NA	NA
East	RE system surface to net floor area [-]	0,08	0,08	NA	NA	NA
West	Occupied area [m²]	132	132	NA	NA	NA
West	Installed capacity [kWp]	23	20	NA	NA	NA
West	RE system surface to net floor area [-]	0,10	0,10	NA	NA	NA
East & West	Occupied area [m²]	246	246	NA	NA	NA
East & West	Installed capacity [kWp]	43	38	NA	NA	NA
East & West	RE system surface to net floor area [-]	0,18	0,18	NA	NA	NA

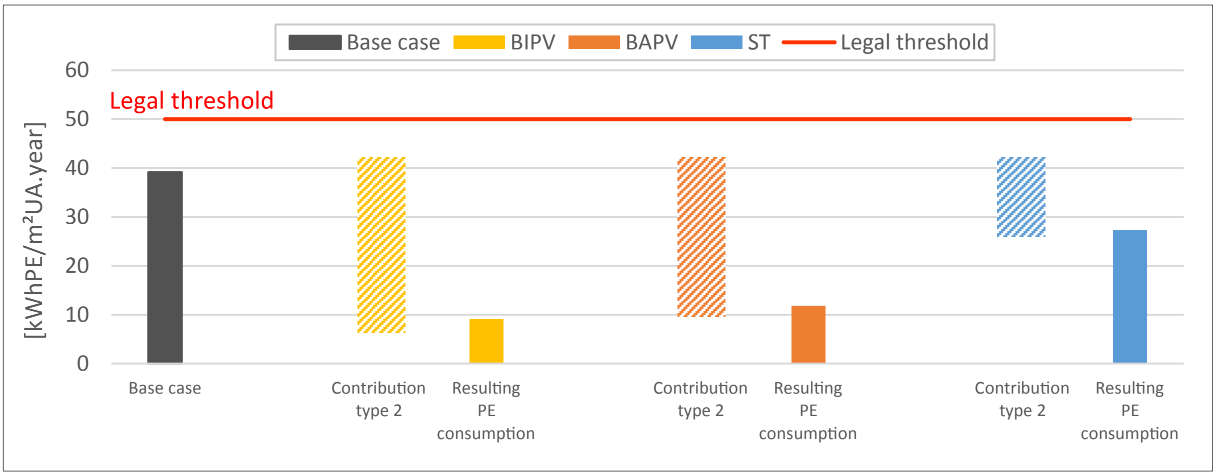


Figure 5.7.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in the Netherlands

Table 5.7.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in the Netherlands

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-77%	-67%	-70%	-62%	-31%
East	-30%	-26%	*NA*	*NA*	*NA*
West	-31%	-27%	*NA*	*NA*	*NA*
East & West	-61%	-53%	*NA*	*NA*	*NA*

Table 5.7.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in the Netherlands

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,79	0,72	2,28	2,87	1,25
East	0,68	0,62	*NA*	*NA*	*NA*
West	0,60	0,55	*NA*	*NA*	*NA*
East & West	0,64	0,58	*NA*	*NA*	*NA*

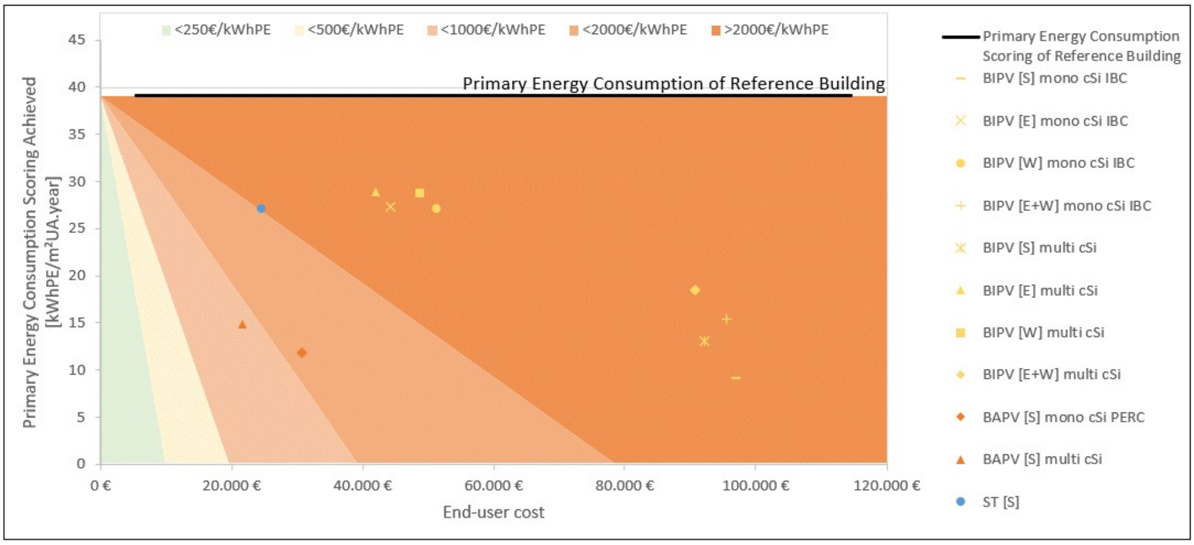


Figure 5.7.4 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in the Netherlands

Table 5.7.8 Validation of renewable energy integration target as set by national regulation for a MFH in the Netherlands

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y
East	Y	N	*NA*	*NA*	*NA*
West	Y	N	*NA*	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*	*NA*

Key findings:

Similar primary energy consumption reductions are achieved with BIPV and BAPV. Indeed, the mono IBC-based BIPV systems benefits from enhanced performances at the module level and a higher system power density than the mono PERC-based BAPV system but benefit from worse irradiance conditions because it is installed on a façade. When looking at the cost-efficiency indicator, BAPV performs largely better than BIPV. Indeed, a cost-efficiency of 2,87% primary energy balance reduction per 1000€

invested is reached for the multi cSi-based, south oriented BAPV system, while the cost-efficiency values for the different BIPV system configurations range from 0,55 to 0,79% primary energy balance reduction per 1000€ invested .The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 1000€ for the BAPV systems.

The target of a ratio of 40% between the renewable production and the total primary fossil energy consumption is reached in all cases with exception of the multi cSi-based BIPV system in west and east orientations as these façades offer a limited available surface and lower yields.

5.7.3 Multifamily house: Case 2/2

In this second MFH case, the heating and DHW needs are covered through a connection to the district heat network.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.7.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in the Netherlands (2/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	250	250	257	257	35
South	Installed capacity [kWp]	44	38	28	25	*NA*
South	RE system surface to net floor area [-]	0,19	0,19	0,19	0,19	0,03
East	Occupied area [m²]	114	114	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	20	17	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,08	0,08	*NA*	*NA*	*NA*
West	Occupied area [m²]	132	132	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	23	20	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,10	0,10	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	246	246	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	43	38	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*	*NA*

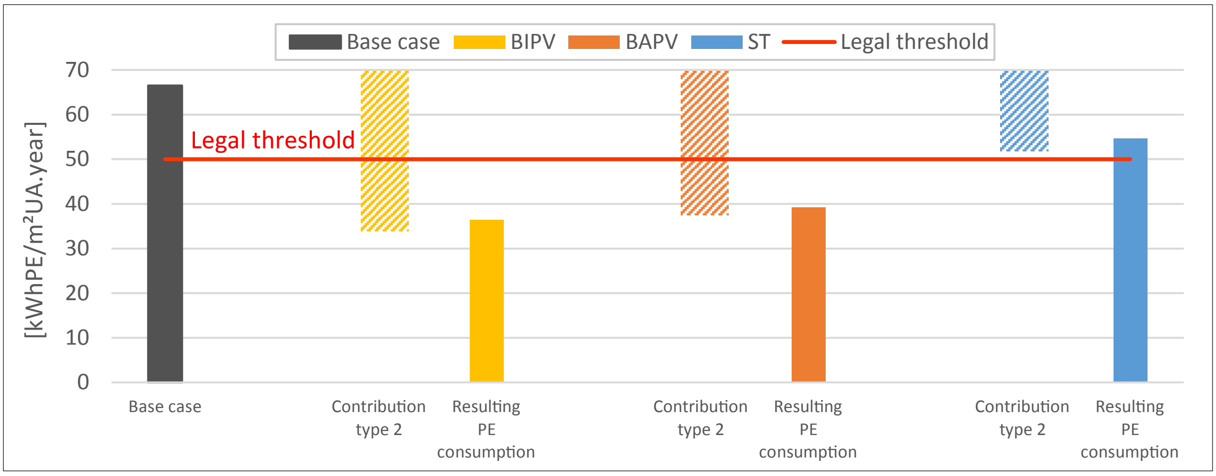


Figure 5.7.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in the Netherlands

Table 5.7.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in the Netherlands

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-45%	-39%	-41%	-37%	-18%
East	-18%	-15%	*NA*	*NA*	*NA*
West	-18%	-16%	*NA*	*NA*	*NA*
East & West	-36%	-31%	*NA*	*NA*	*NA*

Table 5.7.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in the Netherlands

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,47	0,43	1,34	1,69	0,73
East	0,40	0,37	*NA*	*NA*	*NA*
West	0,35	0,32	*NA*	*NA*	*NA*
East & West	0,37	0,34	*NA*	*NA*	*NA*

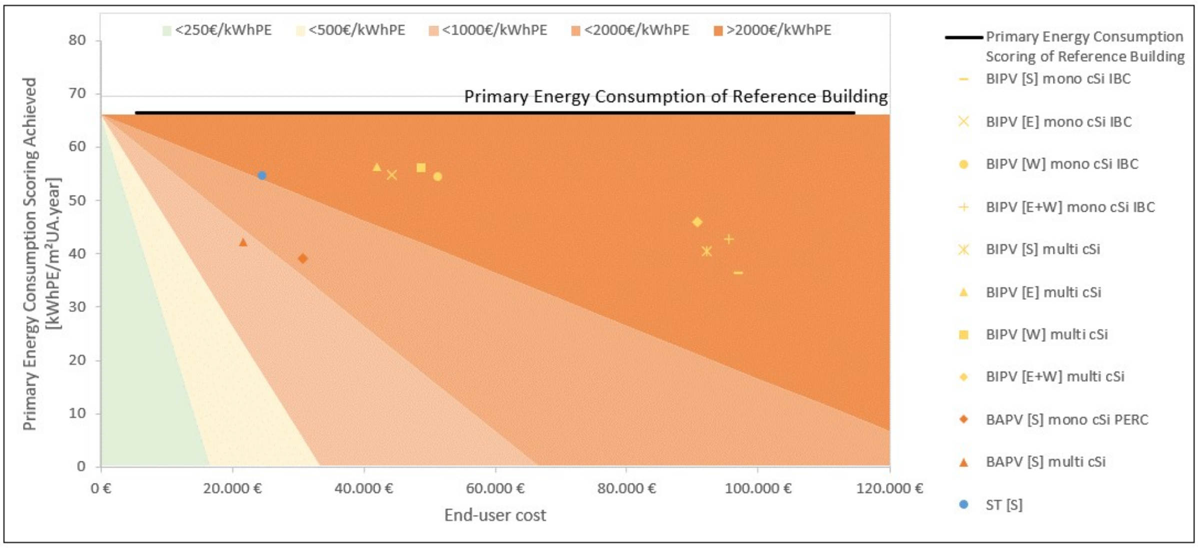


Figure 5.7.6 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in the Netherlands

Table 5.7.12 Validation of renewable energy integration target as set by national regulation for a MFH in the Netherlands

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	N
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*	*NA*

Key findings:

Similar remarks as for the first MFH case apply. Yet, in this case, the threshold is not already reached for the reference building but becomes so for both BIPV and BAPV systems.

5.7.4 Educational building

This educational building's heating is based on a connection to the district heat network, while DHW, ventilation and lighting needs are covered by electricity.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.7.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in the Netherlands

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	255	255	1770	1770	70
South	Installed capacity [kWp]	41	34	194	173	*NA*
South	RE system surface to net floor area [-]	0,04	0,04	0,25	0,25	0,01
East	Occupied area [m²]	316	316	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	51	42	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*
West	Occupied area [m²]	316	316	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	51	42	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,04	0,04	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	632	632	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	101	85	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*	*NA*

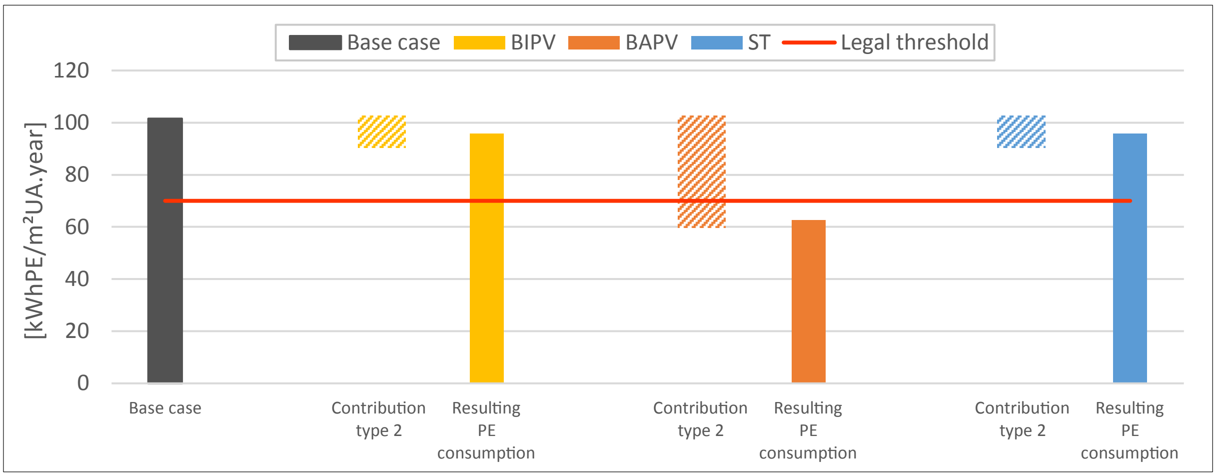


Figure 5.7.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in the Netherlands

Table 5.7.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-6%	-5%	-38%	-34%	-6%
East	-6%	-5%	NA	NA	NA
West	-5%	-4%	NA	NA	NA
East & West	-11%	-10%	NA	NA	NA

Table 5.7.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,09	0,09	0,18	0,23	0,12
East	0,08	0,08	NA	NA	NA
West	0,07	0,07	NA	NA	NA
East & West	0,08	0,08	NA	NA	NA

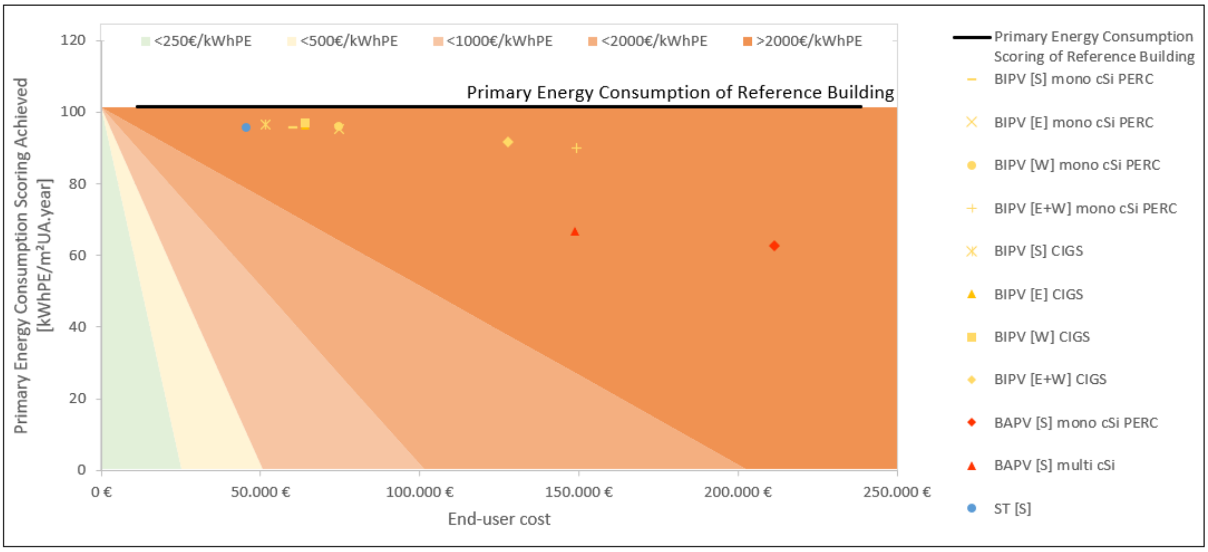


Figure 5.7.8 PE consumption scorings achieved with different renewable systems and associated cost for a EB in the Netherlands

Table 5.7.16 Validation of renewable energy integration target as set by national regulation for a EB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	N	N	Y	Y	N
East	N	N	NA	NA	NA
West	N	N	NA	NA	NA
East & West	N	N	NA	NA	NA

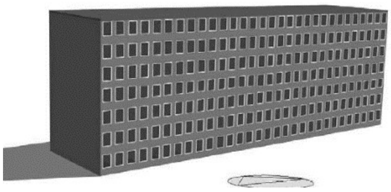
Key findings:

Here, a wide gap between BIPV and BAPV can be observed. This is due both to the less favourable irradiance conditions on the façade where BIPV is installed and to the larger available surface on the educational building's roof compared to its façades.

Overall, the contribution of renewable systems to reducing the primary energy balance is limited except for BAPV systems. Which is why, the legal threshold is only reached for BAPV systems.

Only the BAPV systems allow to reach the renewable energy integration target consisting in a ratio of 40% between the renewable energy production and the total primary fossil energy consumption (after deduction).

5.7.5 Office building: Case 1/2



This office building's heating is based on a gas boiler, while cooling, ventilation and lighting needs are based on electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.7.17 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in the Netherlands

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

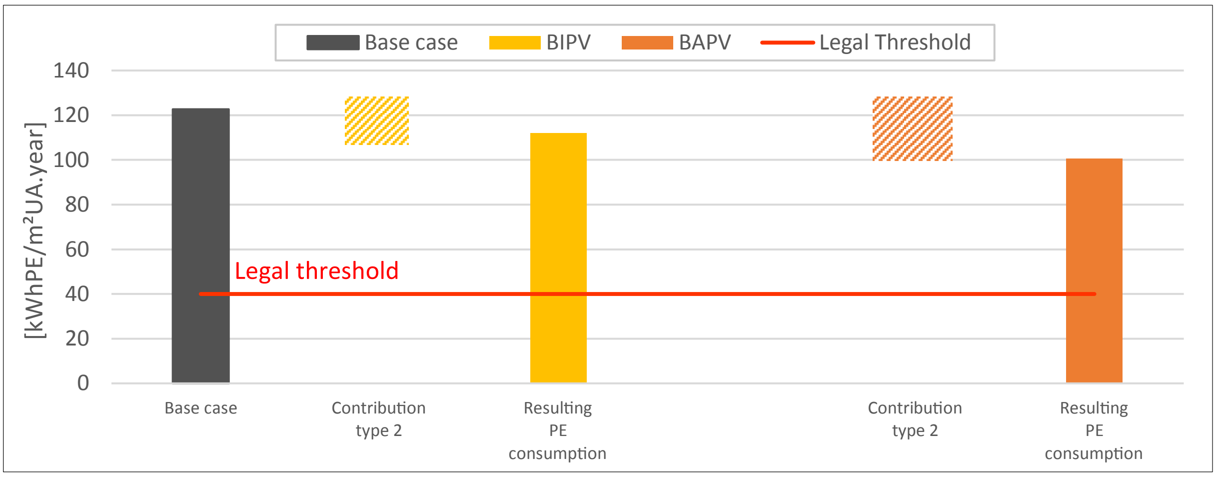


Figure 5.7.9 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in the Netherlands

Table 5.7.18 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-9%	-2%	-18%	-16%
East	-8%	-2%	NA	NA
West	-7%	-2%	NA	NA
East & West	-14%	-3%	NA	NA

Table 5.7.19 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,03	0,01	0,17	0,22
East	0,03	0,01	NA	NA
West	0,02	0,01	NA	NA
East & West	0,02	0,01	NA	NA

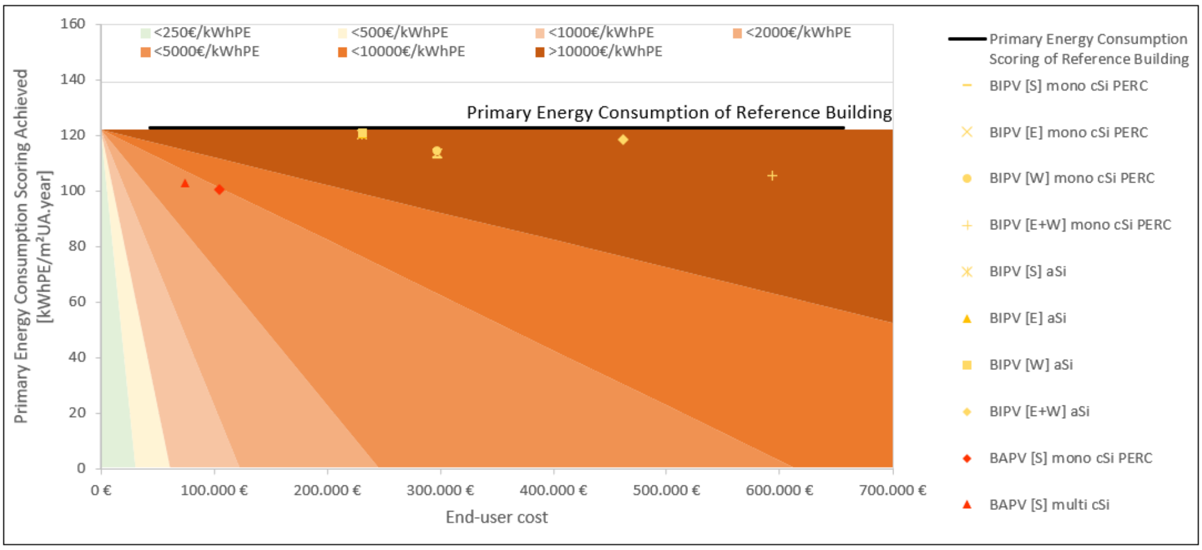


Figure 5.7.10 PE consumption scorings achieved with different renewable systems and associated cost for a OB in the Netherlands

Table 5.7.20 Validation of renewable energy integration target as set by national regulation for a OB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	N	N
East	N	N	NA	NA
West	N	N	NA	NA
East & West	N	N	NA	NA

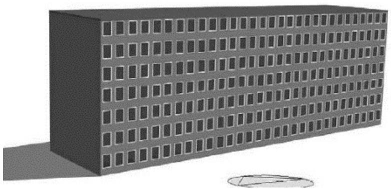
Key findings:

With the mono PERC-based BIPV curtain wall, installed on both east and west facades, the same primary energy consumption reduction as for the mono PERC BAPV south-oriented system, can be reached. Nevertheless, BAPV systems remain largely more cost efficient with cost-efficiency values around 0,2% primary energy balance reduction per 1000€ invested against 0,02% primary energy balance reduction per 1000€ invested for BIPV systems.

It is also worth noting that in this particular case, the legal threshold is out of reach for all the renewable energy systems tested. This can be explained by the highly subpar initial energy performances of the building.

Neither the BIPV systems nor the BAPV systems allow to reach the renewable energy integration target.

5.7.6 Office building: Case 2/2



This office building's needs are all covered by electricity.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.7.21 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in the Netherlands

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

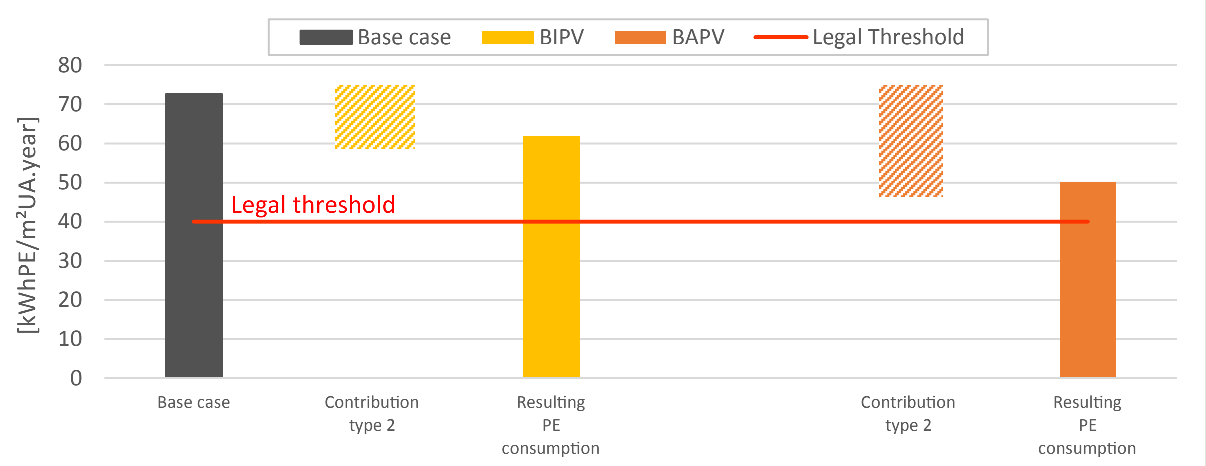


Figure 5.7.11 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in the Netherlands

Table 5.7.22 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-15%	-4%	-31%	-27%
East	-13%	-3%	*NA*	*NA*
West	-11%	-3%	*NA*	*NA*
East & West	-24%	-6%	*NA*	*NA*

Table 5.7.23 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,05	0,02	0,29	0,37
East	0,04	0,01	*NA*	*NA*
West	0,04	0,01	*NA*	*NA*
East & West	0,04	0,01	*NA*	*NA*

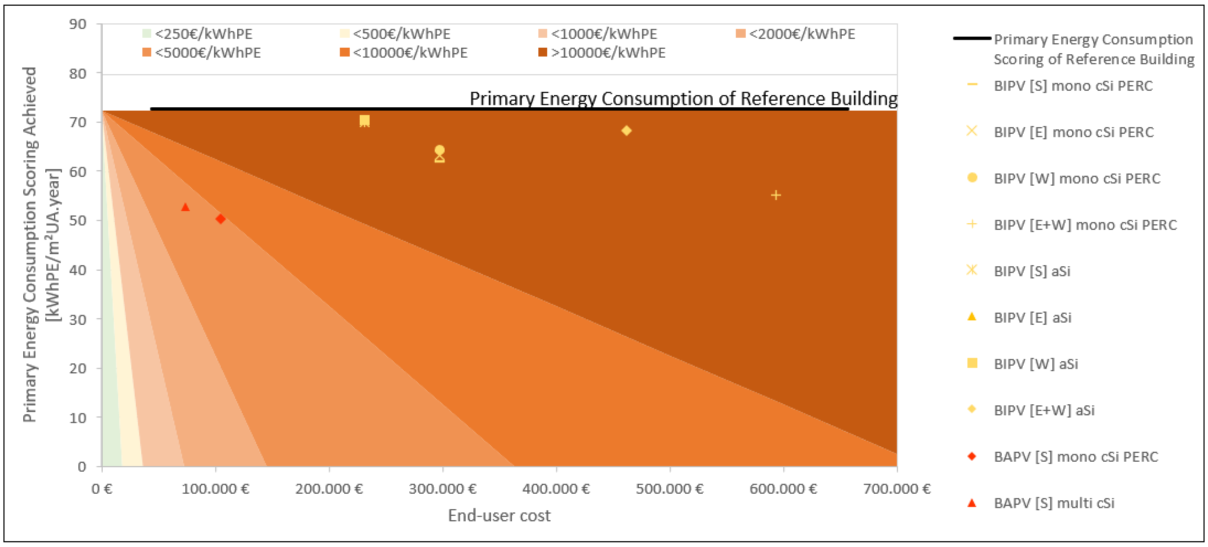


Figure 5.7.12 PE consumption scorings achieved with different renewable systems and associated cost for a OB in the Netherlands

Table 5.7.24 Validation of renewable energy integration target as set by national regulation for a OB in the Netherlands

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	Y	Y
East	N	N	*NA*	*NA*
West	N	N	*NA*	*NA*
East & West	Y	N	*NA*	*NA*

Key findings:

Same remarks as for the office building case 1 apply. Namely, that when with more covered surface, and using the mono PERC-based BIPV curtain wall, the roughly same primary energy consumption scoring as with a south oriented, mono PERC-based BAPV system can be achieved. Nevertheless, from a cost perspective, BAPV systems remain largely more cost efficient with cost-efficiency values around

0,33% primary energy balance reduction per 1000€ invested against 0,03% primary energy balance reduction per 1000€ invested for BIPV systems.

It is also worth noting that in this particular case, the legal threshold is never reached, but the threshold remains in sight, especially for the BAPV systems.

As the primary energy consumption of this office building before considering the installation of a renewable system is lower than in case 1, the renewable energy integration target can be achieved for the BAPV systems and the mono PERC-based BIPV system when installed on both east and west facades.

5.8 Spain

5.8.1 Single-family house: Case 1/2

This single-family house’s equipment for heating and DHW consists in a heat pump, thus needs are covered by electricity. There are no ventilation or cooling needs.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.8.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Spain (1/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	40	40	40	40	40	40	*NA*
South	Installed capacity [kWp]	7	4	5	7	6	8	*NA*
South	RE system surface to net floor area [-]	0,21	0,21	0,21	0,21	0,21	0,21	*NA*
East & West	Occupied area [m²]	80	80	80	60	60	60	*NA*
East & West	Installed capacity [kWp]	14	8	11	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,42	0,42	0,42	0,31	0,31	0,31	*NA*

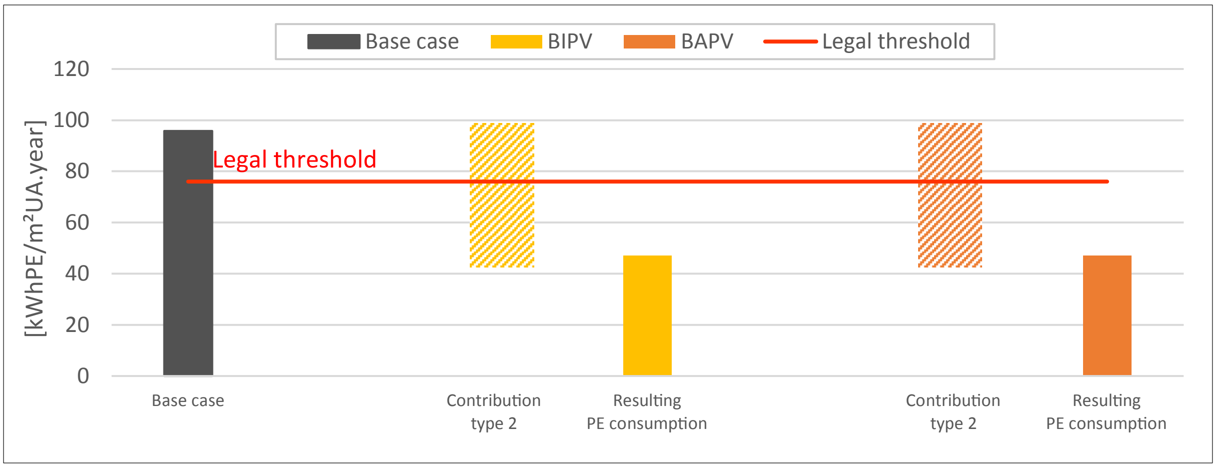


Figure 5.8.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Spain

Table 5.8.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Spain

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	-51%	-39%	-44%	-51%	-47%	-54%	*NA*
East & West	-58%	-44%	-49%	-49%	-45%	-52%	*NA*

Table 5.8.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Spain

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	12	5	8	4	5	3	*NA*
East & West	7	3	4	2	3	2	*NA*

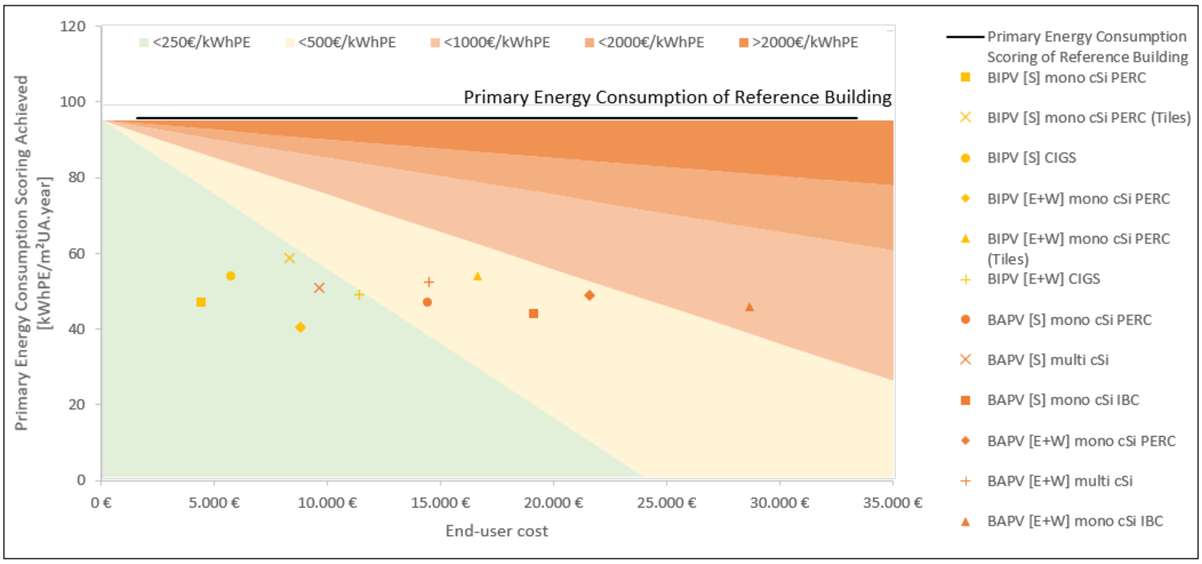


Figure 5.8.2 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Spain

Table 5.8.4 Validation of renewable energy integration target as set by national regulation for a SFH in Spain

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	*NA*
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

The installation of a BIPV or a BAPV system producing electricity allows to reduce the primary energy balance thanks to both: an important share of self-consumed renewable electricity for eligible uses (heating and DHW needs are covered by electricity through a heat pump) and a significantly lower primary energy factor for renewable electricity. Indeed, in Spain, on-site produced electricity cannot be deduced from the primary energy balance. But as the primary energy factors for renewable electricity and electricity from the grid are significantly different, self-consumed electricity for eligible uses is converted into primary energy with a lower factor thus, reducing the total primary energy consumption.

The primary energy balance is approximately reduced by half for both the BIPV and BAPV systems, but BIPV systems are more cost-efficient with a cost-efficiency reaching 12% primary energy balance reduction per 1000€ invested for the mono cSi PERC-based in roof mounting system. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at less than 250€ for 5 out of 6 studied BIPV configurations. Both BIPV and BAPV systems allow to reach a primary energy balance below the legal threshold.

In Spain, the target for the renewable energy integration focuses on DHW needs which must be covered to 60% at least by renewable energy. In this case where a heat pumps provides heat for the DHW, this target is achieved for both BIPV and BAPV systems for all considered orientations and technologies. Yet the sole fact that a heat pump is installed to provide 100% of domestic hot water is enough to comply with the renewable energy integration target.

5.8.2 Single-family house: Case 2/2

In this second SFH case, heating needs are covered by a wood pellets boiler, while DHW needs are covered by a gas boiler. There are no ventilation and cooling needs in this residential case.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 5.8.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Spain (2/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	30	30	30	30	30	30	3
South	Installed capacity [kWp]	5	3	4	5	5	6	*NA*
South	RE system surface to net floor area [-]	0,21	0,21	0,21	0,21	0,21	0,21	0,02
East & West	Occupied area [m²]	60	60	60	60	60	60	*NA*
East & West	Installed capacity [kWp]	11	6	8	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,43	0,43	0,43	0,43	0,43	0,43	*NA*

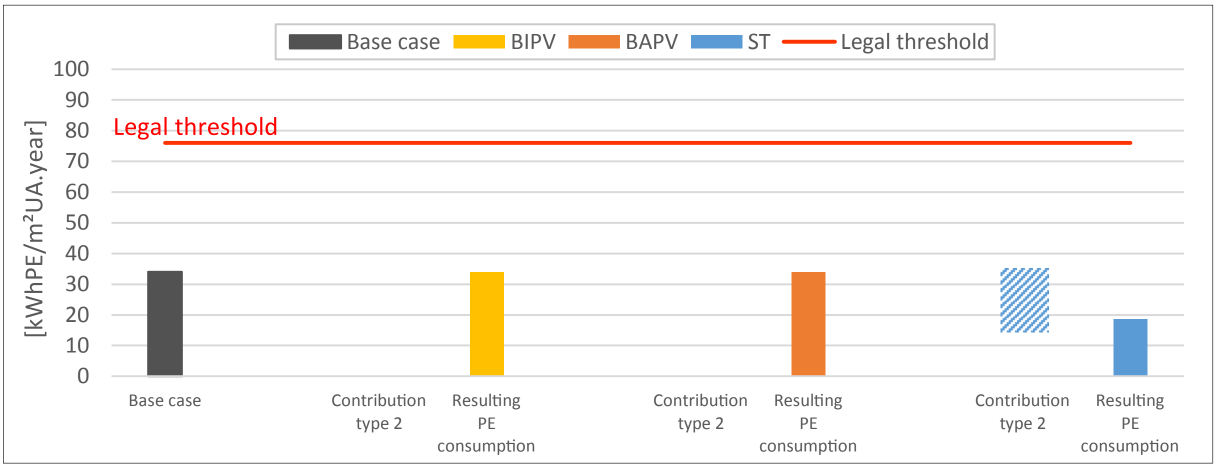


Figure 5.8.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Spain

Table 5.8.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Spain

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	0%	0%	0%	0%	0%	0%	-45%
East & West	0%	0%	0%	0%	0%	0%	*NA*

Table 5.8.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Spain

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	0	0	0	0	0	0	13
East & West	0	0	0	0	0	0	*NA*

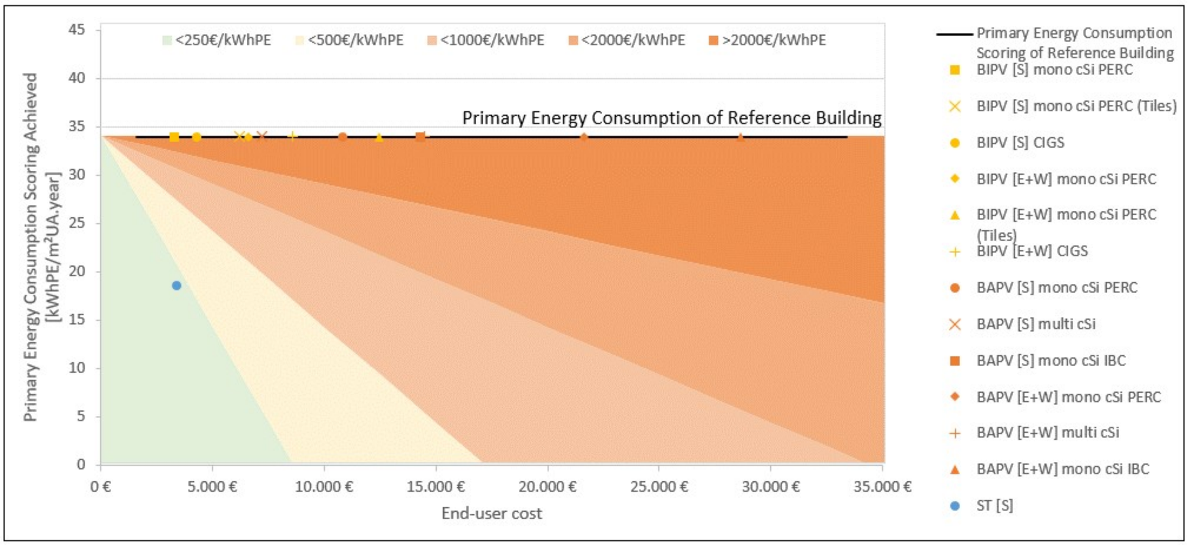


Figure 5.8.4 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Spain

Table 5.8.8 Validation of renewable energy integration target as set by national regulation for a SFH in Spain

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	N	N	N	N	N	N	Y
East & West	N	N	N	N	N	N	*NA*

Key findings:

None of the considered uses (heating, DHW, ventilation and cooling) is based on electricity, therefore neither BIPV systems nor BAPV systems can contribute to reduce the primary energy balance. On the contrary, solar thermal, by covering a part of the DHW needs, allows to reduce the final primary energy consumption.

As the DHW is produced with a gas boiler, the renewable energy integration target (60% of DHW needs covered by renewable energy) is not reached with BIPV and BAPV systems but is reached with a solar thermal system.

5.8.3 Multifamily house

Both the heating and DHW needs are covered by a heat pump.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.8.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in Spain (1/1)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	**Occupied area [m²]**	450	450	500	500	*NA*
South	**Installed capacity [kWp]**	79	69	55	49	*NA*
South	**RE system surface to net floor area [-]**	0,19	0,19	0,21	0,21	*NA*
East	**Occupied area [m²]**	180	180	*NA*	*NA*	*NA*
East	**Installed capacity [kWp]**	32	28	*NA*	*NA*	*NA*
East	**RE system surface to net floor area [-]**	0,08	0,08	*NA*	*NA*	*NA*
West	**Occupied area [m²]**	150	150	*NA*	*NA*	*NA*
West	**Installed capacity [kWp]**	26	23	*NA*	*NA*	*NA*
West	**RE system surface to net floor area [-]**	0,06	0,06	*NA*	*NA*	*NA*
East & West	**Occupied area [m²]**	330	330	*NA*	*NA*	*NA*
East & West	**Installed capacity [kWp]**	58	50	*NA*	*NA*	*NA*
East & West	**RE system surface to net floor area [-]**	0,14	0,14	*NA*	*NA*	*NA*

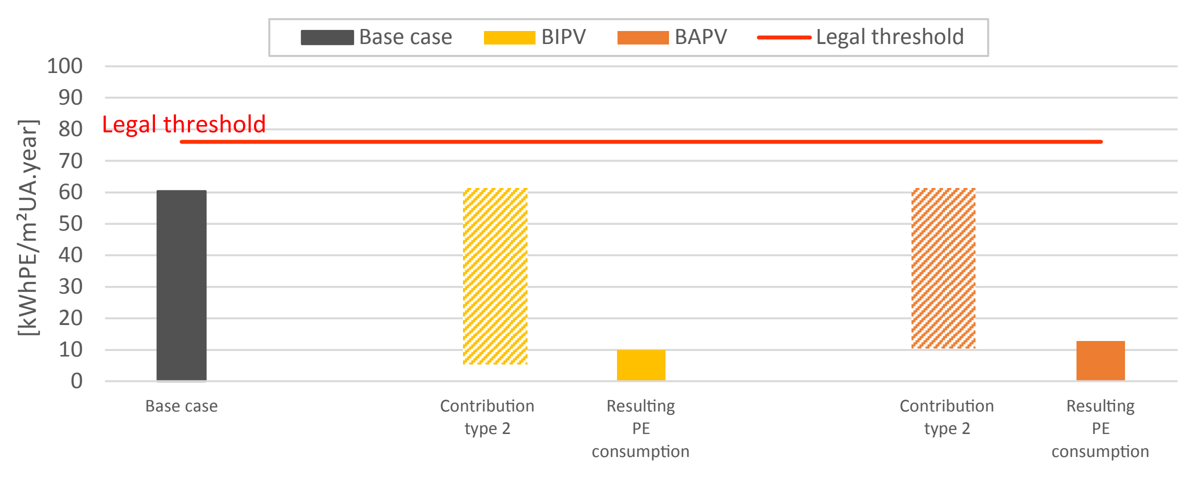


Figure 5.8.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in Spain

Table 5.8.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Spain

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-84%	-82%	-79%	-77%	NA
East	-51%	-46%	NA	NA	NA
West	-36%	-31%	NA	NA	NA
East & West	-62%	-60%	NA	NA	NA

Table 5.8.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Spain

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,40	0,41	1,09	1,51	NA
East	0,60	0,57	NA	NA	NA
West	0,51	0,46	NA	NA	NA
East & West	0,40	0,40	NA	NA	NA

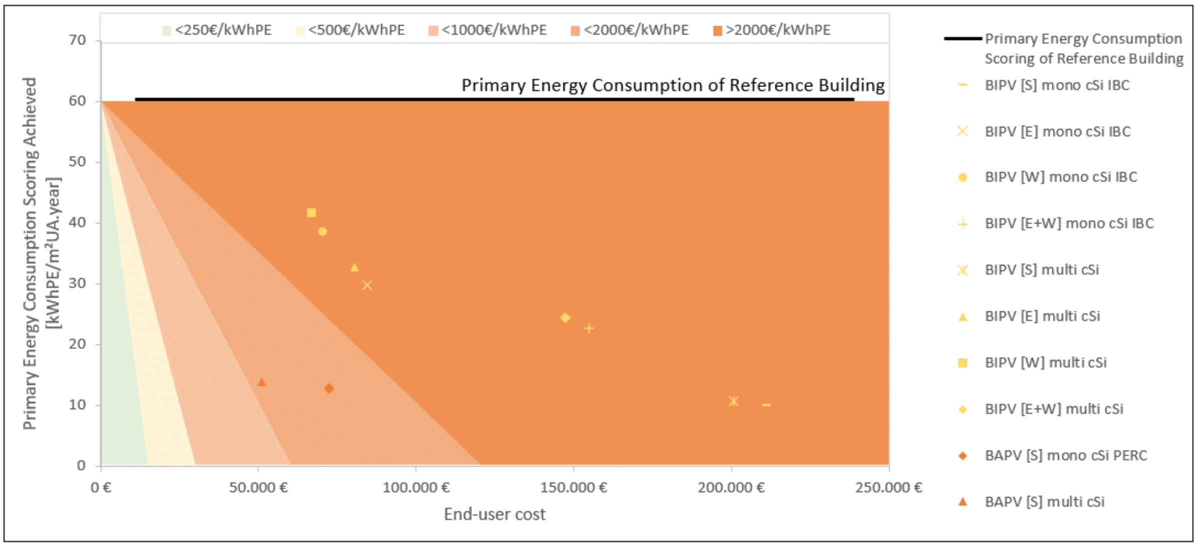


Figure 5.8.6 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Spain

Table 5.8.12 Validation of renewable energy integration target as set by national regulation for a MFH in Spain

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	NA
East	Y	Y	NA	NA	NA
West	N	N	NA	NA	NA
East & West	Y	Y	NA	NA	NA

Key findings:

Similar primary energy balance reductions are achieved with BIPV and BAPV systems. Indeed, the produced renewable electricity can be used for both DHW and heating as theses uses rely on electricity in this case.

Yet, when looking at the cost-efficiency indicator, BAPV performs largely better than BIPV, improving the energy scoring by twice as much to three times as much as BIPV for the same cost.

The renewable energy integration target consists in the coverage of 60% of the DHW needs by renewable energy and is met for most BIPV system configurations and for all BAPV configurations

5.8.4 Educational building

This educational building's heating and DHW needs are covered by gas.

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.8.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in Spain

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	140	140	900	900	50
South	Installed capacity [kWp]	22	19	99	88	*NA*
South	RE system surface to net floor area [-]	0,05	0,05	0,29	0,29	0,02
East	Occupied area [m²]	160	160	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	26	21	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,05	0,05	*NA*	*NA*	*NA*
West	Occupied area [m²]	160	160	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	26	21	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,05	0,05	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	320	320	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	51	43	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,10	0,10	*NA*	*NA*	*NA*

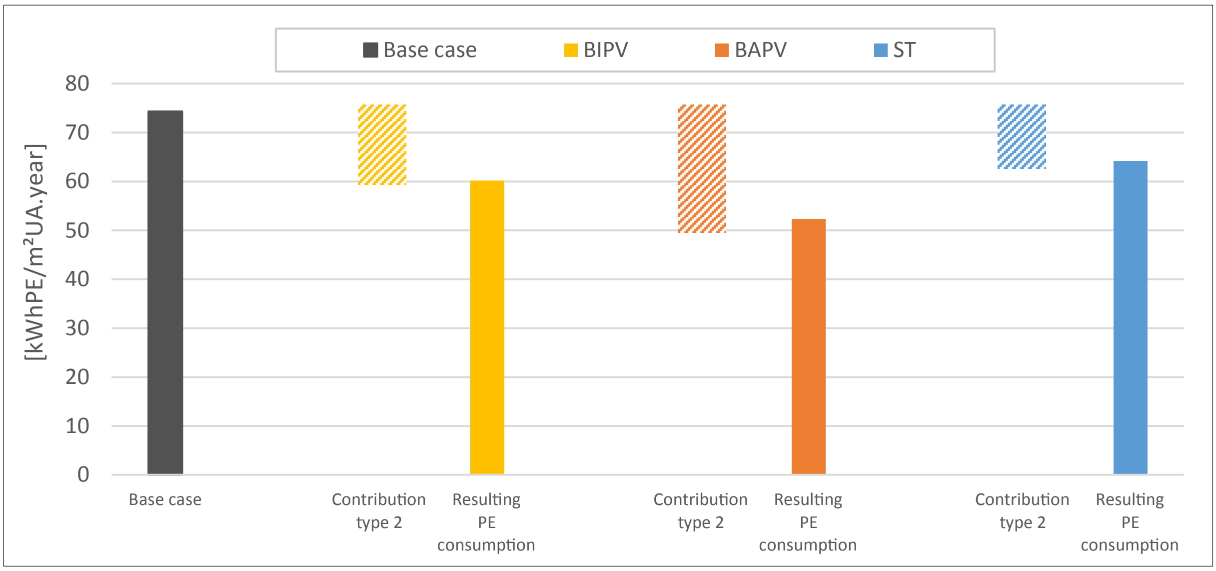


Figure 5.8.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in Spain

Table 5.8.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in Spain

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-19%	-17%	-30%	-30%	-14%
East	-14%	-13%	*NA*	*NA*	*NA*
West	-13%	-12%	*NA*	*NA*	*NA*
East & West	-19%	-18%	*NA*	*NA*	*NA*

Table 5.8.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in Spain

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,58	0,61	0,28	0,39	0,42
East	0,38	0,40	*NA*	*NA*	*NA*
West	0,34	0,36	*NA*	*NA*	*NA*
East & West	0,26	0,28	*NA*	*NA*	*NA*

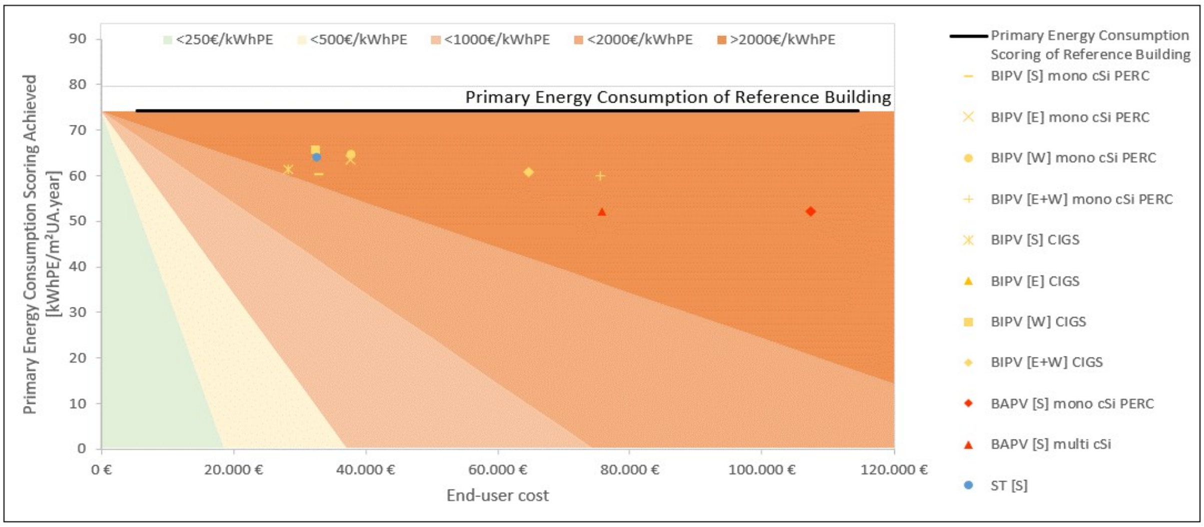


Figure 5.8.8 PE consumption scorings achieved with different renewable systems and associated cost for a EB in Spain

Table 5.8.16 Validation of renewable energy integration target as set by national regulation for a EB in Spain

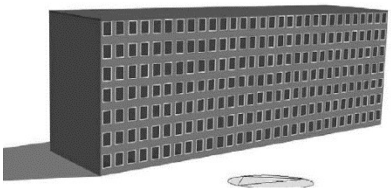
	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	N	N	N	N	N
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	N	N	*NA*	*NA*	*NA*

Key findings:

Even tough heating and DHW needs are not covered by electricity, and because for non-residential buildings, lighting is an eligible use, the part of the produced renewable electricity covering this need can be accounted for by applying a lower primary energy factor, thus reducing the total primary energy balance. The reduction of each kWh_{PE}/m^2 compared to reference building being achieved at more than 2000€ for all studied renewable systems.

As DHW is provided by a gas boiler, the renewable energy integration target is never reached for BIPV and BAPV.

5.8.5 Office building: Case 1/2



The ventilation and cooling needs for this office building are covered by electricity. In addition, lighting is part of the eligible uses for the calculation of the energy balance.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

A further office building case with different heating, cooling and ventilation equipment is presented in in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.8.17 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Spain

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	648	648	973	973
South	Installed capacity [kWp]	65	16	107	95
South	RE system surface to net floor area [-]	0,09	0,09	0,13	0,13
East	Occupied area [m²]	648	648	*NA*	*NA*
East	Installed capacity [kWp]	65	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
West	Occupied area [m²]	648	648	*NA*	*NA*
West	Installed capacity [kWp]	65	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
East & West	Occupied area [m²]	1296	1296	*NA*	*NA*
East & West	Installed capacity [kWp]	130	32	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*

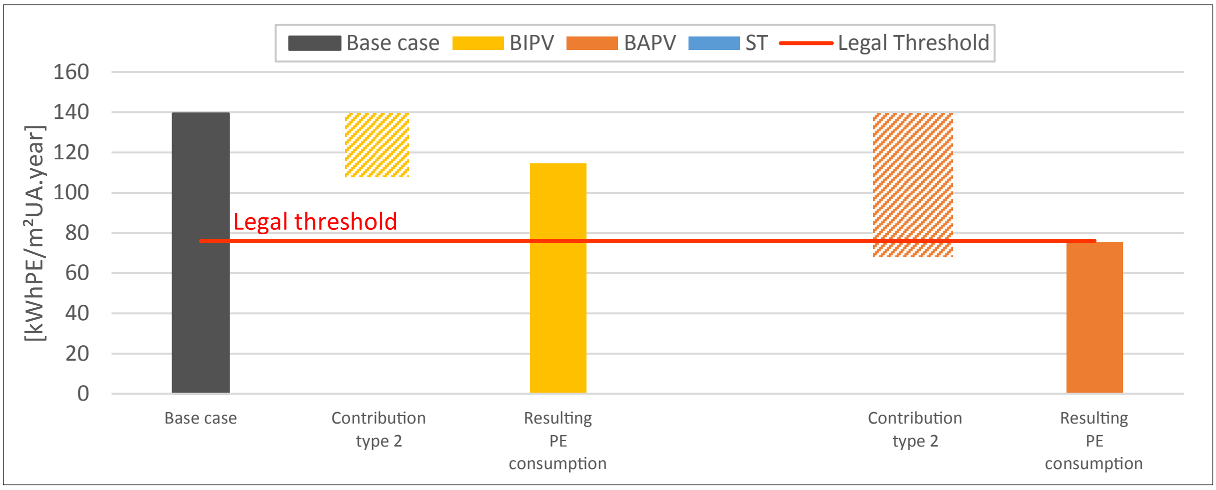


Figure 5.8.9 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Spain

Table 5.8.18 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Spain

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-18%	-4%	-46%	-41%
East	-16%	-4%	NA	NA
West	-13%	-3%	NA	NA
East & West	-29%	-7%	NA	NA

Table 5.8.19 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Spain

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,06	0,02	0,40	0,50
East	0,06	0,02	NA	NA
West	0,05	0,01	NA	NA
East & West	0,05	0,02	NA	NA

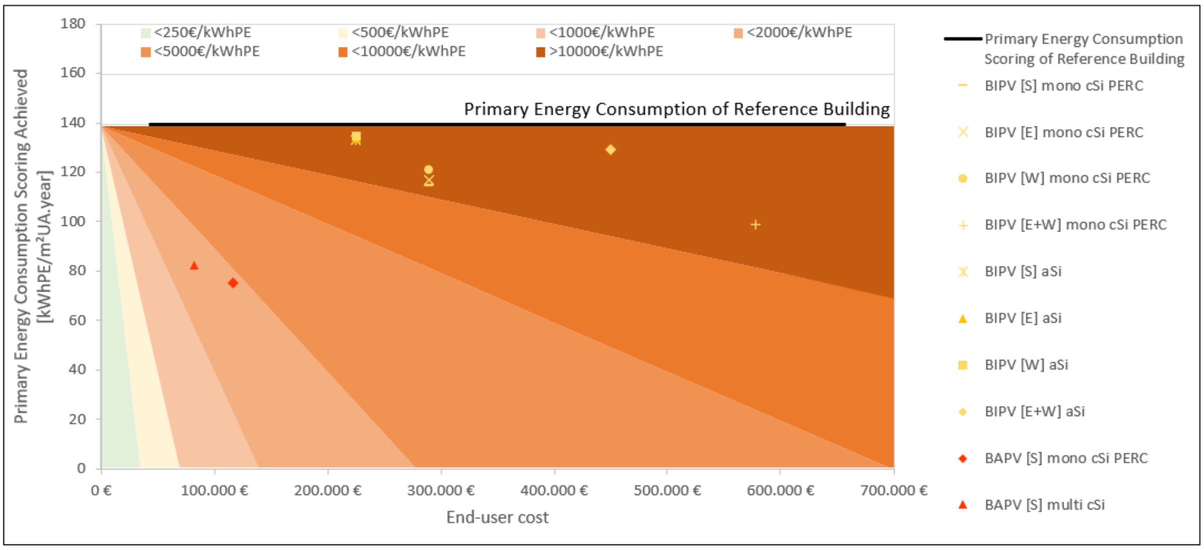


Figure 5.8.10 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Spain

Table 5.8.20 Validation of renewable energy integration target as set by national regulation for a OB in Spain

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	N	Y
East	N	N	NA	NA
West	N	N	NA	NA
East & West	N	N	NA	NA

Key findings:

Produced renewable electricity allows to reduce the primary energy balance for both BIPV and BAPV cases. Nevertheless, BAPV systems, in the studied configurations, allow to decrease the primary energy balance by a higher magnitude, and this with a better cost efficiency than BIPV (6 to 25 times better).

As far as the renewable energy targets are concerned, as it is assumed that there are no DHW needs, it can be considered the 60% coverage by renewable energy of this need is validated for all systems.

Nevertheless, as the building's area exceeds 3000 m², the installed capacity only falls within the mandatory range for the multi cSi-based BAPV system. Indeed, as far as the aSi-based BIPV systems are concerned, the installed capacity is too low and does not fall within the mandatory range. Then, for the mono PERC-based curtain wall applied on west and east facades, as well as for the mono PERC-based BAPV system, the installed capacity exceeds the mandatory limit of 100 kW.

5.9 Switzerland

5.9.1 Single-family house: Case 2/2

In this SFH case, heating needs are covered by a wood pellets boiler, while DHW needs are covered by a gas boiler. There are no ventilation and cooling needs in this residential case.

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

A further single-family house case with different heating, cooling, ventilation and DHW equipment is presented in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Table 5.9.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Switzerland (2/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	30	30	30	30	30	30	4
South	Installed capacity [kWp]	5	3	4	5	5	6	*NA*
South	RE system surface to net floor area [-]	0,23	0,23	0,23	0,23	0,23	0,23	0,03
East & West	Occupied area [m²]	60	60	60	60	60	60	*NA*
East & West	Installed capacity [kWp]	11	6	8	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,45	0,45	0,45	0,45	0,45	0,45	*NA*

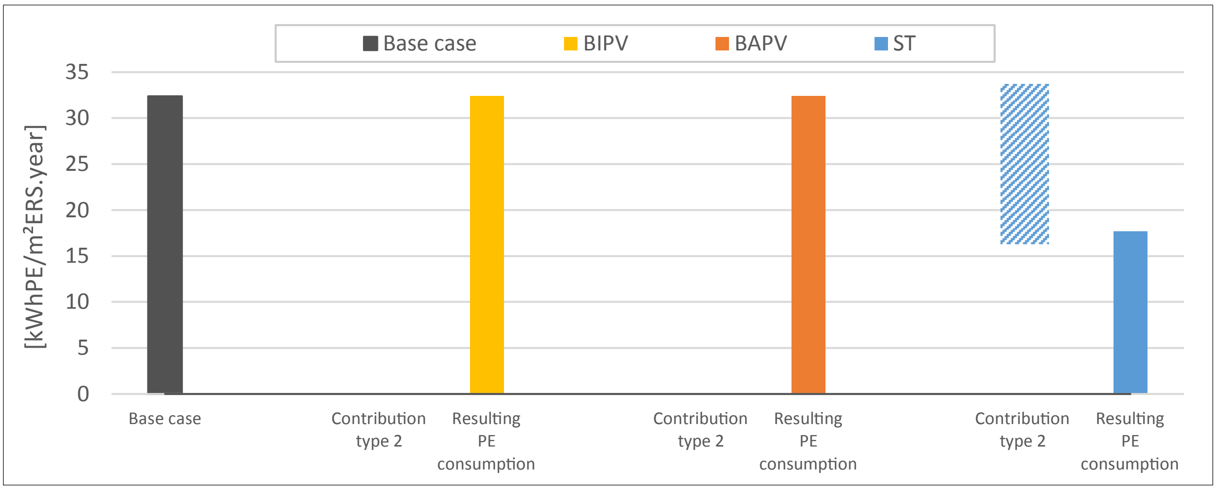


Figure 5.9.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Switzerland

Table 5.9.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Switzerland

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	0%	0%	0%	0%	0%	0%	-45%
East & West	0%	0%	0%	0%	0%	0%	*NA*

Table 5.9.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Switzerland

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	0	0	0	0	0	0	11
East & West	0	0	0	0	0	0	*NA*

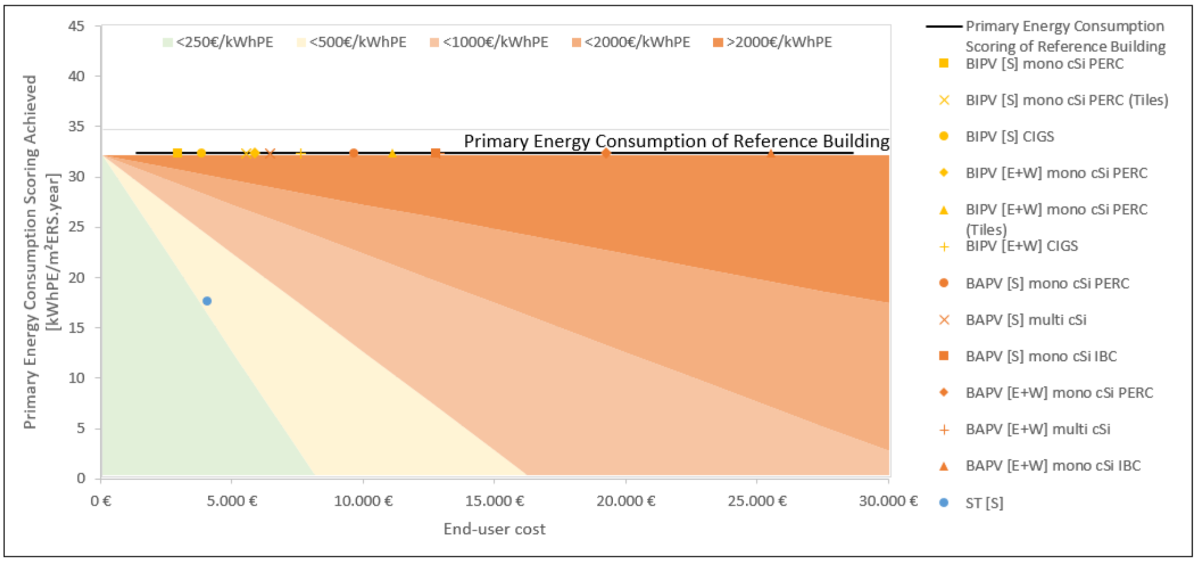


Figure 5.9.2 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Switzerland

Table 5.9.4 Validation of renewable energy integration target as set by national regulation for a SFH in Switzerland

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	N
East & West	Y	Y	Y	Y	Y	Y	*NA*

Key findings:

BAPV and BIPV systems cannot contribute to reduce the primary energy balance while the impact of the solar thermal system on the primary energy balance is notable. This can be explained by the fact that there are no cooling and ventilation needs. Thus, the primary energy consumption for DHW represents an important part in the total primary energy balance, which proportionally increases the contribution of solar thermal.

When looking at the validation of renewable energy integration target, the conclusions are the opposite. Indeed, only the electricity-producing renewable systems allow to comply with the criterion of installing a 0,01 Wp/m² of electrical power.

5.9.2 Multifamily house

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.9.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in Switzerland (1/1)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	450	450	500	500	NA
South	Installed capacity [kWp]	79	69	55	49	NA
South	RE system surface to net floor area [-]	0,18	0,18	0,20	0,20	NA
East	Occupied area [m²]	180	180	NA	NA	NA
East	Installed capacity [kWp]	32	28	NA	NA	NA
East	RE system surface to net floor area [-]	0,07	0,07	NA	NA	NA
West	Occupied area [m²]	150	150	NA	NA	NA
West	Installed capacity [kWp]	26	23	NA	NA	NA
West	RE system surface to net floor area [-]	0,06	0,06	NA	NA	NA
East & West	Occupied area [m²]	330	330	NA	NA	NA
East & West	Installed capacity [kWp]	58	50	NA	NA	NA
East & West	RE system surface to net floor area [-]	0,13	0,13	NA	NA	NA

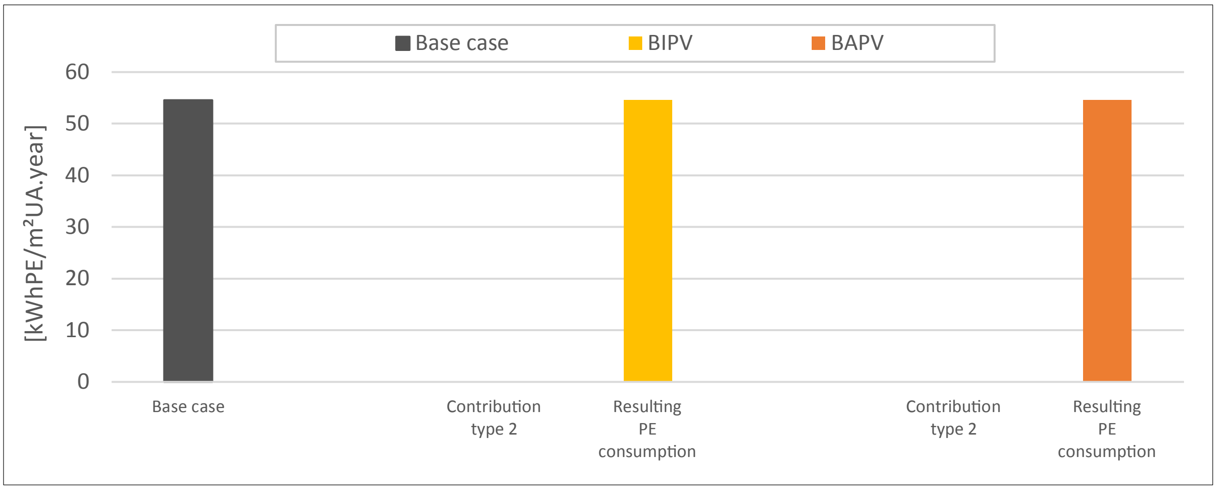


Figure 5.9.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in Switzerland

Table 5.9.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Switzerland

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0%	0%	0%	0%	*NA*
East	0%	0%	*NA*	*NA*	*NA*
West	0%	0%	*NA*	*NA*	*NA*
East & West	0%	0%	*NA*	*NA*	*NA*

Table 5.9.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Switzerland

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,00	0,00	0,00	0,00	*NA*
East	0,00	0,00	*NA*	*NA*	*NA*
West	0,00	0,00	*NA*	*NA*	*NA*
East & West	0,00	0,00	*NA*	*NA*	*NA*

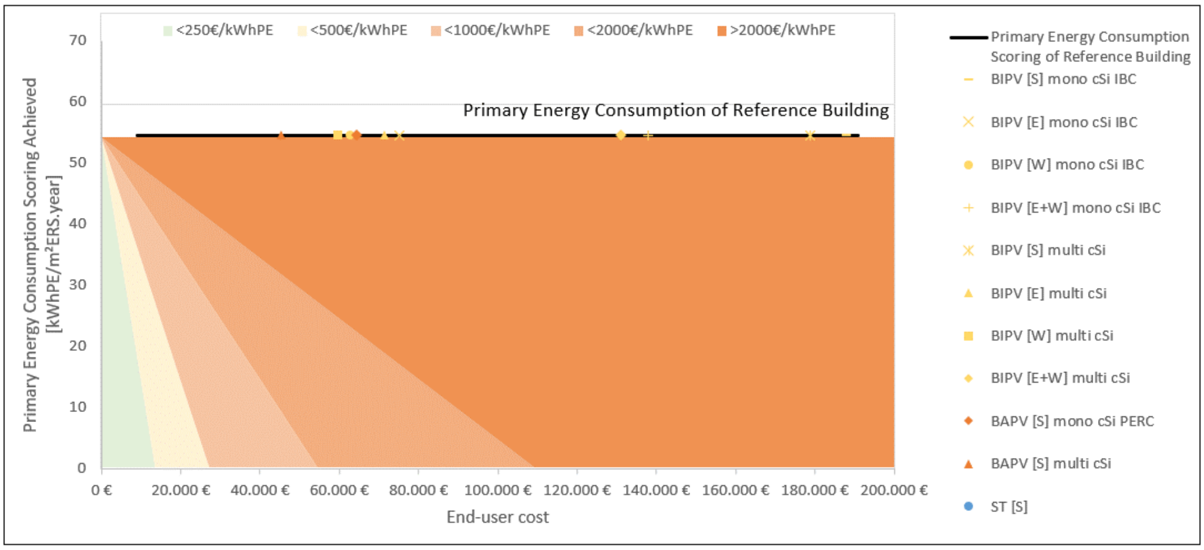


Figure 5.9.4 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Switzerland

Table 5.9.8 Validation of renewable energy integration target as set by national regulation for a MFH in Switzerland

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	*NA*
East	Y	Y	*NA*	*NA*	*NA*
West	Y	N	*NA*	*NA*	*NA*
East & West	Y	Y	*NA*	*NA*	*NA*

Key findings:

Neither the BIPV systems, nor the BAPV systems allow to reduce the primary energy balance. Nevertheless, it is worth mentioning that in Switzerland, for multi-floor buildings, an integration of PV panels in the façade must be foreseen or a compensation tax must be paid.

But the renewable energy integration targets are reached for almost all studied configurations.

5.9.3 Educational building

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.9.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a EB in Switzerland

		BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	130	130	800	800	20
South	Installed capacity [kWp]	21	17	88	78	*NA*
South	RE system surface to net floor area [-]	0,04	0,04	0,23	0,23	0,01
East	Occupied area [m²]	80	80	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	13	11	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,02	0,02	*NA*	*NA*	*NA*
West	Occupied area [m²]	80	80	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	13	11	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,02	0,02	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	160	160	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	26	21	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,05	0,05	*NA*	*NA*	*NA*

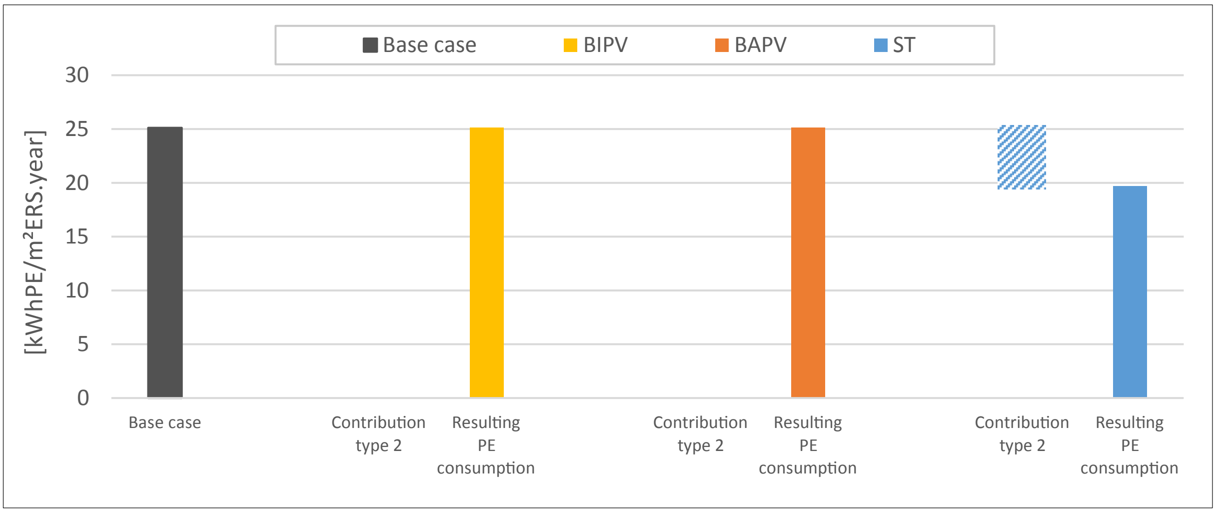


Figure 5.9.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a EB in Switzerland

Table 5.9.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a EB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0%	0%	0%	0%	-22%
East	0%	0%	*NA*	*NA*	*NA*
West	0%	0%	*NA*	*NA*	*NA*
East & West	0%	0%	*NA*	*NA*	*NA*

Table 5.9.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a EB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,00	0,00	0,00	0,00	1,65
East	0,00	0,00	*NA*	*NA*	*NA*
West	0,00	0,00	*NA*	*NA*	*NA*
East & West	0,00	0,00	*NA*	*NA*	*NA*

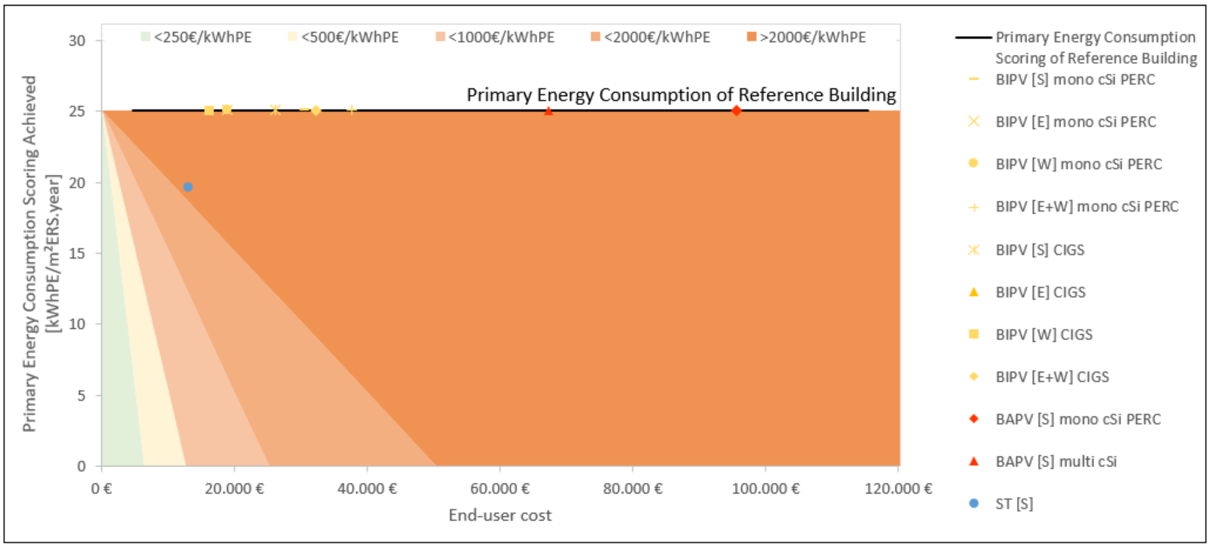


Figure 5.9.6 PE consumption scorings achieved with different renewable systems and associated cost for a EB in Switzerland

Table 5.9.12 Validation of renewable energy integration target as set by national regulation for a EB in Switzerland

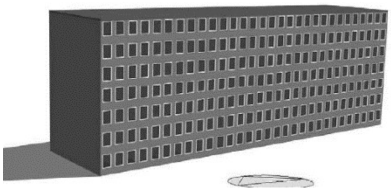
	BIPV mono cSi PERC (facade)	BIPV CIGS (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	N	N	Y	Y	N
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	N	N	*NA*	*NA*	*NA*

Key findings:

Neither the BIPV systems, nor the BAPV systems allow to reduce the primary energy balance. Solar thermal allows a fair reduction of the primary energy balance.

Renewable energy integration targets are reached for BAPV systems only. Solar thermal systems cannot meet the renewable energy integration targets as it concerns electrical installed capacity.

5.9.4 Office building: Case 1/2



A further office building case with different heating, cooling and ventilation equipment is presented in in Appendix 5 as the study of this other case does not provide any further elements of analysis.

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 5.9.13 Occupied areas (m^2) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Switzerland

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m^2]	648	648	973	973
South	Installed capacity [kWp]	65	16	107	95
South	RE system surface to net floor area [-]	0,09	0,09	0,14	0,14
East	Occupied area [m^2]	648	648	*NA*	*NA*
East	Installed capacity [kWp]	65	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
West	Occupied area [m^2]	648	648	*NA*	*NA*
West	Installed capacity [kWp]	65	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
East & West	Occupied area [m^2]	1296	1296	*NA*	*NA*
East & West	Installed capacity [kWp]	130	32	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,19	0,19	*NA*	*NA*

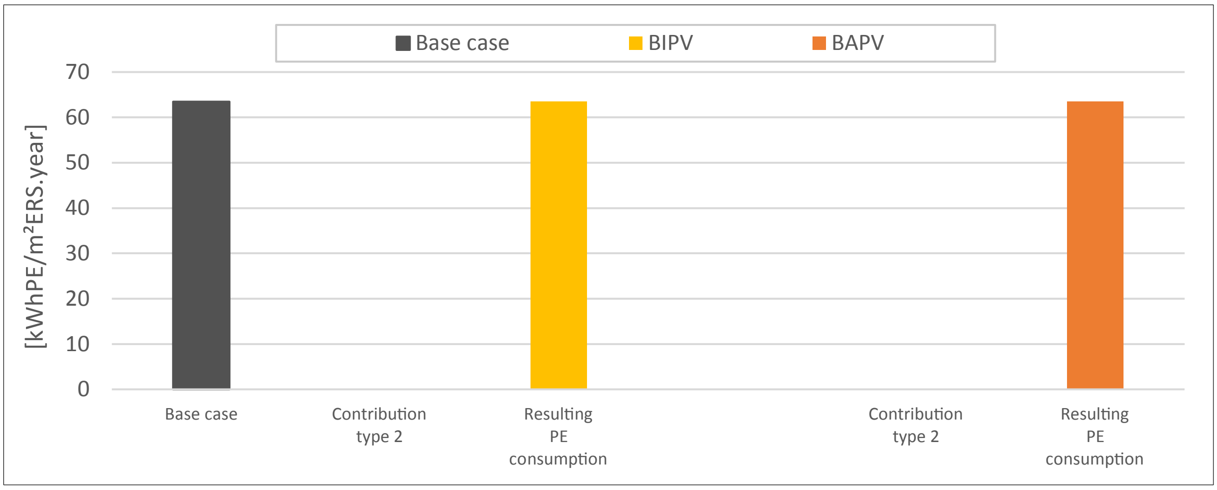


Figure 5.9.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Switzerland

Table 5.9.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0%	0%	0%	0%
East	0%	0%	NA	NA
West	0%	0%	NA	NA
East & West	0%	0%	NA	NA

Table 5.9.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,00	0,00	0,00	0,00
East	0,00	0,00	NA	NA
West	0,00	0,00	NA	NA
East & West	0,00	0,00	NA	NA

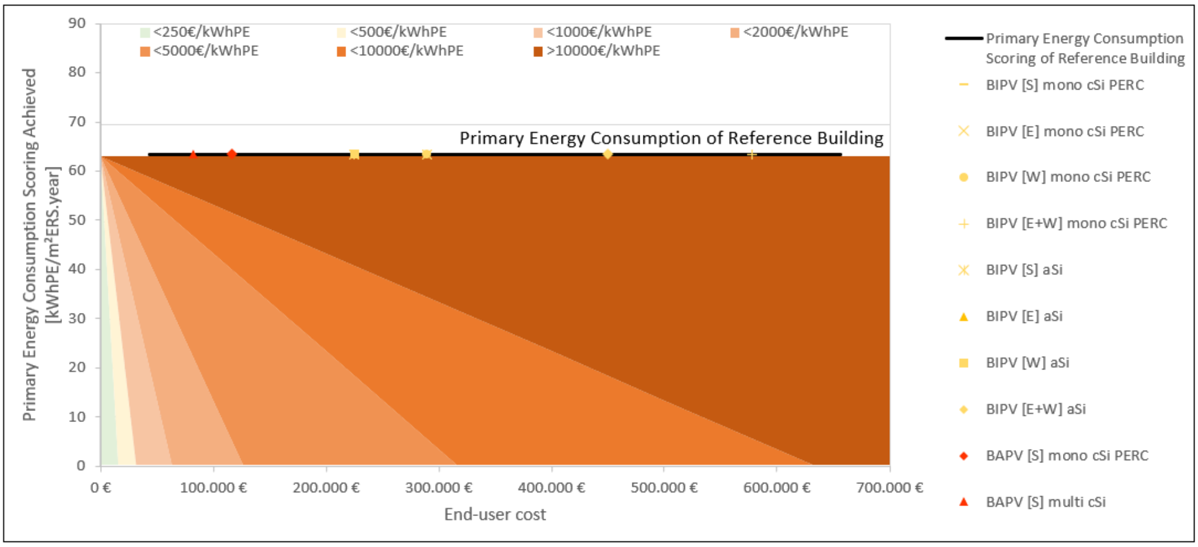


Figure 5.9.8 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Switzerland

Table 5.9.16 Validation of renewable energy integration target as set by national regulation for a OB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	Y	Y
East	N	N	NA	NA
West	N	N	NA	NA
East & West	Y	N	NA	NA

Key findings:

Neither the BIPV systems, nor the BAPV systems allow to reduce the primary energy balance.

Renewable energy integration targets are reached for each studied BAPV system and for the mono PERC-based and east and west-oriented BIPV system.

5.10 Quantified contribution of BIPV systems and competing solution overview

As far as single-family houses are concerned, BIPV and BAPV systems have comparable performances and identical irradiance conditions as they are both positioned on tilted roofs. Therefore, they allow to reduce the primary energy balance by equivalent amounts. Yet, when only taking the extra cost of BIPV as the end-user cost, BIPV systems turn out to be more cost efficient than BAPV. These observations are applicable to all countries, except Spain and Italy, where this is only valid when at least one of the heating, DHW or ventilation systems is using electricity. In Germany, reduction potential could be enhanced by changing the calculation principle. In Switzerland, no reduction is possible.

When it comes to multi-family house, BIPV and BAPV in their studied configurations allow to reduce the primary energy balance by equivalent amounts. Indeed, BAPV systems benefit from more favourable irradiation conditions on the roof than BIPV systems installed as ventilated façades. Nevertheless, the coverage ratio of BIPV ventilated façade systems is higher than BAPV system, in case of flat roof. Thus, allowing higher installed capacities for a same available surface. It is also worth mentioning that depending on the architectural characteristics of the building, the available surface of the roof can be limited, compared to the available surface on façades, which increases the added value of using BIPV. Then, from a cost perspective, BAPV remains more cost-efficient than BIPV. This is due to the fact, that, in general façade installations are relatively expensive. In addition, one of the considered BIPV products for MFH application is based on mono cSi IBC which is a better performing but more expensive technology. Yet, with some improvements with regards to the end-user cost, BIPV could become a good solution. Especially since renewable energy targets are almost always achieved in at least one orientation and for at least one studied technology. In addition, even if in Switzerland there is no possibility to deduce the renewable energy production from the primary energy consumption, façade integrated renewable systems must be systematically foreseen for all multi-floor buildings.

For educational buildings, overall, BAPV systems allow to reduce the primary energy consumption by a significantly larger amount. This is mostly related to the general architectural geometry of the building with an important available surface on the roof and reduced suitable and available surfaces on the facades. But, when looking at the cost-efficiency, the advantage of one PV product over the other is not straightforward, and while in Belgium, Italy and the Netherlands, the advantage goes to BAPV, the opposite situation is observed in France, Germany and Spain. However, renewable energy integration targets are almost never achieved with BIPV. This is mostly due to the important gap between the available surfaces on the façade and available surfaces on the roof and, consequently, to the discrepancy between the amount of electricity that can be generated on the façade (limited by space and irradiance conditions) and the important total consumption of educational buildings.

Finally, in the case of office buildings, in general, covering the eastern and western facades of an office buildings with mono PERC-based BIPV curtain wall allows to achieve a comparable primary energy balance reduction as with a mono PERC-based, south oriented BAPV system on the roof. Yet, in terms of cost efficiency, BAPV systems have largely better results.

As far as solar thermal systems are concerned, based on the results presented in this deliverable, one could argue that solar thermal is not a direct competitor to BIPV. Overall results in terms of primary energy balance reduction and cost-efficiency are rather good for solar thermal systems. Although, multiple renewable energy integration targets are unreachable with the sole installation of a solar thermal systems. Indeed, the installation of a certain electrical capacity or the coverage of needs such as heating, or cooling cannot be validated by solar thermal (or at least not in the studied configuration). As a consequence, if an additional renewable system producing electricity needs to be installed to achieve the target, BIPV has an advantage over BAPV as it can be installed on facades, and thus leaving available space for a solar thermal system on the roof. Hence, rather than a competitor, solar thermal appears as an interesting complementary technology to BIPV both in terms of available areas occupied and needs covered.

In Table 5.10.1 and Table 5.10.2, the average best PE balance relative reductions and cost-efficiencies are gathered for each studied renewable energy system and each considered building type. It should be noted that best cost-efficiency and the best PE balance relative reduction can be obtained, for a given renewable system, with different configurations. Typically, installing a more important capacity will often lead to a more important PE balance relative reduction, even though from a cost-efficiency perspective this might not be relevant. Similarly, the best result for one given indicator can be reached with renewable energy systems having very different installed capacities, or orientations. This should be kept in mind when reading those tables. Therefore, these tables aim at providing a general overview of the results presented in Section 5, but they cannot be a substitute for the previously presented detailed analysis.

Overall, they demonstrate that, while BIPV has the potential to substantially reduce the primary energy balance of buildings, in some cases by a magnitude higher or equal to competing BAPV systems, it is not always the most cost-efficiency choice for this purpose. The only situation where it clearly has the advantage, as already mentioned, is in the case of a roofing installation of a single-family house.

Table 5.10.1 Average best PE balance relative reduction for BIPV, BAPV and ST for all four studied building types.

Building Type	BIPV average best PE balance relative reduction	BAPV average best PE balance relative reduction	ST average best PE balance relative reduction
SFH	**-55%**	**-55%**	-37%
MFH	**-55%**	-50%	-25%
EB	-20%	**-40%**	-11%
OB	-25%	**-33%**	*NA*

Table 5.10.2 Average best cost-efficiencies (% point relative PE balance variation/k€) for BIPV, BAPV and ST for all four studied building types

Building Type	BIPV average best cost-efficiency	BAPV average best cost-efficiency	ST average best cost-efficiency
SFH	**17**	8	9
MFH	0,60	**1,75**	0,96
EB	0,37	0,36	**0,51**
OB	0,05	**0,39**	*NA*

6 QUANTIFYING THE FUTURE CONTRIBUTION OF BIPV IN COMPLYING WITH NZEB REQUIREMENTS

This section aims at evaluating to what extent the improvements developed in the frame of the BIPVBOOST project could contribute to enhance the different types of contribution of BIPV in complying with nZEB regulations. It should be highlighted that only the improvements that are planned within the BIPVBOOST project are analysed here. Other improvements arising from the (BI)PV industry or the construction sector and positively impacting the performances and cost of BIPV in the future are not considered here. Note that all these improvements are presented and analysed more precisely in a cost reduction roadmap developed in a dedicated BIPVBOOST deliverable: “Cost reduction roadmap for the European BIPV sector”.

Section 6 is divided into a generic sensitivity analysis and a specific evaluation of BIPVBOOST improvements.

6.1 Generic sensitivity analysis

First, a generic sensitivity analysis is conducted. In this analysis, the value of various parameters impacted by BIPVBOOST improvements is changed, in order to evaluate their effect on the cost efficiency indicator.

These parameters are the module efficiency, the end-user cost, the system yield, and the system lifetime. Nonetheless, some of these parameters have been removed from the generic sensitivity analysis. Indeed:

- the system lifetime is not a parameter that affects the cost efficiency as defined in this deliverable, therefore it cannot be included in the analysis.
- as the BIPV systems analysed are constraints by the available surface they can occupy, an identical variation of the module efficiency or of the yield results in the same impact on the cost efficiency indicator. Consequently, as a simplification, only module efficiency variations will be analysed at this point.

In addition, note that as it is mathematically demonstrated in Appendix 4, an X% variation of the end-user cost results in an impact on the cost efficiency that is independent from the country, the building type, and the subcase analysed. This is linked to the simplification assumption that end-user costs of the BIPV systems are uniform across the analysed European countries.

The number of combinations {*country; building type; subcase; BIPV system; orientation*} has also been partially reduced by only testing one BIPV system in one orientation, as summarised in Table 6.1.1.

Table 6.1.1 Selected BIPV systems in the generic sensitivity analysis

Product type		BIPV			
Building type		SFH	MFH	EB	OB
Cladding typology		Glazed opaque solution without thermal properties	Glazed opaque solution with thermal properties (insulation layer)	Glazed opaque solution without thermal properties	Glazed semi-transparent solution without thermal protection
Technological system		In roof mounting system	Ventilated façade	Ventilated façade	Curtain wall
PV technology		mono cSi PERC	mono cSi IBC	mono cSi PERC	mono cSi PERC
Degradation rate year 1	[%/year]	1,80%	1,00%	1,80%	1,80%
Degradation rate year >1	[%/year]	0,45%	0,25%	0,45%	0,45%
System power density	[Wp/m²]	179	175	161	100
Application area		Tilted roof	Facade	Facade	Facade
Tested orientation		South	South	South	South

For each country, a chart represents the impact of end-user cost and module efficiency variations on the cost efficiency for all studied building type and cases. For each building type, only one BIPV system is tested in this sensitivity analysis. In the case of Switzerland, as the type 2 potential contribution of BIPV is 0, no sensitivity analysis was conducted.

6.1.1 Belgium

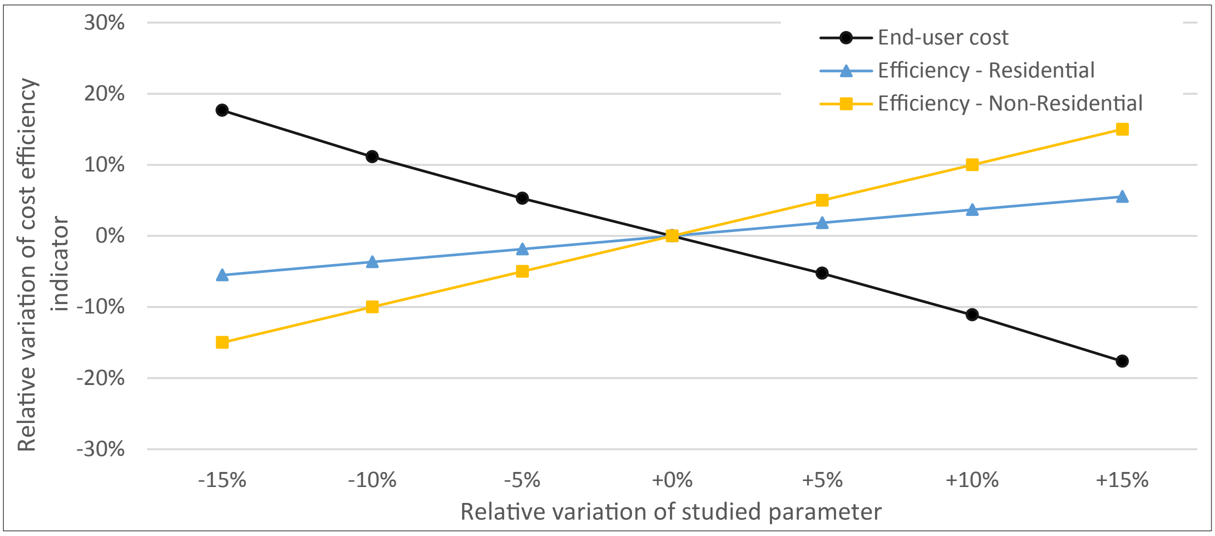


Figure 6.1.1 Sensitivity analysis in the case of Belgium

Here, the most influential factor is the end-user cost, which obviously has a perfectly proportional influence on the cost-efficiency indicator. The efficiency in the non-residential case almost has a similar impact. This is because in the non-residential cases, the total monthly primary energy consumption exceeds the monthly primary energy demand avoided by the renewable energy production more often and/or by a higher magnitude. Therefore, an efficiency increase can have more impact than in the residential case, where a plateau is more rapidly reached, due to the limited primary energy consumption of the household.

6.1.2 France

In the case of France, the same remarks as for Belgium apply, but a seasonal balance is made instead of a monthly balance. The impact of efficiency in the residential is extremely reduced.

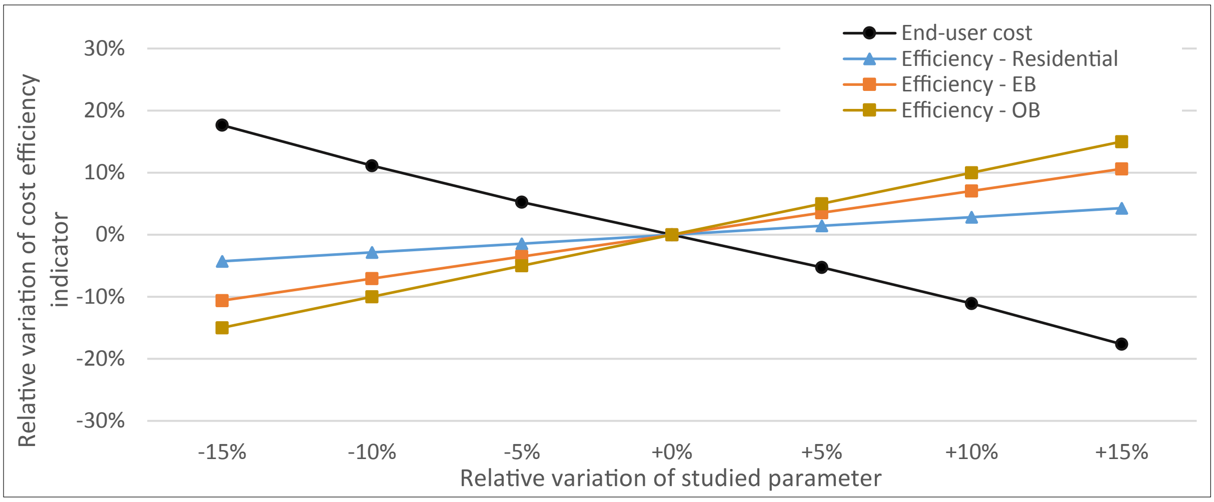


Figure 6.1.2 Sensitivity analysis in the case of France

6.1.3 Germany

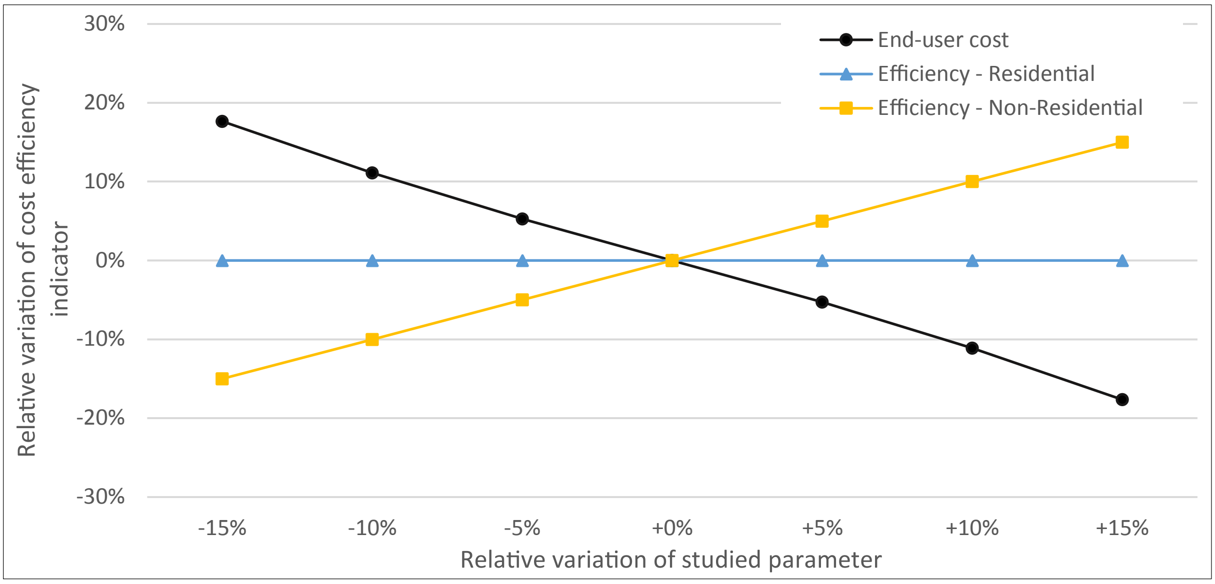


Figure 6.1.3 Sensitivity analysis in the case of Germany

Due to the specificities of the regulation, in the residential cases the produced electricity per square meter is at a level that implies that the deductible production is calculated based on the primary energy consumption of the reference building. Consequently, it is independent from the actual quantity of produced electricity. In the non-residential cases, on the contrary, because the yield of façade applied BIPV system is significantly lower than the one of roof applied systems, the deductible electricity production is directly dependent from the quantity of produced electricity and, consequently, of the module efficiency.

6.1.4 Italy

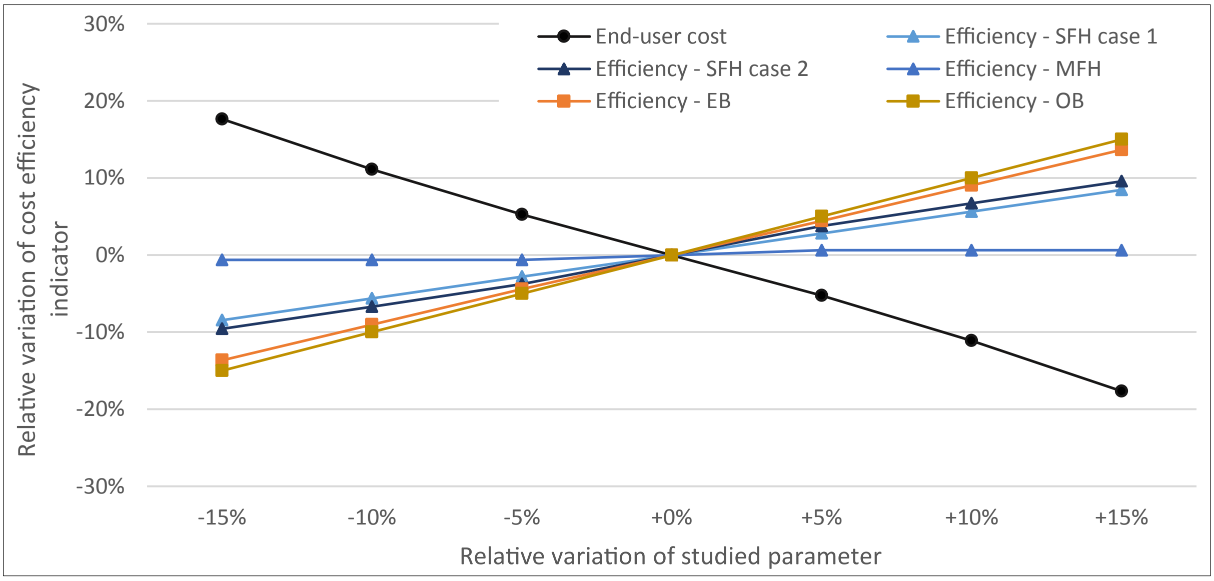


Figure 6.1.4 Sensitivity analysis in the case of Italy

In MFH1, where electricity is the energy vector for all uses, the BIPV produced electricity fulfils all the electricity needs for the eligible uses. If the amount of produced electricity is increased thanks to an increment of the module efficiency, then the additional produced electricity will serve for uses that are not eligible (appliances, lighting, …) for balancing reduction. Thus, the impact is null. But during some months, the total produced electricity allows to cover both the considered and non-considered needs, and consequently a portion of this electricity is exported to the grid. This exported electricity is also taken into account in the primary energy balancing.

6.1.5 Netherlands

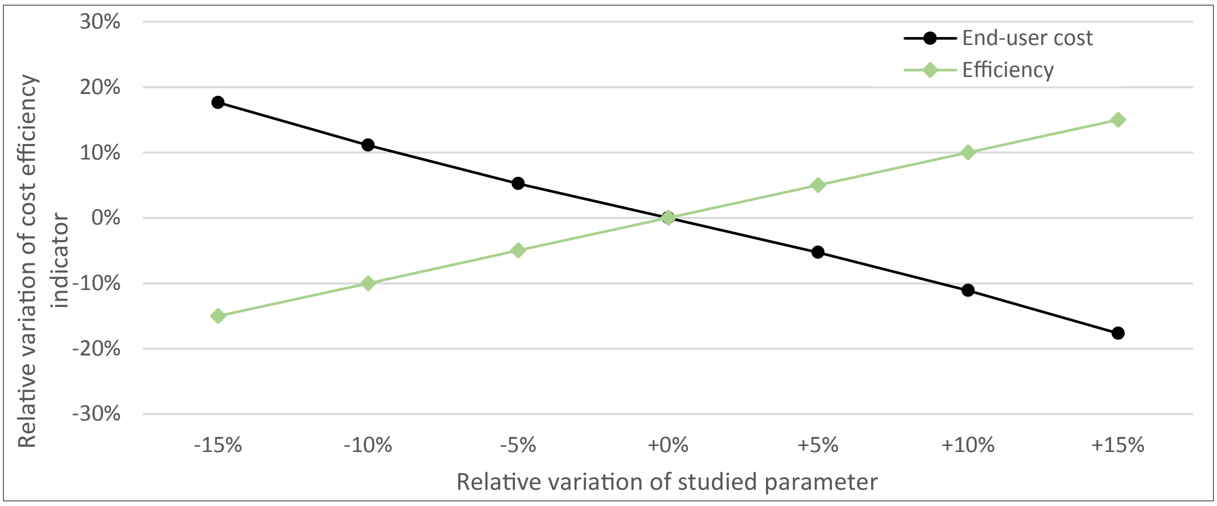


Figure 6.1.5 Sensitivity analysis in the case of the Netherlands

In the Netherlands, the renewable electricity self-consumed for considered needs is not directly taken into account in the primary energy balance, as this balance is based on fossil energy only. Although, it can indirectly impact this fossil primary energy balance by covering part of needs usually covered by fossil energy vectors. In addition, self-consumed electricity for non-eligible uses (i.e. uses that are not accounted in the total primary fossil energy balance) as well as exported electricity are also deductible. With a 15% module efficiency increase, the primary energy avoided by the additional renewable electricity does not compensate completely for the primary energy consumption, therefore, a 15% production increase leads to a 15% deduction increase. Nevertheless, a plateau would be reached, should the module efficiency increase in such a way that an equilibrium is achieved between production and consumption.

6.1.6 Spain

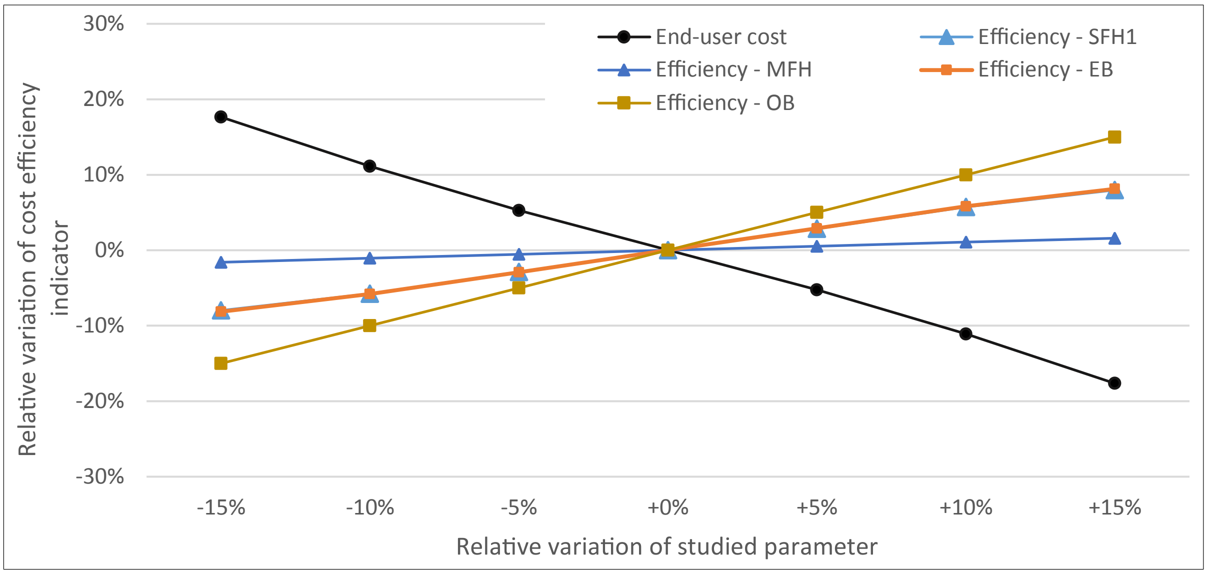


Figure 6.1.6 Sensitivity analysis in the case of Spain

Note that in the case of Spain, the results of SFH2 are not represented as in the base case the cost efficiency is equal to 0. Indeed, in SFH2, none of the eligible uses are fuelled by electricity. Thus, no electricity can be self-consumed for eligible uses.

As far as the MFH case is concerned, and to a lesser extent EB and SFH1, the additional electricity production only increases the self-consumed electricity for eligible uses during the winter season. During the summer months, the production already exceeds the consumption and therefore the electricity production gain cannot be exploited to reduce the primary energy balance.

On the contrary, for the OB cases, a 15% electricity production increase allows to increase the cost-efficiency indicator by 15% as well. This translates the fact that the production never exceeds the consumption, not matter the time of the year considered. Therefore, any electricity production surplus will serve the primary energy balance reduction.

6.1.7 Generic sensitivity analysis overview

Key findings:

The increase of the module efficiency of the studied BIPV products has various impacts across countries and studied cases. A module efficiency increase has the most impact for cases in which the BIPV contribution is limited (due to low electricity production compared to the building's consumption) and for cases in which no stringent rule apply for the deduction of the renewable energy production (typically, in the Netherlands). Overall, limiting factors to the full exploitation of a module efficiency increase are:

- BIPV already allows to bring down the primary energy balance to zero or close to zero, thus there is not much room to increase the BIPV contribution (e.g. Italian MFH case);

- BIPV electricity production cannot contribute to reduce the primary energy balance (e.g. in Switzerland)

- The deductible electricity production is determined by a fixed value (e.g. residential cases in Germany)

- The deductible electricity production is determined through a monthly balance and the production during the summer months already exceeds the consumption. Thus, only the electricity production gain in the winter months can serve to reduce the primary energy balance (e.g. residential Belgian cases)

On the contrary, end-user cost improvements have a constant impact on all cases and countries.

Therefore, decreasing the end-user cost and increasing the module efficiency, as targeted in BIPVBOOST, can greatly benefit the contribution of BIPV in complying with nZEB regulation but the limiting factor to this benefit remains the way local requirements are shaped.

6.2 Assessment of BIPVBOOST improvements’ impact

In this section, the improvements targeting the different studied BIPV systems, as planned within the frame of the BIPVBOOST project, are analysed by measuring their impact on the cost efficiency indicator. An overview of all improvements planned as part of the BIPVBOOST project is provided in Figure 6.2.2 Cost-reduction roadmap proposed by BIPVBOOST projectFigure 6.2.2. It should be noted that the end-user cost reduction that could be brought by some improvements would impact differently the extra cost and the fixed cost. But assumption is made in the following pages that the impact is distributed evenly. In addition, while in Section 6.1, relative variation of the yield were not assessed for previously explained reason, in this part, both parameters are assessed, as the studied improvements can impact the yield and the module efficiency in different manners.

First, the relevant improvements for each type of BIPV systems are identified. Then, the combined effect of these improvements on the three selected parameters is assessed. Finally, for each type of BIPV system, the total effects on the three parameters are combined, to assess their impact on the cost-efficiency indicator. This methodology is schematically represented in Figure 6.2.1

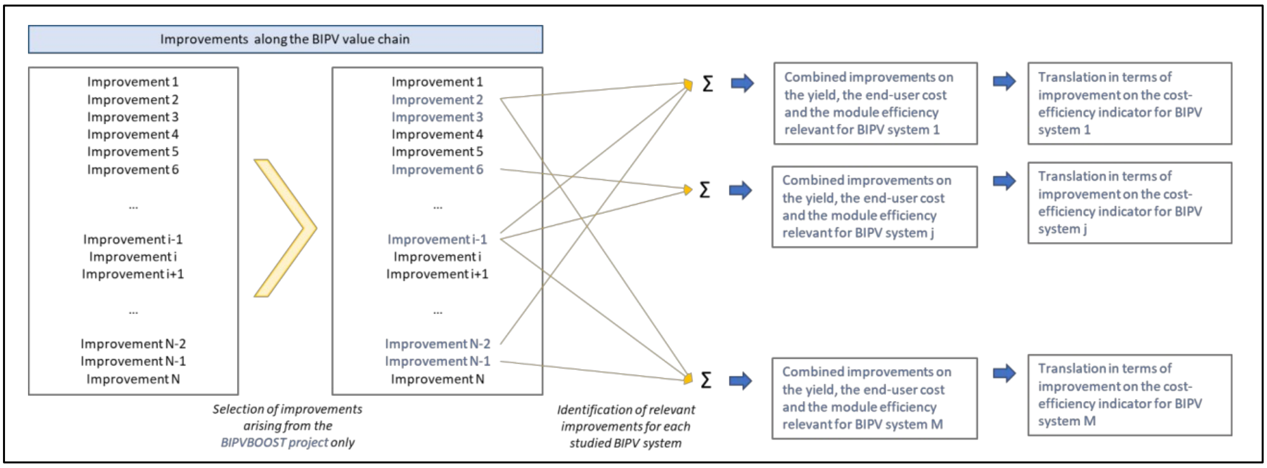
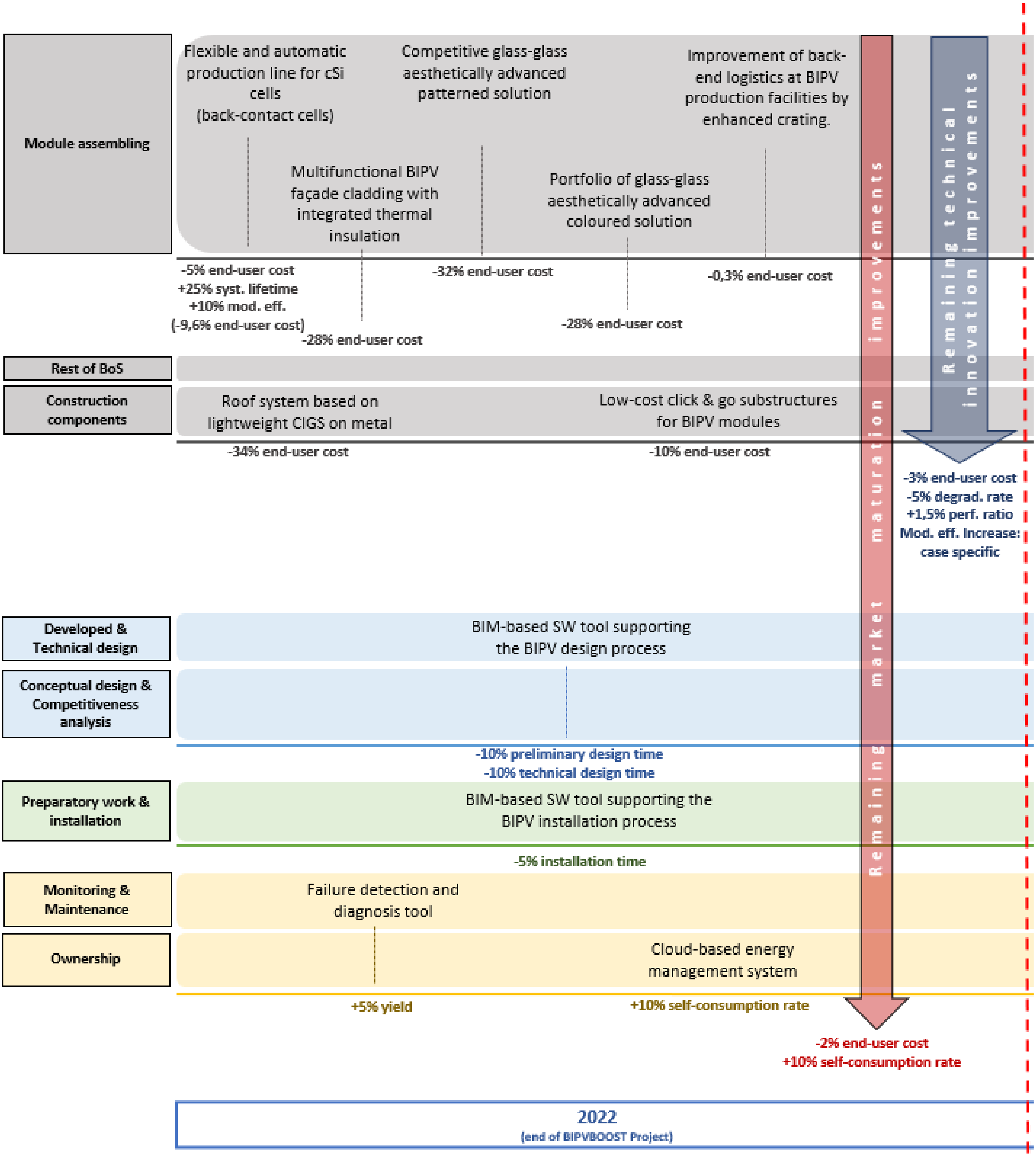


Figure 6.2.1 Overview of the used methodology to assess the impact of BIPVBOOST improvements

Results are presented for each studied BIPV system separately and for two selected cases only: the ones for which the various BIPVBOOST improvements allow the most and the least important absolute cost-efficiency increase compare to the base case without any improvements. In Figure 6.2.3 to Figure 6.2.10, the relative increase of the cost-efficiency indicator compared to the base case allowed by the BIPVBOOST improvements is represented. The results for all the cases can be found in Appendix 6.

Table 6.2.1 Parameters impacted by BIPVBOOST improvements, for the studied BIPV systems

	End user cost	Efficiency	Yield
SFH - PV tiles - mono cSi PERC	√	√	√
SFH - Full roof solution - CIGS	√	X	√
SFH - In roof mounting system - mono cSi PERC	√	√	√
MFH - Rainscreen facade - mono cSi IBC	√	√	√
MFH - Rainscreen facade - multi cSi	√	√	√
EB - Rainscreen facade - mono cSi PERC	√	√	√
EB - Rainscreen facade - CIGS	√	X	√
OB - Semi-transparent curtain wall - mono cSi PERC	√	√	√
OB - Semi-transparent curtain wall - aSi	√	X	√


Module assembling
Flexible and automatic production line for cSi cells (back-contact cells)
Competitive glass-glass aesthetically advanced patterned solution
Improvement of back-end logistics at BIPV production facilities by enhanced crating.
Multifunctional BIPV façade cladding with integrated thermal insulation
Portfolio of glass-glass aesthetically advanced coloured solution
-5% end-user cost
+25% syst. lifetime
+10% mod. eff.
(-9,6% end-user cost)
-28% end-user cost
-32% end-user cost
-28% end-user cost
-0,3% end-user cost
Rest of BoS
Construction components
Roof system based on lightweight CIGS on metal
Low-cost click & go substructures for BIPV modules
-34% end-user cost
-10% end-user cost
Remaining technical innovation improvements
-3% end-user cost
-5% degrad. rate
+1,5% perf. ratio
Mod. eff. Increase: case specific
Remaining market maturation improvements
Developed & Technical design
BIM-based SW tool supporting the BIPV design process
Conceptual design & Competitiveness analysis
-10% preliminary design time
-10% technical design time
Preparatory work & installation
BIM-based SW tool supporting the BIPV installation process
-5% installation time
Monitoring & Maintenance
Failure detection and diagnosis tool
Ownership
Cloud-based energy management system
+5% yield
+10% self-consumption rate
-2% end-user cost
+10% self-consumption rate
2022
(end of BIPVBOOST Project)

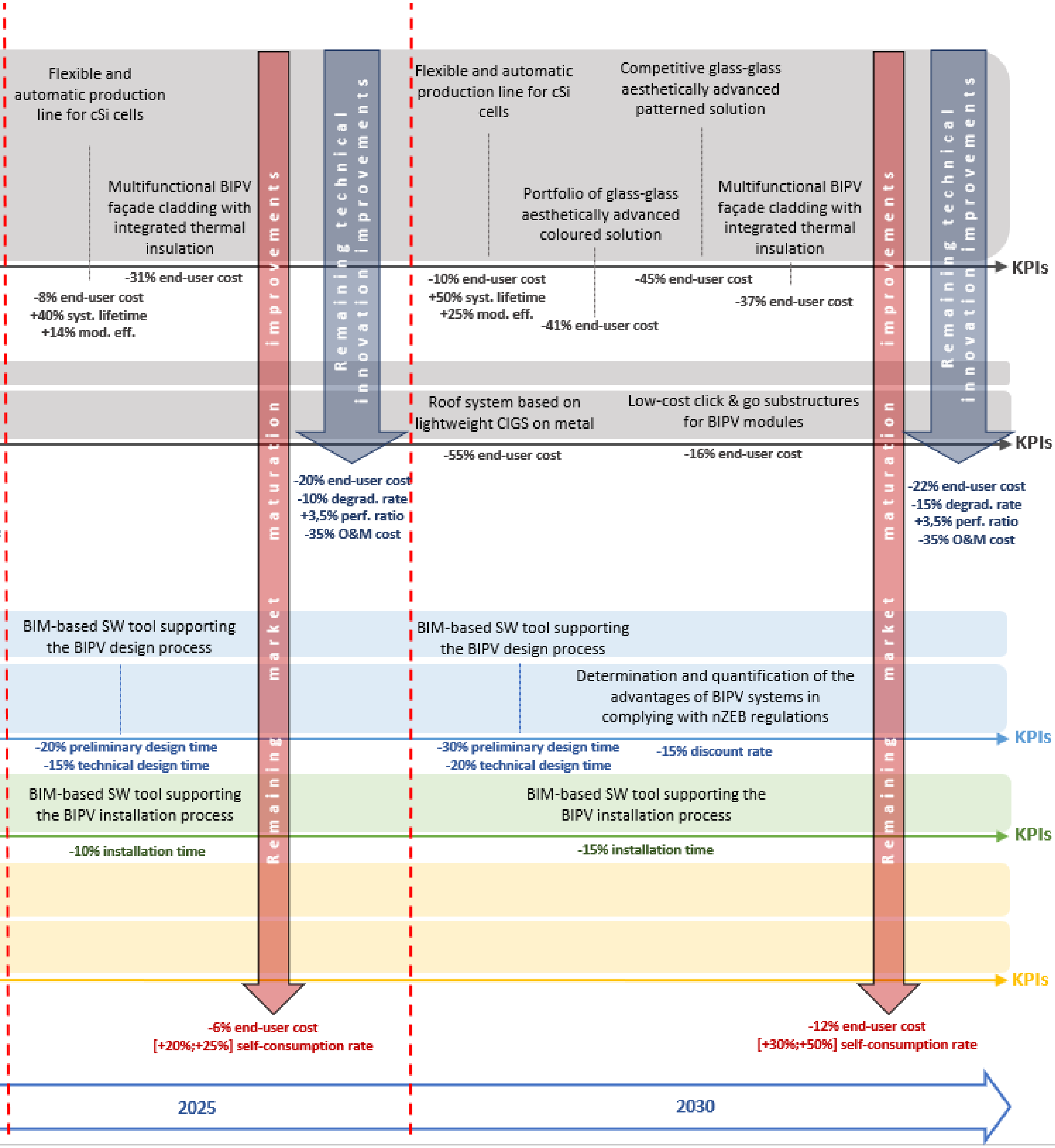


Figure 6.2.2 Cost-reduction roadmap proposed by BIPVBOOST project

6.2.1 Single family houses

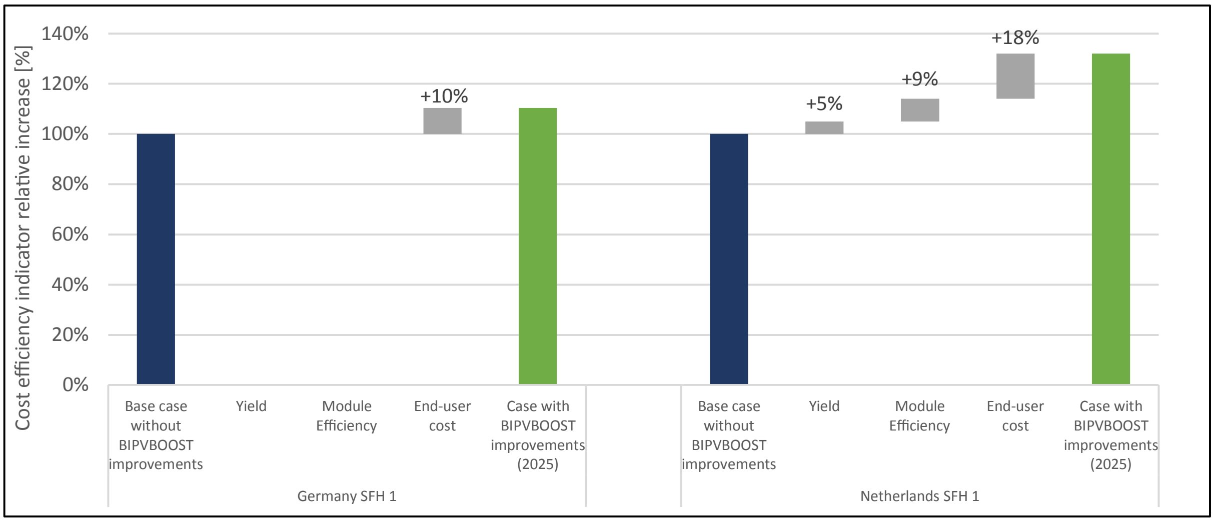


Figure 6.2.4 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to PV tiles (mono cSi PERC)

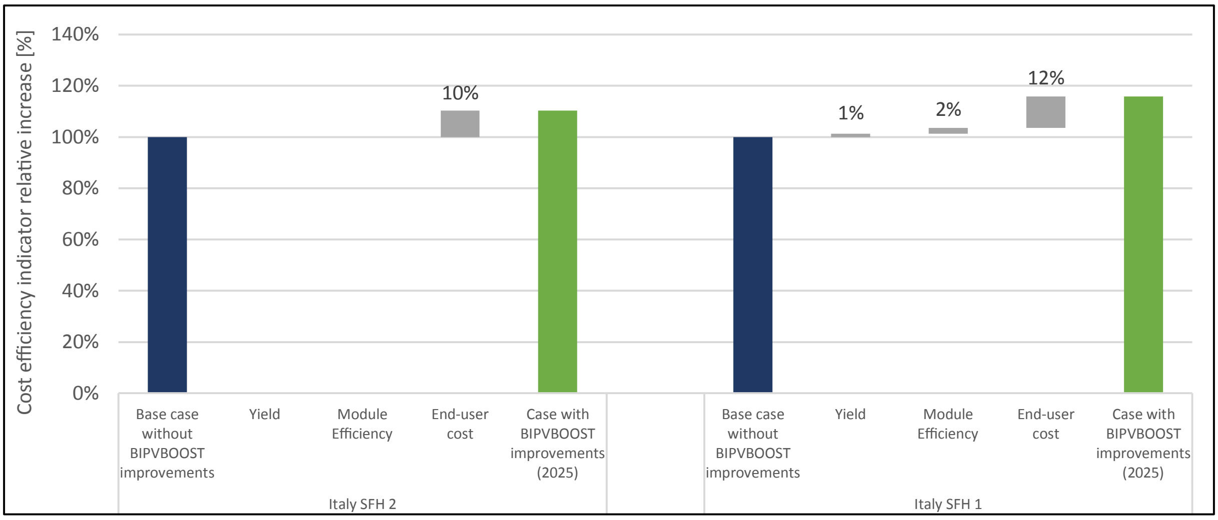


Figure 6.2.3 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to in-roof mounting systems (mono cSi PERC)

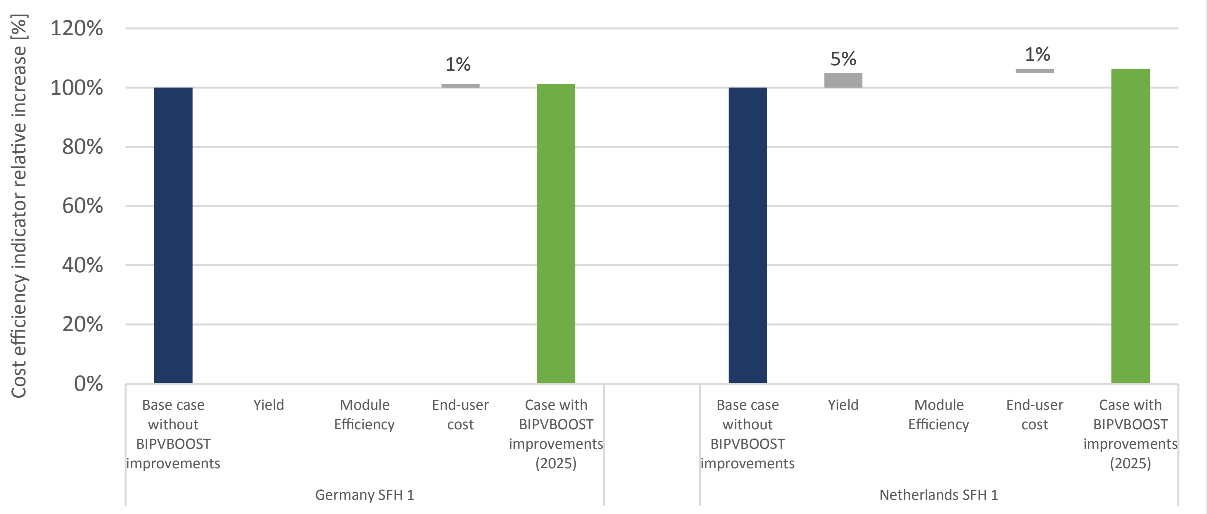


Figure 6.2.5 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to full roof solutions (CIGS)

For all three BIPVBOOST improvements impacting systems that are tested in the case of a SFH, conclusions are similar. In countries and cases where the criteria for the deduction of the renewable electricity production from the primary energy balance are the less stringent, the impact of the combined improvements is the most important. While in Germany, only the end-user cost decrease impacts the cost efficiency results, because of a deductible energy production determined by a fixed value, in the Netherlands, the advantage generated by the BIPVBOOST improvements is the highest.

It should be noted that the difference in terms of order of magnitude of the impact between the PV tiles and the in-roof mounting system on one hand and the CIGS-based full roof solution on the other hand, can be explained by the fact that less BIPVBOOST improvements are impacting the last system.

6.2.2 Multi-family houses

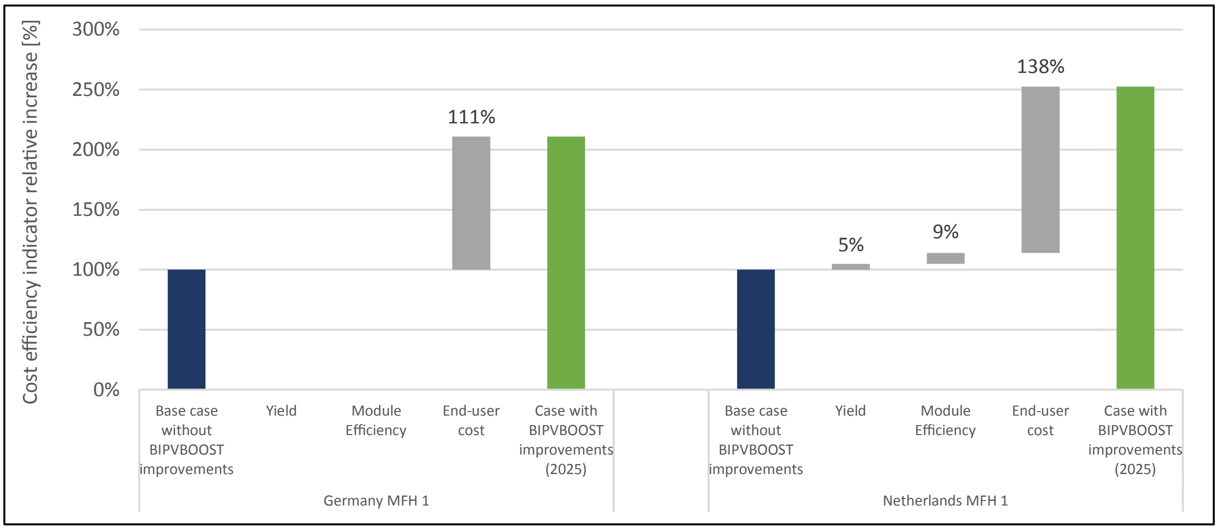


Figure 6.2.6 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to ventilated facades (mono cSi IBC)

The same improvements are considered for the multi cSi and the mono cSi IBC-based ventilated facades on MFH. Hence, results are only displayed for one system.

For both improvements impacting BIPV systems that can have been tested for the MFH case, conclusions are similar. In addition, the same general remarks as for the improvements targeting BIPV systems relevant for SFH apply.

In countries and cases where the criteria for the deduction for the renewable electricity production from the primary energy balance are the less stringent, the impact of the combined improvements is the most important. While in Germany, only the end-user cost decrease impacts the cost efficiency results, because of a deductible energy production determined by a fixed value, in the Netherlands, the advantage generated by the BIPVBOOST improvements is the highest.

Nevertheless, it can be observed for these two systems that the combined relevant BIPVBOOST improvements are more important and therefore lead to a more significant impact on the cost-efficiency indicator.

6.2.3 Educational building

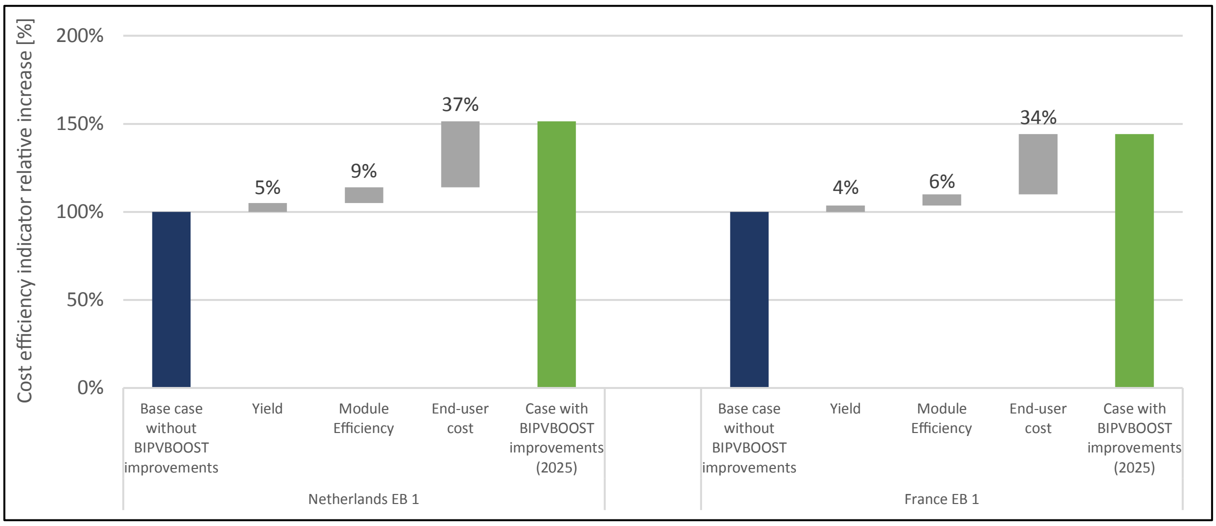


Figure 6.2.8 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to ventilated facades (mono cSi PERC)

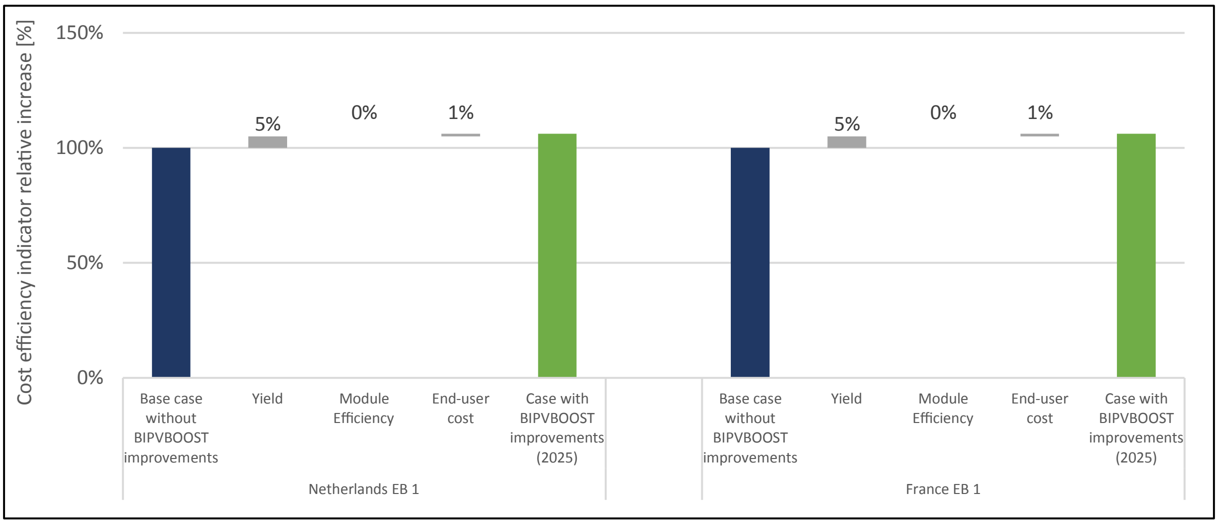


Figure 6.2.7 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to ventilated facades (CIGS)

In the case of improvements impacting BIPV systems that were tested on educational buildings in this deliverable, most impacting improvements are foreseen for the mono c-Si PERC-based system.

6.2.4 Office building

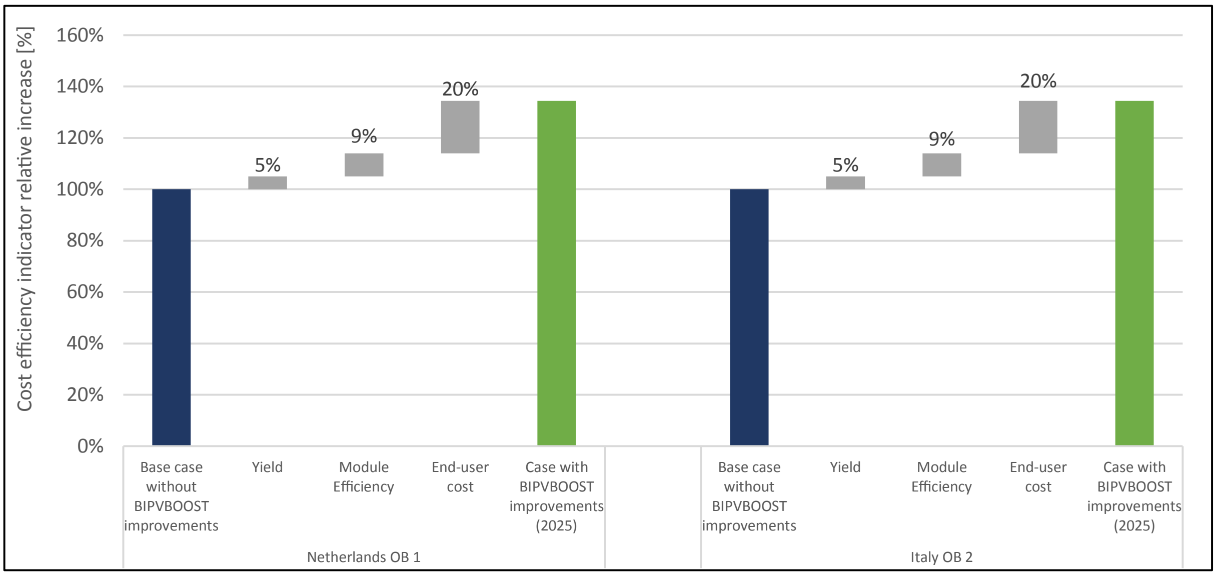


Figure 6.2.9 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to curtain walls (mono cSi PERC)

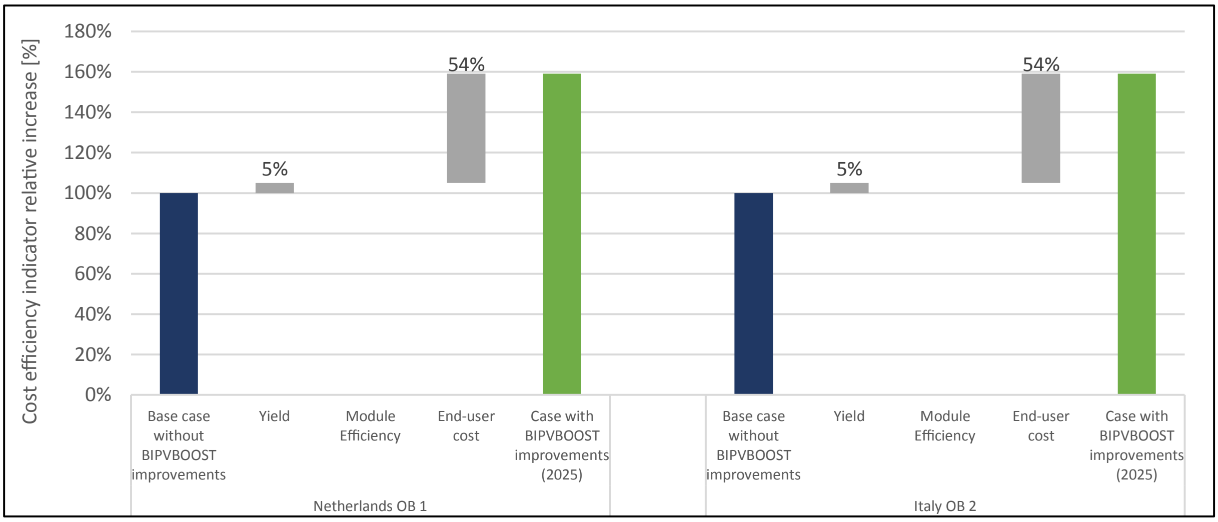


Figure 6.2.10 Cost-efficiency indicator's relative increase allowed by BIPVBOOST improvement related to curtain walls (aSi)

Improvements related to curtain wall are driven by a major cost reduction. Therefore, an end-user cost reduction has the same impact on the cost efficiency through all countries, building types and cases.

6.2.5 Assessment of BIPVBOOST improvements overview

Key findings:

1. All BIPV systems should see their end-user cost decrease, and in most cases significantly decrease, thanks to BIPVBOOST improvements. As demonstrated in Section 6.1, an end-user cost decrease systematically impacts the cost-efficiency of the studied BIPV system, independently from the country or the case. Therefore, decreasing the end-user cost of BIPV systems will allow to increase the cost-efficiency of all studied BIPV systems and, in some cases, lead to BIPV become more cost-efficient than BAPV.

2. Enhancing the module efficiency and the yield will also greatly benefit BIPV contribution in complying with nZEB regulations, in most countries and cases. Indeed, especially in the case of BIPV systems installed on facades, the reduced power output compared to the BAPV systems on the roof was often identified as the reason why BIPV systems were less cost-efficient than BAPV systems. Therefore, improving these parameters in the frame of the BIPVBOOST project is highly relevant for BIPV systems on facades.

3. Note that increasing the system lifetime should also be a consequence of some BIPVBOOST improvements. Even though this element is not taken into account in the calculation and assessments conducted in this deliverable, it is worth mentioning that this will also positively impact the BIPV contribution to buildings' PE balance.

7 KEY TAKEAWAYS & CONCLUSION

This deliverable has highlighted the fact that a potential contribution of BIPV systems in complying with nZEB regulations exists. Yet, the magnitude of this contribution is obviously closely tied to the details of the national (or regional) nZEB regulations and the characteristics of the studied case. Indeed, the way the regulation allows to take into account the renewable electricity produced on-site to reduce the primary energy balance has a massive influence and can make all types of solar systems subpar investment decisions. Therefore, there are important differences in terms of potential contribution of BIPV across the countries (and regions), depending on the building typology and depending on the buildings' equipment for the eligible uses.

Contribution of BIPV in complying with nZEB regulation

From Section 5, different conclusions can be drawn for each of the four studied building typologies.

- For **single-family houses**, **BIPV systems appear as more cost-efficient than BAPV** ones to reduce the primary energy balance.
- In the case of **multi-family houses**, BIPV systems can contribute to reduce the primary energy balance by equivalent amounts as with a BAPV system for a similar occupied area, thanks to higher system power area densities and despite less optimal irradiance conditions (BIPV systems are tested on MFH's facades while BAPV systems are considered on the MFH's roof). Although, from a cost-efficiency perspective, BAPV systems remain more advantageous. This conclusion relies on the fact that multi-family houses are assumed to have flat roofs in this deliverable. In the case of MFH with pitched roofs, which is also quite common in Europe, the results would be more favourable to BIPV and similar conclusions to the tested SFH cases could be drawn.
- For **educational buildings**, the conclusions are quite the opposite. Indeed, because of the architectural characteristics of the reference buildings considered in this report, leading to limited available surfaces on the facades and the important available surface on the roof, allows BAPV systems to reduce the primary energy balance by a larger factor than tested BIPV systems. Nevertheless, the advantage of BAPV in terms of cost-efficiency is not straightforward, and **in some countries BIPV appears as the most cost-efficient solution between both PV solutions**.
- Finally, the results for **office buildings** are less encouraging for BIPV as this renewable energy system only permits to marginally reduce the primary energy balance and this at significantly lower cost-efficiencies than BAPV. Nonetheless, it should be reminded that the potential contribution of BIPV curtain walls' passive properties was not taken into account in the analysis, and could, especially in the most southern locations, improve the results. But, as evoked in Section 4.1.1, the assessment of this contribution needs to be conducted individually for each project as the results are highly dependent on numerous number of parameters such as the location, the building orientation or the weight of cooling needs in total energy needs.
- When it comes to solar thermal systems, it can be considered, based on the results presented in this deliverable, that they are not a direct competitor to BIPV systems. On the contrary, solar thermal systems' rather good results, both in terms of primary energy balance reduction and cost-efficiency for an important number of cases, call for the installation of BIPV systems rather than BAPV systems. Especially as multiple renewable energy integration targets are not designed to be met with solar thermal only. Indeed, by installing BIPV systems on the façades, the available surface on the roof can be used by solar thermal. Therefore, solar thermal systems are quite complementary to BIPV systems both in term of occupied area and covered needs. It is worth highlighting that the idea that there is a great advantage in installing PV systems on facade rather than on roof is supported by the regulation in Switzerland, for example. Indeed, it stipulates that for multi-floor buildings (with typically more façade surface than roof surface), integrated solution on the facades must be foreseen.

Impact of BIPVBOOST project's improvements

Looking at the added value of BIPVBOOST project's outcomes, the analysis conducted in this deliverable shows that BIPVBOOST improvements can highly improve the cost-efficiency of BIPV systems. But most of the time, these improvements can only be partially exploited because of regulatory constraints, such as fixed amount for the deductible production. In addition, the potential multifunctionality of BIPV products is a key asset and should be leveraged to strengthen their attractiveness, for example by adding a layer of thermal insulation. Even though, this is encouraging and shows that BIPVBOOST will bring significant positive impact and clearly reinforce the potential contribution of BIPV in complying with nZEB requirements.

Recommendation to policy makers

The results presented in this deliverable have underlined the fact that the competitiveness of BIPV with regards to the compliance with nZEB regulations, is first and foremost highly dependent on how the regulation is written and especially how it includes the role of renewable energy systems. Therefore, based on this analysis, conclusions can be made with regards to how the nZEB regulations are designed.

Overall, it should be reminded that the first objective when it comes to nZEB regulations is to incite to increase the building energy efficiency in order to reduce its energy consumption. Once the construction sector's competences in this area have been fully exploited, renewable systems and especially BIPV systems, can help to further decrease the building's energy balance. Regulations imposing too stringent criteria for the deduction of renewable energy production from the primary energy consumption can thus lead to limited BIPV potential contribution in complying with nZEB regulations. The absence of any renewable energy integration targets can also limit the attractiveness of all studied renewable systems, including BIPV. Similarly, legal thresholds that can easily be met without any renewable system's contribution are also both reducing the efforts put into improving the building energy performances and diminishing the attractiveness of renewable systems. It can be observed in this deliverable that in many cases, the legal nZEB threshold is rather easily achieved by solely investing in mainstream building components, without any renewable energy systems, thus showing that legal thresholds could be further pushed down in some cases.

Then, in most countries, lighting is not part of the considered uses. As this is a fully electricity-based use, if considered, it could increase the contribution of electricity producing systems to reducing the energy consumption for this use and consequently the primary energy balance.

Moreover, the fact that primary energy factors used for electricity are on average twice as high as those used for fossil fuels leads to contradictory effects. On one hand, higher PEF for electricity is beneficial for BIPV systems in the sense that, even a small amount of electricity produced can lead to a substantial reduction in the primary energy balance. On the other hand, in multiple cases, the contribution of BIPV in reducing the primary energy balance and in meeting the renewable energy integration targets relies on the fact that most eligible uses are covered with electricity. Yet, the important gap between the PEF applied to electricity and the PEF applied to fossil fuels does not encourage, from a mathematical perspective, the installation of heating and DHW systems based on electricity.

Finally, in the event that the legally imposed balancing methodology shifts from a yearly/seasonally/monthly balancing to an hourly or daily balancing it could enhance the advantages of BIPV compared to BAPV. Indeed, through a monthly balance, the more optimal self-consumption rate (which can play an important role, depending on the regulation) reached with a BIPV system on a façade compared to a BAPV on a roof is not taken into account. But with an hourly or daily balancing, this would be possible and give an advantage to BIPV. Yet, in the case of SFH, as both BIPV and BAPV systems are installed on the roof, the impact would be the same for these two PV systems. Nevertheless, even if such balancing would advantage BIPV compared to BAPV, it should be noted that, in general, a yearly balancing is more favourable to PV systems than balancing with higher granularity.

Overall, a case by case analysis is highly required and few general conclusions, if any, are valid across all building typologies and countries. There is no “one fits all” solution and improving the primary energy balance of a building can be achieved in multiple ways, should it be with active or passive materials.

NZEB regulations should be designed in such a way that both the energy performance of buildings and the integration to or the application on buildings of renewable systems are fostered. This could be achieved through different possible means.

- Defining **legal thresholds** for the primary energy balance that are **ambitious enough** so that they require both to put efforts in increasing the buildings energy performances and to take advantage of the use of renewable energy systems.
- For the latter, nZEB regulation should **allow** for the renewable energy production to **contribute largely or fully to reduce the primary energy balance**.
- Encourage the use of **electricity-based heating/DHW/cooling/etc systems** and systematically **take into account** electricity-based uses such as **lighting** in the PE balance calculations.

8 APPENDIX

8.1 Appendix 1a: nZEB regulation in Belgium (Brussels)

Country		**Belgium - Brussels**		
Building typology	**(New / Existing)**	New $^{(a)}$		Existing
Category	**(Resid. / Non-resid.)**	R	NR	
Subcategory		Individual Housing (COBRACE: SFH, MFH)	COBRACE: OB, EB, H, H/R, SF, commercial	
Included energy uses	Heating	x	x	N/A
	Cooling / Air co / Ventilation	x	x	
	Domestic Hot Water	x	x	
	Auxiliary Energy	x	x	
	Lighting		x	
	Plug loads / Appliances / IT			
	Central Services			
	Electric vehicles			
	Embodied Energy			
Physical boundary		Building unit called PER (residential) or PEN (non residential unit) (Arrêté du 26 janvier 2017)		
RES	**System boundary for generation**	On site PV or cogen. systems within building (Annex XVII)		
	Share	N/A (equiv. energy provided by RES is subtracted from Primary Energy required to give the final PE value)		
Balance	**Type of balance**	Energy demand vs. energy generation (Annex XVII)		
	Period of balance	Monthly (Annex XVII)		
Metric		Primary Energy		
Normalization factor		Net Floor area (Annex XVII)		
Conversion factors		Static$^{(b)}$		
Max value for Primary Energy (kWh.m $^{-2}$.y^{-1})		45 $^{(c)}$	Specif. coeff. * E_{spec} $^{(f)}$	45 * 1,2
Other metrics and requirements		Net heating need < 15 kWh.m^{-2}.y^{-1} $^{(d)}$ U_{max} or $R_{min}$$^{(e)}$ according to type of construction element (Annex XIV)	-	Net heating need < 15*1,2 kWh.m-2.y-1 $^{(d)}$ U_{max} or R_{min} according to type of construction element (Annex XIV)
Comments		(a) Arrêté du 21 décembre 2007 (modified): new units and units undergoing construction and/or demolition-reconstruction of at least 75% of the deperdition surface and with (re)placement of all the technical installations. For the latter ones, a multiplying factor of 1,2 is applied to the max. primary energy and net heating values. (b) - COBRACE : national or regional annual weighted average or specific value for local production - Arrêté du 26 janvier 2017 : Art. 5 : Primary energy conversion factors (fp): fossil fuels: 1 electricity: 2,5 electricity produced by cogeneration or PV: 2,5 biomass: 1 external heat: 2 (CO2 factors are also defined - Art. 6) (c) Arrêté du 21 décembre 2007 (modified): If this value is not achieved, following max. value needs to be achieved: 45 + max(0 ; 30-7.5 * C) + 15*max(0 ; 192/VEPR-1) C= compactness; VEPR= total volume of the unit (d) Arrêté du 21 décembre 2007 (modified) + nZEB National Plan: If this value is not achieved (e.g. due to overshadowed or badly oriented location, weak compactness, etc.), it has to be up to a new energy need calculated using default parameters for insulation efficiency (0.12 W/m².K for opaque walls and 1W/m².K for windows and doors), airtightness of 1,5m³/h.m² and efficiency of the ventilation system. (e) U = thermal transmission coefficient R = thermal resistance coefficient (f) Arrêté du 21 décembre 2007 (modified) : Espec = specific max. annual PE consumption of a reference unit, which is composed of standardized envelope and technical installations but takes into account the specific geometry, surface, orientation and composition in functional parts of the considered unit. => specif. coefficients: OB: 0,45; EB: 0,45; H: 0,80; hotels: 0,80; restaurants: 0,70; gathering places: 0,80; commercial: 0,70 ; SF: 0,65; technical room: 0,45; commons: 0,45; other: 0,85		

Sources:

[61] COBRACE (Brussels Air, Climate and Energy Code)

[62] COBRACE (Brussels Air, Climate and Energy Code) – Appendix XIV

[63] COBRACE (Brussels Air, Climate and Energy Code) – Appendix XVII

[64] COBRACE (Brussels Air, Climate and Energy Code) – Appendix XVIII

[65] Arrêté du Gouvernement de la Région de Bruxelles-Capitale du 26 janvier 2017 établissant les lignes directrices et les critères nécessaires au calcul de la performance énergétique des unités PEB

[66] Arrêté du Gouvernement de la Région de Bruxelles-Capitale du 21 décembre 2007 déterminant des exigences en matière de performance énergétique et de climat intérieur des bâtiments

[67] PNEC (National Plan Energy and Climate) - 2016

8.2 Appendix 1b: nZEB regulation in Belgium (Wallonia)

Country/Region		Belgium - Wallonia			
Building typology	**(New / Existing)**	New [a]			Existing [b]
Category	**(Resid. / Non-resid.)**	R	NR		
Subcategory		SFH AB	OB, EB, H, H&R, collective accommodation, commercial, services	Industrial buildings [c]	
Included energy uses	Heating	x	x	N/A	N/A
	Cooling / Air co / Ventilation	x	x		
	Domestic Hot Water	x	x		
	Auxiliary Energy	x	x		
	Lighting		x		
	Plug loads / Appliances / IT				
	Central Services				
	Electric vehicles				
	Embodied Energy				
Physical boundary		Building unit called PER (residential) or PEN (non residential) unit Arrêté du 28 novembre 2013			
RES	**System boundary for generation**	On site In building plot - PV or cogen (Annex A1)			
	Share	N/A (equiv. energy provided by RES is subtracted from Primary Energy required to give the final PE value)			
Balance	**Type of balance**	Energy demand vs. energy generation (Annex A1)			
	Period of balance	Monthly (Annex A1)			
Metric		Primary Energy			
Normalization factor		Heated or conditioned floor area (Annex A1)			
Conversion factors		Static [d]			
Max value for Primary Energy (kWh.m^{-2}.y^{-1})		E_{Spec} : 85 [e] E_w 45	E_w 45 [e] (OB, EB) E_w 90 (H, H&R, collective accommodation, gathering places, commercial/services, SF, technical rooms, commons, other)	-	-
Other metrics and requirements		≤U_{max} according to type of construction element See Annexe C1 (table 2) K ≤ 35 [f]		≤U_{max} according to type of construction element See Annexe C1 (table 2) K ≤ 55 [f]	≤U_{max} according to type of construction element See Annexe C1 (table 2) K ≤ 35 [f]

Comments	(a) Arrêté du 15 mai 2014 - article 14 : Assimilated as new: creation of volume > 800m^3; doubling of the existing volume; replacing installations AND 75% of the envelope (b) No EPB requirements for renovation of industrial buildings (c) Arrêté du 15 mai 2014 - Article 9 : Not for low energy consuming units, i.e. units with a total power of thermal emission equipments divided by heated/conditioned volume <15W/m^3 (d) Décret du 28 novembre 2013 : national or regional annual weighted average or specific value for local production Annex A1 - annex F : Primary energy conversion factors (fp): fossil fuels: 1 electicity: 2,5 electricity produced by cogeneration or PV: 2,5 biomass: 1 (CO2 factors are also defined) (e) Arrêté du 15 mai 2014 : E_{spec} = specific annual Primary energy consumption of the unit (kWh.m^{-2}.an^{-1}) E_W = level of Primary energy consumption of the unit = E_{spec} / reference value * 100 (reference value calculated for PER according to Annex A1 section 6 and based on compactness, for PEN according to Annex A3 annex C) Values as of 01/01/2021 (f) Arrêté du 15 mai 2014 : U: thermal transmission coefficient R: thermal resistance K = thermal isolation level

Sources:

[13] Décret du 28 novembre 2013 relatif à la performance énergétique des bâtiments

[14] Décret du 28 novembre 2013 relatif à la performance énergétique des bâtiments – Appendix 1

[15] Arrêté du Gouvernement wallon portant exécution du décret du 28 novembre 2013 relatif à la performance énergétique des bâtiments

[16] Arrêté du Gouvernement wallon portant exécution du décret du 28 novembre 2013 relatif à la performance énergétique des bâtiments – Appendix A1

[17] Arrêté du Gouvernement wallon portant exécution du décret du 28 novembre 2013 relatif à la performance énergétique des bâtiments – Appendix A3

[18] Arrêté du Gouvernement wallon portant exécution du décret du 28 novembre 2013 relatif à la performance énergétique des bâtiments – Appendix C1

8.3 Appendix 1c: nZEB regulation in Belgium (Flanders)

Country		Belgium - Flanders				
Building typology	(New / Existing)	New			Existing	
Category	(Resid. / Non-resid.)	R	NR		R	NR
Subcategory		SFH, AB	OB, EB, others	Industrial buildings (a)	SFH, AB	OB, EB, others
Included energy uses	Heating	x	x	N/A	x	x
	Cooling / Air co / Ventilation	x	x		x	x
	Domestic Hot Water	x	x		x	x
	Auxiliary Energy	x	x		x	x
	Lighting		x			x
	Plug loads / Appliances / IT					
	Central Services					
	Electric vehicles					
	Embodied Energy					
Physical boundary		Building unit called EPW (residential) or EPN (non-residential)				
RES	System boundary for generation	On-site PV or cogen. systems within building (Appendix V) (equiv. energy provided by PV/or cogen is substracted from Primary Energy required to give the final PE value)				
	Share	(b)	(c)		(d)	
Balance	Type of balance	Energy demand vs. energy generation				
	Period of balance	Monthly (Appendix V)				
Metric		Primary Energy				
Normalization factor		Useful floor area (Energybesluit)				
Conversion factors		Static (e)				
Max value for Primary Energy (kWh.m-2.y-1)		E 30 (f)	OB: E50, EB: E55, H: E70, Day care: E65, gathering places: E65, accommodation: E70, restaurant: E60, Commercial: E60, SF: E50 (E40 for fitnesss and dance), technical rooms: E45, commons: E50, others E80 (f) (g)	-	E 70 (h)	OB: E90, EB: E90, H: E75, Day care: E90, gathering places: E75, accommodation: E85, restaurant: E75, Commercial: E75, SF: E75 (E60 for fitnesss and dance), technical rooms: E50, commons: E90, others E110 (h)
Other metrics and requirements		≤Umax (Appendix VII) S 28 (i)	≤Umax (Appendix VII)	≤Umax (Appendix VII) K ≤ 40	≤Umax (Appendix VII)	

Comments	(a) Energiebesluit van 19 November 2010: Not for industrial EPN units with volume <800 m^3 AND which represent less than 40% of the total industrial building (b) Energiebesluit van 19 November 2010: At least one of the following systems needs to be installed: - PV producing at least 15 kWh.m-2.y-1 ; - solar thermal*; - biomass heating*; - HP*; - heat network*; - financial participation in renewable energy production in VL (>20 EUR/m^2)* * see specific requirements for these latter 5 systems in Artikel 9.1.12/2 Alternatively, individual systems do not need to conform to above specific requirements if total energy from renewables for the EPW unit is ≥ 15 kWh.m-2.y-1 (or if 100% of gross energy needs for space heating are covered by RE (biomass, HP, 100% renewable heat network) (calculation according to Appendix V) (c) Energiebesluit van 19 November 2010: at least 15 kWh.m-2.y-1 of RE produced by one or more of the systems listed in (b) (the individual systems do not need to conform to above specific requirements) or 100% of gross energy needs for space heating are covered by RE (biomass, HP, 100% renewable heat network) (calculation according to Appendix VI) Requirement not applicable to EPN which are part of an industrial or agricultural building AND which have a volume <800m^3 AND represent less than 40% of the total volume (d) Energiebesluit van 19 November 2010: at least 15 kWh.m-2.y-1 from RE or 100% of gross energy needs for space heating are covered by RE (biomass, HP, 100% renewable heat network) (calculation according to Appendix V) (e) Energiebesluit van 19 November 2010: Primary energy conversion factors (fp) fossil fuels: 1 electicity: 2,5 electricity produced by cogeneration or PV: 1,8 biomass: 1 (f) Energiebesluit van 19 November 2010: E = level of Primary energy consumption of the unit = specific annual Primary energy consumption / reference value * 100 (reference value calculated according to Appendix V section 6 and "a" values defined in 9.1.8 of Energie besluit for EPW and according to Appendix VI Appendix C for EPN) Value as of 01/01/2021 (g) Energiebesluit van 19 November 2010 : Not for EPN units which are part of an industrial or agricultural building AND which have a volume <800m^3 AND represent less than 40% of the total volume (h) Energiebesluit van 19 November 2010: for major energy renovations (i) Energiebesluit van 19 November 2010 : value as of 01/01/2021 (energy efficiency of envelope) Calculation method in Appendix XIII

Sources

[19] Decreet houdende algemene bepalingen betreffende het energiebeleid (Energiedecreet van 8 Mei 2009) (Titel XI)

[20] Besluit van de Vlaamse Regering houdende algemene bepalingen over het energiebeleid (Energiebesluit van 19 November 2010) (Titel IX)

[21] Besluit van de Vlaamse Regering houdende algemene bepalingen over het energiebeleid (Energiebesluit van 19 November 2010) (Titel IX) – Appendix V

[22] Besluit van de Vlaamse Regering houdende algemene bepalingen over het energiebeleid (Energiebesluit van 19 November 2010) (Titel IX) – Appendix VI

[23] Besluit van de Vlaamse Regering houdende algemene bepalingen over het energiebeleid (Energiebesluit van 19 November 2010) (Titel IX) – Appendix VII

8.4 Appendix 1d: nZEB regulation in France

Country		France			
Building typology	(New / Existing)	New(a)		Existing (b)	
Category	(Resid. / Non-resid.)	R	NR	R	NR
Subcategory		Housing (arrêté 26/10/10 + article R111-20-6)	OB, EB, crèche (arrêté 26/10/10 + article R111-20-6) + universities, H&R, SF, H, retirement residence, commercial, airport, tribunal, industrial (article 28/12/12 + article R111-20-6)		
Included energy uses	Heating	x			
	Cooling / Air co / Ventilation	x			
	Domestic Hot Water	x			
	Auxiliary Energy	x			
	Lighting	x			
	Plug loads / Appliances / IT				
	Central Services				
	Electric vehicles				
	Embodied Energy				
Physical boundary		Building (Th-BCE-2012) (Th-C-E ex 2008)			
RES	System boundary for generation	Building For electricity production: PV and cogen. are considered (Th-BCE-2012)			
	Share	AEPENR ≥5kWhPE.m-2.y-1 (c)	-	-	-
Balance	Type of balance	Energy demand vs. energy generation			
	Period of balance	Seasonal (summer, winter, mid-season) (Th-BCE-2012)			
Metric		Primary Energy (Th-BCE-2012)			
Normalization factor		"Thermal" surface (SRT) (d)		Net floor surface (SHON: surface de plancher hors-œuvre nette)	
Conversion factors		Static (e)			
Primary Energy consumption (kWh.m-2.y-1)		Cep ≤ Cepmax (f) (g) ~40 to 65 (JRC report)	Cep ≤ Cepmax (f) 110 (OB with A/C) 70 (OB without A/C) (JRC report)	Cep ≤ Cepmax and Cep ≤ Cepref (h) 80-165 (i)	Cep after renovation ≤ 70% Cep before renovation and Cep ≤ Cepref (h)
Other metrics and requirements		Bbiomax (j) (k) (l)		(m) (n)	

Comments	(a) also for additions to existing buildings but not if addition < 50m² for individual houses, and if addition < 50m² or < 150m² and 30% of existing SRT for other buildings (arrêté du 26/10/10 and 28/12/12) (b) For major renovations: i.e. works concerning building with floor surface >1000m² and for which costs >25% of the cost of the building (excl. ground value) (Article R131-26, arrêté 13/06/08 and arrêté 28/12/07) Not for industrial, agricultural buildings with low energy needs for human comfort compared to industrial energy needs. For all other renovations, there are only requirements as to the used elements in arrêté 03/05/07 (c) For individual or accolated house AEPENR = coefficient of renewable energies contribution to Cep of building Calculated according to Th-BCE 2012 Alternative options to this requirement are: domestic hot water production by solar thermal system, connexion to heat network >50% RE, HP for hot water with COP>2 or micro-cogen boiler with yield >90% (PCI) (arrêté 26/10/10) (d) SRT = useful surface multiplied by specific coefficient depending on building use: OB, EB (primary school), hotel, commercial, SF, retirement residence, hospital, industrial, tribunal: 1,1; EB (secondary school, univ.), crèche, restaurant, airport: 1,2 (Annex III of arrêté 26/10/10 and 28/12/12) (e) By convention, conversion coefficient is 2,58 for electricity and 1 for other carriers (article 15 / 14 / 41 of arrêtés 26/10/10 / 28/12/12 / 13/06/08) and 0,6 for wood (article 41 of arrêté 13/06/08) (f) Cep for new buildings is calculated according to Th-BCE 2012 Self-produced electricity is deducted from energy consumption for calculation of Cep (*) Cepmax = 50 multiplied by a series of coefficients depending on building type and category (CE1/CE2), localisation, altitude, average surface (for housing, commercial building, SF) and GHG emission coefficient of used energies (Article 11 and Annex VIII of arrêté 26/10/10 and arrêté 28/12/12) 8 climatic zones defined in Annex 1 of arrêté 26/10/10 and 28/12/12: H1a, H1b, H1c, H2a, H2b, H2c, H2d et H3 (g) (*) In addition, for housing, energy consumption before deduction of self-produced electricity needs to be ≤ Cepmax + 12 kWh/(m².an) (h) Cep for existing buildings is calculated according to Th-C-E ex 2008 Self-produced electricity is deducted from energy consumption for calculation of Cep Cepmax defined in article 13 of arrêté 13/06/08, depending on climatic zone and type of heating system Cep also needs to be ≤ Cepref (reference energy consumption of the bldg defined based on reference values for different parameters (see arrêté 13/06/08 article 17 to 42)) (i) https://www.rt-batiment.fr/batiments-existants/rt-existant-globale/presentation.html (j) Bbio is calculated according to Th-BCE 2012 It is a dimensionless coefficient characterizing the energy efficiency (it evaluates the residual energy need that is not offset by ecological design for heating, cooling, lighting). Bbiomax = average Bbiomax multiplied by coefficients depending on localisation, altitude and average surface (for housing, commercial building, SF) average Bbiomax = average value défined by building type and category (articles 13 / 12 and Annex VIII of arrêté 26/10/10 / 28/12/12) (k) Arrêté 26/10/10: requirements also as to air tightness (article 17), thermal isolation (articles 18 and 19), natural light access (article 20), summer comfort (article 21), energy consumption monitoring system (article 23 and 31) and others (articles 24 to 29 and 32 to 45) Arrêté 28/12/12: requirements also as to thermal isolation (articles 15 and 16), summer comfort (article 17), energy consumption monitoring system (article 19) and others (articles 20 to 33) (l) Additional building classification according to R111-21 and arrêté 12/10/16 (these buildings have derogations as to some construction rules) : - Energetically remarkable building : energy consumption <40% Cepmax for OB, <20% Cepmax for other buildings - Environmentally remarkable building: Lifecycle CO2 emission inferior to defined max levels + one of 3 other requirements linked to waste and materials - Positive energy building : energy balance inferior to a max energy balance (BilanBEPOSmax, corresponding to performance level "energie 3") Arrêté 03/05/07: High Energy Performance Label with 5 levels: - HPE 2005: "Haute Performance Energetique" : Cep < 90% Cepmax - THPE 2005 : "Très Haute Performance Energétique" : Cep < 80% Cepmax - HPE EnR 2005: "Haute Performance Energetique Energies Renouvelables" : HPE + Heating needs covered for >50% by biomass or heating through heat network >60% RE - THPE EnR 2005: "Très Haute Performance Energetique Energies Renouvelables": Cep < 70% Cepmax + one of 6 conditions: 1) domestic hot water needs covered for >50% by solar panels on bldg and heating needs covered for >50% by biomass; 2) domestic hot water needs covered for >50% by solar panels on bldg and heating through heat network >60% RE; 3) domestic hot water and heating needs covered for >50% by solar panels on bldg; 4) RE based electricity production within building > 25 kWh_{PE}/(m².year); 5) building equipped with HP with defined characteristics (annex 4); 6) for collective buildings and tertiary buildings for accommodation purpose, domestic hot water needs covered for >50% by solar panels on bldg - BBC 2005: "Bâtiment Basse Consommation Energetique": 1) for residential bldg, Cep≤50*(a+b) (a depending on climatic zone, b depending on altitude), 2) for non-residential bldg, Cep ≤ 50% Cepmax. For this label exclusively, PE conversion coefficient for wood is 0,6 (m) Arrêté 13/06/08: requirements also as to thermal isolation, summer comfort, ventilation, heating systems, monitoring... (articles 43 to 84) (n) Arrêté 29/09/09 : High energy performance label for renovation

Sources:

[24] Arrêté du 26 octobre 2010 relatif aux caractéristiques thermiques et aux exigences de performance énergétique des bâtiments nouveaux et des parties nouvelles de bâtiments
[25] Décret n° 2012-1530 du 28 décembre 2012 relatif aux caractéristiques thermiques et à la performance énergétique des constructions de bâtiments
[26] Code de la construction et de l'habitation - Article R111-20 to R111-22
[27] Arrêté du 28 décembre 2012 relatif aux caractéristiques thermiques et aux exigences de performance énergétique des bâtiments nouveaux et des parties nouvelles de bâtiments autres que ceux concernés par l'article 2 du décret du 26 octobre 2010 relatif aux caractéristiques thermiques et à la performance énergétique des constructions

[28] Arrêté du 12 octobre 2016 relatif aux conditions à remplir pour bénéficier du dépassement des règles de constructibilité prévu au 3° de l'article L. 151-28 du code de l'urbanisme
[29] Arrêté du 3 mai 2007 relatif au contenu et aux conditions d'attribution du label « haute performance énergétique »
[30] Arrêté du 30 avril 2013 portant approbation de la méthode de calcul Th-BCE 2012 prévue aux articles 4, 5 et 6 de l'arrêté du 26 octobre 2010
[31] Th-B-C-E 2012 Calculation method
[32] Décret n° 2007-363 du 19 mars 2007 relatif aux études de faisabilité des approvisionnements en énergie, aux caractéristiques thermiques et à la performance énergétique des bâtiments existants et à l'affichage du diagnostic de performance énergétique.
[33] Code de la construction et de l'habitation - Article R131-25 to R131-28-6
[34] Arrêté du 13 juin 2008 relatif à la performance énergétique des bâtiments existants de surface supérieure à 1 000 mètres carrés, lorsqu'ils font l'objet de travaux de rénovation importants
[35] Arrêté du 20 décembre 2007 relatif au coût de construction pris en compte pour déterminer la valeur du bâtiment, mentionné à l'article R. 131-26 du code de la construction et de l'habitation
[36] Arrêté du 3 mai 2007 relatif aux caractéristiques thermiques et à la performance énergétique des bâtiments existants
[37] Arrêté du 29 septembre 2009 relatif au contenu et aux conditions d'attribution du label « haute performance énergétique rénovation »
[38] Arrêté du 8 août 2008 portant approbation de la méthode de calcul Th-C-E ex prévue par l'arrêté du 13 juin 2008 relatif à la performance énergétique des bâtiments existants de surface supérieure à 1 000 mètres carrés, lorsqu'ils font l'objet de travaux de rénovation importants
[39] Th-C-E ex 2008 calculation method
[40] Décret n° 2019-771 du 23 juillet 2019 relatif aux obligations d’actions de réduction de la consommation d’énergie finale dans des bâtiments à usage tertiaire

8.5 Appendix 1e: nZEB regulation in Germany

Country		Germany				
Building typology	**(New / Existing)**	New		Existing		
Category	**(Resid. / Non-resid.)**	R	NR	R	NR	
Subcategory					Official Buildings	Other
Included energy uses	Heating	x				
	Cooling / Air co / Ventilation	x				
	Domestic Hot Water	x				
	Auxiliary Energy					
	Lighting		x		x	
	Plug loads / Appliances / IT					
	Central Services					
	Electric vehicles					
	Embodied Energy					
Physical boundary		Building				
RES	**System boundary for generation**	Building				
	Share	15 (b) (c)	15 (b) (g)		15 (b) (f)	
Balance	**Type of balance**					
	Period of balance	Yearly				
Metrics max value	**Primary energy consumption (d) (kWh/(m².y))**	75% of RB (a)		140% of RB (a)		
Normalization factor		Useful area	Net area	Useful area	Net area	
Conversion factors		Static (e)				
Other metrics and requirements		Thermal insulation Thermal bridges Air tightness Summer Heat protection Specific Transmission Heat Losses related to the heat transfer surface	Thermal insulation Thermal bridges Air tightness Summer Heat protection Average Heat Transfer Coefficient of the Heat-transferring Surface	Specific Transmission Heat Losses related to the heat transfer surface	Average Heat Transfer Coefficient of the Heat-transferring Surface	

Comments	(a) RB refers to a reference building with identical Geometry, useful area, orientation as the studied building and having a set of (in the law) predefined parameters (b) Percentage of the Heating and Cooling needs only (c) If the renewable source is solar radiation, the renewable share is considered achieved if: - the installed capacity > 0,02 kW/m²(useful area) Else, the renewable share is considered achieved if: - the Transmissionswärme conditions are more than 15% higher than the required ones (§45 p.36 GEG) - at least 50% of Heating and cooling needs are covered by waste heat (§44 p.36 GEG) - at least 50% of Heating and cooling needs are covered by combined heat and power plant (§44 p.36 GEG) - at least 50% of Heating and cooling needs are covered by a combination of above mentioned solutions (§44 p.36 GEG) (d) The electricity generated through renewables can be substracted from primary energy consumption if: - the production is generated in the immediat spatial connexion to the building - if as much as possible is self-consumed - if the electricity is not used for direct electricity-based heating and only up to a total of: - R (without electrochemical storage): If < 0,02 kWp/m²(useful area) 150 kWh / kWp But in any case < 20% * Yearly Primary Energy Need of RB If > 0,02 kWp/m²(useful area) 150 kWh / kWp + 0,7* Yealy Absolute Energy Need for Systems Engineering But in any case < 20% * Yearly Primary Energy Need of RB - R (with electrochemical storage > 1 kWh/kWp and system): If < 0,02 kWp/m²(useful area) 200 kWh / kWp If > 0,02 kWp/m²(useful area) 200 kWh / kWp + 1* Yealy Absolute Energy Need for Systems Engineering But in any case < 25% * Yearly Primary Energy Need of RB - NR (without electrochemical storage): If < 0,01 kWp/m²(net area) 150 kWh / kWp If > 0,01 kWp/m²(net area) 150 kWh / kWp + 0,7* Yealy Absolute Energy Need for Systems Engineering But in any case < 20% * Yearly Primary Energy Need of RB (or Yearly Electricity need if Electricity use for Ventilation, Cooling, Lighting and DHW > Heating) And <1,8*Yearly Final Energy Production (or monthly electricity production (Potsdam) if Electricity use for Ventilation, Cooling, Lighting and DHW > Heating) - NR (with electrochemical storage > 1 kWh/kWp and system): If < 0,01 kWp/m²(net area) 200 kWh / kWp If > 0,01 kWp/m²(net area) 200 kWh / kWp + 1* Yealy Absolute Energy Need for Systems Engineering But in any case < 25% * Yearly Primary Energy Need of RB (or Yearly Electricity need if Electricity use for Ventilation, Cooling, Lighting and DHW > Heating) And <1,8*Yearly Final Energy Production (or monthly electricity production (Potsdam) if Electricity use for Ventilation, Cooling, Lighting and DHW > Heating) (e) Primary Energy Factor and CO2 equivalent are given (f) The renewable share is also considered achieved if: - the Wärmedurchgangskoeffizient conditions are more than 15% higher than the required ones (§45 p.36 GEG) - at least 50% of Heating and cooling needs are covered by waste heat (§44 p.36 GEG) - at least 50% of Heating and cooling needs are covered by combined heat and power plant (§44 p.36 GEG) (g) The renewable share is also considered achieved if: - the Wärmedurchgangskoeffizient conditions are more than 15% higher than the required ones (§45 p.36 GEG) - at least 50% of Heating and cooling needs are covered by waste heat (§44 p.36 GEG) - at least 50% of Heating and cooling needs are covered by combined heat and power plant (§44 p.36 GEG) - at least 50% of Heating and cooling needs are covered by a combination of above mentioned solutions (§44 p.36 GEG)

Sources

[41] Gesetz zur Vereinheitlichung des Energieeinsparrechts für Gebäude (GeG) (draft bill)

8.6 Appendix 1f: nZEB regulation in Italy

Country		Italy		
Building typology	**(New / Existing)**	New (a)		Existing (a1)
Category	**(Resid. / Non-resid.)**	R	NR	
Subcategory (h)		(E1 = SFH, MFH)	(E1 = EB E2 = OB E5 = CB)	
Included energy uses	Heating	x	x	No requirements as to EPB metrics but several technical requirements according to annex 1 of Decree 26 June 2015
	Cooling / Air co / Ventilation	x	x	
	Domestic Hot Water	x	x	
	Auxiliary Energy	x	x	
	Lighting		x	
	Plug loads / Appliances / IT			
	Central Services		x (1)	
	Electric vehicles			
	Embodied Energy			
Physical boundary		Building unit		
RES	**System boundary for generation**	on-site		
	Share	1kW / 50m^2 (b) 50% (b1)		
Balance	**Type of balance**	Energy needs/Energy production ©		
	Period of balance	Monthly (Decree 192/2005)		
Metrics max value	**Energy Need (kWh/(m^2.y))**	$EPH_{,nd}$ (Useful Energy Need for Heating) < to RB $EPC_{,nd}$ (Useful Energy Need for Cooling) < to RB (d) Winter Heating: (e) Cooling needs (f): < 40 kWh.m^2.a climatic zones A and B < 30 kWh.m^2.a climatic zones C, D, E and F	$EPH_{,nd}$ (Useful Energy Need for Heating) < to RB $EPC_{,nd}$ (Useful Energy Need for Cooling) < to RB (d) Winter Heating: (e) Cooling needs (f): < 14 kWh.m^2.a climatic zones A and B < 10 kWh.m^2.a climatic zones C, D, E and F	
	Primary energy consumption (c) (kWh/(m^2.y))	EPgl (Global Energy Performance) < to RB (expressed in Total Primary Energy and Non Renewable Primary Energy) (d)		
Normalization factor		Useful area		
Conversion factors		Static (g)		
Other metrics and requirements		Mean transmission heat transfer coefficient Ratio of summer effective collecting areas to the net floor area Mean efficiencies of the technical systems for heating, cooling and domestic hot water Mass of external walls/periodic thermal transmittance YIE Periodic thermal transmittance YIE of roofs and floors U-value of the inter-building opaque components (floors and walls) (see decree 59/2009 and annex 1 of decree 26 June 2015)		

Comments	(1) corresponds to internal transports (lift, escalator, …) (Decree 192/2005 and annex 1 of decree of 26 June 2015) (a) Assimilated as new : building extensions of volume >15% or >500m³ (annex 1 of decree 26 June 2015) Requirements also applicable to major renovations of level 1 = renovation affecting building envelope for >50% of gross deperdition surface and heating/cooling system (annex 1 of decree 26 June 2015) (a1) [Major renovation: existing buildings having a useful floor area >1 000 m² undergoing full refurbishment] Major renovation of level 2 = renovation affecting building envelope for >25% of gross deperdition surface and possibly heating/cooling system Other renovations with impact on energy performance (Annex 1 of decree 26 June 2015) (b) It is compulsory to install electrical power from renewables (b1) This percentage refers to Domestic Hot Water needs and to the sum of domestic hot water, heating and cooling This obligation cannot be fulfilled by installations from renewable sources which produce only electricity which, in turn, supplies appliances or systems for the production of domestic hot water, heating and cooling. (Decree 28/2011 - annex 3) (c) Decree 192/2005 and annex 1 of decree of 26 June 2015) Both Total primary energy need and Non renewable primary energy needs are calculated Compensation between energy needs and renewable energy produced on-site is allowed only for the same energy carrier on a monthly basis and up to cover the total energy demand for that carrier (the exported energy is not taken into account). The energy from on-site energy generation systems (defined as system inside building site) crosses the assessment boundary and compensates the energy needs of building (thermal compensates thermal needs and electricity compensates electrical needs). Electricity from renewables used for auxiliaries of a boiler or for the working of a HP can be taken into account but not electricity from renewables used to produce heat through a resistance. Surplus (only electricity is considered) is exported. The balance of primary energy is calculated as primary energy delivered minus primary energy exported. For electrical energy part of monthly surplus (which is exported) can be redelivered to compensate annual energy needs (d) Annex 1 of 26 June 2015 The reference building RB is defined as a virtual building which has the same localisation and is geometrically equivalent to that considered in the project, but with thermo-physical characteristics corresponding to the minimum energy requirements in force (Decree 192/2005). Characteristics of RB in Appendix A of Annex 1 of Decree 26 June 2015 (e) The minimum energy performance value for winter heating expressed in kWh.m².year depend on the climate zone which is defined based of heating degree days and on the building surface area to volume ratio (s/v) (see table in Annex C of Decree 192/2005 modified by 311/2006) (f) Decree 59/2009 Climatic zones defined in Decree 412/1993: Zone A: municipalities with a number of degree-days not exceeding 600; Zone B: municipalities with a number of degree-days greater than 600 and not more than 900; Zone C: municipalities with a number of degree-days greater than 900 and not more than 1,400; Zone D: municipalities with a number of degree-days greater than 1,400 and not more than 2,100; Zone E: municipalities with a number of degree-days greater than 2,100 and not more than 3,000; Zone F: municipalities with a number of degree-days greater than 3,000. (g) fP,tot (total primary energy conversion factor); fP,nren (non renewable primary energy conversion factor); fP,ren (renewable energy conversion factor) - see table 1 in annex 1 of decree 26 June 2015 (h) Decree 412/1993 E.1 Buildings used as residences and similar: E.1 (1) residences used as permanent residences, such as civil and rural houses, colleges, convents, prison houses, barracks; E.1 (2) residences used as residences with occasional occupation, such as holiday homes, weekends and the like; E.1 (3) buildings used as hotels, boarding houses and similar activities; E.2 Buildings used as offices and similar: public or private, independent or contiguous to buildings used also for industrial or craft activities, provided that they are separable from these buildings due to the effects of thermal insulation; E.3 Buildings used as hospitals, clinics or nursing homes and similar, including those used for the hospitalization or care of minors or the elderly, as well as protected structures for the assistance and recovery of drug addicts and other subjects entrusted to social services public; E.4 Buildings used for recreational or religious activities and similar: E.4 (1) such as cinemas and theatres, meeting rooms for congresses; E.4 (2) such as exhibitions, museums and libraries, places of worship; E.4 (3) such as bars, restaurants, dance halls; E.5 Buildings used for commercial and similar activities: such as shops, wholesale or retail stores, supermarkets, exhibitions; E.6 Sports buildings: E.6 (1) swimming pools, saunas and similar; E.6 (2) gyms and similar; E.6 (3) support services for sports activities; E.7 Buildings used for school activities at all levels and similar; E.8 Buildings used for industrial and craft activities and similar.	

Sources

[42] Legge dello Stato 30/04/1976 n. 373
[43] Legge 9 gennaio 1991, n. 10
[44] Decreto Legislativo 19 agosto 2005, n. 192 (modified by decree 311/2006 and law 90/2013)
[45] Decreto Legislativo 19 agosto 2005, n. 192 (modified by decree 311/2006 and law 90/2013) – Appendix
[46] Decreto del Presidente della Repubblica 2 aprile 2009, n. 59
[47] Decreto interministeriale 26 giugno 2015
[48] Decreto interministeriale 26 giugno 2015 – Appendix 1
[49] Decreto interministeriale 26 giugno 2015 – Appendix A
[50] Decreto interministeriale 26 giugno 2015 – Appendix B
[51] Decreto interministeriale 26 giugno 2015 – Appendix 2
[52] Decreto legislativo 3 marzo 2011, n. 28
[53] Decreto del Presidente della Repubblica 26 August 1993, n. 41

8.7 Appendix 1g: nZEB regulation in the Netherlands

Country		Netherlands								
Building typology	**(New / Existing)**	New								
Category	**(Resid. / Non-resid.)**	R	NR							
Subcategory (a)		Housing	OB	Nursery	Gathering place	H	Day care	IB	accommodation	E
Included energy uses	Heating	X$^{(1)}$	X$^{(1)}$							
	Cooling / Air co / Ventilation	X$^{(1)}$	X$^{(1)}$							
	Domestic Hot Water	X$^{(2)}$	X$^{(2)}$							
	Auxiliary Energy	X$^{(2)}$	X$^{(2)}$							
	Lighting		X$^{(2)}$							
	Plug loads / Appliances / IT									
	Central Services									
	Electric vehicles									
	Embodied Energy									
Physical boundary		Single building (NTA 8800)								
RES	**System boundary for generation**	Building plot (for deduction from primary fossil energy consumption) e.g.: PV, wind, co-gen Can be off site RES for calculation of RES share (e.g heating network with heat from RE) but buying green electricity from the netw								
	Share $^{(g)}$	40	30	40	30	30	40	-	40	4
Balance	**Type of balance**									
	Period of balance	Monthly (NTA 8800)								
Metrics max value $^{(b)}$	**Energy Need (kWh/(m².y))**	For Als/Ag$^{(c)}$ ≤ 1,83 : 65 For 1,83<Als/Ag ≤3,0 : 55 + 30 x (Als/Ag – 1,5) For Als/Ag > 3,0 : 100 + 50 x (Als/Ag – 3,0)	For Als/Ag ≤ 1,8 : 90 For Als/Ag > 1,8 : 90 + 30 x (Als/Ag – 1,8)	For Als/Ag ≤ 1,8 : 160 For Als/Ag > 1,8 : 160 + 30 x (Als/Ag – 1,8)	For Als/Ag ≤ 1,8 : 90 For Als/Ag > 1,8 : 90 + 30 x (Als/Ag – 1,8)	350	For Als/Ag ≤ 1,8 : 90 For Als/Ag > 1,8 : 90 + 35 x (Als/Ag – 1,8)	-	For Als/Ag ≤ 1,8 : 100 For Als/Ag > 1,8 : 100 + 35 x (Als/Ag – 1,8)	For Als 1,8 : For Als 1,8 : 19 (Als/Ag
	Primary fossil energy consumption $^{(d}$ (kWh/(m².y))	50	40	70	60	130	50	-	130	7
Normalization factor		Useful area								

Conversion factors	Static (e)
Other metrics and requirements	Environmental performance (f) (article 5.9 bouwbesluit and bepalingsmethode milieuprestat Thermal isolation values (Article 5.3 bouwbesluit and table 5.1B besluit 13/12/19) Air tightness (article 5.4)
Comments	(1) These elements are included in both Energy Need and Primary Fossil energy consumption metrics Of note, in the energy need metric, an arbitrary ventilation system is considered (thus not the real installed one) in order for this metric to be e the primary fossil energy consumption metric, the real ventilation system is considered. (2) These elements are included only in the Primary Fossil energy consumption metric (NTA 8800) (a) Most important subcategories listed. More subcategories in besluit 13/12/19 (b) calculated according to NTA 8800 (c) Als/Ag = geometry ratio (Als = area of losses; Ag = useful area) (d) Avoided primary energy linked to the energy produced from renewables is deducted from Primary fossil energy consumption The monthly characteristic energy consumption can become negative with a relatively large amount of self-produced electricity. This is allowe negative, the monthly amount of self-produced electricity that is used for functions that are not included in the total energy functions for ener primary energy can exceed the amount of primary energy consumed every month (NTA 8800) (e) Primary energy conversion factors (NTA 8800): electricity: 1,45 fossil fuels: 1,0 biomass: 0,0 ; 0,5 or 1,0 depending on the used heater CO2 emission factors are also given (table 5.3) (f) This indicator considers the environmental impacts of building through its entire lifecycle (materials, ...) => lifecycle assessment according t based on NEN 8006 According to table in article 5.9, this concerns housing and office buildings (g) Share defined as ratio between the renewable primary energy electricity produced on site (all production used and exported) + renewable energy needed (after deduction)

Sources

As of 01/07/2020, current EPB regulation on EPC requirements (Energie Prestatie Coefficient) will be replaced by BENG requireme latter are the ones presented here after.

[54] Bouwbesluit 2012 - chapter 5

[55] Besluit van 13 december 2019, houdende wijziging van het Bouwbesluit 2012 en van enkele andere besluiten inzake bijna en

[56] Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken

8.8 Appendix 1h: nZEB regulation in Spain

Country		Spain			
Building typology	**(New / Existing)**	New		Existing (f)	
Category	**(Resid. / Non-resid.)**	R	NR	R	NR
Subcategory					
Included energy uses	Heating	x			
	Cooling / Air co / Ventilation	x			
	Domestic Hot Water	x			
	Auxiliary Energy				
	Lighting		x		x
	Plug loads / Appliances / IT				
	Central Services				
	Electric vehicles				
	Embodied Energy				
Physical boundary					
RES	**System boundary for generation**				
	Share	60% - 70% (c1)		60% - 70% (c3)	
Balance	**Type of balance**				
	Period of balance	monthly			
Metrics max value	**Primary fossil/total energy consumption (kWh/(m^2.y))**	PECfossil : Zone alpha: 20 Zone A: 25 Zone B: 2C: 32 Zone D: 38; Zone E: 43 (a1) PECtotal : Zone alpha: 40 Zone A: 50 Zone B: 56 Zone C: 64 Zone D: 76; Zone E: 86 (a2)		PECfossil : Zone alpha: 70 + 8 *CFI Zone A: 55 + 8 *CFI Zone B: 50 + 8 *CFI Zone C: 35 + 8 *CFI Zone D: 20 + 8 *CFI Zone E: 10 + 8 *CFI (b1) PECtotal : Zone alpha: 165 + 8 *CFI Zone A: 155 + 8 *CFI Zone B: 150 + 8 *CFI Zone C: 140 + 8 *CFI Zone D: 130 + 8 *CFI Zone E: 120 + 8 *CFI (b2)	
Normalization factor		Useful surface			
Conversion factors		static (e)			
Other metrics and requirements		Thermal transmittance; Global heat transmission coefficient; Air tightness Generation of renewable electricity (d)			

Comments	(a1) The exact value depends of the winter climate zone (Anejo B Zonas climaticas) For extrapeninsular territories, the values should be multiplicated by 1,25 These values refer to the primary fossil energy consumption (a2) The exact value depends of the winter climate zone (Anejo B Zonas climaticas) For extrapeninsular territories, the values should be multiplicated by 1,15 These values refer to the total primary (fossil+renewable) energy consumption (b1) CFI refers to the average internal load, calculated as the average value of the internal load during a typical week and not as an average during the occupation time or as the maximum load during the occupation time These values refer to the primary fossil energy consumption For extrapeninsular territories, the values should be multiplicated by 1,4 (b2) CFI refers to the average internal load, calculated as the average value of the internal load during a typical week and not as an average during the occupation time or as the maximum load during the occupation time These values refer to the total primary (fossil+renewable) energy consumption For extrapeninsular territories, the values should be multiplicated by 1,4 (c1) Annual share of energy need for DHW and indoor swimming pool air-conditionning (monthly values must be taken into account) If 100 L/d < DHW demand < 5000 L/d : 60% If DHW demand > 5000 L/d : 70% Are considered a renewable source: - All in-situ renewables - Urban heating systems are considered as a renewable source - Heat pumps intended for the production of DHW and / or pool air conditioning, with seasonal average yield value (SCOPdhw) greater than 2.5 when electrically operated and higher than 1.15 when activated by thermal energy. The value of SCOPdhw shall be determined for the ACS preparation temperature, which shall not be less than 45 ° C. - Residual energy from cooling equipment, dehumidifiers and residual combustion heat of the thermally driven heat pump engine, provided that the use of this residual energy is effective and useful for the ACS. Only the energy obtained by the installation of heat recuperators outside the building's own thermal installation will be taken into consideration. In the case of recovery of residual energy from refrigeration equipment in residential buildings, it will not be possible to account for an energy use greater than 20% of the extracted (c3) DHW demand > 100 L/d & the building of the thermal energy generation unit was fully renovated OR DHW demand > 5000 L/d & +50% demand increase compare to initial demand (d) For buildings with a built surface > 3000 m² 30 kW < Pmin = 0,01 * S < Pins < Plim = 0,05 Sc < 100 kW Sc = Covered built surface S = Built surface (e) Primary nergy conversion factors are provided. See document in sources (f) The category "existing" gathers the following cases: - Extensions in which 10% or more of the built surface or volume of the intervening unit, when the total extended usable floor area exceeds 50m² - Change in the building use when the total usable floor area excceeds 50m² - Extensions in which 10% or more of the built surface or volume of the intervening unit, when the total extended usable floor area exceeds 50m² - Refurbishments in which the thermal generation facilities and more than 25% of the total surface of the final thermal envelope of the building are jointly renewed.

Sources

[57] Documento Basico HE - Ahorro de energia - 12/19

[58] Documento Reconocido del Reglamento de Instalaciones Térmicas en los Edificios (RITE)

8.9 Appendix 1i: nZEB regulation equivalent in Switzerland

Country			Switzerland						
Building typology	**(New / Existing)**		New (a)						
Category	**(Resid. / Non-resid.)**		R		NR				
Subcategory			Individual housing	Collective housing	Administration	Schools	Commercial	Gathering places	Hospitals
Included energy uses	Heating		x		x				
	Cooling / Air co / Ventilation		x		x				
	Domestic Hot Water		x		x				
	Auxiliary Energy		x		x				
	Lighting				(b)				
	Plug loads / Appliances / IT								
	Central Services								
	Electric vehicles								
	Embodied Energy								
Physical boundary			Building						
RES	**System boundary for generation**		Building or neighborhood						
	Share		Electricity production of at least 10 W/m² but no requirement to (c) For SF and restaurants, additionally 20% of DHW needs must be						
Balance	**Type of balance**		N/A (Self-produced electricity is not taken into account in the calculation of weighte electricity produced by cogen installations)						
	Period of balance								
Metric			"Final" energy need						
Normalization factor			Energy reference surface (surface de référence énergétique) N						
Conversion factors			Static (d)						
Max weighted energy need (kWh.m-2.y-1) (e)			35 (f)		40	35	40	40	70
Other metrics and requirements (g)	**Heating 2 alternative procedures**	**Thermal isolation requirements for indiviual envelope elements**	Uli (W/(m2K)) Ψ (W/(m K)) χ (W/K) => values in MoPEC 2014 - section B - Appendix 1						

		Global performance (annex 3 section B)	**Annual heating needs Limit values**	**$QH_{,li0}$ (kWh/m² y) For annual average temperature of 9,4°C (+6% per degree lower; -6% per degree higher)**	16	13	13	14	7	18	18
				$\Delta\Theta H_{,li}$ (kWh/m² y)	15	15	15	15	14	15	17
			Specific heating power Limit values	**$PH_{,li}$ (W/m²) For dimensioning temperature of -8°C**	25	20	25	20	-	-	-
Comments					(a) Includes construction of annexes to existing buildings, except if less than 50m² or l (b) In new buildings or renovations of more than 1000 m², limit values for the electrici (c) Or compensating tax if requirement not met (~Fr. 1000 per kW not realized) Electricity from cogen installation may only be considered if not taken into account For multi-floor building, an integration of PV panels in the façade must be foreseen (d) National weighting factor "g" defined by the EnDK ("Conférence des directeurs can Electricity: 2,0 Fossil fuels: 1,0 Biomass: 0,5 Heating network, depending on part from fossil heat: ≤25% : 0,4 ≤50% : 0,6 ≤75% : 0,8 <75% : 1,0 (e) Calculation according to MoPEC article 1.24 and SIA 380/1 Self-produced electricity is not taken into account in the calculation, exception made c (f) Alternatively to this requirement, one of several combinations of standard solution ...) can be applied as described in MoPEC article 1.25 (g) Additional requirements also as to technical installations Also, a label called "Minergie" exists with 3 different levels Minergie : energy balance improved by 20% compared to MoPEC 2014 requiremen Minergie-P : very low energy consumption (for residential, Minergie indicator < 55 k Minergie-A : positive energy buildings (for residential, Minergie indicator <35 kWh/ The Minergie indicator includes more energy uses than the MoPEC indicator (applianc other requirements. In addition, an "ECO" label exists							

Sources

[59] Modèle de prescriptions énergétiques des cantons (MoPEC)

[60] Facteurs de pondération nationaux pour l'évaluation des bâtiments

8.10 Appendix 2

Table 8.10.1 Studied reference cases for single family houses

General description									
Country		**Belgium**			**France**	**Germany**		**Italy**	
Region		VL	RW	RBC	Nantes	Frankfurt		Rome	
Building Type		SFH	SFH	SFH	SFH	SFH	SFH	SFH	SFH
Building Typology		New	New	New	New	New	New	New	New
Normalisation Area Name		UA	CA	NGFA	TS	UA	UA	UA	UA
Normalisation Area Value	[m²]	135	150	160	158	203	125	162	119
Energetic description									
Heating System		gas boiler	gas boiler	gas boiler	gas condensing boiler	HPa/w	gas boiler	HPa/w	Wood pellets boiler
Energy Vector		gas	gas	gas	gas	electricity	gas	electricity	biomass
Primary Energy Consumption for Heating	[kWhPE/m²]	8,5	7,7	7,2	20,8	37,4	9,4	55,0	10,5
DHW System		gas boiler	gas boiler	gas boiler	Gas condensing boiler	HPa/w	gas boiler	HPa/w	gas boiler
Energy Vector		gas	gas	gas	gas	electricity	gas	electricity	gas
Primary Energy Consumption for DHW	[kWhPE/m²]	22,0	19,8	18,6	17,2	14,8	24,2	22,0	23,5
Ventilation System		mechanical	mechanical	mechanical	Single Flow ventilation	mechanical	mechanical	none	none
Energy Vector		electricity	electricity	electricity	electricity	electricity	electricity	none	none
Primary Energy Consumption for Ventilation	[kWhPE/m²]	17,5	15,8	14,8	1,7	27,5	12,6	0,0	0,0
Cooling System		none	none	none	none	none	none	none	none
Energy Vector		none	none	none	none	none	none	none	none
Primary Energy Consumption for Cooling	[kWhPE/m²]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Primary Energy Consumption for Lighting	[kWhPE/m²]	NA	NA	NA	4,4	NA	NA	NA	NA
Total Primary Energy Consumption	**[kWhPE/m²]**	**48,0**	**43,2**	**40,5**	**44,1**	**79,8**	**46,2**	**77,0**	**34,0**

Table 8.10.2 Studied reference cases for multifamily houses (1/2)

General description						
Country		**Belgium**				
Region		VL	RW	RBC	VL	RW
Building Type		MFH	MFH	MFH	MFH	MFH
Building Typology		New	New	New	New	New
Normalisation Area Name		UA	CA	NGFA	UA	CA
Normalisation Area Value	[m²]	1241	1300	1350	1241	1300
Energetic description						
Heating System 1		HPa/a	HPa/a	HPa/a	district heating network	district hea networ
Energy Vector 1		electricity	electricity	electricity		
Heating System 2		electric heater	electric heater	electric heater		
Energy Vector 2		electricity	electricity	electricity		
Primary Energy Consumption for Heating	[kWhPE/m²]	35,1	38,7	36,5	37,3	41,1
DHW System		decentral electrical continuous flow water heaters with heat recovery	decentral electrical continuous flow water heaters with heat recovery	decentral electrical continuous flow water heaters with heat recovery	district heating network	district hea networ
Energy Vector		electricity	electricity	electricity		
Primary Energy Consumption for DHW	[kWhPE/m²]	29,6	32,6	30,7	26,3	29,0
Ventilation System		central ventilation system	central ventilation system	central ventilation system	mechanical	mechani
Energy Vector		electricity	electricity	electricity	electricity	electrici
Primary Energy Consumption for Ventilation	[kWhPE/m²]	2,8	3,1	2,9	4,9	5,4
Cooling System		none	none	none	none	none
Energy Vector		none	none	none	none	none
Primary Energy Consumption for Cooling	[kWhPE/m²]	0,0	0,0	0,0	0,0	0,0
Primary Energy Consumption for Lighting	[kWhPE/m²]					
Total Primary Energy Consumption	**[kWhPE/m²]**	**67,5**	**74,3**	**70,1**	**68,5**	**75,4**

Table 8.10.3 Studied reference cases for multi family houses (2/2)

General description					
Country		**Germany**		**Italy**	**Nethe**
Region		Frankfurt		Rome	Amst
Building Type		MFH	MFH	MFH	MFH
Building Typology		New	New	New	New
Normalisation Area Name		UA	UA	UA	UA
Normalisation Area Value	[m²]	1241	1241	2146	1241
Energetic description					
Heating System 1		HPa/a	district heating network	HPa/w	HPa/a
Energy Vector 1		electricity		electricity	electricity
Heating System 2		electric heater			electric heater
Energy Vector 2		electricity			electricity
Primary Energy Consumption for Heating	[kWhPE/m²]	25,3	11,2	8,3	20,4
DHW System		decentral electrical continuous flow water heaters with heat recovery	district heating network	HPa/w	decentral electrical continuous flow water heaters with heat recovery
Energy Vector		electricity		electricity	electricity
Primary Energy Consumption for DHW	[kWhPE/m²]	21,3	7,9	40,2	17,2
Ventilation System		central ventilation system	mechanical	natural	central ventilation system
Energy Vector		electricity	electricity		electricity
Primary Energy Consumption for Ventilation	[kWhPE/m²]	2,0	3,5	0,0	1,6
Cooling System		none	none	none	none
Energy Vector		none	none	none	none
Primary Energy Consumption for Cooling	[kWhPE/m²]	0,0	0,0	0,0	0,0
Primary Energy Consumption for Lighting	[kWhPE/m²]				
Total Primary Energy Consumption	**[kWhPE/m²]**	**48,6**	**22,6**	**48,5**	**39,2**

Table 8.10.4 Studied reference cases for educational buildings

General description							
Country		**Belgium**			**France**	**Germany**	
Region		VL	RBC	RW	Nantes	Frankfurt	
Building Type		EB	EB	EB	EB	EB	
Building Typology		Retrofit	Retrofit	Retrofit	Retrofit	Retrofit	
Normalisation Area Name		UA	NGFA	CA	NGFA	NGFA	
Normalisation Area Value	[m²]	6000	7080	6800	3558	7080	
Energetic description							
Heating System 1		district heating network	district heating network	district heating network	gas condensing boiler	district heating network	co
Energy Vector 1					gas		
Heating System 2							
Energy Vector 2							
Primary Energy Consumption for Heating	[kWhPE/m²]	34,7	29,4	30,6	5,4	8,8	
DHW System		electricity-based	electricity-based	electricity-based	electricity-based	electricity-based	co
Energy Vector		electricity	electricity	electricity	electricity	electricity	
Primary Energy Consumption for DHW	[kWhPE/m²]	48,0	40,7	42,4	8,5	29,3	
Ventilation System		central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system	simple flux ventilation system	central ventilation system with heat recovery system	ce me ve sys heat
Energy Vector		electricity	electricity	electricity	electricity	electricity	el
Primary Energy Consumption for Ventilation	[kWhPE/m²]	45,1	38,2	39,8	10,3	27,5	
Cooling System		none	none	none	none	none	
Energy Vector		none	none	none	none	none	
Primary Energy Consumption for Cooling	[kWhPE/m²]	0,0	0,0	0,0	0,0	0,0	
Primary Energy Consumption for Lighting	[kWhPE/m²]	22,1	18,8	19,5	5,2	13,5	
Total Primary Energy Consumption	**[kWhPE/m²]**	**149,9**	**127,0**	**132,3**	**29,4**	**79,1**	

Table 8.10.5 Studied reference cases for office buildings (1/2)

General description						
Country		**Belgium**				
Region		VL		RBC		
Building Type		OB	OB	OB	OB	OB
Building Typology		New	New	New	New	New
Normalisation Area Name		UA	UA	NGFA	NGFA	CA
Normalisation Area Value	[m²]	5200	5200	6150	6150	5950
Energetic description						
Heating System 1		gas condensing boiler	ground-connected reversible HP	gas condensing boiler	ground-connected reversible HP	gas conde boile
Energy Vector 1		gas	electricity	gas	electricity	gas
Heating System 2						
Energy Vector 2						
Primary Energy Consumption for Heating	[kWhPE/m²]	47,3	27,9	40,0	23,6	41,3
DHW System		none	none	none	none	none
Energy Vector		none	none	none	none	none
Primary Energy Consumption for DHW	[kWhPE/m²]	0,0	0,0	0,0	0,0	0,0
Ventilation System		central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system	centra ventilat system heat reco syste
Energy Vector		electricity	electricity	electricity	electricity	electric
Primary Energy Consumption for Ventilation	[kWhPE/m²]	45,2	45,2	38,2	38,2	39,5
Cooling System		compression-based chiller	ground-connected reversible HP	compression-based chiller	ground-connected reversible HP	compress based ch
Energy Vector		electricity	electricity	electricity	electricity	electric
Primary Energy Consumption for Cooling	[kWhPE/m²]	29,6	9,9	25,0	8,3	25,8
Primary Energy Consumption for Lighting	[kWhPE/m²]	35,5	35,5	30,0	30,0	31,0
Total Primary Energy Consumption	**[kWhPE/m²]**	**157,5**	**118,4**	**133,2**	**100,1**	**137,7**

Table 8.10.6 Studied reference cases for office buildings (2/2)

General description							
Country		**Germany**		**Italy**		**Netherlands**	
Region		Frankfurt		Rome		Amsterdam	
Building Type		OB	OB	OB	OB	OB	OB
Building Typology		New	New	New	New	New	New
Normalisation Area Name		NGFA	NGFA	UA	UA	UA	UA
Normalisation Area Value	[m²]	6150	6150	6200	6200	5200	5200
Energetic description							
Heating System 1		gas condensing boiler	ground-connected reversible HP	none	none	gas condensing boiler	ground-connected reversible HP
Energy Vector 1		gas	electricity	none	none	gas	electricity
Heating System 2							
Energy Vector 2							
Primary Energy Consumption for Heating	[kWhPE/m²]	44,0	17,0	0,0	0,0	47,3	16,2
DHW System		none	none	none	none	none	none
Energy Vector		none	none	none	none	none	none
Primary Energy Consumption for DHW	[kWhPE/m²]	0,0	0,0	0,0	0,0	0,0	0,0
Ventilation System		central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system	central ventilation system with heat recovery system
Energy Vector		electricity	electricity	electricity	electricity	electricity	electricity
Primary Energy Consumption for Ventilation	[kWhPE/m²]	27,5	27,5	37,0	37,0	26,3	26,3
Cooling System		compression-based chiller	ground-connected reversible HP	compression-based chiller	ground-connected reversible HP	compression-based chiller	ground-connected reversible HP
Energy Vector		electricity	electricity	electricity	electricity	electricity	electricity
Primary Energy Consumption for Cooling	[kWhPE/m²]	18,0	9,3	60,5	20,2	28,6	9,5
Primary Energy Consumption for Lighting	[kWhPE/m²]	21,6	21,6	14,5	14,5	20,6	20,6
Total Primary Energy Consumption	**[kWhPE/m²]**	**111,1**	**75,4**	**112,0**	**71,7**	**122,8**	**72,6**

8.11 Appendix 3

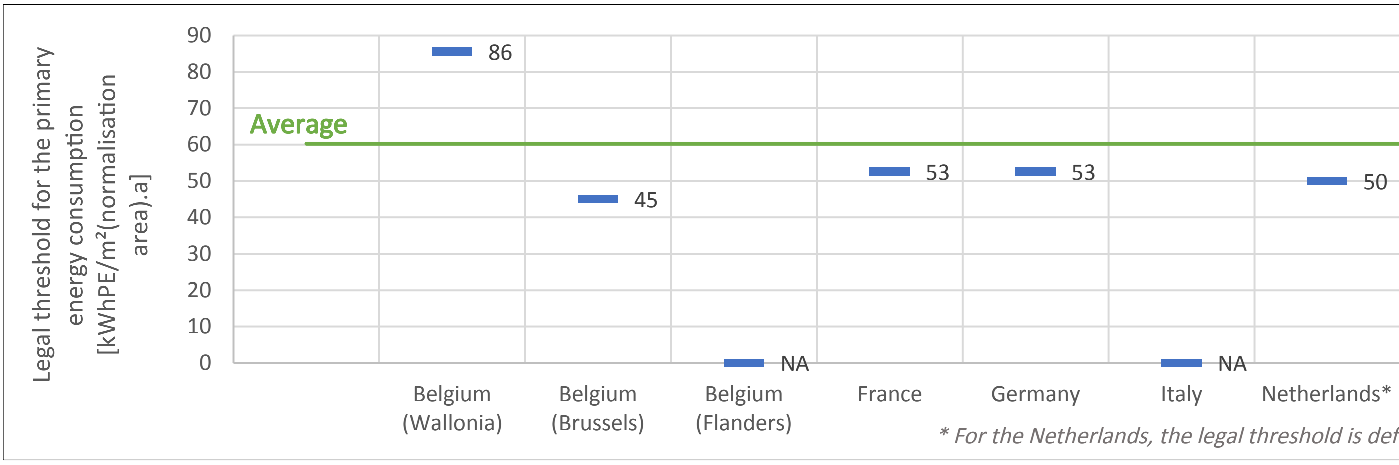


Figure 8.11.2 Legal threshold for new single-family houses and multi-family houses

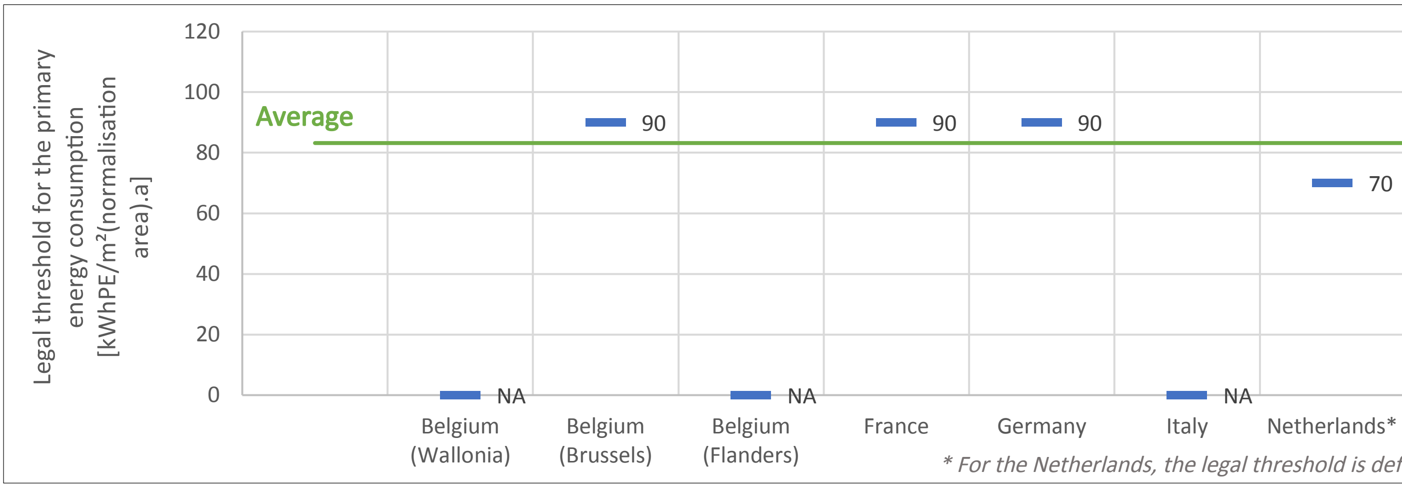


Figure 8.10.1 Legal threshold for new educational buildings

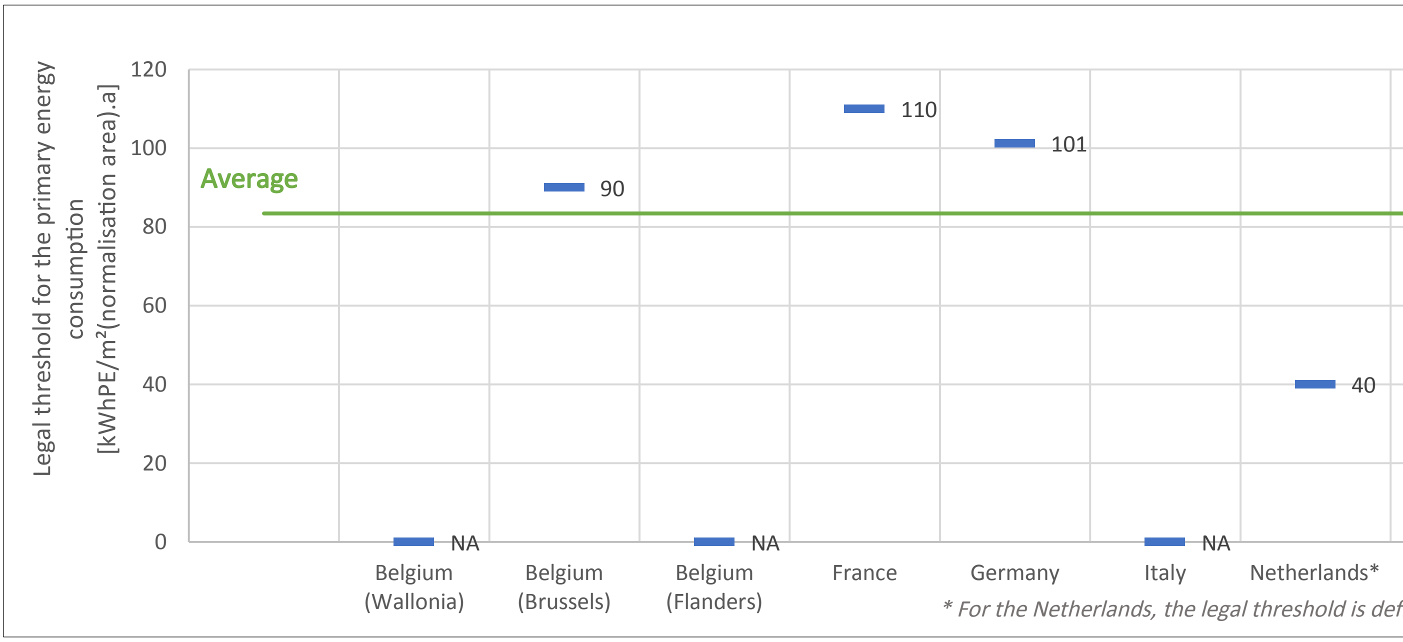


Figure 8.11.3 Legal threshold for new office buildings

8.12 Appendix 4

Because the end-user cost is directly used in the cost efficiency indicator, the impact of a X% end-user cost decrease on the cost efficiency indicator is constant for all countries and cases.

$$CE = \frac{\frac{(E0 - E2)}{E0}}{EUC}$$

$$CE' = \frac{\frac{(E0 - E2)}{E0}}{EUC'}$$

Where:

- CE is the cost efficiency indicator before any BIPVBOOST improvement
- CE' is the cost efficiency indicator after the BIPVBOOST improvement leading to an end-user cost reduction was taken into account
- $E0$ is the primary energy consumption of the reference building
- $E2$ is the primary energy consumption of the reference building with a renewable energy system (BIPV, BAPV or ST) after contribution 1 and 2 were taken into account
- EUC is the end-user cost before any improvement
- $EU\acute{C}$ is the end-user cost after the improvement leading to an end-user cost reduction was taken into account

Let R be the relative impact on the cost efficiency indicator once the improvement leading to an end-user cost reduction is taken into account.

$$R = \frac{(CE - C\acute{E})}{CE} \;\square\; R = \frac{\left(\frac{\frac{(E0-E2)}{E0}}{EUC} - \frac{\frac{(E0-E2)}{E0}}{EUC'}\right)}{\frac{\frac{(E0-E2)}{E0}}{EUC}}$$

Multiply by EUC

$$R = \frac{\left(\frac{(E0 - E2)}{E0} - \frac{EUC * \frac{(E0 - E2)}{E0}}{EUC'}\right)}{\frac{(E0 - E2)}{E0}}$$

Divide by $\frac{(E0-E2)}{E0}$ *(if* $\frac{(E0-E2)}{E0}$ *=0, then R is undefined)*

$$R = 1 - \frac{EUC}{EUC'}$$

With:

$$EU\acute{C} = EUC * (1 - X\%)$$

Where:

- $X\%$ is the improvement's impact on the end-user cost

$$R = 1 - \frac{EUC}{EUC*(1-X\%)} \;\square\; R = 1 - \frac{1}{(1-X\%)}$$

For X% = {5% ; 10% ; 15%}

R = {-5,26% ; -11,11% ; 17,65}

8.13 Appendix 5

8.13.1 Belgium - Multi-family house: Case 2/2

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.1 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in Belgium (2/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	250	250	257	257	35
South	Installed capacity [kWp]	44	38	28	25	NA
South	RE system surface to net floor area [-]	0,19	0,19	0,19	0,19	0,03
East	Occupied area [m²]	114	114	NA	NA	NA
East	Installed capacity [kWp]	20	17	NA	NA	NA
East	RE system surface to net floor area [-]	0,08	0,08	NA	NA	NA
West	Occupied area [m²]	132	132	NA	NA	NA
West	Installed capacity [kWp]	23	20	NA	NA	NA
West	RE system surface to net floor area [-]	0,10	0,10	NA	NA	NA
East & West	Occupied area [m²]	246	246	NA	NA	NA
East & West	Installed capacity [kWp]	43	38	NA	NA	NA
East & West	RE system surface to net floor area [-]	0,18	0,18	NA	NA	NA

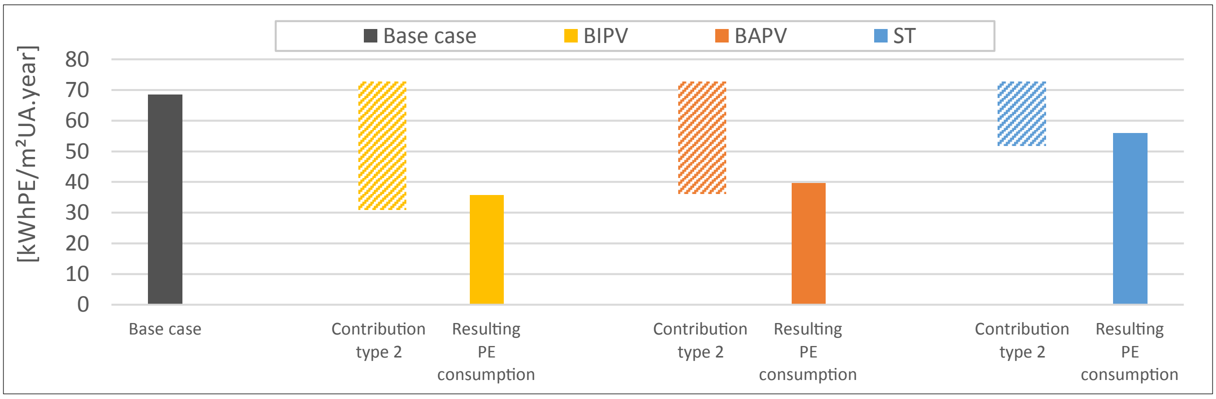


Figure 8.13.1 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in Region of Flanders (Belgium)

Table 8.13.2 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in Belgium

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-48%	-45%	-42%	-40%	-18%
East	-28%	-26%	NA	NA	NA
West	-29%	-26%	NA	NA	NA
East & West	-37%	-36%	NA	NA	NA

Table 8.13.3 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in Belgium

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,47	0,46	1,29	1,74	0,71
East	0,60	0,58	*NA*	*NA*	*NA*
West	0,53	0,51	*NA*	*NA*	*NA*
East & West	0,37	0,37	*NA*	*NA*	*NA*

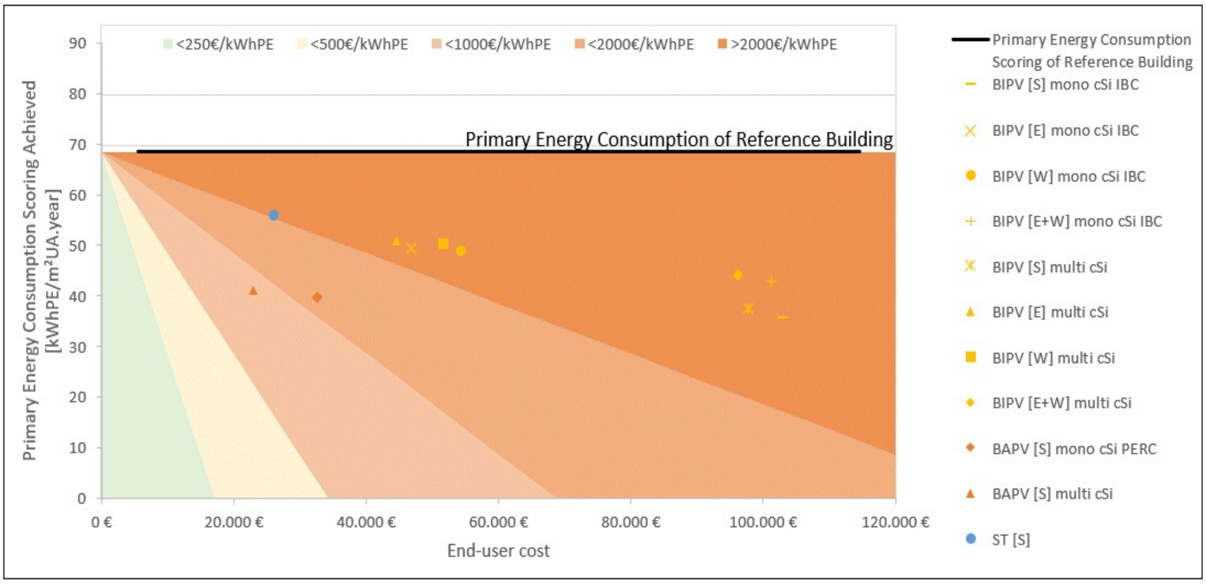


Figure 8.13.2 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in Belgium

Table 8.13.4 Validation of renewable energy integration target as set by national regulation for a MFH in Flanders (Belgium)

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y
East	N	N	*NA*	*NA*	*NA*
West	N	N	*NA*	*NA*	*NA*
East & West	Y	N	*NA*	*NA*	*NA*

8.13.2 Belgium - Office building: Case 2/2

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.5 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Belgium

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

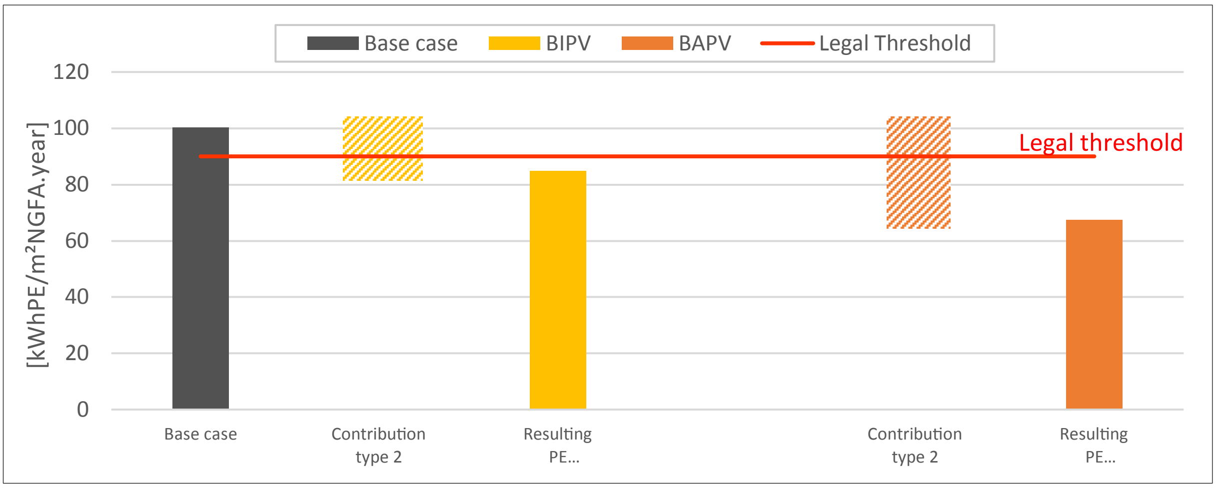


Figure 8.13.3 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Region of Brussels (Belgium)

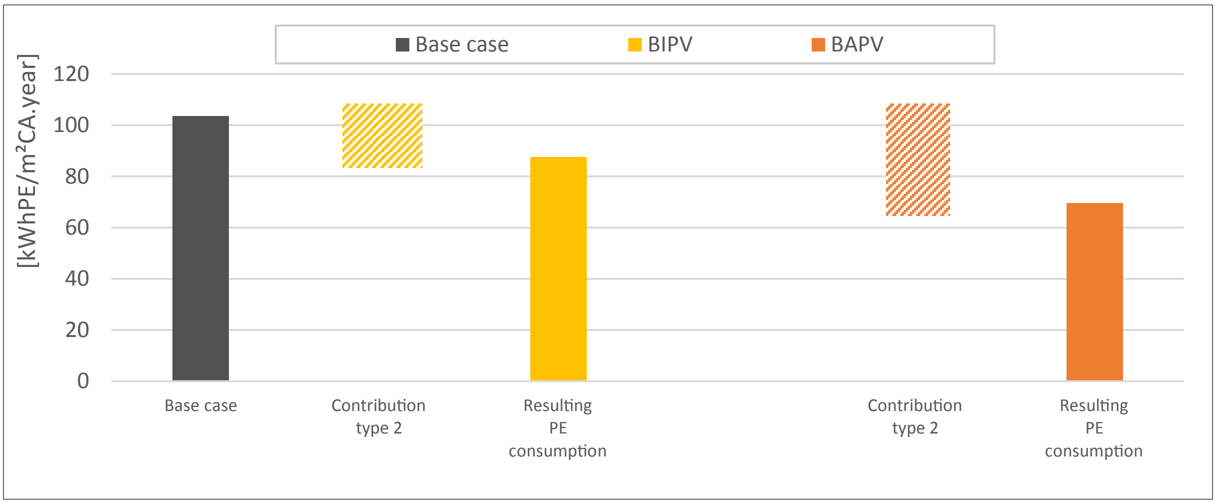


Figure 8.13.5 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Region of Wallonia (Belgium)

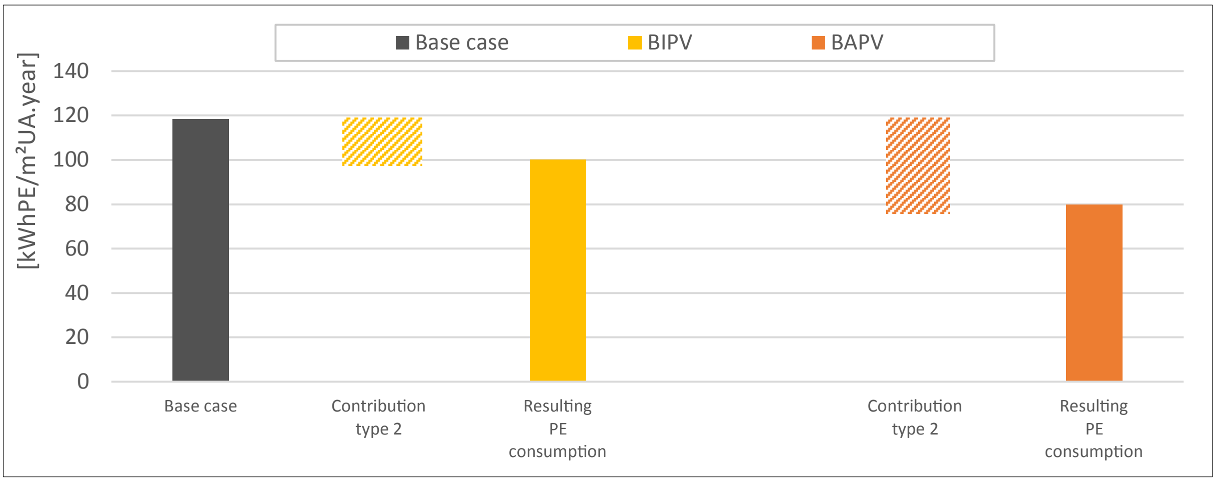


Figure 8.13.4 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Region of Flanders (Belgium)

Table 8.13.6 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Belgium

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-15%	-4%	-33%	-29%
East	-14%	-3%	*NA*	*NA*
West	-12%	-3%	*NA*	*NA*
East & West	-26%	-6%	*NA*	*NA*

Table 8.13.7 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Belgium

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,05	0,02	0,31	0,39
East	0,05	0,01	*NA*	*NA*
West	0,04	0,01	*NA*	*NA*
East & West	0,04	0,01	*NA*	*NA*

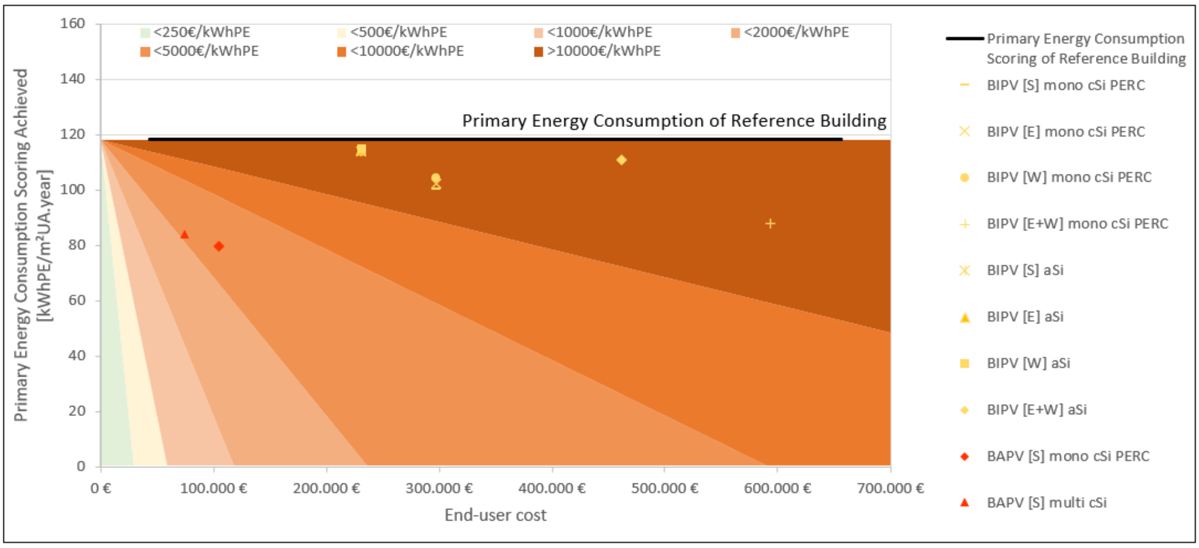


Figure 8.13.6 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Belgium

Table 8.13.8 Validation of renewable energy integration target as set by national regulation for a OB in Belgium

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	Y	N
East	N	N	*NA*	*NA*
West	N	N	*NA*	*NA*
East & West	N	N	*NA*	*NA*

8.13.3 France - Multi-family house: Case 2/2

Both BIPV systems are installed as a ventilated façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.9 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a MFH in France (2/2)

		BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	Occupied area [m²]	250	250	257	257	30
South	Installed capacity [kWp]	44	38	28	25	*NA*
South	RE system surface to net floor area [-]	0,19	0,19	0,19	0,19	0,02
East	Occupied area [m²]	114	114	*NA*	*NA*	*NA*
East	Installed capacity [kWp]	20	17	*NA*	*NA*	*NA*
East	RE system surface to net floor area [-]	0,08	0,08	*NA*	*NA*	*NA*
West	Occupied area [m²]	132	132	*NA*	*NA*	*NA*
West	Installed capacity [kWp]	23	20	*NA*	*NA*	*NA*
West	RE system surface to net floor area [-]	0,10	0,10	*NA*	*NA*	*NA*
East & West	Occupied area [m²]	246	246	*NA*	*NA*	*NA*
East & West	Installed capacity [kWp]	43	38	*NA*	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*	*NA*

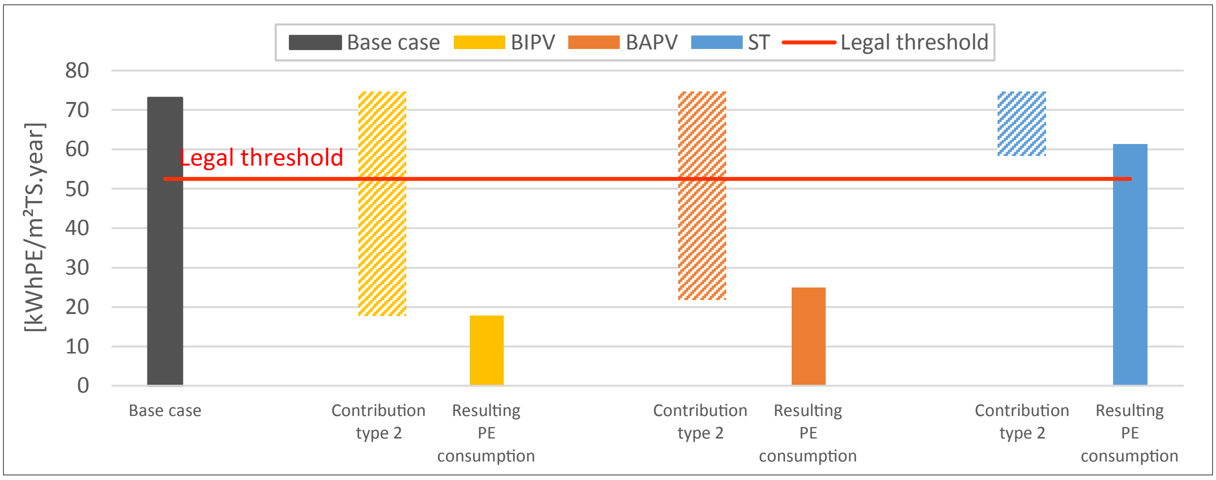


Figure 8.13.7 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a MFH in France

Table 8.13.10 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a MFH in France

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	-76%	-67%	-66%	-60%	-16%
East	-33%	-30%	*NA*	*NA*	*NA*
West	-33%	-30%	*NA*	*NA*	*NA*
East & West	-54%	-49%	*NA*	*NA*	*NA*

Table 8.13.11 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a MFH in France

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	0,65	0,61	1,79	2,30	0,64
East	0,62	0,60	*NA*	*NA*	*NA*
West	0,54	0,52	*NA*	*NA*	*NA*
East & West	0,48	0,45	*NA*	*NA*	*NA*

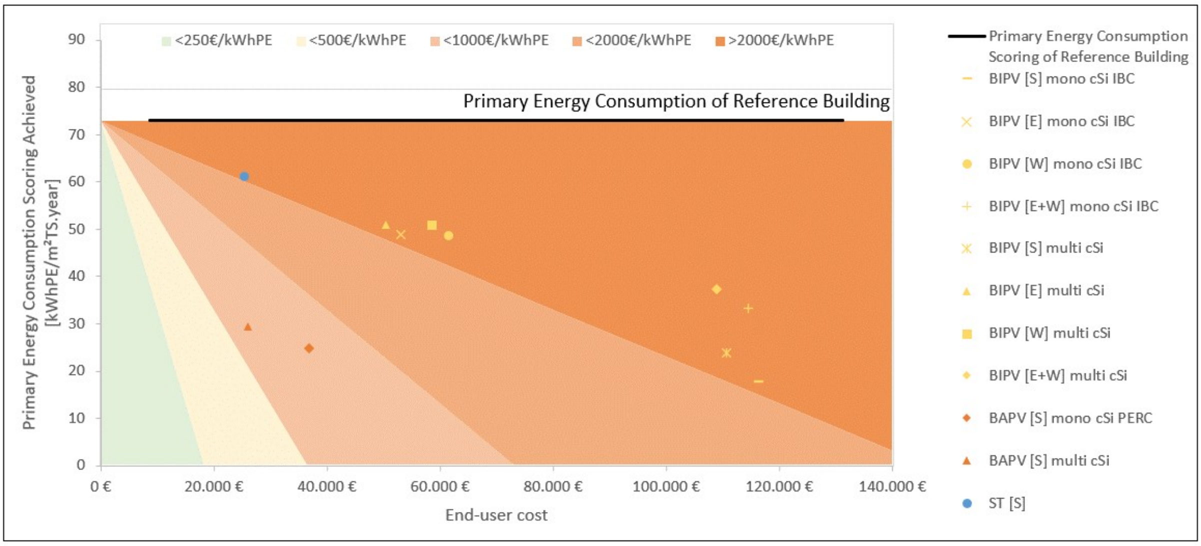


Figure 8.13.8 PE consumption scorings achieved with different renewable systems and associated cost for a MFH in France

Table 8.13.12 Validation of renewable energy integration target as set by national regulation for a MFH in France

	BIPV mono cSi IBC (facade)	BIPV multi cSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	Solar Thermal (roof)
South	*No target*	*No target*	*No target*	*No target*	*No target*
East	*No target*	*No target*	*NA*	*NA*	*NA*
West	*No target*	*No target*	*NA*	*NA*	*NA*
East & West	*No target*	*No target*	*NA*	*NA*	*NA*

8.13.4 France- Office building: Case 1/2

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.13 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in France

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	666	666	879	879
South	Installed capacity [kWp]	67	16	96	86
South	RE system surface to net floor area [-]	0,11	0,11	0,14	0,14
East	Occupied area [m²]	666	666	*NA*	*NA*
East	Installed capacity [kWp]	67	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
West	Occupied area [m²]	666	666	*NA*	*NA*
West	Installed capacity [kWp]	67	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,11	0,11	*NA*	*NA*
East & West	Occupied area [m²]	1331	1331	*NA*	*NA*
East & West	Installed capacity [kWp]	133	33	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,22	0,22	*NA*	*NA*

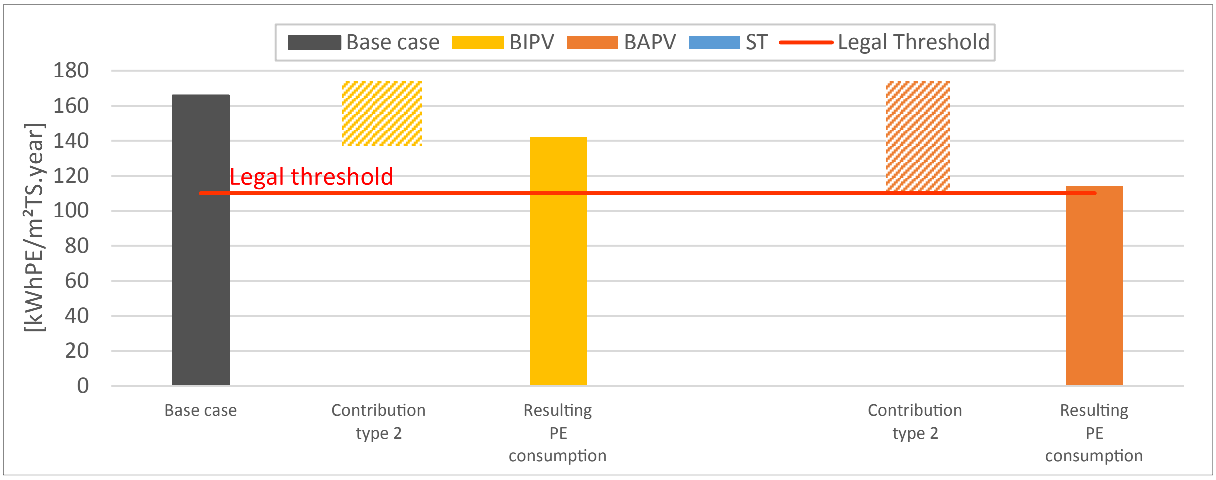


Figure 8.13.9 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in France

Table 8.13.14 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in France

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-14%	-4%	-31%	-28%
East	-13%	-3%	NA	NA
West	-11%	-3%	NA	NA
East & West	-23%	-6%	NA	NA

Table 8.13.15 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in France

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,05	0,02	0,30	0,37
East	0,04	0,01	*NA*	*NA*
West	0,04	0,01	*NA*	*NA*
East & West	0,04	0,01	*NA*	*NA*

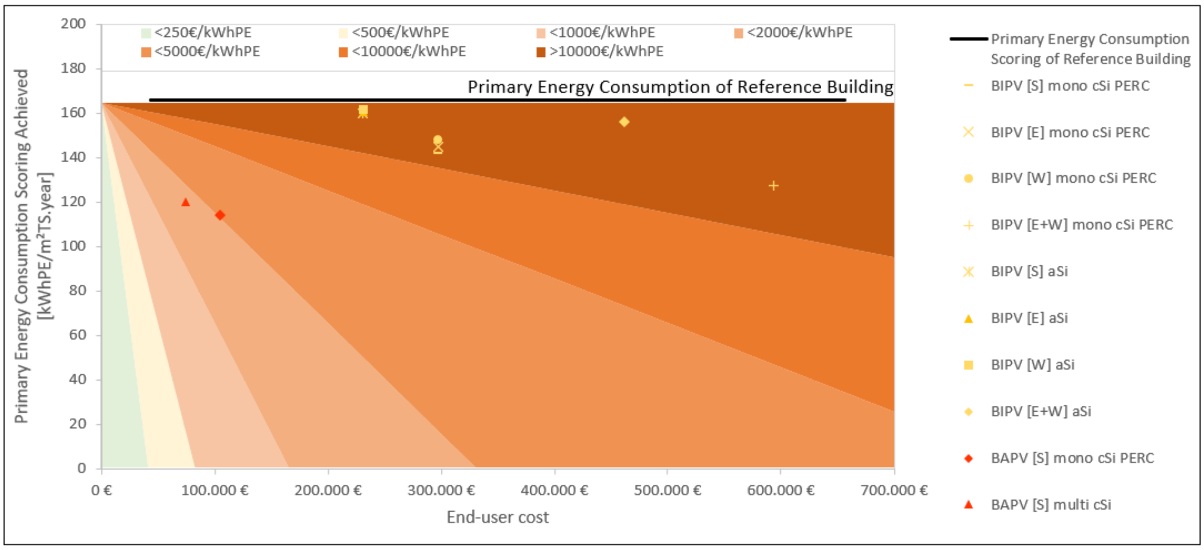


Figure 8.13.10 PE consumption scorings achieved with different renewable systems and associated cost for a OB in France

Table 8.13.16 Validation of renewable energy integration target as set by national regulation for a OB in France

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	*No target*	*No target*	No target	No target
East	*No target*	*No target*	*NA*	*NA*
West	*No target*	*No target*	*NA*	*NA*
East & West	*No target*	*No target*	*NA*	*NA*

8.13.5 Italy - Office building: Case 2/2

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.17 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Italy

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	648	648	973	973
South	Installed capacity [kWp]	65	16	107	95
South	RE system surface to net floor area [-]	0,09	0,09	0,13	0,13
East	Occupied area [m²]	648	648	*NA*	*NA*
East	Installed capacity [kWp]	65	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
West	Occupied area [m²]	648	648	*NA*	*NA*
West	Installed capacity [kWp]	65	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
East & West	Occupied area [m²]	1296	1296	*NA*	*NA*
East & West	Installed capacity [kWp]	130	32	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*

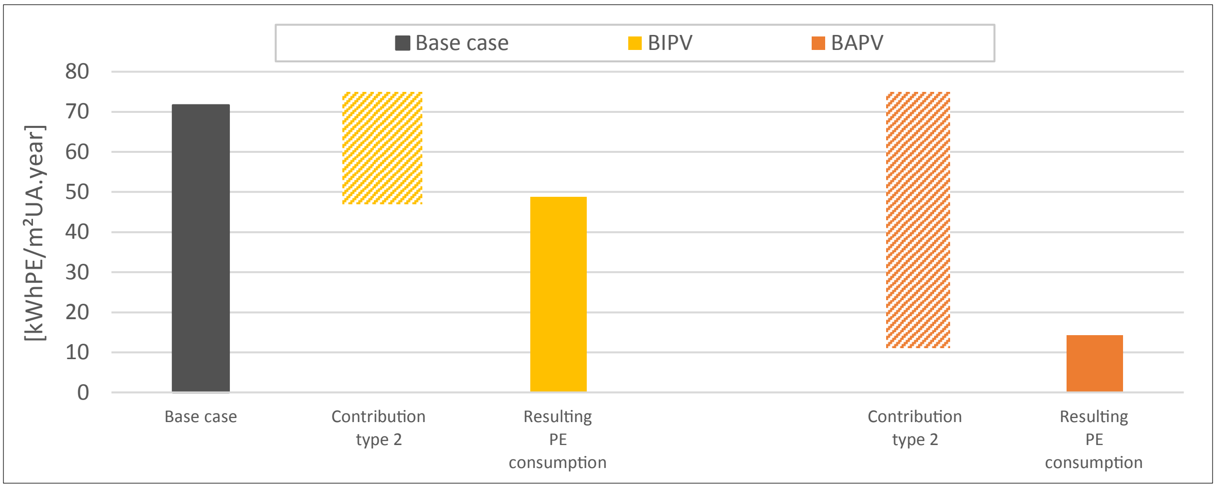


Figure 8.13.11 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Italy

Table 8.13.18 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Italy

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-32%	-8%	-80%	-71%
East	-28%	-7%	*NA*	*NA*
West	-23%	-6%	*NA*	*NA*
East & West	-51%	-13%	*NA*	*NA*

Table 8.13.19 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Italy

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,11	0,04	0,69	0,87
East	0,10	0,03	NA	NA
West	0,08	0,03	NA	NA
East & West	0,09	0,03	NA	NA

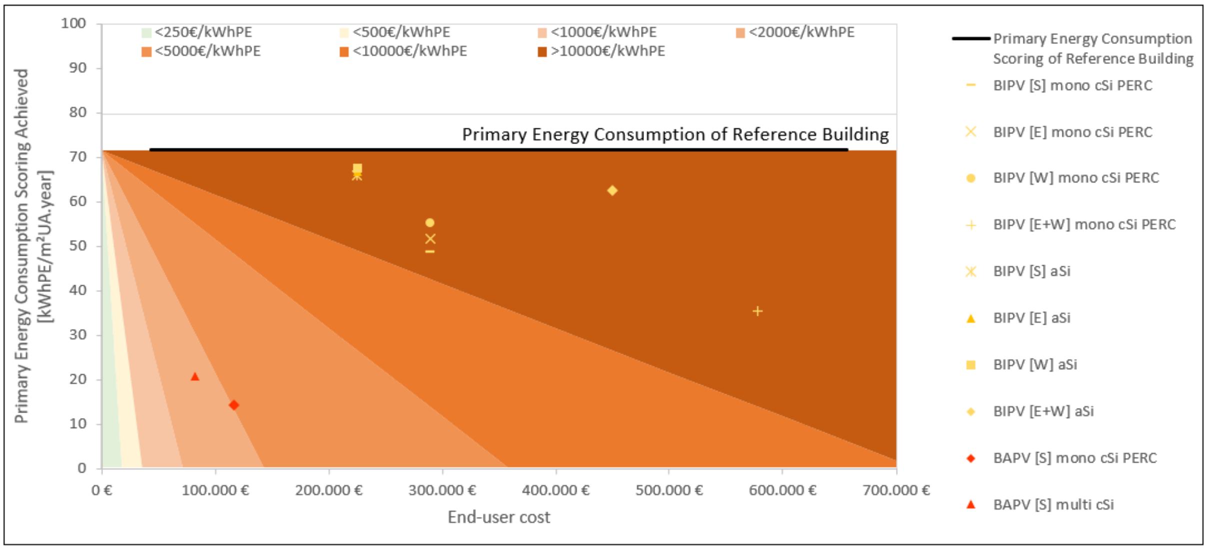


Figure 8.13.12 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Italy

Table 8.13.20 Validation of renewable energy integration target as set by national regulation for a OB in Italy

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	N	N
East	N	N	NA	NA
West	N	N	NA	NA
East & West	N	N	NA	NA

8.13.6 Spain - Office building: Case 2/2

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.21 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Spain

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	648	648	973	973
South	Installed capacity [kWp]	65	16	107	95
South	RE system surface to net floor area [-]	0,09	0,09	0,13	0,13
East	Occupied area [m²]	648	648	*NA*	*NA*
East	Installed capacity [kWp]	65	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
West	Occupied area [m²]	648	648	*NA*	*NA*
West	Installed capacity [kWp]	65	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
East & West	Occupied area [m²]	1296	1296	*NA*	*NA*
East & West	Installed capacity [kWp]	130	32	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,18	0,18	*NA*	*NA*

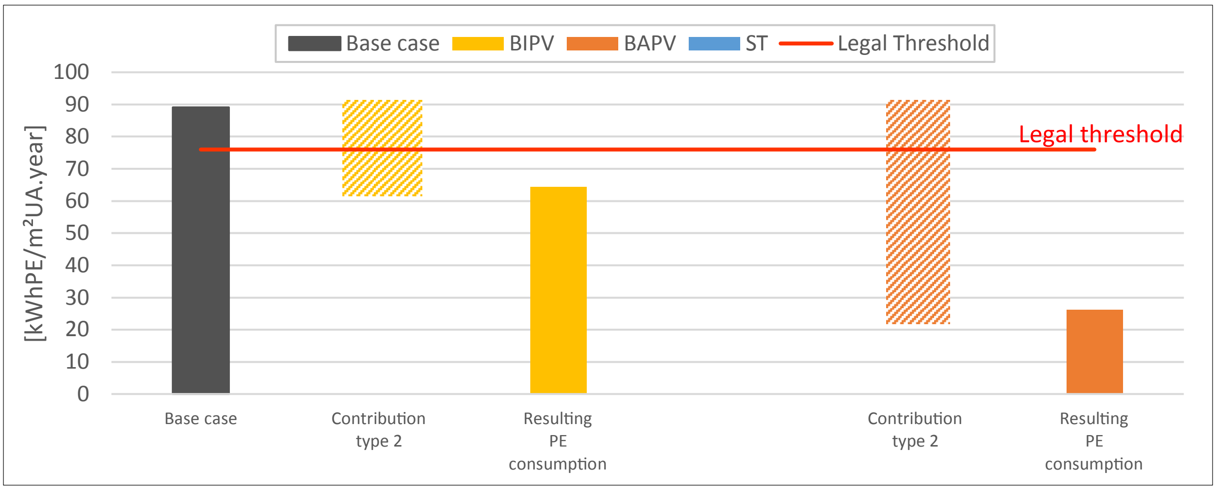


Figure 8.13.13 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Spain

Table 8.13.22 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Spain

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	-28%	-7%	-71%	-64%
East	-25%	-6%	*NA*	*NA*
West	-20%	-5%	*NA*	*NA*
East & West	-46%	-11%	*NA*	*NA*

Table 8.13.23 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Spain

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,10	0,03	0,61	0,78
East	0,09	0,03	*NA*	*NA*
West	0,07	0,02	*NA*	*NA*
East & West	0,08	0,03	*NA*	*NA*

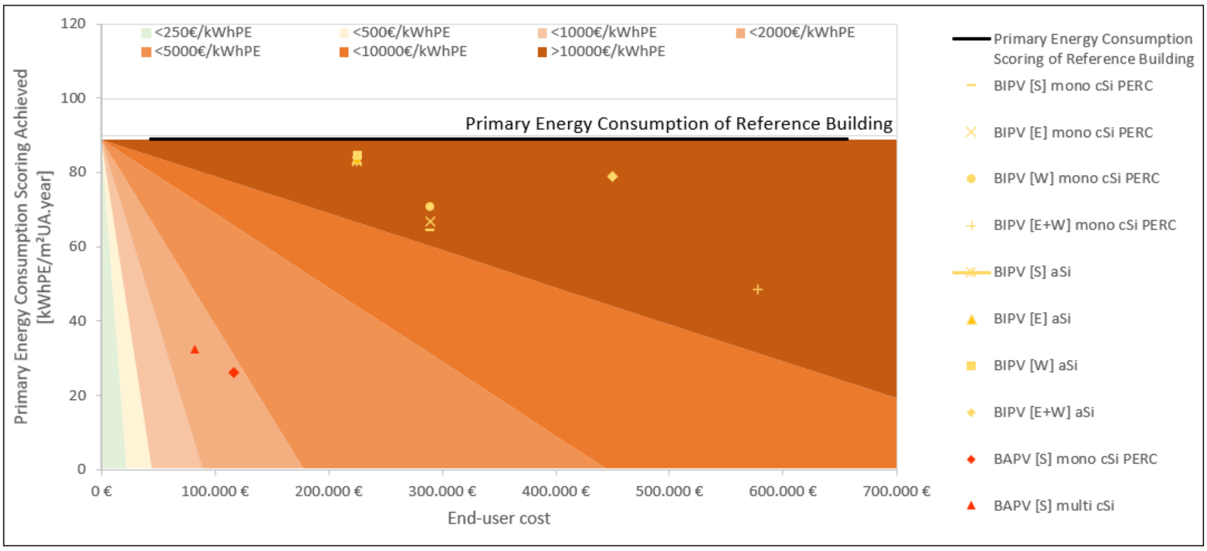


Figure 8.13.14 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Spain

Table 8.13.24 Validation of renewable energy integration target as set by national regulation for a OB in Spain

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	N	N
East	N	N	*NA*	*NA*
West	N	N	*NA*	*NA*
East & West	N	N	*NA*	*NA*

8.13.7 Switzerland - Single-family house: Case 1/2

The three tested BIPV systems (mono cSi PERC-based PV tiles, mono cSi PERC-based in roof mounting system and a CIGS-based full-roof solution) are integrated to a tilted roof. All three BAPV systems are applied to a pitched roof as well.

Table 8.13.25 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a SFH in Switzerland (1/2)

		BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Occupied area [m²]	40	40	40	40	40	40	*NA*
South	Installed capacity [kWp]	7	4	5	7	6	8	*NA*
South	RE system surface to net floor area [-]	0,25	0,25	0,25	0,25	0,25	0,25	*NA*
East & West	Occupied area [m²]	80	80	80	60	60	60	*NA*
East & West	Installed capacity [kWp]	14	8	11	11	9	12	*NA*
East & West	RE system surface to net floor area [-]	0,50	0,50	0,50	0,38	0,38	0,38	*NA*

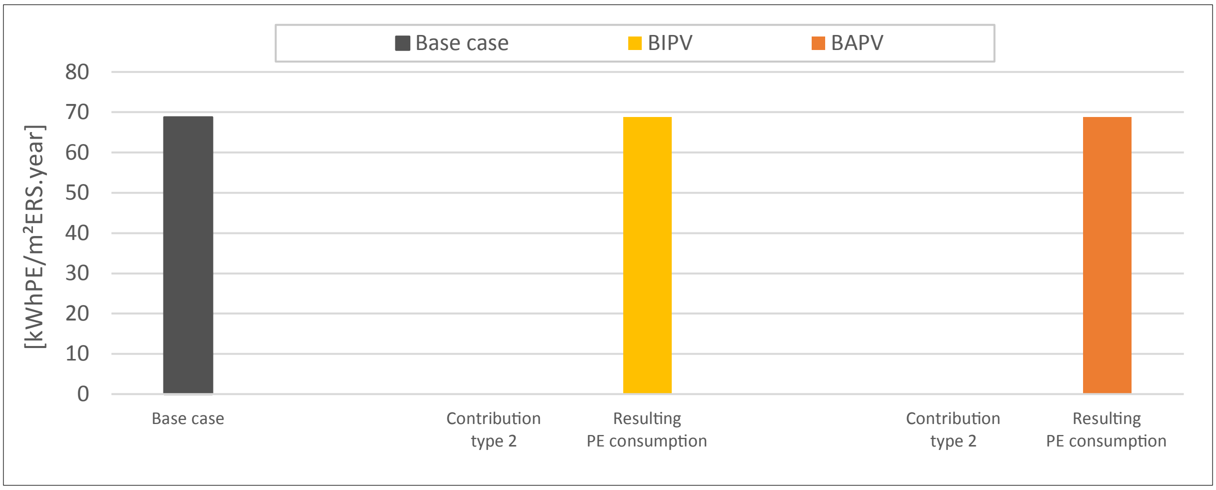


Figure 8.13.15 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a SFH in Switzerland

Table 8.13.26 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a SFH in Switzerland

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	0%	0%	0%	0%	0%	0%	*NA*
East & West	0%	0%	0%	0%	0%	0%	*NA*

Table 8.13.27 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a SFH in Switzerland

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	0	0	0	0	0	0	*NA*
East & West	0	0	0	0	0	0	*NA*

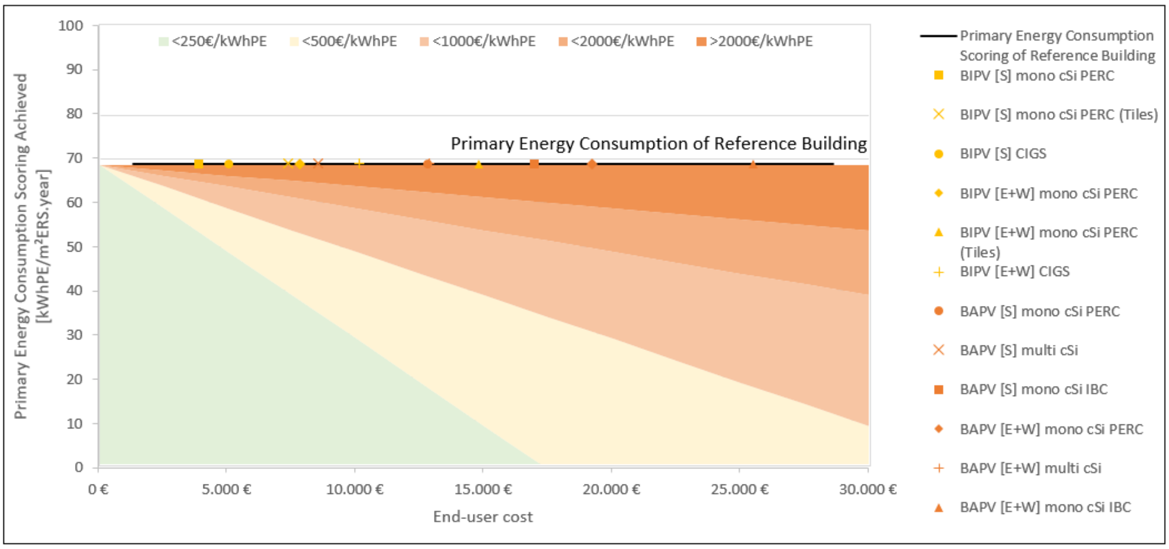


Figure 8.13.16 PE consumption scorings achieved with different renewable systems and associated cost for a SFH in Switzerland

Table 8.13.28 Validation of renewable energy integration target as set by national regulation for a SFH in Switzerland

	BIPV mono cSi PERC (roof)	BIPV mono cSi PERC (Tiles) (roof)	BIPV CIGS (roof)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)	BAPV mono cSi IBC (roof)	Solar Thermal (roof)
South	Y	Y	Y	Y	Y	Y	*NA*
East & West	Y	Y	Y	Y	Y	Y	*NA*

8.13.8 Switzerland - Office building: Case 2/2

Both BIPV systems are integrated to a curtain wall façade whereas the BAPV systems are installed on tilted mounting systems on a flat roof.

Table 8.13.29 Occupied areas (m²) and installed capacities (kWp) of studied renewable system with different technologies and orientations on a OB in Switzerland

		BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	Occupied area [m²]	648	648	973	973
South	Installed capacity [kWp]	65	16	107	95
South	RE system surface to net floor area [-]	0,09	0,09	0,14	0,14
East	Occupied area [m²]	648	648	*NA*	*NA*
East	Installed capacity [kWp]	65	16	*NA*	*NA*
East	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
West	Occupied area [m²]	648	648	*NA*	*NA*
West	Installed capacity [kWp]	65	16	*NA*	*NA*
West	RE system surface to net floor area [-]	0,09	0,09	*NA*	*NA*
East & West	Occupied area [m²]	1296	1296	*NA*	*NA*
East & West	Installed capacity [kWp]	130	32	*NA*	*NA*
East & West	RE system surface to net floor area [-]	0,19	0,19	*NA*	*NA*

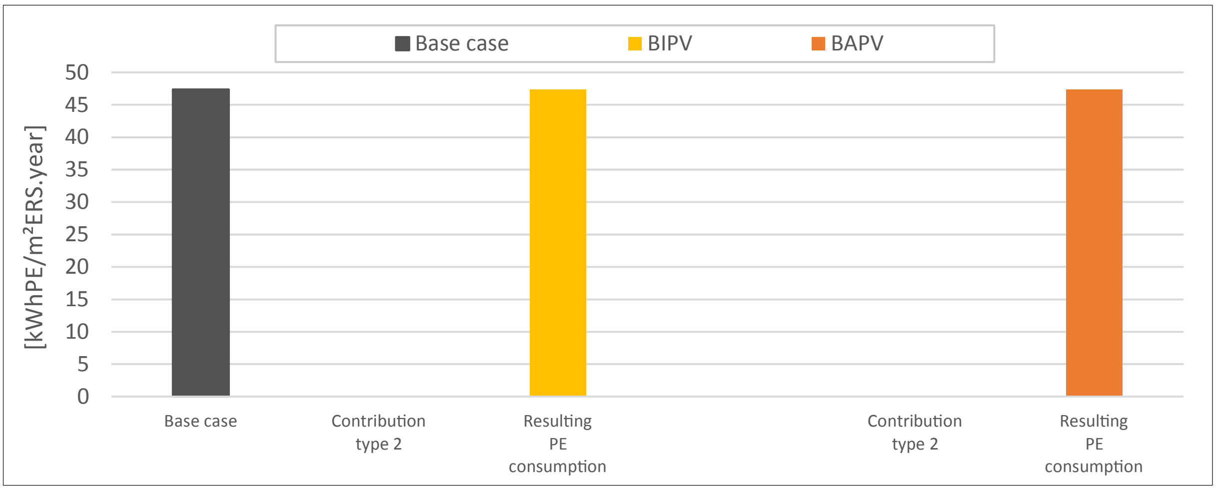


Figure 8.13.17 Type 2 contribution of different renewable technologies (highlighted in blue in previous table) on primary energy balance on a OB in Switzerland

Table 8.13.30 Primary energy balance reduction compared to base case with different renewable technologies and orientations on a OB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0%	0%	0%	0%
East	0%	0%	*NA*	*NA*
West	0%	0%	*NA*	*NA*
East & West	0%	0%	*NA*	*NA*

Table 8.13.31 Cost efficiency [% relative variation / k€ invested] for different renewable technologies and orientations on a OB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	0,00	0,00	0,00	0,00
East	0,00	0,00	*NA*	*NA*
West	0,00	0,00	*NA*	*NA*
East & West	0,00	0,00	*NA*	*NA*

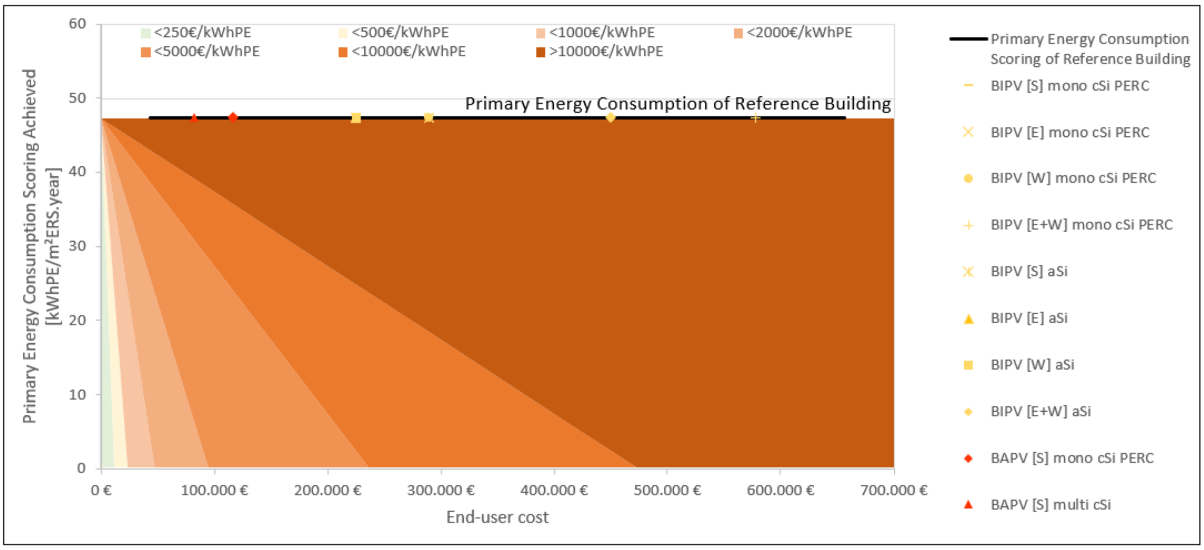


Figure 8.13.18 PE consumption scorings achieved with different renewable systems and associated cost for a OB in Switzerland

Table 8.13.32 Validation of renewable energy integration target as set by national regulation for a OB in Switzerland

	BIPV mono cSi PERC (facade)	BIPV aSi (facade)	BAPV mono cSi PERC (roof)	BAPV multi cSi (roof)
South	N	N	Y	Y
East	N	N	*NA*	*NA*
West	N	N	*NA*	*NA*
East & West	Y	N	*NA*	*NA*

8.14 Appendix 6

8.14.1 Single-family house

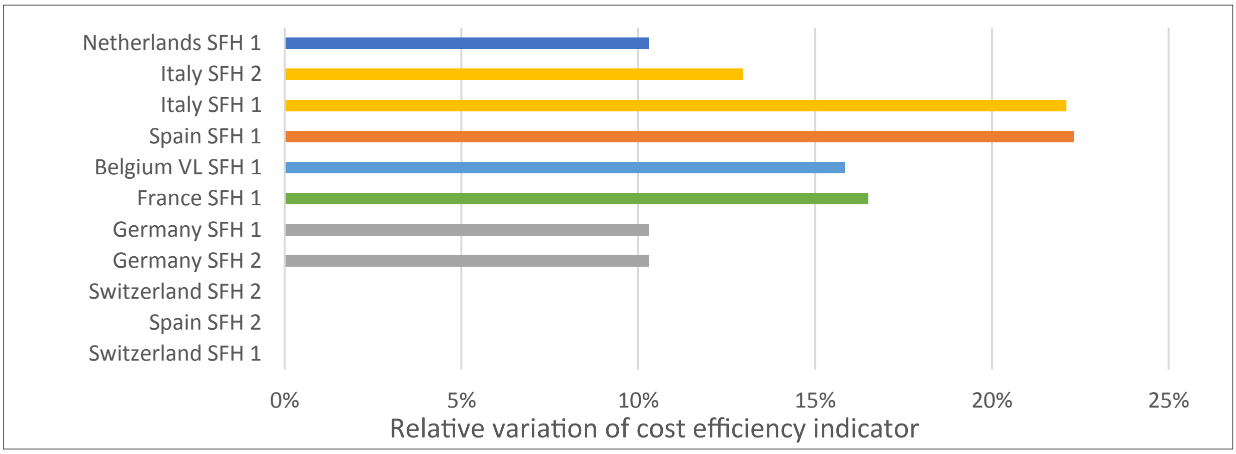


Figure 8.14.3 Impact of BIPVBOOST improvement related to PV tiles (mono c-Si PERC)

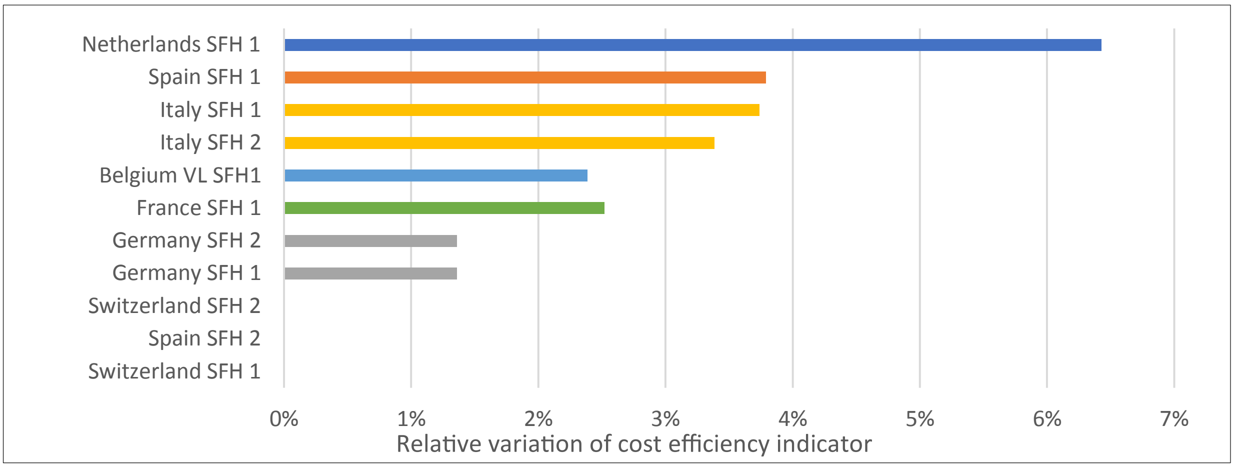


Figure 8.14.2 Impact of BIPVBOOST improvement related to full roof solutions (CIGS)

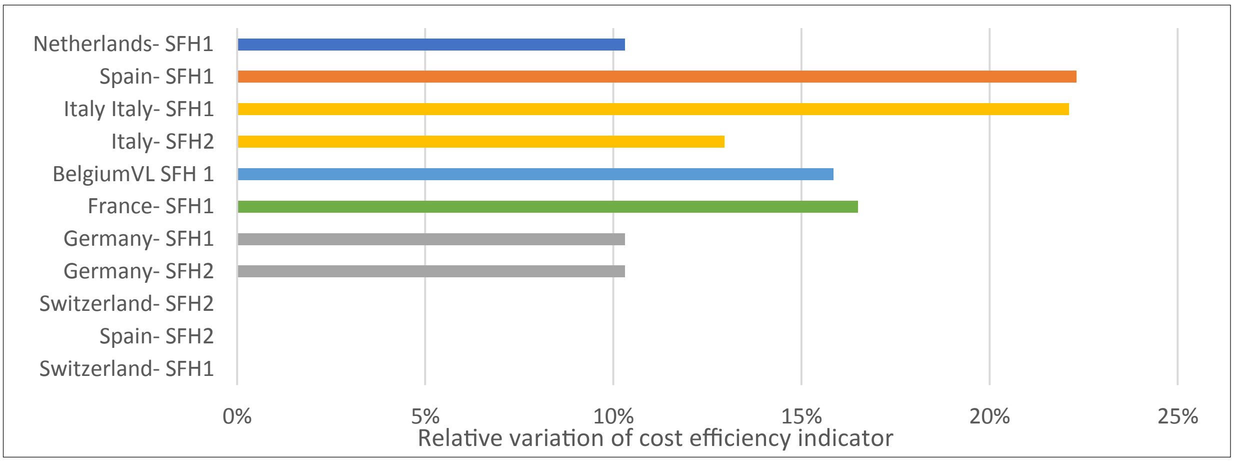


Figure 8.14.1 Impact of BIPVBOOST improvement related to in-roof mounting system (mono c-Si PERC)

8.14.2 Multifamily house

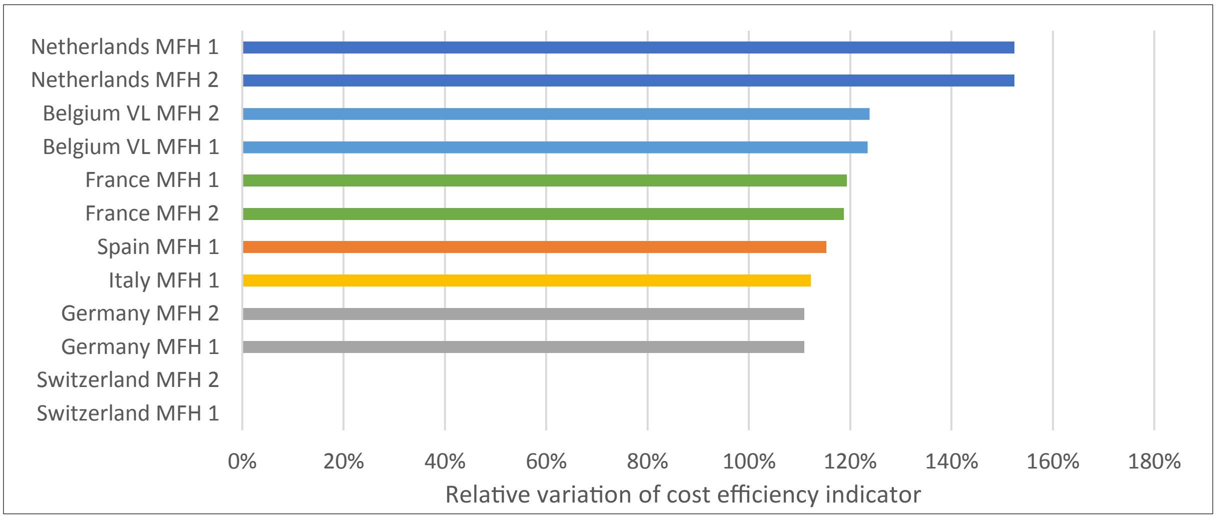


Figure 8.14.4 Impact of BIPVBOOST improvement related to ventilated facades (mono c-Si IBC)

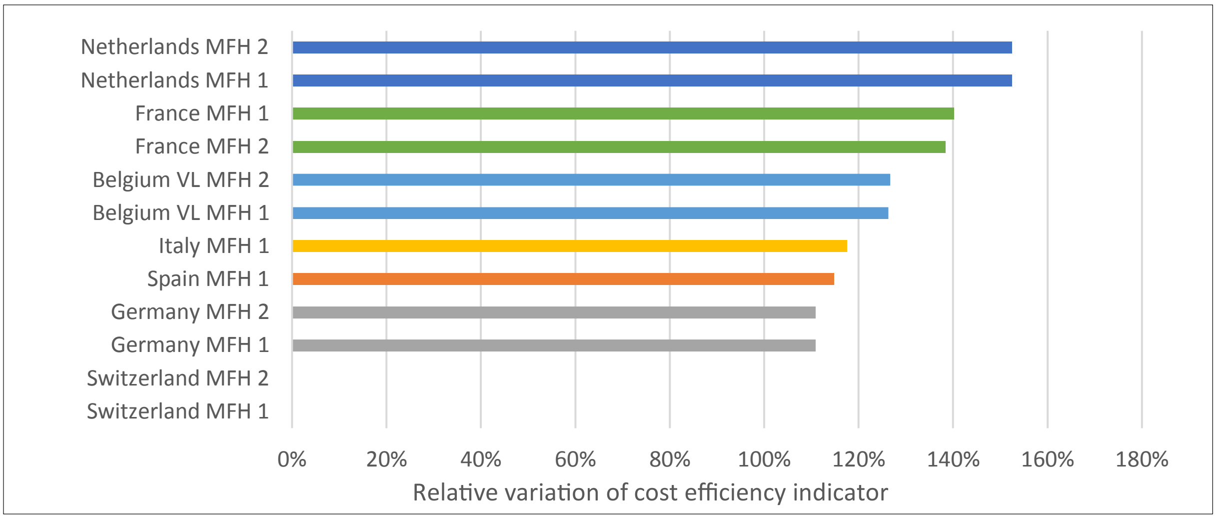


Figure 8.14.5 Impact of BIPVBOOST improvement related to ventilated facades (multi c-Si)

8.14.3 Educational building

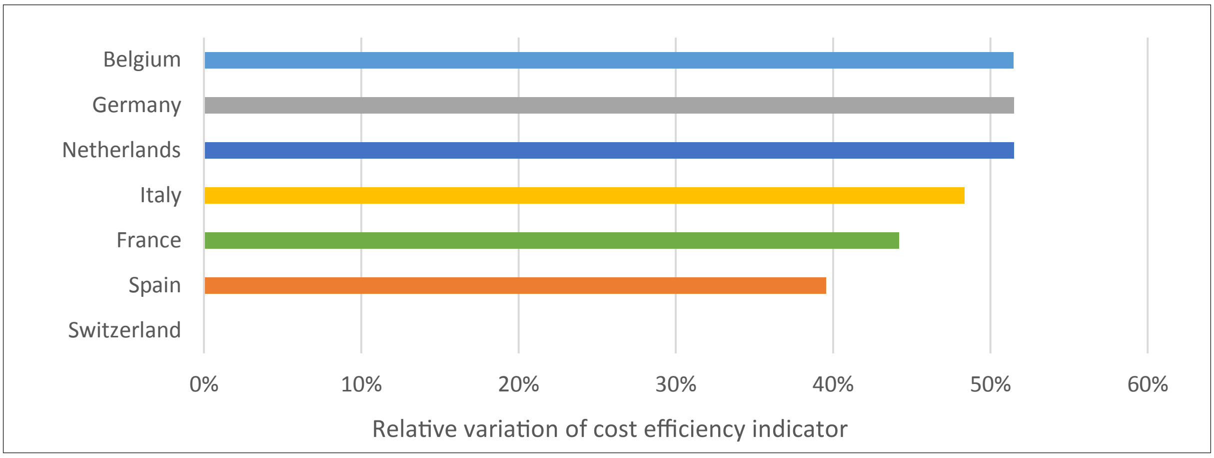


Figure 8.14.7 Impact of BIPVBOOST improvement related to ventilated facades (mono c-Si PERC)

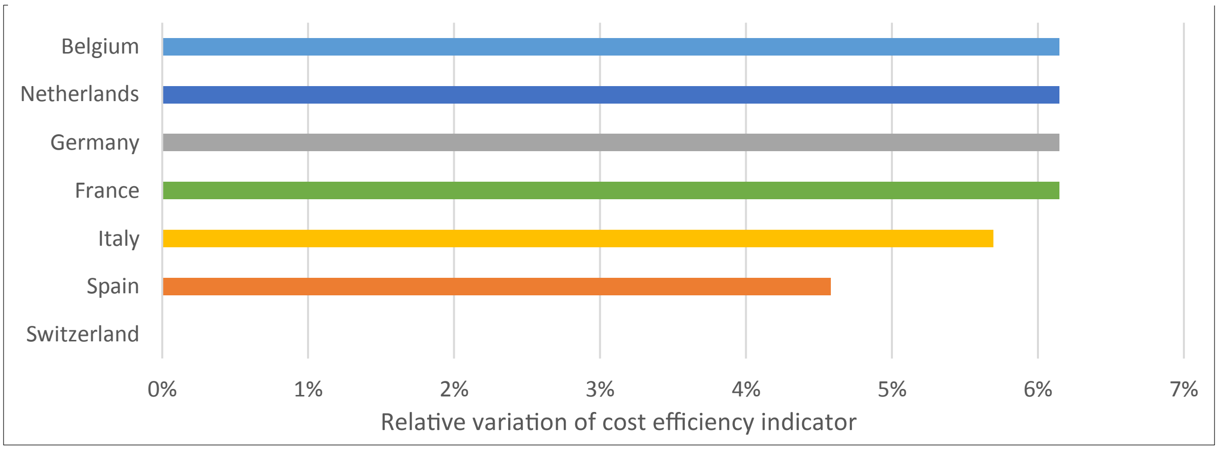


Figure 8.14.6 Impact of BIPVBOOST improvement related to ventilated facades (CIGS)

8.14.4 Office building

Improvements related to curtain wall are driven by a major cost reduction. Therefore, impacts are the same for all cases and coutries.

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10 Tables

11 Figures