

INDOOR AIR QUALITY, THERMAL COMFORT AND DAYLIGHT

ANALYSIS OF RESIDENTIAL BUILDING REGULATIONS
IN EIGHT EU MEMBER STATES

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EXECUTIVE SUMMARY

Background

Air quality - be it indoors or outdoors - is one of the major environmental health concerns for Europe¹. For this reason, and since people spend 60-90%² of their life in indoor environments (homes, offices, schools, etc.), indoor air quality plays a very important role in the health of the population, particularly for vulnerable groups such as babies, children and the elderly². According to the World Health Organization³, 99 000 deaths in Europe and 19 000 in non-European high income countries were attributable to household (indoor) air pollution in 2012.

Indoor air quality (IAQ) refers to the quality of the air inside buildings and is related to people's health, comfort and ability to work. To define IAQ, parameters such as ventilation rate and exposure to mould or chemicals should be taken into account⁴. Indoor air pollutants are emitted from sources inside the building but can also come from outside. For instance, pollutants are emitted when cleaning or when burning fuel for cooking and heating. But even furniture and construction materials, as well as dampness, lack of or improper ventilation or contaminated outdoor air, can be responsible for poor indoor air quality⁵.

Thermal comfort is described as "that condition of mind which expresses satisfaction with the thermal environment"⁶. It is strongly linked to environmental factors such as air temperature and humidity as well as to personal factors (clothing insulation, metabolic heat)⁷. Thermal comfort plays an important role in human health and well-being since, when building occupants feel too warm, it can cause a feeling of tiredness, while when they feel too cold, they can be restless and distracted⁸.

A good level of daylight is also an integral part of a proper indoor environment. The benefits of daylight are highlighted in numerous studies with one of the most recent ones⁹ summarising them as:

- Economic and ecological, due to reduced energy consumption and CO₂ emissions;
- Psychological, as daylight effectively stimulates the human visual and circadian systems;
- Well-being, as it enables occupants to fulfil two very basic human requirements: to be able to focus on tasks and to perceive well the space, as well as experience some environmental stimulation.

Based on the above-mentioned considerations, it is obvious that indoor air quality, appropriate thermal comfort and sufficient daylight play a major role in occupants' lives. Buildings should therefore be designed to ensure these conditions.

The need to mitigate climate change and to reduce energy import dependency provides additional challenges for the design and operation of buildings, requiring a dramatic reduction in the energy consumption and emissions associated with buildings. The building sector in the EU is responsible for more than a third of the energy consumption and a similar share of the CO₂ emissions associated with human activities. Building policies are thus becoming more demanding in respect to the improvement of energy performance and the reduction of CO₂ emissions. Consequently, buildings are being better

¹ Health & Consumer Protection Directorate-General, "Opinion on risk assessment on indoor air quality", 2007. Available at: http://ec.europa.eu/health/ph_risk/committees/04_scher/docs/scher_o_055.pdf

² Health & Consumer Protection Directorate-General, "Promoting actions for healthy indoor air (IAIAQ)", 2011. Available at: http://ec.europa.eu/health/healthy_environments/docs/env_iaiaq.pdf

³ World Health Organization, "Burden of disease from Household Air Pollution for 2012". Available at: http://www.who.int/phe/health_topics/outdoorair/databases/HAP_BoD_results_March2014.pdf?ua=1

⁴ Occupational Safety & Health Administration: <https://www.osha.gov/SLTC/indoorairquality/faqs.html>

⁵ Health & Consumer Protection Directorate-General, "Indoor Air Quality", 2008. Available at: http://ec.europa.eu/health/scientific_committees/opinions_layman/en/indoor-air-pollution/index.htm

⁶ British Standard BS EN ISO 7730

⁷ "Thermal Comfort, The six basic factors", Health and Safety Executive. Available at: <http://www.hse.gov.uk/temperature/thermal/factors.htm>

⁸ "Thermal Comfort", Green Education Foundation. Available at: <http://www.greeneducationfoundation.org/green-building-program-sub/learn-about-green-building/1239-thermal-comfort.html>

⁹ Rosin Paul, Adamatzky Andrew, Sun Xianfang, "Cellular Automata in Image Processing and Geometry", Springer International Publishing Switzerland, 2014

insulated and made more airtight so as to prevent heat loss via transmission and uncontrolled airflows. The improvement of building airtightness should also mitigate factors that have a negative impact on the indoor environment such as mould and polluted outdoor air. To ensure a good indoor climate and air exchange in buildings, a ventilation control system is required (for which both natural and mechanical solutions exist). Therefore, in addition to energy efficiency criteria, attention needs to be paid to all indoor comfort parameters in building codes. In other words, the evolution towards meeting the requirements for energy performance in existing buildings should impose appropriate minimum requirements to secure a good indoor air quality for the occupants.

The Energy Performance of Buildings Directive (EPBD, 2010/31/EU) clearly states that minimum energy performance requirements "shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation"¹⁰. Consequently, integral planning and good building codes are needed to adequately address these challenges. Best practice projects and voluntary standards for very low energy buildings already prove that buildings can be energy efficient, sustainable and at the same time contribute to outstanding IAQ, daylight and thermal comfort. But how do today's building codes address these topics? What are the best practice approaches and where does legislation need improvement?

The EPBD asks EU Member States (MS) to significantly improve their regulatory and policy framework to ensure that minimum energy performance requirements will be met and that nearly zero-energy buildings targets will be reached. Additionally, the EPBD indicates that indoor climate conditions shall be taken into account when putting minimum energy requirements in place. However, within the EU legislation there are currently no clear requirements describing how this can be achieved. Therefore, it is important to have a better understanding of the role of indoor climate requirements in national regulations in order to compare them with the European technical standards and to create evidence for potential future improvements.

Ensuring that indoor air quality and other aspects of indoor climate are being treated with the same level of importance as energy efficiency will enable energy renovation and comfort enhancement investments to be mutually reinforcing.

Aim of the study

This report about IAQ, thermal comfort and daylight requirements in selected MS addresses a range of topics increasingly important for European buildings and their inhabitants. The overall aim of the report is to provide an overview of the regulatory framework for IAQ, thermal comfort and daylight, and to highlight the importance of having appropriate requirements for thermal comfort, ventilation and daylight conditions. The report provides concluding recommendations for further policy development relevant for indoor climate. The assessment focuses on the respective building codes for new and existing residential buildings in selected MS: Belgium (Brussels Region), Denmark, France, Germany, Italy, Poland, Sweden and the UK (England and Wales). A critical and comparative evaluation is provided whilst best practice approaches are highlighted.

¹⁰ Article 4 of the EPBD, 2010/31/EU. Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF>

MAIN FINDINGS

An overview of the main findings of the study is presented below.

New residential buildings

Indoor air quality is recognised as an important aspect of the building codes in all focus countries of this survey. The benefits of securing proper indoor air quality, either for the well-being of inhabitants or for the safety and health of the building and its fabric, are also underlined in various forms in the building regulations of the countries studied.

Ventilation is included in the building regulations of all surveyed MS. In Denmark, France, Sweden and Brussels-Capital Region (BE), there are clear minimum requirements, while in Germany, Italy, Poland and the UK there is only a recommendation for minimum ventilation rates. The indicators for minimum ventilation rates vary from one country to another and are generally different from EU standards (e.g. EN 13779 and EN 15251).

The most commonly used units are litres per second and cubic meters per hour while the air exchange rate is regulated based on the assumed number of occupants (e.g. Poland: 20 m³/h per occupant), or on the type of room (e.g. UK: Kitchen 13-60 l/s and WC 6 l/s), or on the floor area (e.g. 0.35 l/s per m²). Even though the use of the same metrics is less important, it seems that there is a need for further European harmonisation in order to facilitate a proper comparison across MS and an easier transfer of knowledge and practices among countries. Mandatory mechanical ventilation is in effect in two cases, i.e. for multi-family (DK) and high-rise (PL) buildings. For the other cases, there are recommendations for mechanical ventilation in two countries (Br-Region in BE, DE), while in Italy, especially in warmer regions, natural ventilation is encouraged.

It is worth mentioning the fact that the Danish regulation specifically requires ventilation systems to be easy to maintain, even by the occupants. This should be considered as a good practice since ventilation systems need periodical maintenance to operate correctly over their lifetime. Maintenance of ventilation systems should be undertaken systematically and should therefore be an easy and affordable procedure. Last but not least, it seems that most surveyed countries have to further improve their calculation tools to address adequately hybrid and demand-controlled ventilation in order to have comprehensive calculation methods which can ensure that the ventilation needs are met.

Minimum efficiency requirements for **heat recovery systems** are in place in some countries (Sweden, Poland, Italy) when new mechanical ventilation systems are installed. **Airtightness** requirements differ largely across the EU. Six of the surveyed MS already have precise requirements in place. Similar to ventilation, indicators for airtightness requirements vary throughout Europe (e.g. volume per hour, litres per second per m²). Random airtightness tests are required in Denmark and France, but are voluntary in the rest of the surveyed countries and are usually required only when applying for financial subsidies or energy certification in the high classes. Regulations for heat recovery and airtightness, mainly introduced for energy efficiency reasons, have to be completed by relevant ventilation requirements in order to secure proper indoor living conditions.

The **CO₂ concentration** in fully occupied buildings – where inhabitants are the main polluters – in relation to outdoor concentration is indicated by the European standard EN 15251. Requirements to limit CO₂ levels in residential buildings are in place in France, while in the UK there are recommended levels. Limitations for **nitrogen oxide** are also in place in some countries (e.g. Denmark). The national implementation of the European regulation on construction products¹¹ and further national standards address the evaporation of unhealthy chemicals. However, this legislation is not considered for the purpose of this analysis.

¹¹ http://ec.europa.eu/enterprise/sectors/construction/index_en.htm

Aspects of **thermal comfort**¹² related to low temperature or draught are often improved through measures that are primarily addressed at improving the energy performance of a building. Today still, between 50 and 125 million Europeans suffer from cold in winter (bpie.eu/fuel_poverty.html). However, there is an increasing risk of overheating which also has to be addressed. Thermal comfort should therefore be acknowledged in building regulations and the use of simple and efficient measures, e.g. solar shading, solar protective glazing and ventilative cooling¹³ should be encouraged. In all surveyed countries, there are requirements in place relating to the *thermal transmittance* of external building elements, but only a few of them underline the co-benefits of thermal comfort.

Indoor air temperature is an indicator of thermal comfort in all surveyed countries and there are requirements and recommendations in place for lower and upper limits during winter and summer respectively. In a few countries such as France and the UK, operative temperature is also used to assess thermal comfort. Five out of eight countries require minimal temperatures in dwellings in winter (i.e. France, Germany, Poland, Sweden and the UK). Only Italy demands a lower limit in summer (max. cooling) and upper limit in winter (max. heating).

Five countries within this survey (Brussels-Capital Region-Belgium, Denmark, France, Germany and the UK) have *overheating* limitations (either mandatory or recommended), where overheating indicators differ by temperature and time limit. The extremes are found in Brussels-Capital Region (> 25°C for 5%/yr) and the UK (> 28°C for 1%/yr), but only as a recommendation in the latter case. Passive systems to avoid overheating are common in southern climates, but minimum requirements are mainly limited to solar shades while others such as ventilative cooling, the use of building mass, natural ventilation and night time ventilation are rarely considered. In Sweden, the building codes explicitly ask for consideration of some passive solutions and, in Brussels-Capital Region, a minimum share of 50% for passive systems is recommended for new buildings.

Maximum *relative air velocity* limits are inconsistent in Europe; they range from 0.15 to 0.40 m/s (in summer) and from 0.15 to 0.25 m/s (in winter). Maximum values for air velocity in order to avoid draughts are required in Sweden and recommended in Denmark, Italy, Poland, the UK and Brussels (from 2015).

The use of **daylight** is an important element to achieve a good indoor environment in buildings, with a major impact on the inhabitants health¹⁴. Moreover, maximising the use of daylight in buildings offsets electric lighting and has a consistent energy saving potential. Acknowledging the importance of daylight use in buildings, all surveyed countries include at least a basic reference for it in their building codes. Daylight requirements or recommendations in MS legislation mainly specify a minimum share of window/glazing area per floor area, indicate minimum levels for daylight or simply stipulate the need for sunlight access in buildings and a view to the outside. As good practice, the Danish building codes are the only ones requiring minimal solar gains in winter while the Swedish regulations recommend the use of daylight management systems for permanently installed luminaries. Additionally, in France solar gains are part of the Building Code since 2012 (RT 2012), through the required bioclimatic indicator (Bbio). Only some building codes within the surveyed ones (i.e. Brussels-Capital Region, Denmark, Germany) highlight the importance of having a view to the outside as part of visual comfort.

Compliance procedures are mainly focusing on the structural analysis and energy performance aspects during the design and construction of new buildings such as U-Values, right installation of heating equipment, airtightness, availability of EPCs, etc. Compliance with indoor air quality or thermal comfort standards is rarely checked by the designated control bodies and if so, mainly at the design stage rather than by performing onsite measurements.

¹² Thermal comfort is described as "that condition of mind which expresses satisfaction with the thermal environment" (British Standard BS EN ISO 7730)

¹³ "Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces". Source: <http://www.buildup.eu/> communities/ventilativecooling

¹⁴ Lighting Research Center, "Daylighting Resources-Health". Available at: http://www.lrc.rpi.edu/programs/daylighting/dr_health.asp#sad

Existing residential buildings

For existing buildings, **indoor air quality** related requirements, such as minimum ventilation rates, airtightness or limitation of pollutants, can hardly be found in the analysed building codes. Only recommendations on IAQ aspects can be found in most of the building codes. Energy efficiency improvements do often apply without mandatory consideration of the influences in terms of building physics or indoor air quality. Tackling this lack of proper IAQ requirements to accompany the thermal and energy performance requirements has to be further considered as a priority. Among the surveyed countries, the Swedish building codes are unique at the moment by underlining potential conflicts between energy saving requirements and good indoor air quality in existing buildings, stipulating that in such cases priority should be given to the latter. Generally, renovation measures resulting in more airtight buildings are not accompanied by a compulsory assessment of the ventilation needs. Therefore, in such situations, air change rates below the required values are reported. This is a serious shortcoming in building codes which has to be addressed through an improvement of the regulatory framework for renovation. Potentially, this aspect should be considered in the future recast of EU-related legislation such as the EPBD.

When major renovation is undertaken, the most common requirement across surveyed countries concerns the **thermal transmittance** of buildings' elements (U-Values), as required by the EPBD. Among the countries surveyed, only the southern ones (France and Italy) include shading requirements in the event of refurbishment.

Energy Balance requirements that include solar gains when assessing the energy performance of windows are included in the Danish and British building regulations. Considering solar gains together with heat losses of a window provides a more comprehensive assessment of its energy performance.

Increased **thermal comfort** is often considered as a main driver for the decision of an owner-occupier to invest in renovation. However, thermal comfort resulting from improved energy performance is rarely captured by national and/or European legislations.

Introducing requirements for **daylight** use in existing buildings can be more challenging, since possible interventions to further increase daylight availability may be limited due to structural and aesthetic reasons.

The Danish regulations stipulate requirements for a minimal solar gain in winter when replacing windows. No requirements have been identified across the surveyed building codes stipulating any minimal daylight preservation when renovating a building, except in the UK where the regulation Right to Light is in place. This regulation secures that changes to neighbouring buildings must not reduce daylight availability in existing buildings.

As in the case of new buildings, **compliance** checks are only done on structural analysis and energy performance aspects, while no indoor air quality or thermal comfort verification procedures have been identified.

Indoor air quality and other aspects of thermal comfort have to be seriously considered when strengthening the energy performance requirements for buildings and building elements. Today, as identified in the eight focus countries of this study, there are no clear and strict requirements in place for indoor air quality and thermal comfort. There is a need to emphasise thermal comfort aspects in order to have proper living and working indoor conditions.

RECOMMENDATIONS

The main findings of this study lead to several **recommendations**:

- Indoor health and comfort aspects should be considered to a greater extent in European building codes than it is current practice. When planning new nZEBs or nZEB refurbishments, requirements for a healthy and pleasant indoor environment should be included. While indoor climate is mentioned in the EPBD, the importance of indoor air quality, thermal comfort and daylight has to be strengthened in a future recast. Such requirements should also be reflected in national renovation strategies as developed under Articles 4 and 5 of the Energy Efficiency Directive.
- In EU and national legislation, stricter energy performance requirements should be completed with appropriate requirements and recommendations to secure proper indoor air quality, daylight and thermal comfort. For instance, requirements for stricter insulation and airtightness should be complemented by appropriate minimum requirements for indoor air exchange and ventilation. As there are several ways to obtain significant savings in energy consumption in buildings while at the same time improving the indoor climate, clear legislative provisions for conflicting situations will create certainty for planners and architects. At the same time legislation should be technology-neutral.
- Unused potentials for energy savings should be further exploited in European and national legislation taking a system-approach to the building. This means that the building's envelope and its insulation, use of daylight, demand-controlled ventilation, heat recovery through mechanical ventilation systems, installations to avoid overheating such as ventilative cooling and solar shading (e.g. by overhangs, louvers and awnings) should be analysed and optimised in a systematic way in order to achieve the highest energy saving possible.
- Indoor air quality, thermal comfort and daylight indicators should be integrated in the Energy Performance Certification as relevant information regarding the actual living conditions in the building.
- The development of a proper cost indicator and calculation formula to estimate the benefits of a healthy indoor environment should be considered and further integrated in the European methodology to calculate cost-optimal levels at macroeconomic level.
- Co-benefits of a healthy indoor environment should be taken into account when assessing the macroeconomic impact of energy renovation measures (e.g. reduction of health service costs).
- Windows are elements of the building envelope and play an important role in the overall energy performance of the building. Therefore, thermal transmittance, daylight usage and solar gains should be considered in the overall energy performance of buildings, both for new and existing buildings undergoing energy renovation. Requirements for ventilation and to prevent overheating should be taken into account in the same context.
- Passive systems to avoid overheating are common in southern climates, but minimum requirements are mainly limited to solar shades. Additional measures, such as the management of glazing areas of the building envelope, dynamic external shading, consideration of solar gains and the use of building mass, natural and night time ventilation strategies, etc. have to be further covered within national and European legislation.
- The mandatory compliance tools to evaluate energy performance according to national EPBD transposition should to a larger extent reward and facilitate the use of energy efficient ventilation solutions and measures to prevent overheating.

1 INTRODUCTION

Air quality - be it indoors or outdoors - is one of the major environmental health concerns for Europe¹⁵. For that reason and as people spend 60-90%¹⁶ of their life in indoor environments (homes, offices, schools, etc.), indoor air quality plays a very important role for the health of the population and particularly for vulnerable groups such as babies, children and the elderly². According to the World Health Organization¹⁷, in 2012 99 000 deaths in Europe and 19 000 in non-European high income countries were attributable to household (indoor) air pollution.

"Indoor Air Quality is the environmental characteristics inside buildings that may affect human health, comfort or work performance."

(Source: IAQ Scientific Findings Resource Bank)

Indoor air quality refers to the quality of the air inside buildings and is related to people's health, comfort and ability to work. In order to define IAQ, parameters such as ventilation rate and exposure to mould or chemicals should be taken into account¹⁸. Indoor air pollutants are emitted from sources inside the building but can also come from the outside. For instance, pollutants are emitted when cleaning or when burning fuel for cooking and heating. But even furniture and construction materials, as well as dampness, lack of or improper ventilation or contaminated outdoor air can be responsible for poor indoor air quality¹⁹.

Thermal comfort is described as "that condition of mind which expresses satisfaction with the thermal environment"²⁰. It is strongly linked to environmental factors such as air temperature and humidity as well as to personal factors (clothing insulation, metabolic heat)²¹. Thermal comfort plays an important role in human health and well-being since, when building occupants feel too warm, this can cause a feeling of tiredness, while when they feel too cold they can be restless and distracted²².

A good level of daylight is also an integral part of a proper indoor environment. The benefits of daylight are highlighted in numerous studies, with one of the most recent²³ summarising them as:

- Economic and ecological, due to reduced energy consumption and CO₂ emissions;
- Psychological, as daylight effectively stimulates the human visual and circadian systems;
- Well-being, as it enables occupants to fulfil two very basic human requirements: to be able to focus on tasks and to perceive well the space, as well as experience some environmental stimulation.

Based on the abovementioned analysis, it is obvious that proper indoor air quality, appropriate thermal comfort and sufficient daylight play a major role in occupants' lives and buildings should therefore be designed to ensure these conditions.

¹⁵ Health & Consumer Protection Directorate-General, "Opinion on risk assessment on indoor air quality", 2007. Available at: http://ec.europa.eu/health/ph_risk/committees/04_scher/docs/scher_o_055.pdf

¹⁶ Health & Consumer Protection Directorate-General, "Promoting actions for healthy indoor air (IAIAQ)", 2011. Available at: http://ec.europa.eu/health/healthy_environments/docs/env_iaiaq.pdf

¹⁷ World Health Organization, "Burden of disease from Household Air Pollution for 2012". Available at: http://www.who.int/phe/health_topics/outdoorair/databases/HAP_BoD_results_March2014.pdf?ua=1

¹⁸ Occupational Safety & Health Administration: <https://www.osha.gov/SLTC/indoorairquality/faqs.html>

¹⁹ Health & Consumer Protection Directorate-General, "Indoor Air Quality", 2008. Available at: http://ec.europa.eu/health/scientific_committees/opinions_layman/en/indoor-air-pollution/index.htm

²⁰ British Standard BS EN ISO 7730

²¹ "Thermal Comfort, The six basic factors", Health and Safety Executive. Available at: <http://www.hse.gov.uk/temperature/thermal/factors.htm>

²² "Thermal Comfort", Green Education Foundation. Available at: <http://www.greeneducationfoundation.org/green-building-program-sub/learn-about-green-building/1239-thermal-comfort.html>

²³ Rosin Paul, Adamatzky Andrew, Sun Xianfang, "Cellular Automata in Image Processing and Geometry", Springer International Publishing Switzerland 2014

The need to mitigate climate change and to reduce energy import dependency provides additional challenges for the design and operation of buildings, requiring a dramatic reduction in the energy consumption and emissions associated with buildings. The building sector in the EU is responsible for more than a third of the energy consumption and a similar share of the CO₂ emissions associated with human activities. Building policies are thus becoming more demanding in respect to the improvement of energy performance and the reduction of CO₂ emissions. And consequently, buildings are being better insulated and made more airtight to prevent heat loss via transmission and uncontrolled airflows. The improvement of building airtightness should also mitigate factors that have a negative impact on the indoor environment, such as mould and polluted outdoor air. To ensure a good indoor climate and air exchange in buildings, a ventilation control system is required, for which both natural and mechanical solutions exist. Therefore, in addition to energy efficiency criteria, attention needs to be paid to all indoor comfort parameters in building codes and, in parallel, the evolution towards meeting the requirements for energy performance in existing buildings should impose appropriate minimum requirements to secure a good indoor air quality for occupants.

The Energy Performance of Buildings Directive (EPBD, 2010/31/EU) clearly states that minimum energy performance requirements "shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation"²⁴. Consequently, integral planning and good building codes are needed to adequately address these challenges. Best practice projects and voluntary standards for very low energy buildings already prove that buildings can be energy efficient, sustainable and at the same time contribute to outstanding IAQ, daylight and thermal comfort. But how do today's building codes address these aspects? What are best the practice approaches and where does legislation need improvement?

The EPBD asks Member States (MS) to significantly improve their regulatory and policy framework to ensure that minimum energy performance requirements will be met and that nearly zero-energy buildings targets will be reached. Additionally, the EPBD indicates that indoor climate conditions shall be taken into account when putting minimum energy requirements in place. However, within the EU legislation there are currently no clear requirements describing how this can be achieved. Therefore, it is important to have a better understanding of the role of indoor climate requirements in national regulations, in order to compare them with the European technical standards and to create evidence for potential future improvements.

Reducing buildings' energy demand and the associated CO₂ emissions is imperative for the mitigation of climate change and to increase energy security, but it is equally important to ensure proper indoor climate. It is therefore essential to guarantee that indoor air quality and other aspects of indoor climate are being treated with the same level of importance as energy efficiency, so that energy renovation and comfort enhancement investments are mutually reinforcing.

This report addresses a range of topics which are increasingly important for European buildings and their inhabitants. The overall aim is to provide an overview of the regulatory framework for IAQ, thermal comfort and daylight in selected MS, and to highlight the importance of having appropriate requirements for thermal comfort, ventilation and daylight conditions. The report provides concluding recommendations for further policy development relevant for indoor climate. The assessment focuses on the respective building codes for new and existing residential buildings in selected MS: Belgium (Brussels Region), Denmark, France, Germany, Italy, Poland, Sweden and the UK (England and Wales). A critical and comparative evaluation is provided whilst best practice approaches are highlighted.

²⁴ Article 4 of the EPBD, 2010/31/EU. Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF>

Map 1 - Geographical coverage of the study



1 INDOOR AIR QUALITY (IAQ)

1.1 IAQ in new dwellings

Summary of findings in this chapter:

- All analysed MS have at least a basic reference to IAQ included in their Building Codes.
- Some MS clearly underline the co-benefits of IAQ regulation, i.e. for the well-being of occupants.
- 4 (out of 8) MS require minimum ventilation rates (Brussels-Capital Region, Denmark, France, Sweden).
- 4 (out of 8) MS recommend minimum ventilation rates (Germany, Italy, Poland and the UK (England and Wales)).
- The most commonly used units for ventilation rates are litres per second and cubic meters per hour, while the air exchange rate is regulated based on the assumed number of occupants, on the type of room, or on the floor area (Table 1).
- The majority of all regulated parameters is already covered and defined by European Standards. Nevertheless, the values found in standards and those in national regulations are largely not harmonised.
- Mandatory mechanical ventilation has been identified for two cases: multi-family buildings in Denmark and high-rise residential buildings in Poland.
- For all other cases, recommendations vary from rather pro mechanical ventilation (Brussels-BE and DE) or neutral position (DK, FR, SE, UK) to pro natural ventilation (IT).
- Denmark is the only country where the user-friendliness of ventilation systems is required by law.
- Most of the countries analysed still need to improve their calculation tools to adequately address hybrid and demand-controlled ventilation.
- Requirements related to heat recovery, including minimum efficiency, apply for some countries (Sweden, Poland, Italy), but only if mechanical ventilation systems are newly installed.
- Airtightness requirements differ largely over Europe: 6 MS already have precise values in place; Germany generally requires a state-of-the-art level of airtightness and Italy follows a regional approach.
- Indicators for airtightness vary throughout Europe (e.g. volume per hour, litres per second per m²) as well as for testing conditions (pressure: 50 to 100 Pa).
- Airtightness tests are required in France and Denmark (random check of min. 5%, all from 2015). For other countries, voluntary airtightness tests are common when applying for financial subsidies, high classes in energy performance certificates (EPC), etc.
- MS and international organisations, such as the World Health Organization, have partly defined their own inhomogeneous set of benchmarks for indoor pollutants and other IAQ indicators.
- The CO₂ concentration in dwellings in France must be less than 1 000 ppm; and, in the UK, values between 800 and 1 000 ppm are considered to be within acceptable levels.
- Indoor air quality is also positively influenced by national regulations concerning fire places (boilers) and by construction product regulations at the manufacturing stage. However, these regulations are not part of the study.

WHY INDOOR AIR QUALITY IS IMPORTANT:

- In urban areas, 60-90% of people's life is spent in buildings*.
- In 2012, 99 000 deaths in Europe and 19 000 in non-European high income countries were attributable to household (indoor) air pollution**.
- Indoor air pollution can be 2-5 times higher than in outside air***.
- Targeting the reduction of their energy demand, buildings are becoming more airtight and IAQ should be carefully considered.
- Economic dimension of increased IAQ: health aspects & productivity.

* Health & Consumer Protection Directorate-General, "Promoting actions for healthy indoor air (IAIAQ)", 2011.

** World Health Organization, "Burden of disease from Household Air Pollution for 2012".

***Environmental Protection Agency

1.1.1 Ventilation rates

In most standards and guidelines, IAQ is related to a required level of ventilation. Indicators and units to define the air exchange rate vary largely throughout Europe and are not always easy to compare. The air exchange rate can be defined as the quotient of fresh airflow and air volume of the relevant space. The unit 1/h (or h⁻¹ (per hour) or ach (air changes per hour)) defines the number of times the indoor air volume is replaced within one hour. Another approach defines fixed volumes (m³ or litre) per time (s or h), also linked to the number of occupants, or the type of room, or the floor area. In some countries the required rates vary in addition according to the number of occupying people. Moreover, some regulations consider the overall ventilation rate in the building; others have added emphasis on the minimum supply air per bedroom and living room. Requirements can apply for outside air supply and/or required exhaust rates.

Many MS are considering adopting improved ventilation codes, standards and practices. The EPBD, mainly dealing with the energy efficiency of buildings, contains a reference to ventilation in very general terms: "these (energy) requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation..."²⁵.

The European Committee for Standardization has issued the following non-mandatory standards with regard to IAQ:

- EN 13779: Ventilation for non-residential buildings. Performance requirements for ventilation, air-conditioning and cooling systems²⁶; and
- EN 15251: Indoor environmental input parameters for design and assessment of the energy performance of buildings, addressing indoor air quality, thermal environment, lighting and acoustics²⁷.

EN 15251 gives, in Annex B2, default values to use if no national regulation is available. A minimum ventilation rate per floor area between 0.05 to 0.1 l/(s·m²) during unoccupied hours is recommended if no value is given at national level. In residential buildings, "unoccupied periods" mainly means periods when there is no demand.

Required ventilation rates in the countries within the scope of the study are listed in the following table, while a deeper insight into the ventilation rates in the eight studied countries is provided in the following paragraphs:

²⁵ Article 4 "Setting of minimum energy performance requirements", EPBD Recast

²⁶ Available at: http://standards.cen.eu/dyn/www/f?p=204:110:0:::FSP_PROJECT,FSP_ORG_ID:24553,6138&cs=12A085D540F27A006B62E32D4714C4E9A

²⁷ Available at: http://standards.cen.eu/dyn/www/f?p=204:110:0:::FSP_PROJECT,FSP_ORG_ID:24552,6138&cs=1AAF5A672C76C7DC4F78CCAAE6304DE5D

Table 1 - Ventilation standards in dwellings (Source: BPIE based on feedback from country experts)

Country and Standard Reference	Whole Building Ventilation Rates	Living Room	Bedroom	Kitchen	Bathroom + WC	WC only
Brussels (NBN D 50-001)	3.6 m ³ /(h·m ²) floor surface area	Minimum 75 m ³ /h (limited to 150 m ³ /h)	Minimum 25m ³ /h (limited to 72m ³ /h)	Open kitchen Minimum 75 m ³ /h (exhaust)	Minimum 50 m ³ /hour (limited to 75 m ³ /h)	Minimum 25 m ³ /h
Denmark (BR10)	Min. 0.3 l/s·m ² (supply)	Min. 0.3 l/(s·m ²) (supply)		20 l/s (exhaust)	15 l/s (exhaust)	10 l/s (exhaust)
France (Arrêté 24.03.82)	10-135 m ³ /h (depending on room number and ventilation system)			Continuous: 20 – 45 m ³ /h		Minimum 15 m ³ /h
Germany (DIN 1946-6)	15-285 m ³ /h (details see chapter)			45m ³ /h (nominal exhaust flow)	45 m ³ /h (nominal exhaust flow)	25 m ³ /h (nominal exhaust flow)
Italy (Legislative Decree 192/2005, UNI EN 15251)	Naturally ventilated: 0.3 – 0.6 vol/h	0.011 m ³ /s per person for an occupancy level of 0.04 persons/m ²			4 vol/h	
Poland (Art 149 (1) – Journal of Laws 2002 No. 75, item. 690, as amended and PN-B-03430:1983/Az3:2000)	20 m ³ /h for each permanent occupant should be calculated according to the Polish standard but not less than 20 m ³ /h	20 -30 m ³ /h for each permanent occupant (for public buildings) For flats, it is a summary of flow from all rooms		30 m ³ /h to 70 m ³ /h without windows	50 m ³ /h	30 m ³ /h
Sweden (BFS2014:13 – BBR21)	Supply: min 0.35 l/(s·m ²) floor area					
UK (Approved Document F)	13-29 l/s (depending on bedrooms)			13-60 l/s (extract)	8-15 l/s (extract)	6 l/s (extract)
EN 15251	0.35 – 0.49 l/(s·m ²)	0.6 – 1.4 l/(s·m ²)		14-28 l/s	10-20 l/s	7-14 l/s

Requirement Recommendation European standard

BRUSSELS-CAPITAL REGION

In the event of new, modified or removed window(s) in a residential unit, air ventilation systems have to be in line with the Belgian Standard NBN D 50-001 "ventilation devices in residential buildings", except some adjustments that are specified in the legislation²⁸. Standard NBN D 50-001 defines the following minimum ventilation flows for renewal of air in dwellings:

Table 2 - Minimum ventilation flows for renewal of air in dwellings

Nominal ventilation flow	
In living rooms, study rooms, bedrooms, hallways, stairs ... all rooms of a house (except the WC) where the same conditions apply to the determination of the nominal flow rate	
Special conditions	
Living room (supply)	Minimum 75 m ³ /h Should be limited to 150 m ³ /h
Bedroom and study room (supply)	Minimum 25m ³ /h Should be limited to 72m ³ /h
Open kitchen (exhaust)	Minimum 75 m ³ /h
Closed kitchen , bathroom and utility room (exhaust)	Minimum 50 m ³ /h Should be limited to 75 m ³ /h
WC (exhaust)	Minimum 25 m ³ /h Fixed value (i.e. independent of the area)

General rules to apply in the above table:

Nominal flow rate = $3.6 \times \text{floor area}$

A minimum flow rate must also be realised: at least the nominal flow and at least the "minimum rate" of the table. The flow can be limited to the maximum value (see table).

Example 1: a living room of 15m² > the ability of the supply must be at least 75 m³/h, even if the required nominal rate is $15 \times 3.6 = 54$ m³/h.

Example 2: a living room of 100m² > the ability of the supply may be limited to 150 m³/h, even if the required nominal flow rate is $100 \times 3.6 = 360$ m³/h.

For systems with natural supply, the maximal supply flow may not exceed twice the nominal one²⁹.

Further, according to the requirements of Annex VI of the Decree of December 21, 2007, "Determining requirements for energy performance and indoor climate of buildings" air ventilation systems must be installed with:

- Appropriate size and position of openings to ensure that no small animals can enter³⁰;
- Manual or automatic change of the ventilation grid configuration in five different positions: "fully open", 3 intermediary ones and "fully closed" (up to 50 Pa)³¹;
- Height of placement of at least 1.8 meters from the ground to avoid any problem of comfort³².

Moreover, Chapter 1 of Annex VIII in the same decree involves technical installation requirements for new units such as distribution of conditioned air, control devices and air inlets.

Bruxelles Environnement, the public administration for environment and energy in the Brussels-Capital Region, recommends that windows should be designed to allow hygienic ventilation. An optimum design of windows should allow rapid discharge of indoor pollution.

²⁸ Government Decree on 21 December 2007, Annex VI, page 418, section 1.

²⁹ Standard NBN D 50-001, 4.3.1.2 & 4.3.1.4

³⁰ Decree of 21 December 2007, annex VI, comma 2, letter a

³¹ <http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel05-assurer-le-confort-respiratoire-au-sein-du-batiment-durable.html?IDC=117&IDD=4480>

³² Decree of the 21 December 2007, annex VI, comma 2, part c. Derogations on minimum height are allowed.

DENMARK

The Danish Building Regulation (BR10) clearly addresses the importance of indoor air quality and ventilation. Article 6.1(1) states: "Buildings must be constructed such that, under their intended operational conditions, a healthy, safe and comfortable indoor climate can be maintained in rooms occupied by any number of people for an extended period". Satisfactory health conditions also include comfort and wellbeing, air quality, acoustic indoor climate and light conditions. For architects and planners, the Danish Building Research Institute provides additional non-binding guidelines for daily practice: "the indoor climate handbook"³³.

To ensure good indoor air quality, BR 10 requires ventilation for buildings in general. This includes natural, mechanical and hybrid ventilation. In detail, each habitable room, as well as the dwelling as a whole, must have a fresh air supply of no less than $0.3 \text{ l/(s}\cdot\text{m}^2\text{)}$ of heated floor area, even if demand-controlled ventilation is provided. Moreover, kitchens must be provided with extractor hoods with exhaust ventilation above the cooker³⁴. It must be possible to increase air changes in kitchens (extraction of a flow of 20 l/s) and bathrooms (minimum flow of 15 l/s). Extraction of a flow of 10 l/s must be possible from separate rooms containing sanitary conveniences, utility rooms and basement rooms.

For example, in a dwelling of 65 m^2 with one kitchen and one bathroom/WC, it must be possible to increase ventilation to $0.54 \text{ l/(s}\cdot\text{m}^2\text{)}$ (significantly more than the background air change of $0.3 \text{ l/s}\cdot\text{m}^2$). In a dwelling of 110 m^2 with one kitchen and two bathrooms/sanitary conveniences, it must be possible to increase ventilation to a total ventilation rate of $0.45 \text{ l/(s}\cdot\text{m}^2\text{)}$.

According to BR 10, ventilation systems must be designed, built, operated and maintained so that they achieve no less than the intended performance when they are in use. Fresh air must be provided through openings directly to the external air or by ventilation installations with forced air supply.

The provisions on ventilation only address general ventilation needs. Additional ventilation may be needed. In such cases, requirements for additional ventilation apply pursuant to the Danish Working Environment Act. Ventilation requirements of rooms with heat producing appliances are described in the Danish Gas Regulations (Part 8 and Section A).

Guidelines³⁵ included in BR 10 point to the importance of user-friendly installations: ventilation opening directly to the external air should be made such that users are encouraged to use the openings as intended and to employ the options to adjust the quantity and distribution of the intake fresh air correctly. A ventilation opening directly to the external air should therefore be adjustable, easy to regulate, and operable from room floor level.

Transfer of air from one room to another must not be from a more to a less air-polluted room. In dwellings, the rooms with higher air pollution will be, for example, kitchens, bathrooms, rooms containing sanitary conveniences and utility rooms. Additionally, ventilation installations and ventilation openings leading directly to the external air must not transfer substances to the ventilated rooms, including microorganisms, which render the indoor climate unhealthy.

³³ <http://www.sbi.dk/indeklima/generelt/anvisning-indeklimahandbogen>

³⁴ Danish Building Regulation Article 6.3.1.2(1)

³⁵ Danish Building Regulation Article 6.3.1.1(2)

For single-family houses with natural ventilation, BR 10 requires the following minimum area of natural ventilation openings for fresh air supply in:

Habitable rooms: Opening windows, hatches or external doors and one or more fresh air vents with a total unobstructed opening of no less than 60 cm² per 25 m² room floor area;

Kitchens and bathrooms: An opening of no less than 100 cm² onto an access space. Additionally, for the removal of indoor air an exhaust duct with a cross section of no less than 200 cm² is foreseen. For kitchens, BR10 also foresees an opening window, hatch or external door;

Separate utility rooms and rooms containing sanitary conveniences: An opening of no less than 100 cm² onto an access space. In addition, if the room comprises an external wall, it must have an opening window, hatch or external door. Furthermore, for the removal of indoor air, an exhaust duct with a cross section of no less than 200 cm² is foreseen;

Basement rooms: Supply of fresh air through one or more fresh air vents. Moreover, the removal of indoor air must be done from at least one basement room via an exhaust duct with a cross section of no less than 200 cm².

In addition, relevant ventilation standards used in Denmark are:

- The Code of Practice for mechanical ventilation installations DS 447³⁶;
- The international standard DS/EN ISO 7730³⁷ entitled “Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria”; and
- The Guideline “Indoor Climate” (A.1.2) issued by the Danish Working Environment Authority³⁸.

FRANCE

According to the French Code of Construction³⁹, air exchange rates and the expulsion of emissions have to guarantee that air quality does not constitute a danger for the occupants.

To ensure good ventilation, also in times when windows are often closed (e.g. winter period), minimum airflows for the whole building and specific airflows for kitchens are defined. The exact volume depends on the number of rooms and presence (or not) of mechanical ventilation⁴⁰. The following tables present the airflow requirements (Table 3) and the airflow requirements in the case of “dynamic” mechanical ventilation⁴¹ (Table 4) according to the Decree of 24 March 1982 (last amended by the Decree of 15 November 1983).

³⁶ Danish Energy Agency, “Standards in the legislation”: http://danishcprcontactpoint.dk/standards_legislation

³⁷ Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=39155

³⁸ Danish Working Environment Authority, “Guideline: Indeklima”: <http://arbejdstilsynet.dk/da/regler/at-vejledninger/i/a-1-2-indeklima.aspx>

³⁹ Code de la construction et de l’habitation, Article R*111-9. Available at: <http://www.legifrance.gouv.fr/affichCodeArticle.do?idArticle=LEGITEXT000006074096&dateTexte=20121108&oldAction=rechCodeArticle&895892&cidTexte=LEGITEXT000006074096&dateTexte=20121108&oldAction=rechCodeArticle>

⁴⁰ French Decree of 24th March 1982

⁴¹ Dynamic mechanical ventilation is a mechanical ventilation which modifies extraction rates according to “indoor pollutants” and can prevent condensation

Table 3 - Airflow requirements

	Main rooms*						
	1	2	3	4	5	6	7
Total airflow [m³/h]	35	60	75	90	105	120	135
Airflow in the kitchen	20	30	45	45	45	45	45

Table 4 - Airflow requirements in the case of dynamic mechanical ventilation

	Main rooms*						
	1	2	3	4	5	6	7
Total airflow [m³/h]	10	10	15	20	25	30	35

*Note: For France, no differences between bedrooms and living rooms apply. One of the reasons for that is that you cannot define for sure which room will be used for what purpose and this can change from one inhabitant to another.

However, in the case of only one main room and toilet, if adjacent, a common air outlet can be put in the toilet with an extraction flow rate of 15 m³/h, while for single detached or semi-detached houses located in a hotter climate (zones H2 or H3⁴², map 2), the requirements of the above tables can be skipped if the following rules are followed instead⁴³:

- Each main room must have an air inlet opening formed by a orifice in the wall, a “natural airflow” or a mechanical ventilation device
- The kitchen requires an air outlet (“natural airflow” or mechanical ventilation)
- Other side rooms may include
 - An air outlet (“natural airflow” or mechanical ventilation)
 - A lockable external opening

Map 2 - Geographical location of climate zones (H1, H2, H3) in France⁴⁴



No national requirements for natural ventilation openings apply to France, nevertheless rules differ for French overseas departments.

⁴² Annex of Decree of the “Arrêté du 24 mars 1982”. Climate zones are also defined in “Arrêté du 26 octobre 2010”

⁴³ Arrêté du 24 mars 1982, Article 6

⁴⁴ Source: H3C-CARAÏBES

GERMANY

The German Energy Saving Ordinance (EnEV 2014) includes, in Article 6 "Airtightness, minimal air exchange", a very basic reference to IAQ for new construction. It requires all new buildings to be built airtight according to the state-of-the-art. In addition, they have to be built in a manner that ensures appropriate air exchange for a healthy and warm indoor environment. The general wording of EnEV 2014 leaves it up to the planner and architect to decide whether additional mechanical ventilation is needed or not. But this wording shall ensure that requirements targeting the issues of healthy indoor air quality or the provision of sufficient air for combustion in fireplaces do not conflict with the airtightness for the purpose of energy efficiency. Several questions arising in connection with recent standardisation (DIN 1946-6) will be clarified with the 2017 amendment of the Energy Saving Ordinance.

The German Energy Saving Ordinance describes a virtual "Reference Building"⁴⁵ including non-binding characteristics that influence the energy performance: U-Values, technical installations, etc. The Reference Building serves as a description of the energy performance requirement; for new buildings, the energy performance of the Reference Building marks the maximal primary energy demand requirement of the building in question. The residential Reference Building includes a mechanical, demand-controlled exhaust air systems with DC ventilation (air exchange rate $n_{nutz} = 0.55 \text{ h}^{-1}$). This characteristic has a significant influence on the required maximal primary energy demand⁴⁶. As the Reference Building is a non-binding description, ventilation systems are not obligatory per se. Nevertheless, official governmental explanations related to EnEV 2009⁴⁷ state that mechanical ventilation is reasonable to avoid damages caused by moisture and mould. In terms of energy performance calculation, natural and mechanical systems are treated equally.

The non-binding standard DIN 1946-6 "Ventilation of dwellings" provides more guidance on the topic. DIN 1946-6 applies to natural ventilation and fan-assisted ventilation of dwellings and similarly-used groups of rooms (dwelling units). It has been intensively reviewed and re-published in May 2009, but up until today DIN 1946-6 is neither a legal requirement nor a de-facto standard.

To be in line with DIN 1946-6, a "concept for ventilation" is required per building unit for:

- All new construction;
- Refurbishment of a single-family home (SFH) and a multi-family home (MFH) if more than 1/3 of windows are replaced;
- SFH if more than 1/3 of the roof area is refurbished.

These requirements are not imposed by legal prescriptions, but are just a part of a technical standard. Such a technical standard should be followed to achieve a good construction level, but is not compulsory. The standard aims at identifying whether mechanical ventilation is advisable or whether natural ventilation is enough. The indoor air concept can be developed by every expert involved in the planning or maintenance of ventilation systems or in the planning and refurbishment of buildings. Software for the ventilation concept is available for free and provided by the Federal Association for Ventilation of Dwellings⁴⁸.

According to DIN 1946-6 mechanical ventilation is required for a building unit if the necessary air volume flow for moisture-proofing exceeds the air volume flow caused by infiltration ($q_{V,ges,NE,FL} > q_{V,Inf,wirk}$)⁴⁹. Additionally, Standard 1946-6 calls for four different levels of ventilation that guarantee a minimum air exchange for different kind of uses. The four levels are:

⁴⁵ EnEV 2014, Annex 1, Table 1

⁴⁶ Fachkommission Bautechnik der Bauministerkonferenz Auslegungsfragen zur Energieeinsparverordnung – Teil 12

⁴⁷ Die Begründung der Bundesregierung zum Entwurf der EnEV 2009 (Bundesrats-Drucksache 569/08, S.109) führt zu Anlage 1 Tabelle 1 Zeile 8 aus: „Eine Abluftanlage ist in der Energiebedarfsbilanz gegenüber der Fensterlüftung (kontrollierte Stoßlüftung) gleichwertig, zur Vermeidung von Feuchteschäden und Schimmelpilzbildung als bauphysikalisch sinnvoll anzusehen.“

⁴⁸ Bundesverband für Wohnungslüftung e.V., www.wohnungslueftung-ev.de/faq-normen/faq-din-1946-6.html

⁴⁹ DIN 1946 -6

1. Ventilation for protection against humidity: A basic ventilation level that should guarantee minimal ventilation depending on energy performance/ insulation levels. This avoids damages caused by wet air. This level has to be ensured at all times, independently of the user.

2. Reduced ventilation: Requires minimal additional ventilation for minimal hygienic requirements and for the protection of fabric from minor pollution. This level has to be ensured at all times, mostly independently of the user.

3. Nominal ventilation ("Nennlüftung"): Describes the ventilation required for a hygienic and healthy indoor air quality and protection of fabric for an average use. The user's behaviour (active ventilation via window) can be taken into account.

4. Intensive ventilation: For intensive uses, cooking, washing etc. The user's behaviour (active ventilation via window) can be taken into account.

The following table presents the minimal airflows in m³/h for the four above-mentioned levels of ventilation.

Table 5 - Minimal airflows in m³/h (including infiltration) per unit according to DIN 1946-6

Level	Description of level	Floor area in m ²									
		30	50	70	90	110	130	150	170	190	210
Level 1	Ventilation for protection against humidity, High thermal protection [m ³ /h]	15	25	30	35	40	45	50	55	60	65
	Ventilation for protection against humidity, Low thermal protection [m ³ /h]	20	30	40	45	55	60	70	75	80	85
Level 2	Reduced ventilation [m ³ /h]	40	55	65	80	95	105	120	130	140	150
Level 3	Nominal ventilation [m ³ /h]	55	75	95	115	135	155	170	185	200	215
Level 4	Intensive ventilation [m ³ /h]	70	100	125	150	175	200	220	245	265	285

Furthermore, for nominal exhaust airflow rate (level 3) in the case of mechanical ventilation for rooms with or without windows, the following minimal airflows should be followed:

- 45 m³/h for kitchen and bathrooms
- 25 m³/h only for WC and utility rooms
- 100 m³/h for Sauna or Fitness

Particularly for level 1 "Ventilation for protection against humidity", which defines the lowest "requirement", the architect has to consider additional ventilation systems, if air exchange via leakages is not enough. This ventilation classification/group was introduced in 2009 especially in view of highly efficient and airtight buildings. It defines that mould can be avoided if a humidity of 80% on surface is not exceeded. The influence of thermal bridges is taken into account. In cases of higher requirements for energy efficiency, noise protection and IAQ, DIN 1946-6 always requires the installation of a ventilation system.

DIN 18017-3 applies for ventilation of bathrooms and toilets without windows and requires the following minimal exhaust airflow rates:

- 60 m³/h in case of demand-controlled system (can be temporarily reduced to 15 m³/h (all) or 0 m³/h if the building meets at least the insulation standards of 1995)
- 40 m³/h for permanent outgoing airflow (and min 20 m³/h during nights)

ITALY

Italy follows a regional approach concerning building regulations: local health agencies and the municipalities are responsible for building requirements⁵⁰. Local regulations define the health requirements of dwellings, including orientation, air ventilation and daylight requirements.

Only some regional laws refer to national standards. In addition, voluntary guidelines have been introduced for other regions. As a consequence, the landscape of requirements and de facto standards must be considered as very inhomogeneous in Italy. This study focuses on existing national level technical standards. However, there are some more ambitious approaches defined at local level (local building regulations). Mechanical ventilation has already been introduced in the building guidelines of 345 municipalities (mainly in northern Italy) and is mandatory in 105 building regulations; while in 30 building regulations it is subsidised⁵¹.

Standards UNI 10339 (directly related to ventilation) and UNI TS 11300 (focusing on energy efficiency but also dealing with ventilation aspects) are listed in the Legislative Decree 192/2005, the national implementation of the EPBD. European Standard EN 15251 (Italian version UNI EN 15251) is also a reference document in the field of indoor environment.

Based on the Standards listed in Legislative Decree 192/2005, in the case of natural ventilation 0.3 vol/h are used in the design phase⁵². Moreover, the Standards suggest:

- An exchange rate of 4 vol/h for bathrooms and
- A flow of external air of 0.011 m³/s per person for an occupancy level of 0.04 persons/m² in dining rooms and bedrooms⁵³.

Additionally, according to the Standard UNI EN 15251:1995, usually an air exchange level of 0.6 vol/h is adopted for the residential sector⁵⁴. In the case of mechanical ventilation, the ventilation rate provided may be lower during unoccupied periods⁵⁵.

In Italy, no national requirements for minimum area of natural ventilation openings apply.

POLAND

In Poland mechanical or natural ventilation must ensure appropriate air exchange for premises designed to accommodate people. This includes rooms without windows as well as other rooms where ventilation is necessary for health, technological or safety reasons.

According to the legislation Art 149.1, for residential premises, the ventilation rates shall not be lower than 20 m³/h for each permanent occupant. Moreover, based on the Polish Norms PN-B-03430:1983/Az3:2000, the recommended minimum volumetric flow rate of ventilation air for an apartment is determined as a sum of the respective spaces flow:

- For collective rooms (i.e. lounges, study rooms, dining rooms) the ventilation rates should not be lower than 20 m³/h per occupant;
- For rooms with air conditioning and ventilation, with no possibility to open the windows, the ventilation rates should not be lower than 30 m³/h per occupant;

⁵⁰ Decree of the President of the Republic 380 of 6 June 2001

⁵¹ Half of the communities are in the region of Lombardia, about 80% of the municipalities are located in the north. Report ONRE 2013

⁵² UNI TS 11300-1, part 12.1.1. Available at: http://www.cti2000.it/doc/regolamento_11300.2.pdf

⁵³ UNI 10339:1995. Available at: <http://www.nuovasuperiride.com/download/NORMA%20UNI%202010339.pdf>

⁵⁴ UNI EN 15251. Value for the type II of residence. Value for example suggested by mechanical ventilation producer Vortice (presentation at ProEnergy+ fair in 2013) and by other sources, such as: http://www.casaclima.com/ar_842__ACADEMY-Impianti-Termomeccanici-ventilazione-ambientale--ventilazione-residenziale-normativa-ventilazione-Ventilazione-ambientale-la-normativa.html

⁵⁵ http://www.studiolosiferrari.it/cms_rc/allegati/695__4139_ALDES_INFORMA_03.pdf

According to part 7.3.2.1. If no national legislation is available, the standard provides recommended values in table B.4. According to part 7.3.2.2 even if the rate may be lower, the exchange rate has to be provided. http://amslaurea.unibo.it/6368/1/federico_di_camillo_tesi.pdf

Table 6 - Minimum flow rates

Space type	Flow rate
Kitchen with a window, equipped with a gas or coal cooker	70 m ³ /h
Kitchen with a window, equipped with an electric cooker	
Apartment for less than 3 people	30 m ³ /h
Apartment for more than 3 people	50 m ³ /h
Kitchen without a window, equipped with an electric cooker	50 m ³ /h
Kitchen without a window, equipped with a gas oven with a mandatory mechanical ventilation	70 m ³ /h
Bathroom (with or without WC)	50 m ³ /h
Separate WC	30 m ³ /h
Auxiliary room, with no windows	15 m ³ /h
Living apartment (separated from the kitchen, bathroom and toilet with 2 or more doors) or rooms located on higher levels.	30 m ³ /h

Moreover, the minimum exchange rate for cellars is 0.3 per hour and for laundry rooms, 2 per hour. It is also recommended that (in addition) ventilation should be designed to allow a periodic increase of the volume flow of air to at least 120 m³/h.

Regarding the ventilation vents, there are a number of specific requirements concerning their size (i.e. there is an obligation to install vents in windows or outer walls both for natural and mechanical ventilations):

- Ventilation vents (i.e. intake & exhaust) should be installed in a way that the airflow is not mixed;
- Vents and installation ducts (i.e. mechanical ventilation and AC) need to be designed and constructed in a way to minimise the deposition of pollutants on the surfaces in contact with ventilation air;

In residential buildings without mechanical ventilation or air conditioning, windows should allow ventilation openings of at least 50% of the area for a given room, with the minimum area of the windows to floors being 1/8 in occupied rooms, or 1/12 in unoccupied rooms.

SWEDEN

The Swedish Building Code, BFS 2014:3 - BBR 21, recently updated in June 2014, intensively addresses – in a separate chapter (chapter 6) – requirements related to hygiene, health and environment. “Buildings and their installations shall be designed so that air (...) quality, and light, moisture, temperature and hygienic conditions will be satisfactory during the life of the building and thus the damage to people’s health can be avoided.” BFS contains binding obligations and recommendations, which are both described in this report.

Buildings and systems shall be designed in order to at least guarantee the quality of outside air. The air supplied to the room must not be of lower quality than the outside air⁵⁶.

Good air quality requirements need to be defined depending on the use of the room. Nevertheless, BFS requires an overall exchange rate for dwellings in BBR 21, 6:21 “Good air quality in rooms used for longer periods”:

⁵⁶ The Swedish Air Quality Ordinance 2010:477 defines the quality requirements for outdoor air.

Ventilation systems shall be designed for a minimum airflow of $0.35 \text{ l}/(\text{s} \cdot \text{m}^2)$ in the cases of both new buildings and alterations of buildings⁵⁷. In residential buildings where ventilation can be controlled separately for each dwelling, the ventilation system can be designed with presence and demand-controlled ventilation, e.g. CO_2 controlled. However, the outdoor airflow must not be lower than $0.10 \text{ l}/(\text{s} \cdot \text{m}^2)$ of floor area when the space is unoccupied and $0.35 \text{ l}/(\text{s} \cdot \text{m}^2)$ when the space is occupied.

BFS 2014:3 - BBR 21 explicitly points to the fact that a reduction of ventilation flows may increase health risks. The reduction must not cause damage to the building and its installations.

When planning, it is important to take into account how the pollution of the air varies over time and in the building. Temporary pollution that can be localised can be dealt with by using local exhaust ventilation, such as in kitchens and bathrooms.

In addition, the quality of the air supplied to the building should not only be ensured by appropriate siting and design of the air intake and the intake chamber, but also by supply air purification or anything similar. Fresh air intake should be positioned so that the impact of exhaust and other sources of pollution are minimised. It is important to take into consideration the height above the ground, the direction of and distance from traffic, the discharge, the wastewater pipelines vents, the cooling towers and the chimneys. Recommendations for the location and distance between air outlet and air intake are in the Energy and Environmental Technology Association Guidelines R1 - Guidelines for the specification of the indoor climate. If natural ventilation is used, the dwelling shall have the necessary openings to keep up the airflow in the building (functional demand).

Rules on air quality and ventilation are also issued by the Public Health Agency and by the Swedish Work Environment Authority. Ventilation rates should not be lower than 0.5 volume (of the room) per hour⁵⁸. In addition, values depend on the density of the specific urban area and include: nitrogen dioxide and nitrogen oxides, sulphur dioxide, carbon monoxide, ozone, benzene and different particulate matters.

UK (ENGLAND & WALES)

In England and Wales, according to the Building Regulations 2010, the construction of new buildings and building work on existing buildings must comply with all technical requirements set out in the British Building Regulations, as follows:

1. There shall be adequate means of ventilation provided for people in the building;
2. Fixed systems for mechanical ventilation and any associated controls must be commissioned by testing and adjusting as necessary to ensure that the objective referred to in 1) is met.

The "Approved Document F1 – Means of ventilation" provides guidance about compliance and sets out what, in ordinary circumstances, may be accepted as reasonable provision for compliance (presumption of compliance). However, there is no obligation/no guarantee for compliance.

⁵⁷ BFS 2014:3 - BBR 21, 6:251. Same value confirmed in FoHMFS 2014:18. BFS 2014:3 - BBR 21, 6:9241

⁵⁸ FoHMFS 2014:18

The Approved Document F1 provides three different ways to meet the official requirements:

- Follow the ventilation rates of the following table.

Table 7 - Ventilation rates that should be followed

Extract ventilation rates			
	Intermittent extract/ Minimum rate	Continuous extract/ Minimum high rate	Continuous extract/ Minimum low rate
Kitchen (l/s)	30 adjacent to hob; 60 elsewhere	13	Total extract rate should be at least the whole dwelling ventilation rate given in the following table
Utility room (l/s)	30	8	
Bathroom (l/s)	15	8	
Sanitary accommodation (l/s)	6	6	

Whole dwelling ventilation rates					
No of bedrooms	1	2	3	4	5
Whole dwelling ventilation rate ^{a,b} (l/s)	13	17	21	25	29

a. The minimum ventilation rate should not be less than 0.3 l/s per m² of internal floor area.

b. This is based on two occupants in the main bedroom and a single occupant in all other bedrooms. If a greater level of occupancy is expected, add 4 l/s per occupant.

Purge ventilation provision is required in each habitable room and should be capable of extracting a minimum of four air changes per hour (ach) per room directly to outside. Normally, openable windows or doors can provide this function. Otherwise, a mechanical extract system should be provided.

- Follow the system guidance set out for dwellings with and without basements (paragraphs 5.8 -5.13, Approved Document F). For dwellings without basement, the guidance covers all levels of Design Air Permeability. Alternative guidance is also provided for dwellings designed to an air permeability less than (>) 5 m³/(h·m²) at 50 Pa where the experienced developer will not construct significantly more airtight dwellings (not better than 3 m³/(h·m²) at 50 Pa).
- Use other ventilation systems only if it can be demonstrated to the Building Control Body that they satisfy the requirement e.g. by showing that they meet the moisture and air quality criteria set out in Approved Document F1.

According to the non-binding Approved Document F1, mechanical ventilation is not needed if the following criteria are met:

- For a hinged or pivot window that opens 30° or more or for parallel sliding windows, the height x width of the opening part should be at least 1/20th of the floor area of the room;
- For a hinged or pivot window that opens between 15° and 30°, the height x width of the opening part should be at least 1/10th of the floor area of the room;
- If the window opens less than 15° it is not suitable to provide purge ventilation;
- If the room has more than one openable window, the areas of all the opening parts may be added to achieve the required proportion of the total floor area (determined by the opening angle of the largest window in the room);
- For an external door, the height x width of the opening part should be at least 1/20th of the floor area of the room;
- If the room contains a combination of at least one external door and at least one openable window, the areas of all the opening parts may be added to achieve at least 1/20th of the floor area of the room.

1.1.2 Airtightness

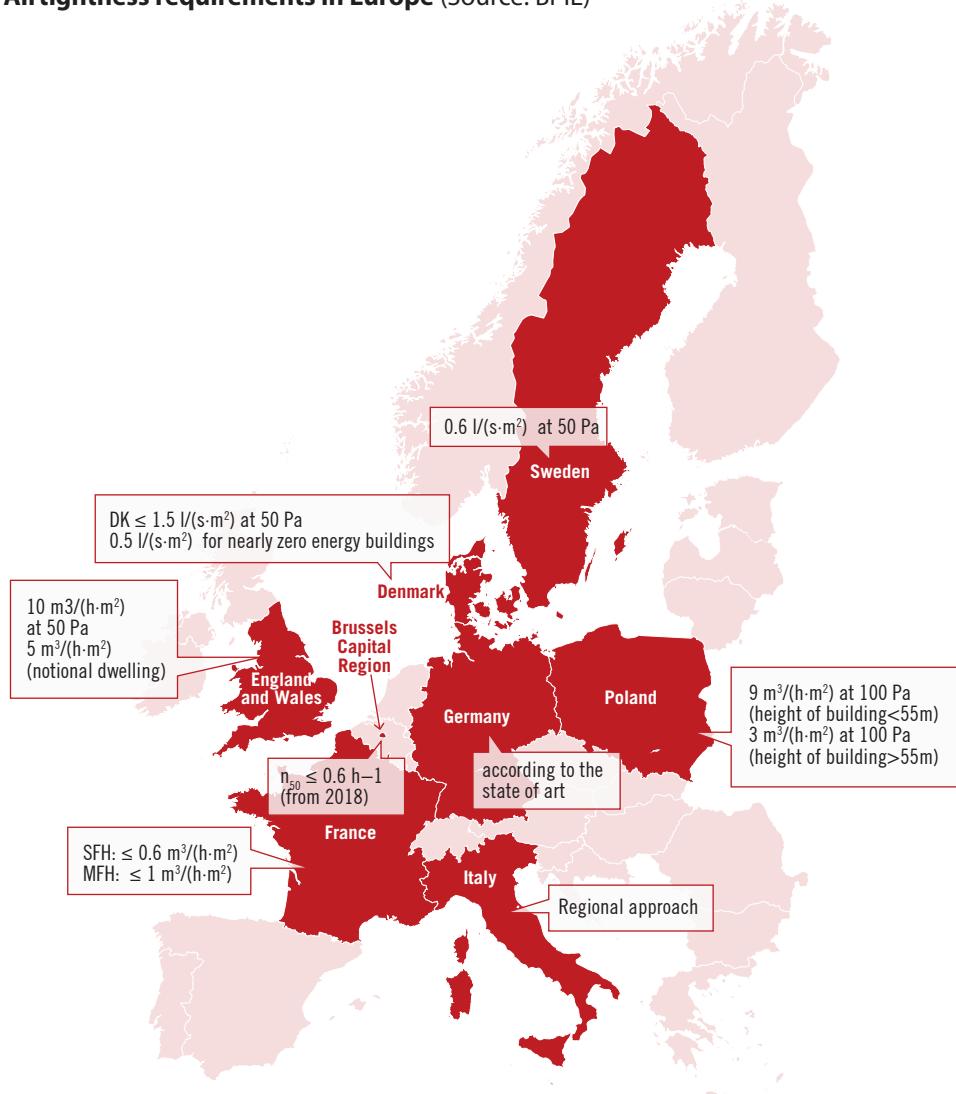
Building airtightness, which describes the resistance of the building envelope to inward or outward air leakage, is a crucial aspect of better energy performance of buildings. Although it is now included in many energy performance related regulations (e.g. in Belgium, Denmark, France, Germany, Sweden and the United Kingdom), in practice there are major differences in the way it is taken into account.

In some countries, a better airtightness than the default value can only be taken into account if proven by measurements (blower door test), whereas other countries also allow the use of quality management approaches (e.g. in France). Furthermore, there are countries with a minimum requirement (e.g. in Denmark, the UK) and others with guidelines for maximum envelope leakage (e.g. Germany). The default value for building airtightness differs from country to country, which is not surprising given the differences in building traditions and construction types.

The European Standard EN 13829 describes the measurement method of air permeability of buildings through fan pressurisation. Due to different surface and volume calculation methods in Member States, measured airtightness data (usually expressed in terms of the infiltration airflow rate at 50 Pa divided by the cold surface area or the building volume) are not fully comparable.

The following map gives an overview about the variety of MS approaches. Detailed explanations can be found country-wise below.

Map 3 - Airtightness requirements in Europe (Source: BPIE)



BRUSSELS-CAPITAL REGION

Starting from 2018, the individual dwelling's PEB (Performance Energétique des Bâtiments) units⁵⁹ require an airtightness of maximum 0.6 volume per hour⁶⁰. Before 2018, there is no requirement on airtightness.

DENMARK

Air changes through leakage in the building envelope must not exceed 1.5 l/(s·m²) of the heated floor area when tested at a pressure of 50 Pa on the basis of DS/EN 13829⁶¹. In the case of low energy buildings class 2015, air changes through the building envelope must not exceed 1.0 l/(s·m²). For building class 2020 (nearly zero energy buildings) air changes through the building envelope must not exceed 0.5 l/(s·m²). The result of the pressure test must be expressed as the average of measurements using overpressure and under pressure. In the case of buildings with high ceilings, in which the surface area of the building envelope divided by the floor area is greater than 3, air changes must not exceed 0.5 l/(s·m²) of the building envelope and in the case of low energy buildings 0.3 l/(s·m²).

If air change rates have been tested, the test results may be used to calculate the energy consumption through ventilation. If there is no documentation, 1.5 l/(s·m²) at 50 Pa must be used (default value).

FRANCE

For individual buildings, the airtightness has to be equal or lower than 0.6 m³/(h·m²) and for multi-family residential buildings, the airtightness has to be equal or lower than 1 m³/(h·m²). The Thermal Regulation RT 2012 requires mandatory airtightness tests for all new dwellings. This airtightness is measured under 4Pa, with the indicator Q_{4Pa} (Standard NF EN 13829).

GERMANY

Leakages in exterior building elements have to be avoided⁶² and airtightness has to be according to the state-of-the-art (DIN 4108-7). Therefore, the air leakage rate (n_{50}) must not exceed⁶³ 3 h⁻¹ in houses with natural ventilation and 1.5 h⁻¹ in dwellings using mechanical ventilation, whereas for the Passivhaus standard the limit is set at 0.6 h⁻¹. In calculation tools, the airtightness value results from the blower door test.

ITALY

Italy has no requirements on airtightness at national level, but some regions do. As best practice, the Province of Bolzano introduced, on 1 March 2010, mandatory blower door tests (carried out according to EN 13829) in case of energy certification of new dwellings⁶⁴. In other regions, it is often requested in the certification of buildings with a higher energy class (e.g. it is requested to reach the A+ energy class in the province of Trento⁶⁵).

⁵⁹ PEB units: set of adjacent premises located in the same building, subject to the same kind of work and having the same assignment.

⁶⁰ Decree of the 21 December 2007, article 10 ter, comma 2.

⁶¹ DS/EN 13829, Thermal performance of buildings – Determination of air permeability of buildings – Fan pressurisation method.

⁶² Energy Saving Ordinance 2014, Article 6 (1)

⁶³ "Report on national and European regulations and requirements regarding airtightness", ETHICS Project. Available at: http://www.stb.rwth-aachen.de/projekte/2008/ETHICS/docs/ETX-136_Deliverable_WP1_a.pdf

⁶⁴ "Attuazione della certificazione energetica degli edifici in Italia". The blower door test is required within the energy certification scheme of Agenzia Casa Clima, which is the sole responsible for the certification in Bolzano region but it also spreading its protocol in the entire country.

⁶⁵ Link to the relevant legislation available at http://www.casaenergetica.it/servizi/blower_door_test/obbligo_tenuta_aria.html

POLAND

Since 2014, all residential and public buildings need to be designed and manufactured in the way that connectors between envelope partitions, transition element of installation and building components guarantee high airtightness levels of the envelope⁶⁶. Specific requirements in this regards are as follows:

- In low or moderately high buildings (up to 55 m), the air permeability of windows and doors (at the pressure of 100 Pa) shall not be higher than $2.25 \text{ m}^3/(\text{m}\cdot\text{h})$ in relation to the length of the contact line or $9 \text{ m}^3/(\text{m}\cdot\text{h})$ in relation to the surface area, which corresponds to class 3 of the Polish standard for air permeability;
- In high-rise buildings (more than 55 m), the air permeability of windows and doors (at the pressure of 100 Pa) shall not be higher than $0.75 \text{ m}^3/(\text{m}\cdot\text{h})$ in relation to the length of the contact line or $3 \text{ m}^3/(\text{m}\cdot\text{h})$ in relation to the surface area, which corresponds to class 4 of the Polish standard for air permeability.

The recommended airtightness is:

1. For buildings with natural and/or hybrid ventilation: $n_{50} < 3.0 \text{ l/h}$;
2. For buildings with mechanical ventilation or air-conditioning: $n_{50} < 1.5 \text{ l/h}$.

It is officially recommended to carry out the airtightness test after the construction phase (for residential, collective, public and production buildings).

SWEDEN

According to BFS 2011⁶⁷, the air leakage rate through the building envelope, which can be determined by Standard SS-EN 13829, shall not be higher than $0.6 \text{ l/(s}\cdot\text{m}^2)$ (at 50 Pa). Specifically, for single-family homes ($<50\text{m}^2$) if this requirement as well as an average heat transfer coefficient less than $0.33 \text{ W/m}^2\text{K}$ are satisfied, no requirement for maximum energy use ($\text{kWh/m}^2/\text{year}$) has to be fulfilled.

UK (ENGLAND AND WALES)

The dwelling complies with the requirements if the measured air permeability is not worse than the limit of $10 \text{ m}^3/(\text{h}\cdot\text{m}^2)$ at 50 Pa. At the same time, the notional dwelling specification sets the airtightness level at $5 \text{ m}^3/(\text{h}\cdot\text{m}^2)$ at 50 Pa (Approved Document L1A, England & Wales), whereas, as stated in the Approved Document F1 “*through good design and execution, domestic and non-domestic buildings can currently achieve an air permeability down to 2 to 4 $\text{m}^3/(\text{h}\cdot\text{m}^2)$ at 50 Pa*” and additionally “*it can be anticipated that there will be a continual trend towards more airtight buildings due to drivers for higher energy efficiency and lower emissions*”.

⁶⁶ The Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions to be met by buildings and their location (Journal of Laws 2002 No. 75, item. 690, as amended)

⁶⁷ Available at: <http://www.boverket.se/globalassets/publikationer/dokument/2012/bbr-engelsk/bfs-2011-26-bbr-eng-9.pdf>

1.1.3 Indoor pollutants and other IAQ indicators

The standard EN 15251 states that one way of evaluating the indoor air quality is by measuring the average CO₂ concentration in the building where people are the main pollution source, when the building is fully occupied. The standard gives some general guidance on air quality and mentions the following numeric values for concentration of CO₂:

Table 8 - Examples of recommended CO₂ concentration above outdoor concentration for energy calculations and demand control (Source EN 15251)

Category	Corresponding CO ₂ above outdoors in ppm for energy calculations
I (High level of expectation - spaces occupied by very sensitive and fragile persons)	350
II (Normal level of expectation - for new buildings and renovations)	500
III (Moderate level of expectation - for existing buildings)	800
III (Moderate level of expectation - for existing buildings)	>800

Beside CO₂ concentration and humidity (see Chapter 2.1.3), there are no other generally accepted criteria and measuring methods for pollutants in EN 15251. Only if specific complaints (e.g. smell, sick building symptoms, etc.) persist and ventilation measurements show that the requirements for fresh air supply are met, should measurements of specific pollutants (e.g. formaldehyde, other Volatile Organic Compounds, fine dust (PM 10 or PM 2.5)) be made. How this should be done is outside the scope of EN 15251. Nevertheless, MS and international organisations, such as the World Health Organization, have partly defined their own inhomogeneous set of benchmarks.

BRUSSELS-CAPITAL REGION

Bruxelles Environnement, the public administration for environment and energy in the Brussels-Capital Region, reported the limit values established by the World Health Organization⁶⁸:

- For NO₂: 40 µg/m³ for continuous exposure, <200 µg/m³ for a maximum exposure of 1 hour;
- For SO₂: 50 µg/m³ for 1 year and 125 µg/m³ for 24 hours.
- For toluene: 260 µg/m³ in the home or 70 ppb calculated on a week (average value)
- For xylenes: 870 mg/m³ (0.2 ppm);
- For VOC: 100 µg/m³ for an exposure over 30 minutes (10 mg/m³ for sensitive people).

Further recommendations are:

- Provide an air quality level of at least INT3⁶⁹ (INT1 is recommended for an optimum level of comfort)⁷⁰.
- Select appropriate materials and construct new buildings / renovate buildings following appropriate procedures in order to avoid the production of pollutants. For an optimum level of comfort each material (even painting) should be selected according to its impact⁷¹.
- Encourage the use of fuel with a low concentration of sulphur (e.g. natural gas).

⁶⁸ <http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel04-eviter-les-polluants-interieurs.html?IDC=117&IDD=6167>

⁶⁹ According to Standard NBN EN 15251 (defines four levels of air quality where 2 is the average)

⁷⁰ Further details in the Guide for sustainable buildings elaborated by Bruxelles Environnement, recommendation G-WEL04 for avoiding the indoor pollutants available at: <http://guidebatimentdurable.bruxellesenvironnement.be/fr/thematiques.html?IDC=21&action=searchRecommandations-searchThemes>

⁷¹ Additional specifications regarding the recommendation about materials and labelling are provided at <http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel04-eviter-les-polluants-interieurs.html?IDC=117&IDD=6167>

DENMARK

Pollutants from building materials are regulated in BR 10 stating that building materials must not emit gases, vapours, particles or ionising radiation that can result in an unhealthy indoor climate. Therefore, building materials with the lowest possible pollutants' emission for indoor climate should always be chosen. For that reason, a labelling scheme for construction products, the Danish Indoor Climate Labelling scheme⁷², has been set up.

The Danish Working Environment Authority has issued special regulations to handle some building materials, such as those containing asbestos, mineral wool and fly ash, which must be complied with, whether the work is carried out for an employer or not.

BR 10 describes specific recommendations and benchmarks for a number of pollutants:

Formaldehyde-based construction products may only be used if the emission of formaldehyde does not give rise to an unhealthy indoor climate. WHO recommends that the total formaldehyde content of indoor air should not exceed 0.1 mg/m³. CE marking, which indicates a product's compliance with EU legislation, must show that the construction product is covered by class E1.

Materials containing **asbestos** are not to be used at all.

Mineral wool-containing materials with surfaces which are in contact with the indoor climate⁷³ must be installed in a safe manner, and the materials used must be durable and fit for purpose, such that they do not emit **mineral wool fibres** into the indoor climate.

Fly ash and slag from coal firing, used as a base for building, must be covered with a layer of gravel or similar, no less than 0.20 m deep and with a weight of 300 kg/m².

Oxides of nitrogen emitted to the indoor climate from combustion in cookers, central heating boilers etc. must be restricted by the removal of the flue gases.

Ingress of **radon** to the indoor climate must be limited by making the structure, which is in contact with the subsoil, airtight or by using other measures for an equal effect. According to international recommendations, a national reference level for existing dwellings between 100 and 300 Bq/m³ should be adopted. On this basis, the Danish Enterprise and Construction Authority recommends that simple and cheap improvements should be made to existing buildings when the radon level is between 100 Bq/m³ and 200 Bq/m³, and that more effective measures should be taken when the radon level exceeds 200 Bq/m³. New buildings must be constructed to ensure that the radon content does not exceed 100 Bq/m³.

Pollution from former refuse tips (waste recycling centre), gas works, polluted industrial sites etc., resulting in an unhealthy or unsafe indoor climate is not to be permitted.

Should the plot be developed without full prior remediation of pollution in the soil, the influx of soil pollution to the indoor climate must be limited by ensuring that the structure which is in contact with the subsoil is airtight and impermeable or by using other measures for an equal effect. In exceptional cases, where the plot, prior to construction work, is not remediated, partly for the protection of the groundwater and the upper layers of the subsoil, the municipal council may impose further requirements.

⁷² More information at: www.teknologisk.dk/dim

⁷³ This requirement does not apply to thermal insulation materials which are not directly connected to the indoor climate.

FRANCE

In France the fulfilment of the requirements for air ventilation in dwellings implies also compliance with air quality requirements for carbon monoxide in dwellings (Arrêté du 23 février 2009, first chapter, article 1). Additionally, asbestos has been prohibited since 1997⁷⁴; and for certain substances the limit is lower than 1µg/m³ (Arrêté du 30 avril 2009, Article 2):

- Trichloroethylene ("Trichloréthylène N° de CAS: 79-01-6")
- Benzene ("Benzène, n° CAS 71-43-2")
- Phthalate ("Phtalate de bis (2-éthylhexyle), n° CAS 117-81-7")
- Dibutyle phthalate ("Phtalate de dibutyle, n° CAS 84-74-2")

Concerning volatile compounds emissions, mandatory labelling of building products (valid also for existing buildings) was introduced with Decree n° 2011-321 of March 23, 2011. Moreover, according to the "Code de la construction, Article R*111-8" dwellings have to be protected from water infiltration, whereas French legislation does not include maximum/minimum values for carbon concentration or humidity in dwellings.

The CO₂ concentration in indoor places must be lower than 1 000 ppm⁷⁵.

GERMANY

There is no specific legislation including IAQ indicators for toxic particles. However, the national implementation of European's construction product regulation and further national standards address evaporation of unhealthy chemicals.

In Germany, NA 041-02-50 AA "Grundlagen" ("Fundamentals") from the Heating and Ventilation Technology Standards Committee (NHRS) at DIN is in charge of cooperation, implementation and development of national annexes to European Standards. The German annex for EN 15251⁷⁶ has been copied from VDI⁷⁷ 4706 "criteria for indoor air climate" where detailed specification can be found.

ITALY

Italian legislation does not define limit values for indoor air quality in residential buildings during occupancy. However, there are a few requirements addressing the avoidance of bad indoor air quality, such as:

- In the case of new constructions or renovated buildings, potential issues of surface or interstitial condensation have to be avoided and verified according to the national decree 59/2009⁷⁸.
- Based on a decree of the Health Ministry from October 2008, the maximum concentration of **formaldehyde** allowed is 0.1 ppm (0.124 mg/m³) for building products, and in particular for envelope elements made out of timber⁷⁹.
- For new dwellings the limit value of **radon emission** which has to be considered in the design phase is 200 Bq/m³⁸⁰.

⁷⁴ <http://www.territoires.gouv.fr/amiante>

⁷⁵ Règlement Sanitaire Départemental Type. Circulaire du 9 août 1978

⁷⁶ European Standard for Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

⁷⁷ Verein Deutscher Ingenieure

⁷⁸ Decree of the President of the Republic 59/2009, Article 4, comma 17.

⁷⁹ The test methodology and the related standards are defined in article 3.

⁸⁰ European Commission Recommendation 90/143/Euratom, article 3, letter b. No national legislation has been developed for dwellings while for workplace the Decree Law 241/2000 has been established. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1990:080:0026:0028:IT:PDF>

POLAND

The Regulation of the Minister of Health and Social Welfare 12 March 1996⁸¹ defines the limit values for indoor air quality in buildings in Poland.

The substances not allowed in building materials are: **acrylamide, acrylonitrile, asbestos, chloramine, carbon tetrachloride, cadmium** (as an additive to pigments), lead (as an additive to pigment)⁸², **ash** and **slag** from coal firing. Additionally, **chlorophenol, farbasol, ethylene glycol** and others are not allowed in buildings materials for internal use.

Benzene can be used in building materials only up to 0.1% of the mass, and other aromatic hydrocarbons, such as xylene, toluene, etylobenzene, etyloeksen, up to 20% of the mass. For the **chlorohydrocarbons** (other than carbon tetrachloride) the maximum share is 5% of the mass.

The maximum threshold for the use of radioactive substances in the building materials is specified by the following formula:

$$f = 0.00027 \cdot Sk + 0.0027 \cdot SRa + 0.0043 \cdot Sth \geq 1$$

The concentration of **radon** in building materials shall not exceed 185 Bq/kg.

In addition, the regulation sets the maximum levels of pollutant concentration in the indoor air (Table 9). Those are specified for two types of buildings:

- A) Residential buildings and other buildings /premises of permanent occupation of people
- B) Public buildings

Table 9 - Maximum concentration of selected pollutants in the buildings based In Poland⁸³

	Buildings type A	Buildings type B
Benzene	10 µg/m³	20 µg/m³
Trichloroethylene	150 µg/m³	200 µg/m³
Toluene	200 µg/m³	250 µg/m³
Xylene	100 µg/m³	150 µg/m³
Ozone	100 µg/m³	150 µg/m³
Carbon monoxide	3000 µg/m³	6000 µg/m³
(30 min concentration)	(10000 µg/m³)	10000 µg/m³

⁸¹ Regulation of the Minister of Health and Social Welfare (1996) on allowable concentrations and intensities of harmful factors given off by building materials, equipment and fittings in premises designed to accommodate people (Official Gazette of the Republic of Poland No. 19, item 231, 1996) (MP 1996 nr 19 poz 231)

⁸² Lead can be used in the buildings materials only as an anti-corrosion substance, with an exemption for buildings of food and agro industry.

⁸³ Ibidem

SWEDEN

Material and construction products used in the building shall not negatively affect the indoor environment or the surroundings of the building. Therefore, the Swedish Building Code sets down the following requirements for indoor pollutants that must be followed.

Gamma radiation in frequently occupied rooms must not be higher than 0.3 µSv/ h⁸⁴; and the annual average radon radiation must not be higher than 200 Bq/m³ ⁸⁵. Additionally, buildings and their installations shall be designed so that micro-organisms cannot affect the indoor air to the extent that there is harm to human health or bothersome odours. Furthermore, if **carbon** emission concentration in a room is greater than 1000 ppm, it should be considered as an indication that ventilation is not satisfactory (General recommendation by Public Health Agency referenced in BFS 2014:3 - BBR 21).

UK (ENGLAND AND WALES)

The Approved Document F1 (common for England and Wales) sets the following performance criteria for dwellings, as part of the recommended ventilation provisions to control moisture and pollutants:

- There should be no visible mould on external walls in a properly heated dwelling with a typical moisture generation.
- Exposure to NO₂ (nitrogen dioxide) should not exceed:
 - 288 µg/m³ (150 ppd) - 1 hour average
 - 40 µg/m³ (20 ppd) – long term average
- CO (carbon monoxide):
 - 100 mg/m³ (90ppm) – 15 minutes average time
 - 60 mg/m³ (50ppm) – 30 minutes average time
 - 30 mg/m³ (25ppm) – 1 hour average time
 - 10 mg/m³ (10ppm) – 8 hours average time
- TVOC (volatile organic compound): 300 µg/m³ average over 8 hours
- Control of bio-effluents for adapted individuals will be achieved by an air supply rate 3.5 l/s/person

Regarding the CO₂ levels in dwellings, a figure of 800-1000 ppm is often used as an indicator that the ventilation rate is adequate⁸⁶.

⁸⁴ BFS 2014:3 - BBR 21, 6:12. The same value should ("bör") bring to a further investigation according to FoHMFS 2014:16

⁸⁵ BFS 2014:3 - BBR 21, 6:23. The same value should ("bör") be considered as possible cause of damage to people according to FoHMFS 2014:16.

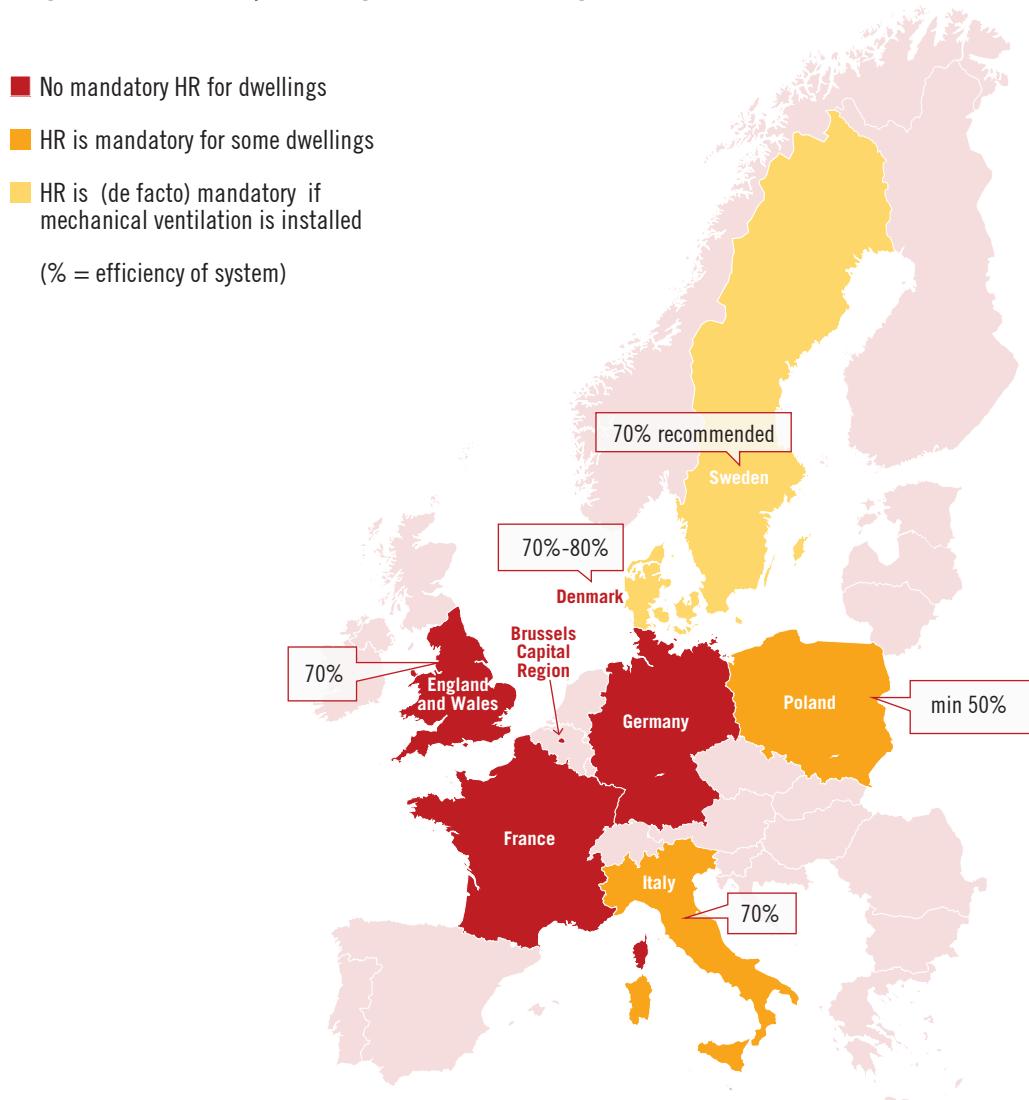
⁸⁶ Chartered Institution of Building Services Engineer, "CIBSE Guide B, 2005".

1.1.4 Heat recovery (HR)

Increasing the air exchange rate to improve IAQ may increase energy consumption, but this may be compensated by heat recovery. Requirements for heat recovery are rarely found in national building codes for dwellings. The EPBD Recast does not even mention it as an option to be considered. Most of the requirements identified refer to minimum efficiency in the case of new installations but not to a mandatory installation per se.

The following map provides a rough overview of the topic and some national background information is listed below.

Map 4 - Heat recovery (HR) requirements in Europe (Source: BPIE)



BRUSSELS-CAPITAL REGION

While heat recovery is not mandatory (unless a system with more than 5000 m³/h is installed), it is assumed for calculation purposes (in order to determine the heating energy net demand), irrespective of the type of ventilation system to be installed, that a reduction factor for air pre-heating equal to 0.32 is achieved unless a heat recovery device with performance greater than 80% is present⁸⁷. The performance of a heat recovery system is evaluated according to Annex G of Annex IX of the Governmental Decree of 21 February 2013. Annex G follows NBN EN 308 except for a few points listed in the annex.

⁸⁷ In other words, in the energy performance calculation methodology, a reduction factor of 0.32 corresponds to a performance of 80% with well-balanced flows to and from the heat recovery device.

DENMARK

Ventilation installations must include/combine heat recovery with a dry temperature efficiency of at least 70%⁸⁸. However, this requirement may be waived when the surplus heat from the exhaust air cannot be reasonably used. The heat recovery unit can be combined with a heat pump for heat recovery. This must have a minimum COP (coefficient of performance) of 3.6 in heating mode⁸⁹.

Ventilation installations that supply one dwelling must combine heat recovery with a temperature efficiency of no less than 80%. This provision also applies to the installation of equipment in each housing unit in multi-storey buildings.

FRANCE

The French legislation does not specifically require heat recovery systems for new dwellings. However, for new buildings or part of new buildings, air treatment for heating and cooling has to work in an "efficient way" (where heat recovery systems can be part of the solution). Specifically, an air cooling process cannot follow an air heating process (or the other way around) through the use of energy consuming devices, unless a heat recovery system is provided (Arrêté du 26 Octobre 2010, Article 29).

GERMANY

The use of heat recovery systems (at least category H3⁹⁰ according to DIN EN 13053: 2007-11) is only mandatory for the installation or replacement of very big ventilation systems ($> 4000 \text{ m}^3/\text{h}$ airflow). Therefore, there is de facto no requirement for heat recovery systems in residential buildings. Analysis from 2002⁹¹ pointed to much higher costs than what is economically feasible to make HR a requirement within EnEV. Nevertheless, heat recovery can be taken into account for EnEV calculations if:

1. Airtightness is verified through a blower door test;
2. The system guarantees a minimum air exchange rate.

Heat recovery does not count as a renewable energy source which is required for all new constructions to cover a certain percentage of heat energy demand, depending on the energy source⁹². Nevertheless, it counts as an alternative solution (compensating measure) if the system has:

- At least 70% degree of heat recovery;
- A coefficient of performance ("Leistungszahl") of at least 10.

ITALY

In the case of new or renovated heating systems combined with/ based on mechanical ventilation, heat recovery must be included according to the following table⁹³.

⁸⁸ The efficiency must be measured in accordance with DS/EN 308

⁸⁹ COP in heating mode must be documented in accordance with DS/EN 14511

⁹⁰ Classes of the heat recovery level and pressure loss. From H5 (no requirement) to H1.

⁹¹ BMVBS-Online-Publikation, Nr. 05/2012, « Untersuchung zur weiteren Verschärfung der energetischen Anforderungen an Gebäude mit der EnEV 2012 – Anforderungsmethodik, Regelwerk und Wirtschaftlichkeit”

⁹² Erneuerbare Energien Wärmegesetz

⁹³ Decree of the President of the Republic 412/1993, Article 5, comma 13 refers to annex C in the same decree.

Table 10 - Limit value of working hours of the mechanical ventilation per year (according to the airflow rate) for which a heat recovery system has to be introduced

G - air flow [m ³ /h]	M - working hours per years	
	From 1400 to 2100 degree days	Above 2100 degree days
2000	4000	2700
5000	2000	1200
10000	1600	1000
30000	1200	800
60000	1000	700

Note: linear interpolation has to be considered if the required range is not provided. (Decree of the President of the Republic 412/1993, annex C)

Regional and local regulations

In regions where mechanical ventilation is mandatory (for new buildings and deep renovations), it is usually associated with a minimum performance for the heat recovery systems. For example in the municipality of Divignano (Province of Novara, Piemonte Region) and in the municipality of Bottanuco (Province of Bergamo, Lombardia Region), mechanical ventilation with a heat recovery system with an efficiency not lower than 70% is required⁹⁴.

POLAND

Mechanical ventilation and/or air conditioning systems with a capacity of $\geq 500 \text{ m}^3/\text{h}$ should (if possible) be equipped with heat recovery from exhaust air (with the minimum temperature efficiency of 50%) or recirculation. It is not required for installations that are used less than 1 000 hours per year.

When using recirculation, the outdoor airflow cannot be less than the value calculated based on hygienic requirements. For ventilation in technological systems, the use of heat recovery should result from the technological and economic calculation.

Air conditioning wiring and pipes used for air recirculation and leading to the heat recovery equipment, as well as guide wires from outside air through heated spaces, shall have insulation against heat and damp.

SWEDEN

Only if the alternative validation method⁹⁵ of the energy demand for buildings is used and if the heated floor area is between 60 – 100 m², must the building be equipped with a heat recovery system or heat pump. In other buildings it is presumed that heat exchange is taken into consideration in order to fulfil the energy performance requirements. An efficiency of at least 70% is recommended for heat recovery systems.

UK

According to the Domestic Building Services Compliance guide⁹⁶, which came into force in April 2014, the heat recovery efficiency balance of mechanical ventilation systems incorporating heat recovery should be not less than 70%.

⁹⁴ http://www.legambiente.it/sites/default/files/docs/sito_onre_2013_min.pdf

⁹⁵ Implementation of the EPBD in Sweden. Available at: http://www.epbd-ca.org/Medias/Pdf/country_reports_14-04-2011/Sweden.pdf

⁹⁶ Domestic Building Services Compliance: http://www.planningportal.gov.uk/uploads/br/domestic_building_services_compliance_guide.pdf

1.1.5 Mechanical and natural ventilation

BRUSSELS-CAPITAL REGION

In Brussels-Capital Region both mechanical and natural ventilation systems can be installed; the same requirements apply for primary energy demand. Regarding ventilation in dwellings, Brussels legislation⁹⁷ refers to the NBN D50-001 standard which defines four approaches: natural ventilation (systems A), single flow controlled mechanical ventilation (CMV) provided for inlet flow (systems B) and outlet flow (systems C), as well as double flow controlled mechanical ventilation (systems D)⁹⁸. Furthermore, there is a distinction between continuous ventilation (“base ventilation”) and intermittent/periodic ventilation (“intensive ventilation”) which is needed in case of overheating or pollutant activities and – according to the standard NBN D50-001 – requires the presence of openings (windows or external door) in kitchens, dining rooms and bedrooms. Moreover, in open kitchens, systems A are not allowed unless a hood with ventilation is installed.

The guidelines written by Bruxelles Environnement suggest introducing passive systems for cooling⁹⁹. In order to provide a good quality for indoor air, it is suggested to introduce a single flow CMV over natural ventilation, although double flow CMV is suggested for an optimum level of indoor air¹⁰⁰.

DENMARK

Single-family houses may use natural or mechanical ventilation. It is assumed that people in one-family houses open the windows, have ventilation openings etc., so a good indoor climate can be obtained even without a mechanical system. Apartments in multi-storey buildings must be mechanically ventilated. Mechanical ventilation is mechanical exhaust, mechanical supply and heat recovery.

FRANCE

Neither regulations for ventilation nor RT 2012 impose a mechanical ventilation system for residential buildings. Generally, natural ventilation, mechanical ventilation and hybrid ventilation are allowed¹⁰¹. Specifically, for overseas departments (Guadeloupe, Guyana, Martinique, Reunion and Mayotte), natural ventilation has to be prioritised for dwellings and new parts of dwellings¹⁰².

GERMANY

As the Reference Building is a non-binding description, mechanical ventilation systems are not obligatory, but indirectly recommended by the government¹⁰³. In terms of energy performance calculation, both systems are treated equally.

⁹⁷ Annex VI of the Decree of the 21 December 2007.

⁹⁸ In the legislation these types are usually labelled with the letter A (natural ventilation), B (CMV for inlet flow), C (CMV for outlet flow) and D (double-flow CMV).

⁹⁹ http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel02-assurer-le-confort-thermique-au-sein-du-batiment-durable.html?IDC=1059&ID_D=4559&querySearch=G_WEL02

¹⁰⁰ <http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel05-assurer-le-confort-respiratoire-au-sein-du-batiment-durable.html?IDC=117&IDD=4480>

¹⁰¹ Th-BCE 2012, 8.7

¹⁰² Code de la construction, article *R162-4.

¹⁰³ Die Begründung der Bundesregierung zum Entwurf der EnEV 2009 (Bundesrats-Drucksache 569/08, S.109) führt zu Anlage 1 Tabelle 1 Zeile 8 aus:

„Eine Abluftanlage ist in der Energiebedarfsbilanz gegenüber der Fensterlüftung (kontrollierte Stoßlüftung) gleichwertig, zur Vermeidung von Feuchteschäden und Schimmelpilzbildung als bauphysikalisch sinnvoll anzusehen.“

The calculation methods Standard DIN V 4701-10 and DIN V 18599 allow a differentiated approach. DIN V 4701-10 (old method restricted to residential buildings) allows calculations for buildings where the apartments or even single rooms are equipped with different ventilation systems (including natural ventilation). Due to the legal restrictions to consider the partial equipment of a building with heat recovery systems, this provision of the standard might not be frequently applied in practice. The same is possible in calculations carried out by the new method according to DIN V 18599. Since the Energy Saving Ordinance prescribes residential buildings to be calculated as "Single Zone Model", in both cases a differentiation of the conditions of use – including total air-exchange rates – is not possible.

A mix of natural and mechanical ventilation might be possible in theory, but is not easy to calculate due to the influence of infiltration, which is influenced by the pressure-balance in the case of mechanical ventilation.

ITALY

At national level, the Decree of the President of the Republic 59/2009 (Article 4, comma 18, letter c) leaves much freedom for the planner regarding the ventilation design. However, it recommends natural ventilation and - if not sufficient - effective mechanical ventilation to be considered for new buildings and deep refurbishment¹⁰⁴. Nevertheless, mechanical ventilation is mandatory for new construction and deep renovations in at least 105 regional building regulations all over Italy, according to the "ON-RE report" published in 2013¹⁰⁵.

Hybrid ventilation is included in standard series UNI TS 11300 (listed in Legislative Decree 192/2005) as well as in some voluntary sustainability protocols (e.g. ITACA) and in some building regulations (e.g. Bologna).

POLAND

The Regulation of the Minister of Infrastructure – dated April 12, 2002 on the technical conditions to be met by buildings and their location (Art 147)¹⁰⁶ – specifies the conditions of use of mechanical and/or natural ventilation in buildings.

In every occupied room, there is a requirement to use appropriate mechanical or natural ventilation. The mechanical, exhaust and supply/exhaust ventilation is obligatory in high-rise buildings (>25m, >9 storeys) and in buildings where the adequate quality of the indoor environment is not possible by means of natural ventilation. In all the other buildings, the use of natural and hybrid ventilation is permitted.

Hybrid ventilation and mechanical ventilation should have an adjustable performance fan.

In rooms where mechanical ventilation or air conditioning (AC) is provided, natural or hybrid ventilation should not be used. In other words, the use of natural and mechanical ventilation in ventilated rooms is prohibited. This requirement does not apply to rooms with air conditioning equipment with no uptake of outside air.

For the stream of air flowing through the fully open diffuser, the pressure difference on both sides of 10 Pa, should be within certain limits¹⁰⁷:

- From 20 to 50 m³/h, for natural ventilation
- From 15 to 30 m³/h, for mechanical ventilation

¹⁰⁴ Decree of the President of the Republic 59/2009, Article 4, comma 18, letter c.

¹⁰⁵ http://www.legambiente.it/sites/default/files/docs/sito_onre_2013_min.pdf

¹⁰⁶ The Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions to be met by buildings and their location (Journal of Laws 2002 No. 75, item. 690, as amended)

¹⁰⁷ PN-B-03430:1983/Az3:2000

SWEDEN

The required airflow of 0.35 l/(s·m²) can be ensured via mechanical or natural ventilation. Boverket, the National Board of Housing, Building and Planning, published a handbook on natural ventilation in 1995 that can be used for guidance by developers, planners and building committees¹⁰⁸. The demands are functional, so authorities do not mind hybrid ventilation as long as an airflow of 0.35 l/(s·m²) can be ensured.

UK (ENGLAND & WALES)

The ventilation strategy adopted in Approved Document F¹⁰⁹ ("Means of Ventilation") suggests natural ventilation, a mechanical ventilation system or a combination of both (i.e. mixed mode or hybrid ventilation system).

For mainly naturally ventilated buildings, it is common to use a combination of ventilators. For example, in dwellings it is common to use intermittent extractor fans for extraction ventilation, trickle ventilators for whole dwelling ventilation and windows for purge ventilation. For mechanically ventilated or air conditioned buildings, it is common for the same ventilators to provide both local extraction and whole building/ dwelling ventilation.

1.2 IAQ in existing dwellings

Summary of findings

- Strict and legally-binding requirements, such as minimum ventilation rates, airtightness or limitation of pollutants, can hardly be found in the analysed building codes.
- Most references to IAQ aspects are recommendations.
- Energy efficiency improvements do often apply without mandatory consideration of the (negative) influences in terms of building physics or indoor air quality.
- Generally, renovation measures resulting in more airtight buildings are not accompanied by a compulsory assessment of ventilation needs. Therefore, in many such situations air change rates below the required values are reported.
- Swedish law is unique as it points to the potential conflicts between energy saving requirements and good indoor air quality in existing buildings. Good indoor air quality has priority.

BRUSSELS-CAPITAL REGION

In the case of renovations which include the suppression or the replacement of windows, the requirement of intensive ventilation of Annex VI of the Government Decree on December 21, 2007 has to be met (see new buildings). Overall energy performance requirements (including airtightness) are not requested unless renovation measures concern 75% of the surface of loss ("superficie de déperdition") and include the replacement of all technical installations. In that case, the overall energy performance requirements

¹⁰⁸ BFS 2014:3 - BBR 21. The handbook is mentioned in section 6:251 (airflow) and 6:9241 (ventilation flow)

¹⁰⁹ Approved by the Secretary of State to provide practical guidance on ways of complying with the requirements (...) of the Buildings Regulation.
Available at: http://www.planningportal.gov.uk/uploads/br/BR_PDF_ADF_2010.pdf

of new PEB units apply with a multiplication factor of 1.2 except on the overheating limit¹¹⁰. Additionally, the ventilation requirements mentioned for new buildings (Standard NBN EN 15251) can also be used in the case of renovation.

DENMARK

Buildings in general must be ventilated. Ventilation systems must be designed, built, operated and maintained so that they achieve no less than the intended performance while in use. Provisions which address health-related factors, such as the ventilation provisions, must be complied with throughout the building's lifetime.

Existing buildings have to fulfil requirements according to the building codes in force when the building was built. The first national building code came into force in 1961. Since then, Denmark has had about 10 codes and the requirements regarding ventilation have changed over the years. One requirement that has been rather constant, although expressed in various ways, is that the air change rate should be about 0.5 h^{-1} .

In the case of renovation, it may be that some requirements in BR 10 have to be fulfilled, but it depends on the character and the extent of the renovation.

FRANCE

"Arrêté du 24 mars 1982" on the ventilation of housing specifies the airflow requirements for dwellings and does not restrict the application of these requirements to new buildings only. In any case, how ventilation is ensured is not specified. A guidance document «La ventilation», n° 3672 published by ADEME (the French energy agency) states that "it is difficult to control airflow by natural ventilation".

In order to reduce the potential sources of pollutants, the same requirements for new buildings apply for building products. In existing buildings, the presence of asbestos has to be eventually identified, monitored and treated (depending on the situation¹¹¹) in order to protect the occupants¹¹².

Moreover, in the case of the rent or sale of a dwelling built before January 1, 1949, an evaluation of risk exposure to lead has to be made¹¹³. Generally, for all buildings, if during building works a concentration of lead higher than $1000 \mu\text{g}/\text{m}^2$ is detected, further measurements are required¹¹⁴. Additionally, the alteration of building elements may require a risk evaluation of exposure to lead¹¹⁵.

In the case of new transparent surfaces, they must be equipped with air intakes, except when the building is already equipped with air intakes or with mechanical ventilation. The total air rate allowed by these intakes should be at least $45 \text{ m}^3/\text{h}$ for rooms and $90 \text{ m}^3/\text{h}$ for living rooms.

Regarding heat recovery, no requirements apply for existing buildings.

GERMANY

For refurbishments where more than 1/3 of windows are replaced or more than 1/3 of the roof area (applies only to single-family homes) is refurbished, a ventilation concept needs to be considered according to the technical standard DIN 1946-6 (details in § 1.1.1 Ventilation rates).

¹¹⁰ Decree of the 21st of December 2007, article 15

¹¹¹ Main responsibilities of the owners are listed by the government. http://www.territoires.gouv.fr/IMG/pdf/tableau_obligations_amiante_des proprietaires.pdf

¹¹² Décret n° 2011-629 du 3 juin 2011

¹¹³ Arrêté du 19 août 2011

¹¹⁴ Arrêté du 12 mai 2009, article 6

¹¹⁵ "Arrêté du 25 avril 2006 relatif aux travaux en parties communes nécessitant l'établissement d'un constat de risque d'exposition au plomb"

For all the other cases, there are no specific guidelines beside the general requirement to provide a healthy indoor air climate. It is a great responsibility for the planner and architect to provide the right recommendation on whether a (mandatory) energy saving measure requires additional changes in order to protect the fabric and the occupants' health.

Additionally, the modification of the building must not lead to lower energy performance than before the change.

ITALY

The standards on ventilation used for new buildings are also valid for existing buildings. Furthermore, in some regions additional requirements for heat recovery may apply.

POLAND

In Poland, the same ventilation rates' general rules and recommendations apply for new and existing buildings.

SWEDEN

The Swedish Environmental code is valid for all residential buildings. Therefore, existing buildings should also try to fulfil the following requirement as much as possible: a minimum outdoor airflow of $0.35 \text{ l/m}^2\text{s}$. This requirement should be applied according to the case.

In the case of alteration of any part of a building, the building code regulations need to be fulfilled. According to these regulations, the size of the alteration needs to be taken into account (if there is only one window then this window will have to comply). The possibilities of the building will also be considered. For example, when a window needs to be replaced, the historical value of the building can restrict the choice of windows.

The modification of a building must not lead to lower energy performance unless there are exceptional circumstances. Exceptional circumstances can exist when other requirements have to be fulfilled such as providing a good indoor environment¹¹⁶. Alternative solutions may not comply with new building requirements, however it should be demonstrated that an alternative approach can fulfil the requirement for a good air quality¹¹⁷. When modifying a building, materials negatively affecting the indoor environment should be removed or their impact be reduced¹¹⁸.

UK (ENGLAND & WALES)

There are no specific requirements (ventilation rates, airtightness, etc.) for existing buildings. The general requirement based on The Building Regulations 2010 is as follows:

When building work is carried out on an existing building, the work shall comply with the applicable requirements of Schedule 1- Building Regulations 2010 (i.e. requirements applying to all new dwellings), and the rest of the building should not be made less adequate in relation to the requirements than before the work was carried out.

¹¹⁶ BFS 2014:3 - BBR 21, 9:91. Planning and Building Regulation 2011-338 (chapter 3, paragraph 14) specifies also that both low energy consumption and satisfactory thermal comfort have to be guaranteed.

¹¹⁷ BFS 2014:3 - BBR 21, 6:9241. Air quality requirements may also demand a different approach for existing buildings according to the general advice in section 6:924.

¹¹⁸ BFS 2014:3 - BBR 21, 6:911 (materials in case of alteration of buildings, unless there are exceptional reasons to keep them).

2 THERMAL COMFORT

2.1 Thermal comfort in new dwellings

Thermal comfort is strongly linked to environmental factors such as air temperature, humidity and air velocity as well as to personal factors (clothing insulation, metabolic heat)¹¹⁹. Unfortunately, it is impossible to create a thermal indoor climate where everybody is satisfied, since everyone's has a different temperature perception. It is generally recognised that even for a perfect building scenario it is almost impossible to have less than 5% of occupants dissatisfied. The international standard EN ISO 7730¹²⁰ addresses this topic and provides methods to predict the general thermal sensation and degree of discomfort of people by using two methods:

- **PMV (Predicted Mean Vote)**
- **PPD (Predicted Percentage of Dissatisfied)**

The PMV predicts the mean value of the thermal votes for a large group of people subjected to the same environmental conditions. The PPD determines how many occupants will fall outside the limits of comfort, and thus determines how many are thermally dissatisfied, feeling too cold or too warm.

Thermal comfort is defined in EN ISO 7730 as "that condition of mind which expresses satisfaction with the thermal environment".

Aspects of thermal comfort related to low temperatures or draught are often improved by measures primarily aimed at improving the energy performance of a building. Such benefits have the potential to become one of the first sales arguments when it comes to energy efficiency investments in new or existing buildings. Moreover, despite the fact that indoor thermal comfort and health are important topics in the fuel/energy policy debates which is a serious problem in many EU countries, only few of them put it as a priority on the policy agenda (e.g. the UK, Ireland, France, etc.)¹²¹. Furthermore, there is an increasing risk of overheating which has to be addressed. Therefore, thermal comfort should be acknowledged in building regulations and the use of simple and efficient measures, e.g. solar shading, solar protective glazing and ventilative cooling should be encouraged.

WHY IS THERMAL COMFORT IMPORTANT?

- Between 30% and 50% of excess winter deaths can be attributable to cold indoor temperatures*.
- Excess heat negatively affects the health of people suffering from cardiovascular diseases, diabetes, Parkinson's, Alzheimer's and epilepsy**.
- Excess cold and mould in homes lead to asthma/respiratory illness and affects negatively the mental health of the occupants***.
- Children's educational attainment and emotional wellbeing can be affected by thermal discomfort****.

* WHO: "Environmental burden of disease associated with inadequate housing"

** Ormandy D, Ezratty V: "Health and thermal comfort: From WHO guidance to housing strategies"

*** BPIE: "Alleviating fuel poverty in the EU. Investing in home renovation, a sustainable and inclusive solution"

**** WHO: "Health in the green economy. Co-benefits to health of climate change mitigation, Housing Sector"

¹¹⁹ "Thermal Comfort, The six basic factors", Health and Safety Executive. Available at: <http://www.hse.gov.uk/temperature/thermal/factors.htm>

¹²⁰ "Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria"

¹²¹ More information on the fuel poverty situation in the EU countries can be found in the BPIE study "Alleviating fuel poverty in the EU. Investing in home renovation, a sustainable and inclusive solution" (2014) Available at: http://bpie.eu/fuel_poverty.html

Summary of findings:

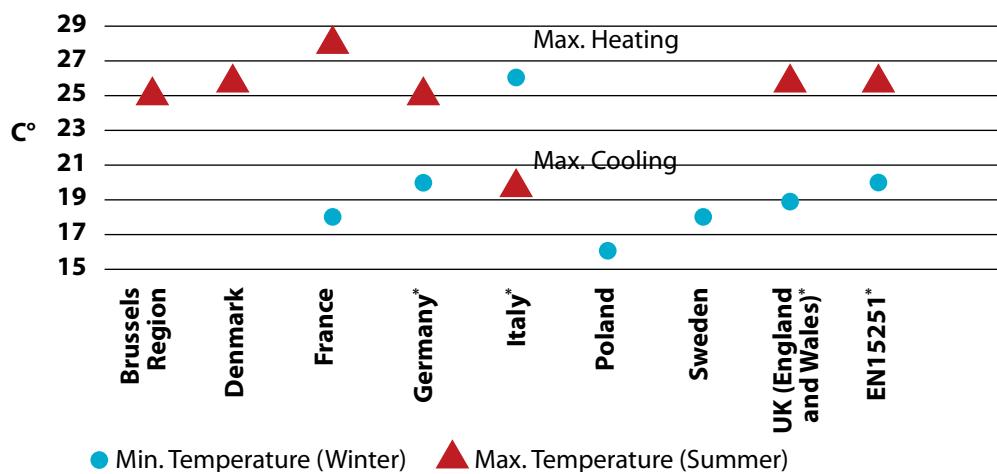
- All countries studied introduced minimum requirements for the thermal transmittance of external building elements but only some of them (Denmark, Sweden) underline the co-benefits of thermal comfort;
- The most commonly used indicator of thermal comfort is the indoor air temperature, where requirements/recommendations range between 16°C (Poland, winter case, lower limit of indoor temperature) and 28°C (France, summer case, upper limit of indoor temperature). In some countries (e.g. France, the UK), operative temperature is also used to assess thermal comfort;
- 5 (out of 8) countries introduced a limit on overheating (Brussels, Denmark, France, Germany, the UK), where overheating indicators differ by temperature and time limit. Extremes are: Brussels with >25°C for 5%/year and the UK with >28°C for 1%/year, but only as a recommendation in the latter case (by the Chartered Institution of Building Services Engineers);
- 4 (out of 8) countries require minimal temperatures in dwellings in winter (France, Germany, Poland, Sweden);
- Only Italy demands a lower limit in summer (max. cooling) and upper limit in winter (max. heating);
- Passive systems to avoid overheating are common in southern climates (Italy and France), but minimum requirements are mainly limited to solar shades and only Italy has a requirement on thermal mass for buildings in the warmer parts of the country. Additional measures, such as solar protective glazing, use of building mass, natural ventilation, night time ventilation etc. need further promotion within European legislation;
- Sweden explicitly asks to consider different passive solutions;
- Leading examples in Europe are the French indicator "TIC" (Indoor Conventional Temperature) and the German "Sonneneintragskennwert" (Solar Transmittance Value) which take several (passive) aspects into account;
- Sweden is unique in requiring a minimal surface temperature of floors, which differs depending on the type of room;
- Denmark is the only country requiring minimal solar gains in winter in case of new buildings and major refurbishment;
- Maximum relative air velocity limits are inconsistent in Europe. They range from 0.15 to 0.40 m/s (in summer) and from 0.15 to 0.21 m/s (in winter). In most countries, the relative air velocity does not depend on the air temperature;
- Maximum values for air velocity to avoid draughts are required in Sweden and recommended in Denmark, Italy, Poland, the UK and Brussels (from 2015);
- Recommendations concerning the humidity (in order to avoid water condensation or an air too dry) are given in Germany, Poland, Italy, Sweden and the UK (soft reference).

2.1.1 Minimal and maximal temperature requirements

Temperature is the most significant component to assess the level of comfort in a room. Typically when people refer to temperature, they mean the air temperature. However, the experience of thermal comfort depends on more than simply air temperature. When assessing thermal comfort, we must examine both the general room temperature, as well as the uneven distribution of heat in the room and radiation.

The following picture provides an overview of the national requirements or recommendations related to minimal and maximal indoor air temperature. Details per country will be explained in the section below.

Figure 1 -Temperature requirements in Europe (Source: BPIE)



*Germany: up to 27°C in summer, depending on the region (from 25°C to 27°C)

Italy: heating and cooling limits to reduce energy consumption (no thermal comfort indicator)

Sweden: values vary depending on the occupant group

UK: values vary depending on the room use

EN 15251: recommended design values

BRUSSELS-CAPITAL REGION

Starting from January 2015, overheating (defined as temperatures of more than 25 °C) has to be limited to 5% of the time during the year¹²². For an optimum level of comfort Bruxelles Environnement recommends the stricter value of 3%. Until end of 2014, each unit has to meet the requirement to limit the risk of overheating described in Chapter 8 of Annex II.¹²³

Additional recommendations from Bruxelles Environnement are:

- The level of comfort provided shouldn't be higher than the one requested by regulation.
- The maximum difference between internal and external temperature should be between 5°C and 7°C (in summer).
- An optimum level of comfort should also be guaranteed introducing devices on which you can select different temperatures per areas and time.

For new buildings, the PEB (Building Energy Performance) regulation takes into account systems such as solar protection. Active cooling is only required if the overheating indicator is higher than 6500 Kh (Kelvin-hour). On the contrary, if the overheating indicator is less than 1000 Kh, active cooling is not needed.

¹²² Decree of 21 December 2007, article 10 ter/2nd (for dwellings) and article 10 quinquies/5th (for offices and educational buildings)

¹²³ Decree of 21 December 2007 (articles 7 and 21 bis) amended by decree on 21st of February 2013

In order to meet the passive contribution, it is recommended to provide efficient solar shading ($g < 0.5$) for glazing surfaces larger than 4 m^2 facing the sun. Moreover, if free cooling or night ventilation are not feasible (regarding energy consumption), other passive systems should be foreseen.

DENMARK

As far as the thermal indoor climate is concerned, the planning of buildings and the choice of materials, window areas, cooling options, orientation and solar screening must ensure that satisfactory temperature conditions are achieved, even in summertime. Therefore, minimum insulation requirements are not only a response to the requirement for energy savings, but also a means to provide comfort and avoid the risk of condensation. Moreover, the building code sets down component requirements to eliminate the risk of mould growth due to cold surfaces. However, it is not possible to construct a building and meet the overall energy requirements (energy frame) solely by fulfilling these minimal component requirements.

Functional requirements and methods of specification, verification and monitoring of the thermal indoor climate are described in the DS 474 Danish Code for Indoor Thermal Climate, as well as in the International DS/EN ISO 7730.

According to DS 474 appropriate indoor temperatures are:

- Not more than 100 hours above 26°C ;
- Not more than 25 hours above 27°C .

The sanction for overheating is calculated by a fictive energy use, equal to the energy used by an imaginary mechanical cooling system that keeps the indoor temperature at 26°C ¹²⁴, so it is easy to quickly see the effect of shading systems and other cooling systems. Moreover, the maximum hours above a certain temperature are calculated by the Danish compliance tool Be10, which has been developed (SBI, 2011) to calculate the energy performance in buildings and ensure that the energy requirements have been met.

Concerning the energy balance through roof lights, the energy gains from 2015 should not be less than 0 kWh/m 2 /year.

FRANCE

The French indicator TIC (Indoor Conventional Temperature) expressed in $^\circ\text{C}$ is the maximum operative temperature ensuring comfort during the hot season while avoiding recourse to air conditioning systems. The principle is simple: comfort temperature levels in summer are defined through a reference indicator Ticref that should not be exceeded over more than 5 consecutive days. The Tic_{ref} is calculated by the method of Th-2012 BCE approved by a decree of the Minister of Construction and Housing and the Minister for Energy. The parameters to be considered are set out in Annex XI¹²⁵.

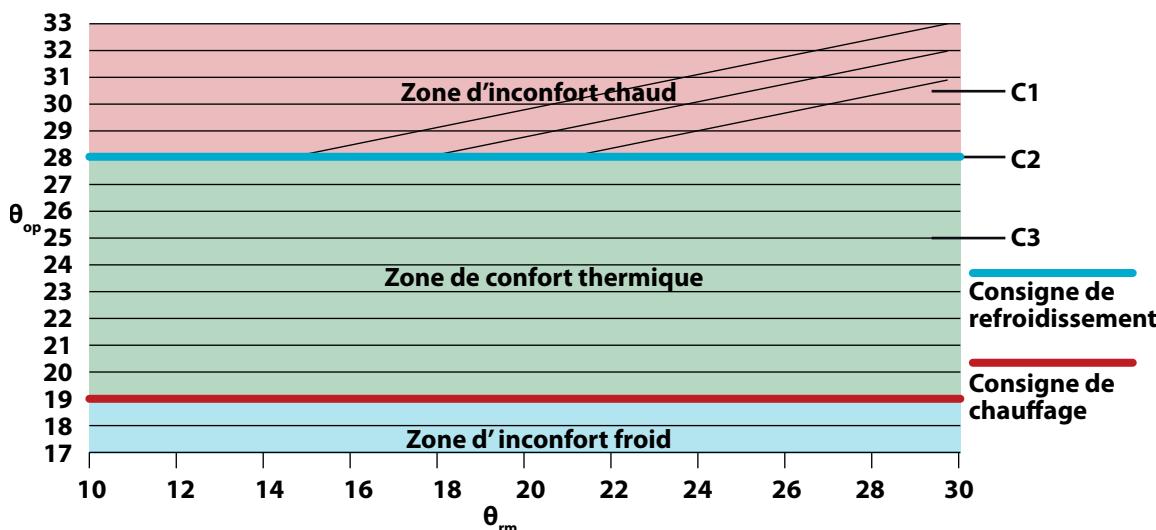
The value of the maximum comfort temperature is the same throughout the year when a mechanical system is used (28°C), while in the case of natural ventilation, different limit values are established according to the type of building and external temperature (Figure 2)¹²⁶.

¹²⁴ EPBD Country Reports

¹²⁵ Annexe XI de l'arrêté du 26 Octobre 2010 et de l'arrêté du 28 Décembre 2012

¹²⁶ Th-BCE 2012, sections 6.2.1 and 6.2.3.2.1

Figure 2 - Minimum and maximum temperature of comfort (vertical axis) according to external temperature (horizontal axis) and type of building (categories C1, C2 and C3)



In addition, the French Energy Code¹²⁷ requires certain comfort temperatures which have to be guaranteed by heating or cooling systems. Moreover, all accommodation within a residential building must be heated and hot water provided with limited energy expenditure, under the conditions laid down by the Construction Code, Article R * 111-20.

Heating equipment in **all housing** must maintain a minimum of 18°C at the centre of the housing parts. It must also include individual temperature controls allowing the heating provided to occupants to reach a minimum temperature of 18°C¹²⁸.

Regarding the energy performance of separating walls (between continuously occupied zones and temporary occupied zones), the maximum thermal transmittance is 0.36 W/m²·K¹²⁹.

Window openings and automated systems are taken into account for ventilative cooling and algorithms based on indoor and outdoor temperature sensors can be used to reduce the indoor temperature in regulatory thermal studies. The windows of any of the premises used to sleep and included in the CE1 category of buildings¹³⁰ have to be equipped with mobile solar shades, so that the solar factor¹³¹ is less than or equal to the solar factor defined in the table below¹³².

Table 11 - Shades requirements according to climate zone, altitude and solar factor¹³³

Climate zone	Altitude	
H1a and H2a	All	
H1b and H2b	>400 m	≤=400 m
H1c and H2c	>800 m	≤=800 m
H2d and H3	>400 m	≤=400 m

¹²⁷Article L241-1 of the "Code de l'énergie, Partie législative, Livre II (la maîtrise de la demande d'énergie et le développement des énergies renouvelables)", titre iv (les installations de chauffage et de climatisation)"

¹²⁸Code de la construction, article R111-6.

¹²⁹Arrêté du 26 octobre 2010, Article 18. Specific requirements related to thermal bridges are defined in article 19

¹³⁰Roughly, CE1 category includes all buildings apart from dwellings, schools and office buildings located in noisy areas in the hottest regions of France.

¹³¹Expressed as a number between 1 and 0, where 1 indicates the maximum possible solar heat gain, and zero, no solar heat gain.

¹³²Arrêté du 26 octobre 2010, Article 21

¹³³Arrêté du 26 octobre 2010, Article 21

Openings exposed to noise at BR1 level ¹³⁴			
Orientation	Solar factor		
North	0.65	0.45	0.25
Other directions	0.45	0.25	0.15
Horizontal (roof windows)	0.25	0.15	0.1

Openings exposed to noise at BR2 or BR3 levels			
Orientation	Solar factor		
North	0.45	0.25	0.25
Other directions	0.25	0.15	0.15
Horizontal (roof windows)	0.15	0.1	0.1

GERMANY

In summertime, the EnEV requires a building to be in line with an indicator for maximum solar gains ("Sonneneintragskennwert") calculated according to DIN 4108 -2.

Maximum solar gains to avoid overheating for more than 10% of the time (under standardised conditions) have to be checked for each room, depending on the climatic region (A,B,C), the thermal capacity of the building (light, middle, heavy), the use of night ventilation, the window tilt, and more. Therefore, the recommended indoor air temperature is limited at 25°C, 26°C and 27°C for climatic regions A, B and C respectively.

For single-family homes and semi-detached houses no calculation is required if shading elements (e.g. blinds) (reduction rate $F_c \leq 0.3$) are installed or a maximum share of window area is not exceeded: roof windows, 7%, other windows, 10% (south, west, east) or 15% (north) in relation to the floor space.

According to DIN 4701-10, the temperature in apartments should be able to reach at least 20°C and 22°C in bathrooms. Landlords are in charge of providing appropriate technical equipment for new and existing dwellings. There were court cases for apartments that were too cold, leading to a court decision of significant rent reductions.

ITALY

In Italy, minimal and maximal temperatures are required in order to limit the waste of energy for cooling and heating. In detail, cooling systems have to be limited to 26°C (with -2°C of tolerance)¹³⁵ in summer. The temperature provided by heating systems during winter needs to be limited in each building unit to 20°C (with +2°C of tolerance)¹³⁶. Other temperature requirements for the sake of thermal comfort do not exist. However, control devices for indoor temperatures in single rooms or zones are mandatory in the case of new or modified thermal systems¹³⁷.

¹³⁴ Noise exposition class (BR, "classe d'exposition au bruit") is defined in annex II of "Arrêté du 26 octobre 2010".

¹³⁵ Decree of the President of the Republic 74/2013, Article 3

¹³⁶ Decree of the President of the Republic 74/2013, Article 3

¹³⁷ Decree of the President of the Republic 59/2009, Article 4, comma 21

Regarding the control of temperature variations, the designer has to verify, for new buildings and deep refurbishments, that¹³⁸:

- For all walls (excluding the ones facing north), the periodic thermal transmittance YIE must be lower than 0.12 W/m²·K or the surface thermal mass must be higher than 230 (kg/m²)¹³⁹.
- For all floors and roofs the periodic thermal transmittance YIE must be lower than 0.20 W/m²·K.

The above-mentioned requirements are valid for buildings which are not in climate zone "F" and where the maximum (summer) irradiance value for the selected location is not lower than 290 W/m². Moreover, alternative systems (e.g. green roof) can be used to achieve the same results provided that appropriate documentation and certification can demonstrate equivalent fulfilment of the requirements.

External shades¹⁴⁰ are mandatory for new buildings and deep refurbishments; and may be omitted if a technical report on economic unsustainability is provided and if the windows have a solar factor (defined in the standard UNI EN 410) not higher than 0.5.

Regional and local regulation

Some regional legislation has explicitly defined the minimum percentage of window surface for which shades have to be provided (Table 12). In 324 Building Regulations shading for windows with orientation to south-east/south-west are required¹⁴¹.

Table 12 - Minimum percentage of shades for selected regions (Source: ON-RE 2013 Report)

	Percentage of shades per windows area	Reference Legislation
Piemonte	70%	L.R. n. 13 del 31/05/07, DGR 4/8/2009 n. 45
Liguria	70%	L.R. n. 22 del 29/05/2007, Rr 6/07 e L.R. n. 16 del 2009
Emilia-Romagna	50%	Delibera del Consiglio Regionale n. 156 del 04/03/08. Delibera di Giunta n.1362 del 20/9/2010
Lombardia	70%	Delibera della Giunta Regionale n. 8/8745 del 22/12/08
Trento Province	100%	L.P. n. 1 del 04/03/08. D.P.R. 2/4/2009 n. 59. D.G.P del 17/6/2010
Bolzano Province	100%	D.P.R. 29/9/2004. Delibera n. 2189 del 30/12/2010

For new buildings or deep refurbishment, the thermal transmittance of common walls must not be higher than 0.8 W/m²K¹⁴².

New buildings, refurbishments and extensions have to comply with winter energy performance requirements (affecting indirectly the indoor comfort)¹⁴³. The contribution of dynamic shading systems can be included in the calculation of the energy needs for cooling¹⁴⁴ as long as the energy performance of the shading is class 2¹⁴⁵.

¹³⁸ Decree of the President of the Republic President 59/2009, Article 4, comma 18.

¹³⁹ Surface mass is defined in Legislative Decree 192/2005, annex A, comma 29. It includes mortar joints but not plaster.

¹⁴⁰ Decree of the President of the Republic President 59/2009, Article 4, comma 19.

¹⁴¹ ONRE Report. http://www.legambiente.it/sites/default/files/docs/sito_onre_2013_min.pdf

¹⁴² Decree of the President of the Republic 59/2009, Article 4, comma 16.

¹⁴³ Decree of the President of the Republic 59/2009, Article 4, comma 2.

¹⁴⁴ UNI 11300

¹⁴⁵ Law 9 of 21 February 2014, article 1, comma 8-bis; the Italian standard UNI EN 14501:2006 classifies shadings according to their performances. Shadings are also defined in Legislative Decree 192/2005, Annex A (about definitions), comma 45

POLAND

In Poland, heating equipment should allow users to obtain an indoor temperature lower than the value specified by legislation, but cannot be lower than 16°C (for rooms with a temperature of 20°C and above, as specified in the legislation). Additionally, buildings should be designed and constructed in such a way that they reduce the risk of overheating in the summer¹⁴⁶.

In residential buildings, the surface area of windows and other transparent surfaces ($u \geq 0.9 \text{ W/m}^2/\text{K}$) shall not be greater than calculated from the following equation:

$$A_{omax} = 0,15 A_z + 0,03 A_w$$

Where:

- A_z is the sum of the horizontal of all the floors above ground (in the outer contour of the building) in a strip width of 5 m along the walls;
- A_w is the sum of the remaining areas of the horizontal projection of all floors after deducting A_z .

In all kind of buildings, solar gains (g) are calculated as a product between the solar gains of the window type (Table 13) and the solar protection ratio of the shading system (Table 14). In summer season, solar gains cannot be higher than 0.35.

Table 13 - Solar gains per window type

Window type	Solar gains (g_s)
Single glazing windows	0.85
Double glazing	0.75
Double glazing with selective coating	0.67
Triple glazing	0.7
Triple glazing with selective coating	0.5
Double-window	0.75

Table 14 - Solar protection ratio of the shading system

Type of solar shading system	Absorption of the system	Permeability of the system	Solar protection (fc)	
			Internal fin	External fin
Shading adjustable fins	0.1	0.05	0.25	0.1
		0.1	0.3	0.15
		0.3	0.45	0.35
White shading	0.1	0.5	0.65	0.55
		0.7	0.80	0.75
		0.9	0.95	0.95
Coloured shading	0.3	0.1	0.42	0.17
		0.3	0.57	0.37
		0.5	0.77	0.57
Shading with aluminium coating	0.2	0.05	0.20	0.08

This requirement does not apply to: vertical and steep ($>60^\circ$) surfaces, directed from north-west to north-east (direction midnight +/- 45°), windows with solar shading and a window of less than 0.5 m².

¹⁴⁶ The Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions to be met by buildings and their location (Journal of Laws 2002 No. 75, item. 690, as amended)

SWEDEN

According to the Swedish Building Code, buildings and their installations must be designed to guarantee a satisfactory thermal comfort¹⁴⁷. Based on that, the recommended minimal operative temperature for the average dwellings is 18°C, and 20°C for dwellings inhabited by older people. Furthermore, among the different rooms of a dwelling, the operative temperature difference should not exceed 5°C. Additionally, surface temperatures (floor) should not be less than 16°C (in sanitary premises, a minimum of 18°C and in premises for children, min 20°C) and should be limited to a maximum of 26°C.

Rules on thermal comfort are also issued by the Public Health Agency and by the Work Environment Authority¹⁴⁸. Dwellings must be designed with a maximum average U-value of 0.4 W/m²K regardless of the climate zone and the energy supply system. For buildings more than 50 m², additional requirements apply for the overall energy performance, which take into account the climate zone and the use of electrical heating (Table 15). The strictest requirements apply to dwellings using electrical heating in southern climates (55 kWh/m²a). Nevertheless, for buildings with a floor area less than 50 m² only the requirements on average regarding thermal transmittance (0.33 W/m²K) and airtightness need to be fulfilled¹⁴⁹.

Table 15 - Requirements for residential buildings (Source: Country report 2012, CA EPBD)

Year	Other heating source			Electrical heating (>10 W/m ² , installed heating)				
	Climatic zone			U-Value W/m ² ·K	Climatic zone			U-Value W/m ² ·K
	North	Middle	South		North	Middle	South	
	kWh/m ²				kWh/m ²			
2006	130		110	0.5	95*		75*	0.5
2009	150	130	110	0.5	95	75	55	0.4
2012	130	110	90	0.5	95	75	55	0.4

*Electrical pane in one or two-family houses

Furthermore, in order to maintain energy efficiency and thermal comfort, devices for the automatic control of heating systems should be provided in each room¹⁵⁰.

The National Board of Housing, Building and Planning (Boverket) proposes measures such as installation of windows and modification of their size, solar shading and sun protective glazing to be considered in order to reduce the cooling needs¹⁵¹. These measures should also be considered prior to installing cooling systems, in the event of a change in the use of the building¹⁵².

¹⁴⁷ BFS 2014:3 - BBR 21, 6:41

¹⁴⁸ BFS 2014:3 - BBR 21, 6:21. <http://www.folkhalsomyndigheten.se/amnesområden/halsoskydd-och-miljohalsa/inomhusmiljö/>

¹⁴⁹ BFS 2014:3 - BBR 21, 9:11

¹⁵⁰ BFS 2014:3 - BBR 21, 9:52, specified for residential buildings.

¹⁵¹ BFS 2014:3 - BBR 21, 9:51

¹⁵² BFS 2014:3 - BBR 21, 9:94

UK (England & Wales)

Based on the binding Building Regulations 2010, reasonable provisions shall be made for the conservation of fuel and power in buildings by:

- Limiting heat gains and losses
 - 1. Through thermal elements and other parts of the building fabric; and
 - 2. From pipes, ducts and vessels used for space heating, space cooling and hot water services;
- Providing fixed building services which
 - 1. Are energy efficient;
 - 2. Have effective controls; and
 - 3. Are commissioned by testing and adjusting as necessary to ensure they do not use more fuel and power than is reasonable in those circumstances.

Heating systems should be designed to be able to maintain a temperature of 18°C in sleeping rooms and 21°C in living rooms when the temperature outside is at the local design temperature, commonly -1°C. The adequacy of loft insulation and cavity wall insulation is important and would be considered as part of any Housing Health and Safety Rating System (HHSRS) assessment, as would significant draughts¹⁵³.

In dwellings, according to the Chartered Institution of Building Services Engineers (CIBSE)¹⁵⁴, the following criteria are recommended for overheating:

- Living areas: 1% annual occupied hours over operative temperature of 28°C.
- Bedrooms: 1% annual occupied hours over operative temperature of 26°C.

CIBSE also provides general indoor comfort temperatures for non-air conditioned dwellings:

- Living areas should be at an operative (maximum) temperature of 25°C.
- Bedrooms should be at an operative (maximum) temperature of 23°C, noting that sleep may be impaired above an operative temperature of 24°C.

The Approved Document L1A sets out an approach to limit the heat gains, also mentioning that the provision of adequate levels of daylight is another factor to take into account when trying to limit solar gains (BS 8206-2).

Furthermore, the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP 2012)¹⁵⁵, Appendix P (Assessment of internal temperature in summer) contains a procedure that should be followed by designers to assess whether a house has high internal temperature in hot weather or not. This assessment is related to the factors contributing to the internal temperature: solar gain (taking into account the orientation, shading and glazing transmission); ventilation (taking into account the window opening in hot weather), thermal capacity and medium summer temperature for the dwelling location. Specifically for the calculation of solar gains in summer, blinds or curtains that can be drawn to reduce solar gain as well as overhangs are taken into account. Based on the assessment results, reasonable provision is achieved if the dwelling does not have a high risk of high internal temperatures (Table 16). The assessment should be done regardless of whether or not mechanical cooling is in place.

¹⁵³ <http://www.privatehousinginformation.co.uk/site/138.asp>

¹⁵⁴ "Investigation into Overheating in Homes" https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7604/2185850.pdf

¹⁵⁵ http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

Table 16 - Levels of threshold temperature corresponding to likelihood of high internal temperature during hot weather¹⁵⁶

Threshold	Likelihood of high internal temperature during hot weather
< 20.5°C	Not significant
≥ 20.5°C and < 22.0°C	Slight
≥ 22.0°C and < 23.5°C	Medium
≥ 23.5°C	High

Further information about techniques to avoid overheating can be found in 'Reducing overheating – a designer's guide', CE 129, Energy Efficiency Best Practice in Housing, by the Energy Saving Trust (2005).

The SAP 2012 does not provide an estimation for cooling needs. However, it states that the cooling requirement is based on a standardised cooling pattern of 6 hours/day operation and cooling of part or of all the dwelling to 24°C.

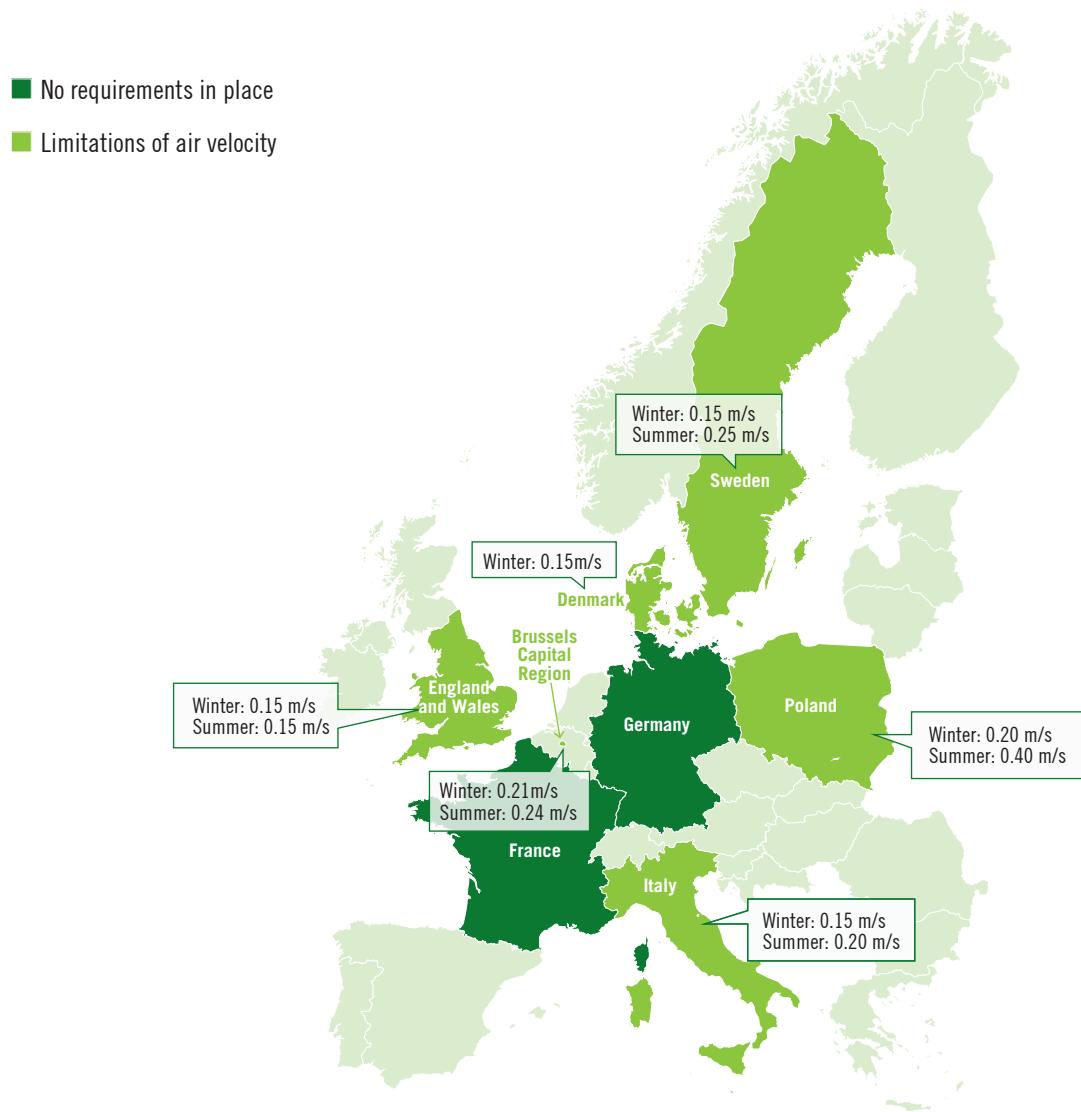
¹⁵⁶ SAP 2012: The Government's Standard Assessment Procedure for Energy Rating of Dwellings http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

2.1.2 Air velocity

Air velocity is an important factor in thermal comfort because people are sensitive to it. Small air movement in cool environments may be perceived as draught. If the air temperature is less than the skin temperature, it will significantly increase the convective heat loss. Very low levels of air movement can also cause a feeling of discomfort and stuffiness in a room.

The following map gives an overview of legal limitations of air velocity throughout Europe.

Map 5 - Maximal allowed air velocities in Europe (Source: BPIE)



BRUSSELS-CAPITAL REGION

According to the recommendations¹⁵⁷ from Bruxelles Environnement, the air velocity in summer should not be higher than 0.24 m/s, whereas for optimum thermal comfort, air velocity should be limited to 0.12 m/s. In winter conditions, the recommended air velocity limit is set at 0.21 m/s and, for an optimum thermal comfort, it should be no higher than 0.10 m/s.

¹⁵⁷ <http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel02-assurer-le-confort-thermique-au-sein-du-batiment-durable.html?IDC=1048&IDD=4559>

DENMARK

In Denmark, the air velocity should not exceed 0.15 m/s to avoid draughts, except during summertime with temperatures above 24°C.

FRANCE

No requirements regarding air velocity are identified so far in France.

GERMANY

No requirements regarding air velocity are identified so far in Germany.

ITALY

The Italian Standard (UNI 10339:1995) foresees that for residential buildings, the air velocity should be between 0.05 and 0.15 m/s during the winter period and 0.05 and 0.20 m/s during the summer period.

POLAND

The Polish Standard PN-B-03421:1978 specifies the comfort indoor parameters taking into account the physical activity of occupants (Table 17).

Table 17 - Indoor comfort parameters

	Winter	Summer
Low metabolic rate		
indoor temperature	20-22 °C	23-26 °C
airflow	up to 0.2 m/s	0.3 m/s
Average rate of metabolism		
indoor temperature	18-22 °C	20-23 °C
airflow	up to 0.2 m/s	0.4 m/s
High rate of metabolism		
indoor temperature	15-18 °C	18-21 °C
airflow	up to 0.3 m/s	0.6 m/s

SWEDEN

Cooling devices must be designed to avoid troublesome radiation asymmetry or draughts¹⁵⁸. In addition, the air velocity in a room is not expected to exceed 0.15 m/s during the heating season and air velocity from the ventilation system shall not exceed 0.25 m/s during other times of the year¹⁵⁹.

UK (England & Wales)

In order to avoid draughts, air velocity has to be limited to 0.15 m/s during the whole year¹⁶⁰.

¹⁵⁸ BFS 2014:3 - BBR 21, 6:43 (heating and cooling requirements).

¹⁵⁹ BFS 2014:3 - BBR 21, 6:42 (thermal comfort).

¹⁶⁰ Brelih N., Seppänen O., "Ventilation rates and IAQ in European Standards and national regulations", Published in the proceedings of the 32nd AIVC conference and 1st TightVent conference in Brussels, 12-13 October 2011.

2.1.3 Humidity

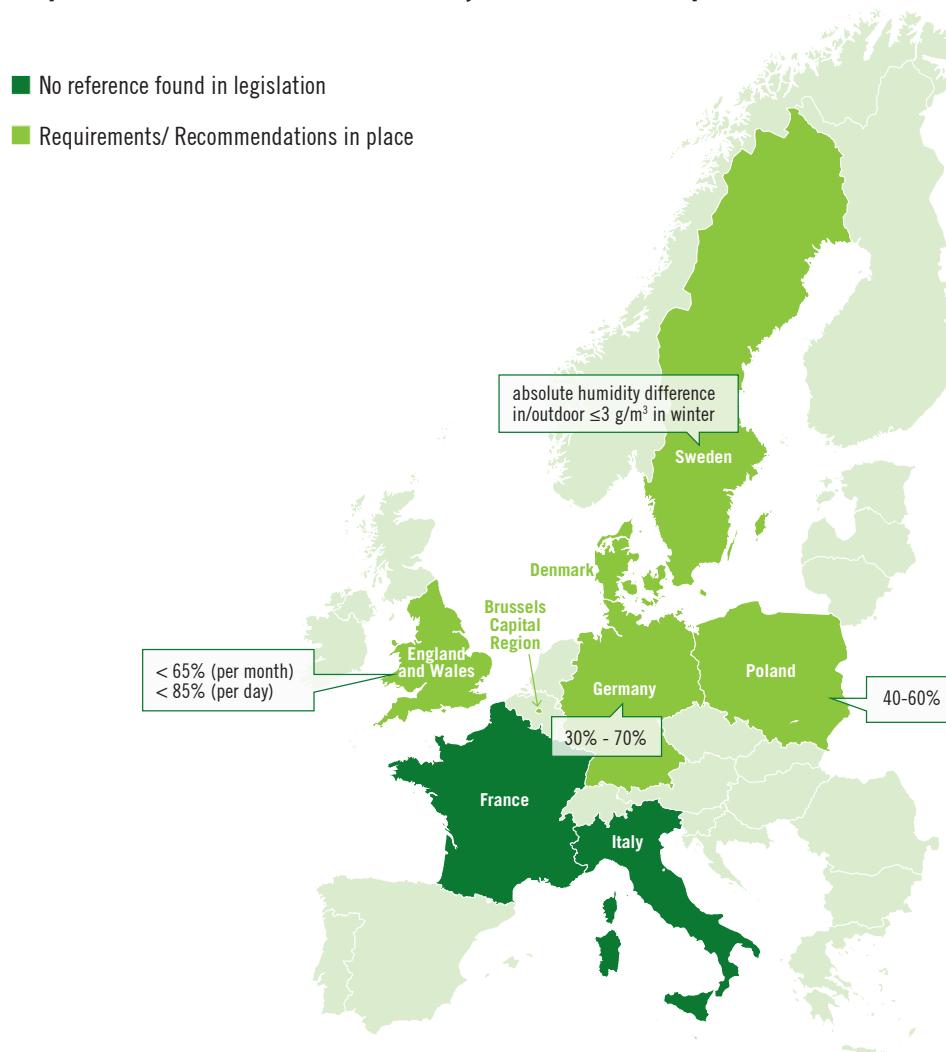
Humidity is of particular concern in residential ventilation as most of the adverse health effects and building disorders (condensation, moulds etc.) are related to humidity. Several of the humidity sources cannot be influenced or controlled by the designer¹⁶¹.

The following table, presenting the levels of relative humidity for the four expectations related categories set down in EN 15251, as well as the following map summarising the current humidity standards in Europe allow us to have a first overview of the criteria related to humidity.

Table 18 - Example of recommended design criteria for humidity in occupied spaces if humidification or dehumidification systems are installed (Source: EN 15251)

Category	Relative humidity
I (High level of expectation - for spaces occupied by very sensitive and fragile persons)	30%-50%
II (Normal level of expectation - for new buildings and renovations)	25%-60%
III (Moderate level of expectation - used for existing buildings)	20%-70%
IV (Values outside the criteria for the above categories - accepted for a limited part of the year)	<20% or >70%

Map 6 - Overview of (de facto) humidity standards in Europe (Source: BPIE)



¹⁶¹ EN 15251

BRUSSELS-CAPITAL REGION

Elementary requirements related to the healthiness of IAQ have to be fulfilled, for example the limitation of humidity causing mould or damage to the walls¹⁶².

DENMARK

Non-binding recommendations for relative humidity are specified in DS 474, Code for Indoor Thermal Climate.

FRANCE

The French building code does not include specific requirements on air humidity or moisture.

GERMANY

In Germany, there is no legislation related to humidity. Nevertheless, according to the non-binding DIN EN 13779, the minimum and maximum indoor relative humidity ranges from 30 to 70%.

ITALY

In Italy, no legislation setting humidity criteria in buildings has been adopted so far.

POLAND

To avoid water condensation (and consequently mould) on the inner surface of the external wall, the following requirements need to be fulfilled since 2014¹⁶³:

- External walls (residential, $>20^{\circ}\text{C}$) should have a thermal co-efficiency (fr_{si}) level calculated according to the Polish Standards. The value of 0.72 might be considered assuming the average monthly amount of relative indoor moisture is equal to $\Phi = 50\%$.
- In the winter season, condensation is accepted if the partition structure allows the evaporation of condensate in the summer and if there is no degradation of building materials due to the partition of the condensation.
- The temperatures in the AC system (e.g. refrigerant, cooling surfaces) should be adjusted so there is no condensation on the surfaces.

In addition, the Polish Standard PN-B-03421:1978 specifies the comfort indoor parameters taking into account the physical activity of the occupants (recommended to be considered in calculations).

Table 19 - Comfort parameters related to humidity

Metabolic rate	Winter			Summer		
	Relative humidity		Max airflow	Relative humidity		Max airflow
	Optimal	Minimal		Optimal	Maximal	
Low	40-60%	30%	0.2 m/s	40-55%	70%	0.3 m/s
Average	40-60%	30%	0.2 m/s	40-60%	70%	0.4 m/s
High	40-60%	30%	0.3 m/s	40-60%	70%	0.6 m/s

Note: In addition the ranges of indoor temperatures are specified.

¹⁶² Decree of 4 September 2003 (article 3, comma 2), defining the minimum requirements according to the decree of 17 July 2003 ("Code du Logement")

¹⁶³ The Regulation of the Ministry of Infrastructure dated 12 April 2002 on the technical conditions to be met by buildings and their location (Journal of Laws 2002 No. 75, item. 690, as amended)

SWEDEN

Air humidity and moisture safety are major concerns of the Swedish Building Code (BFS 2014:3) and addressed to a unique extent in the European legislation. Buildings must be designed so as to avoid moisture conditions causing damage, smell or the appearance of microbes thereby affecting hygiene or health. Maximum moisture conditions are defined as an upper limit for which such negative effects do not happen¹⁶⁴.

A voluntary methodology specifying the maximum moisture condition is defined in the report "Determination of the Critical Moisture Level for Mould Growth on Building Materials"¹⁶⁵.

All requirements should be verified at the design stage by moisture security planning. In addition, other actions during the construction process can also affect moisture safety. At the planning, design, execution and control stages of moisture safety, the Industry Standard ByggaF - method for moisture resistant construction - can be used as guidance. Buildings, their products and construction materials should be protected against moisture and dirt. Verification that materials have not been moisture-damaged during construction should be undertaken through inspections, measurements and documented tests. The performance of building components and building details important for the future of moisture safety should be documented.

Water for humidification or cooling should not emit noxious, irritating or odorous substances indoors.

In winter, the difference in absolute humidity between indoor and outdoor should not be higher than 3 g/m³.

FoHMFS 2014:14 (Regulation of the Public Health Agency of Sweden) defines the moisture situations which can require additional investigation¹⁶⁶.

UK (England & Wales)

According to the Approved Document F (Means of ventilation), the moving average relative humidity in a room during the heating season should be less than the values defined in the following table.

Table 20 - Indoor air relative humidity

Moving average period	Room air relative humidity
1 month	65%
1 week	75%
1 day	85%

During warmer spring and autumn periods, the outdoor air has higher relative humidity compared to colder periods. Therefore, the moisture removal capacity of the outdoor air is lower and provisions for purge ventilation (e.g. windows) should be used.

¹⁶⁴ BFS 2014:3 - BBR 21, 6:52

¹⁶⁵ Johansson P, Doctoral thesis, available at : <http://lup.lub.lu.se/luur/download?func=downloadFile&recordId=4406856&fileId=4419062>

¹⁶⁶ 6:2525 Återluft

2.1.4 Thermal requirements for exterior building elements

Exterior building elements form the building envelope and include external walls, floors, roofs, ceilings, windows and doors. The thermal performance of exterior building elements is critical in determining the space heating and cooling needs for living and working spaces within the building. For that reason, the EU policies for buildings energy efficiency address in particular the exterior buildings' elements as a main measure to reduce the energy demand for heating and cooling, which nowadays represents more than 60% of the total energy consumption of European dwellings.

Several articles of the EPBD recast stipulate that MS have to introduce thermal requirements for exterior buildings' elements, to be defined both for new and existing buildings in the event of major renovation and to further adjust these requirements based on a cost-optimal methodology. Moreover, the whole-building approach becomes stringent when moving to very-low energy buildings and the EPBD recast fosters the introduction of energy performance requirements in the MS building codes. Therefore, all new buildings constructed from 2021 onwards in the MS have to be at nearly zero-energy levels, implying a very high energy performance while the remaining energy demand will have to be covered to a significant extent by renewable energy sources onsite or nearby. Therefore, the thermal requirements for building components are in a very dynamic stage in the MS with fast changes towards stricter levels.

Nevertheless, while the whole-building approach is likely to prevail, minimum thermal requirements for building envelope components have to be further developed. Renovation measures are, very often, undertaken only partially at the level of one wall, or through window replacement or by increasing the roof insulation. Additionally, both for new buildings and renovations there are good arguments for a sustainable approach, first by reducing the building energy demand and improving the thermal insulation of its envelope, and only afterwards by deciding to use clean energy to supply the remaining energy needs.

A compact airtight building has a reduced indoor-outdoor thermal transfer and hence has low energy demand which is good from the energy performance perspective. At the same time, the higher the thermal insulation of the building envelope, the higher the need to secure a proper indoor air quality. The thermal requirements for building envelope components have therefore a strong influence on indoor living conditions and have to be associated with other requirements to secure minimum ventilation and eliminate the harmful impact of indoor pollutants.

In this chapter, the thermal requirements for exterior building components are assessed for the focus countries. The main findings of the chapter are as follows:

- In all focus countries, there are thermal requirements in place for all exterior building components.
- There is a high dynamic to improve thermal requirements for exterior building components due to the latest policy developments at EU level.
- In Denmark the requirements for windows are based on the energy balance rather than only on U-values.
- In the UK, the CO₂ emissions of fabric components are also counted on top of U-values.

BRUSSELS-CAPITAL REGION

Thermal requirements apply to all construction elements, new or modified, whose modification is subject to planning permission. The main thermal transmittance (U_{\max}) and thermal resistance (R_{\min}) values are shown in the table below.

Table 21 - U and R values (extract of Annex XI of the decree of 21 February 2013)¹⁶⁷

Building element	Thermal transmittance (m ² K/W)	Thermal resistance (m ² K/W)
Elements delimiting one heated volume		
Windows (including frame)	$U_{w,\max} = 1.8$	
Glazing (excluding frame)	$U_{g,\max} = 1.1$ (*)	
Roofs and ceilings	$U_{\max} = 0.24$	
Walls not touching the ground	$U_{\max} = 0.24$	
Walls adjacent to the ground		$R_{\min} = 150$
Walls adjacent to not-heated volumes¹⁶⁸		$R_{\min} = 1.5$
Curtain wall	$U_{CW,\max} = 2.0$	
	$U_{g,\max} = 1.1$ (*)	
Walls from glass bricks	$U_{\max} = 2.0$	
Floors exposed to external environment	$U_{\max} = 0.3$	
Other types of floors (e.g. adjacent to not-heated volumes)	$U_{\max} = 0.3$	$R_{\min} = 1.75$
Elements delimiting two heated volumes	$U_{\max} = 1.0$	

* Transmittance at the centre of the glazed surface vertically oriented

DENMARK

The Building Code sets down component requirements to eliminate the risk of mould growth due to cold surfaces. However, it is not possible to construct a building and meet the overall energy requirements (energy frame) solely by fulfilling the following minimal component requirements. Therefore, for new buildings, the requirement for windows is based on the Energy Balance (E_{ref}) and not the U-value requirement¹⁶⁹. The Energy Balance requirement includes the heat loss (u-value) and solar gain when assessing the energy performance of windows. It thereby includes and recognises the free solar gain that comes through a window and has an influence on the energy consumption of buildings.

¹⁶⁷ Decree of 21 February 2013, amended decree of 21 December 2007
http://www.bruxellesenvironnement.be/uploadedFiles/Contenu_du_site/Professionnels/Themes/%C3%89nergie/01_PEB_et_climat_int%C3%A9rieur/01Travaux_PEB/07L%C3%A9gislation/ARRETE_210213_AnnexeXI_FR.pdf

¹⁶⁸ "Vide sanitaire" or "cave en dehors du volume protégé" (Annex IV)

¹⁶⁹ Danish Building regulations, chapter 7.2.

Table 22 - Minimal component requirements(Source: CA EPBD, Country reports and the revised TASK 1, www.ecodesign-windows.eu)

Building element	U-Value	Energy Balance requirement (E_{ref})
External walls and basement walls towards ground	0.3 W/m ² K	
Slabs on ground etc.	0.2 W/m ² K	
Loft and roof construction	0.2 W/m ² K	
Windows	-	-33 kWh/m ² /year
Roof windows	-	-10 kWh/m ² /year

FRANCE

The maximal thermal transmittance between the part of a building continuously occupied and the part of a building discontinuously occupied is 0.36 W/m²K¹⁷⁰. Apart from this general requirement, the thermal transmittance of the building's elements also contributes to the determination of the Cep (Consumption in primary energy) indicator.

GERMANY

DIN 4108 - Part 2 ("Mindestwärmeschutz") indicates the mandatory minimum insulation requirements for new buildings to avoid moisture and mould on the indoor surfaces of external walls. Until April 2014, when the 2003 version of the standard was still the legal reference, this requirement was applied only for "Aufenthaltsräume" (rooms inhabited by people for longer periods – e.g. not applied to the staircases of multi-family homes). Despite the recent changes within the standard, most authorities have not yet updated the references which still keep the aforementioned restriction. The authorities are also inclined to neglect the changes in connection with the EnEV's enforcement.

- $R^{171} \geq 1.20 \text{ m}^2\text{K/W}$: Exterior walls; walls of heated rooms against soil, open entrance areas, garages etc.
- $R \geq 0.90 \text{ m}^2\text{K/W}$: Floors to soil
- $R \geq 1.20 \text{ m}^2\text{K/W}$: Roof and upper ceilings

These minimal insulation requirements are accompanied by much stricter requirements for hygienic reasons - based on maximal primary energy demand- for the purpose of energy saving.

ITALY

In the case of new buildings or deep refurbishment, the thermal transmittance of common walls must not be higher than 0.8 W/m²K¹⁷². Usually this limit is not used: meeting the requirements on the energy performance indicator already forces the designer to choose lower values for transmittance.

POLAND

For Poland the maximum value of thermal transmittance for external building elements are specified as follows:

¹⁷⁰ Arrêté du 26 Octobre 2010, Article 18. Specific requirements related to thermal bridges are defined in Article 19.

¹⁷¹ The inverse of R and the Wärmeübergangswiderstände results in the heat transmission coefficient.

¹⁷² Decree of the President of the Republic 59/2009, Article 4, comma 16.

Table 23 - U-values for building elements

Building elements	U-Values (in W/m ² K)		
	From 1 January 2014	From 1 January 2017	From 1 January 2021
External walls			
t≥16 °C	0.25	0.23	0.2
8 °C ≤ t <16 °C	0.45	0.45	0.45
t ≤ 8 °C	0.90	0.90	0.90
Internal walls			
Δt≥8 °C	1.0	1.0	1.0
Δt<8 °C	No requirements	No requirements	No requirements
Wall between heated and non-heated rooms	0.3	0.3	0.3
Roofs			
t≥16 °C	0.2	0.18	0.15
8 °C ≤ t <16 °C	0.3	0.3	0.3
t ≤ 8 °C	0.7	0.7	0.7
Floor ground			
t≥16 °C	0.3	0.3	0.3
8 °C ≤ t <16 °C	1.2	1.2	1.2
t ≤ 8 °C	1.5	1.5	1.5
Windows, balcony doors, transparent surfaces (not-to-open)			
t≥16 °C	1.3	1.1	0.9
t<16 °C	1.8	1.6	1.4
Roof windows			
t≥16 °C	1.5	1.3	1.1
t<16 °C	1.8	1.6	1.4
Windows in internal walls			
Δt≥8 °C	1.5	1.3	1.1
Δt<8 °C	No requirements	No requirements	No requirements
Wall between heated and non-heated rooms	1.5	1.3	1.1
Doors in external walls, and between rooms of which one is non-heated	1.7	1.5	1.3

SWEDEN

Alternatively to requirements on overall energy performance, airtightness and heat recovery, for buildings smaller than 100m² with a window area of maximum 20% of the heated floor area and no cooling demand, the following minimum requirements have to be met:

Table 24 - Alternative requirements (Source: BFS 2014:3)

U/Values [W/m ² K]	Building with a surface up to 50 m ² or heated by other than electrical heater	Building with a surface from 51 to 100 m ² or heated by electrical heaters
Roofs	0.13	0.08
Walls	0.18	0.1
Floors	0.15	0.1
Windows	1.3	1.1
Doors	1.3	1.1

UK (England & Wales)

In the UK, if the actual dwelling is constructed based entirely on the notional dwelling specifications, it will meet the CO₂ and fabric energy targets. Developers are, however, free to interpret the specification provided the overall level of CO₂ emissions and the rate of fabric energy efficiency performance are achieved or improved. The following table presents the reference U values for the notional dwelling, as well as the limiting or worst acceptable fabric values for Wales and England. Even though these values set a threshold, in order to achieve the Target CO₂ Emission Rate (TER) and the Target Fabric Energy Efficiency (TFEE) rate, the fabric values should be significantly better than limiting values.

Table 25 - Reference and limiting fabric values for England and Wales

Fabric element	Notional dwelling specification (reference values for England) ¹⁷³	Limiting value (England) ¹⁷⁴	Worst acceptable fabric performance values for Wales ¹⁷⁵
Roof	0.13 W/(m ² K)	0.20 W/(m ² K)	0.15 W/(m ² K)
External walls including :			
- Semi-exposed walls	0.18 W/(m ² K)	0.30 W/(m ² K)	0.21 W/(m ² K)
- Floor	0.13 W/(m ² K)	0.25 W/(m ² K)	0.18 W/(m ² K)
Windows and glazed doors with >60% glazed area	1.4 W/(m ² K) g-value=0.63	2 W/(m ² K)	1.60 W/(m ² K)
Common wall	0	0.20 W /(m ² K)	0.20 W /(m ² K)

¹⁷³ SAP 2012: The Government's Standard Assessment Procedure for Energy Rating of Dwellings http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

¹⁷⁴ Approved document L1A: Conservation of fuel and power in new dwellings: http://www.planningportal.gov.uk/uploads/br/BR_PDF_AD_L1A_2013.pdf

¹⁷⁵ Approved Document L1A for use in Wales: <http://wales.gov.uk/docs/desh/publications/140624building-regs-approved-document-l1a-fuel-power-en.pdf>

2.2 Thermal comfort in existing dwellings

Summary of findings:

- Some countries require minimal (winter) and maximal (summer) temperatures in existing buildings in order to guarantee a minimum level of comfort.
- In the focus countries, only the southern ones (France and Italy) have introduced shading requirements in the case of refurbishment.
- Element-based requirements (U-Values) in the case of (major) refurbishment, as required by the EPBD for energy saving reasons, are the most common.
- Energy balance requirements that include solar gain when assessing the energy performance of windows are included in the Danish and the British building regulations. Considering solar gains together with the heat losses of a window provide a more comprehensive assessment of its energy performance.
- Increasing thermal comfort is often quoted as a main driver for owner-occupiers to invest in refurbishment, however thermal comfort results arising from improved energy performance are rarely captured by national and/or European legislation.

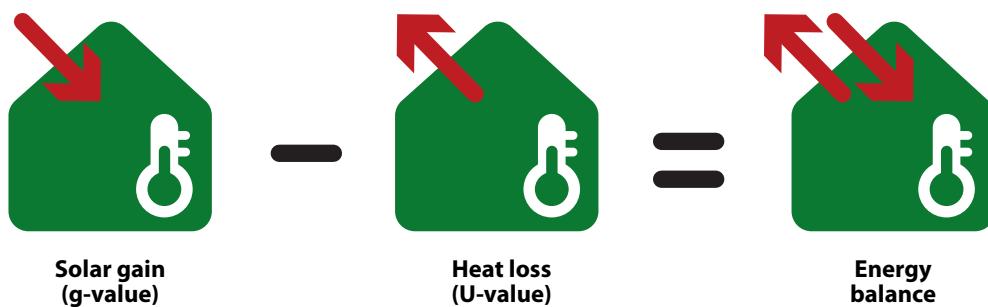
BRUSSELS-CAPITAL REGION

There are no specific requirements for thermal comfort in summer conditions¹⁷⁶. Nevertheless, in winter, the elements covered by any work as part of a major renovation (and contributing to heat losses¹⁷⁷) are subject to the requirements mentioned for new buildings. However, in the event only a part of the window is modified (the frame or the glazing), performance requirements are applied only to this part¹⁷⁸.

DENMARK

In Denmark the energy performance of windows is based on energy balance, which means that the solar gain is included when assessing the performance of the window.

Figure 3 : Energy balance figure



¹⁷⁶ In the decree of 21 December 2007 (article 14), only the compliance to annex XI (thermal transmittance) is mentioned.

¹⁷⁷ For residential buildings, this surface is determined by all the building elements which separate heated spaces from unheated spaces.
http://www.bruxellesenvironnement.be/uploadedFiles/Contenu_du_site/Professionnels/Themes/%C3%89nergie/01_PEB_et_climat_int%C3%A9rieur/02Le_certificat_PEB/Utils/01R%C3%A9sidentiel/RBC_protocole%20PEB_%20partie%20III%20140111.pdf

¹⁷⁸ Governmental Decree of 21 December 2007, Article 14 (referring to Article 8 and Article 9). Performance requirements are in annex IV (pages 413 and 414).

Therefore, when replacing windows, the energy balance (solar gain – heat loss) through the window in the heating season must not be less than -33 kWh/m²/year and not less than -10 kWh/m²/year for roof windows¹⁷⁹. The energy gain is calculated as stated in Appendix 6 of the Danish Building Regulation. The requirement applies to a reference window of 1.23m x 1.48m fitted with the manufacturer's standard pane. The surface temperature of window frames in external walls must not be lower than 9.3°C.

Table 26 - Requirements for energy gain through windows and roof lights

Year	2010	2015	2020
Energy label	C	B	A
Windows (kWh/m²/year)	-33	-17	0
Roof windows (kWh/m²/year)	-10	0	10

The following requirements apply to the involved building elements.

Table 27 - Requirements for the insulation of the building envelope and linear losses

Table of U values	W/m ² K
External walls and basement walls in contact with the soil	0.20
Partition walls and suspended upper floors adjoining rooms/spaces that are unheated or heated to a temperature more than 5 K lower than the temperature in the room concerned	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors	0.12
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly connected to the roof	0.15
External doors, hatches, secondary windows and skylight domes	1.65
Linear losses	W/m·K
Foundations	0.12
Joint between external wall, windows or external doors and hatches	0.03
Joint between roof structure and roof lights or skylight domes	0.10

The implementation of energy saving measures is limited to those measures sufficiently cost-effective. If energy performance certification of the property has been carried out, such measures will usually be cited on the energy performance certificate (EPC).

Constructional factors may render cost-effective compliance with the provisions impossible without harming moisture resistance. However, there may be less extensive work whereby energy demand can be reduced. If so, this is the work which needs to be carried out.

¹⁷⁹ Danish Buildings Regulations

FRANCE

In France, when installing or replacing a cooling system, non-north-facing windows must be fitted with solar protection with a solar factor of 0.15 (or class 3/4 as defined in NF EN 14501) if it did not previously exist¹⁸⁰. When installing or replacing roof windows, solar shading must be installed, and the global solar factor of the window with shading must be inferior to 0.15. External shadings are supposed to fulfil this requirement.

In the case of a new installation or a replacement of building elements, a minimum thermal resistance is required (Table 28)¹⁸¹.

Table 28 - Thermal insulation requirements for the installation or substitution of a building element¹⁸²

Building elements	Minimum thermal resistance (m ² K/W)
External walls and inclined roof with a tilt higher than 60°	2.3
Walls adjacent to not heated spaces	2
Flat roofs	2.5
Floor attics ("Planchers de combles perdus")	4.5
Inclined roof with a tilt lower than 60°	4
Lower floor ("planchers") on the ground or collective parking	2.3
Lower floor ("planchers") on the crawl space ("vide sanitaire") or an unheated space	2

For a new installation or window replacement (some exceptions exist, such as skylights, glass block walls, windows < 0.5m²) a maximum thermal transmittance of 2.3 W/m²K is required and 2.6 W/m²K for sliding elements ("Ouvrants à menuiserie coulissante"). In any case, the thermal resistance of the glazing unit "window" has to be lower than 2 W/m²K¹⁸³. Closing equipment (i.e. shutters or blinds) can be taken into account for the total thermal resistance¹⁸⁴.

Furthermore, cooling systems must not to be activated until the temperature is higher than 26°C¹⁸⁵. There are no specifications for airflow rates or humidity in existing dwellings.

GERMANY

For a minimum level of thermal comfort in winter, each landlord has to guarantee that an indoor temperature of at least 19°C can be reached. On the contrary, there are no requirements for summertime, but DIN 4108-2 describes how to design a house to prevent overheating.

There are no additional requirements related to thermal comfort in the existing building stock. Nevertheless, for refurbishments, minimum U-Values per building element apply, if more than 10% of the specific element is refurbished or the building is further extended with a new construction (Figure 4).

¹⁸⁰ Arrêté du 3 mai 2007, article 32

¹⁸¹ Arrêté du 3 mai 2007, article 3

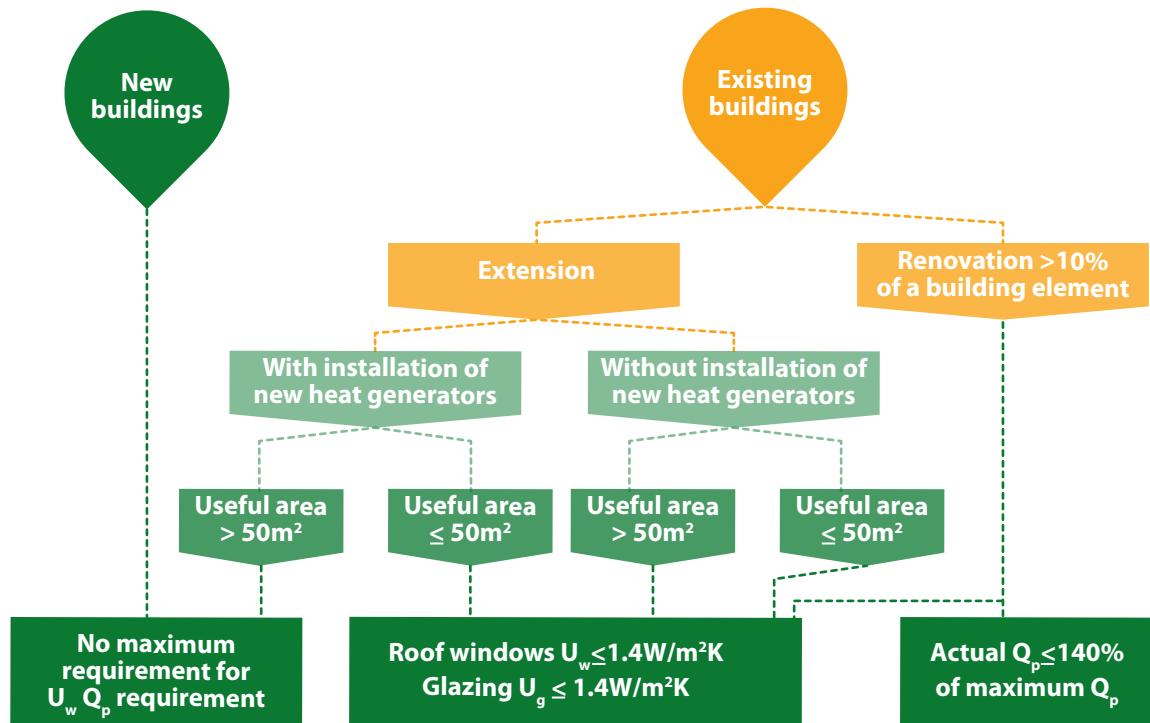
¹⁸² Arrêté du 3 mai 2007, chapter I, article 3

¹⁸³ Arrêté du 3 mai 2007, article 9

¹⁸⁴ Arrêté du 3 mai 2007, annexe IV

¹⁸⁵ Code de la construction, article R131-29

Figure 4 - Winter heat protection¹⁸⁶



Requirements have been introduced in order to reduce the energy consumption of the building stock. The positive influences on thermal comfort (e.g. reduction of draughts, higher surface temperatures) achieved by such measures are not specifically mentioned in the EnEV (Energy Saving Ordinance).

Table 29 - Min. U-value [W/m²K] in the case of a new installation or replacement of the element

	Min. U-value [W/m²K] in case of new installation or replacement of the element
Roofs	0.24 W/(m ² ·K)
Walls	0.24 W/(m ² ·K)
Floors	0.50 W/(m ² ·K)
Windows	1.3 W/(m ² ·K)
Roof windows	1.4 W/(m ² ·K)
Exterior doors	1.8 W/(m ² ·K)

ITALY

In Italy, in the event of a modification in existing buildings -apart from partial refurbishment or modification of thermal systems- external shades are required nationwide. Additionally, verifications related to the containment of temperature variations have to be made when modifying existing buildings, apart from partial refurbishment or the modification of thermal systems.

In other cases of refurbishment¹⁸⁷, the energy performance indicators are not applied. Instead, maximum values for thermal transmittance (in W/m²K) are provided¹⁸⁸.

¹⁸⁶ Available at: http://www.zinco.de/dachlandschaften.com/vortraege/manuskripte/Manuskript_VELUX.pdf

¹⁸⁷ Legislative Decree 192/2005, Article 3, letter c, comma 1

¹⁸⁸ Decree of the President of the Republic 59/2009, Article 4, comma 4, letter a and b.

Table 30 - Maximum values for thermal transmittance in W/m²K for external walls according to the climate zone in the event of partial refurbishment

Climate zone	Thermal transmittance (W/m ² K)				
	Walls	Roofs	Floors	Windows (including frames)	Central transmittance of windows
A	0.62	0.38	0.65	4.6	3.7
B	0.48	0.38	0.49	3	2.7
C	0.4	0.38	0.42	2.6	2.1
D	0.36	0.32	0.36	2.4	1.9
E	0.34	0.3	0.33	2.2	1.7
F	0.33	0.29	0.32	2	1.3

Compliance with the energy performance indicators for winter (affecting indirectly the indoor comfort) is also required when refurbishing, including a surface extension higher than 20% of the initial surface¹⁸⁹.

POLAND

In Poland, requirements for existing and new buildings are the same.

SWEDEN

Concerning indoor climate and heating needs, the National Board of Housing, Building and Planning (Boverket) recommends that existing buildings fulfil the requirements defined for new buildings. Like most European countries, Sweden requires minimal U-values for refurbishments or replacement of building elements in existing buildings.

Table 31 - Transmittance requirements for building alterations¹⁹⁰

	Min. U-values (W/m ² K)
Roofs	0.13
Walls	0.18
Floors	0.15
Windows	1.2
Doors	1.2

If fulfilling the requirement for indoor climate and heating needs specified for new buildings (section 6:4)¹⁹¹ is not possible, the risk of draught due to a lack of insulation should then be avoided.

¹⁸⁹ Decree of the President of the Republic 59/2009, Article 4

¹⁹⁰ BFS 2014:3 - BBR 21, 9:92. Requirements implemented through BFS 2011:26

¹⁹¹ BFS 2014:3 - BBR 21, 6:94. For example, U-values higher than 1.0 W/m² C° may cause cold drafts.

UK (England & Wales)

According to the Approved Document L1B for England, a reasonable provision would be to upgrade the thermal elements whose U-value is worse than the threshold value in column (a) of the following table to achieve the U-values given in column (b) provided this is technically, functionally and economically feasible.

Table 32 - Upgrading retained thermal elements

	(a) Threshold U-value (W/m ² K)	(b) Improved U-value (W/m ² K)
Wall – cavity insulation	0.70	0.55
Wall – external or internal insulation	0.70	0.30
Floor	0.70	0.25
Roof	0.35	0.18

Moreover, in cases in which windows, roof windows, roof lights or doors are to be installed, they should be draught-proofed units with performance no worse than given in the following table.

Table 33 - Standards for controlled fittings

Fitting	Standard
Window, roof window or roof light	Window Energy Rating Band C or better, or U-value 1.6 W/m ² -K
Doors with >50% of internal face glazed	U-value = 1.8 W/m ² -K
Other doors	U-value = 1.8 W/m ² -K

The Approved Document L1B for Wales¹⁹² gives guidance on extensions, conversions (change in energy status), on requirements for additional energy efficiency improvements called consequential improvements, renovations, changes of use, etc. The new thermal elements should achieve or improve the U-values set out in the following table.

Table 34 - U values for new thermal elements

	Extensions	Conversions / Renovations / Material change of use	
	Maximum U-values for new thermal elements (W/m ² -K) (a)	Maximum U-values for retained fabric (W/m ² -K) (b)	*Limiting U-values for retained fabric (W/m ² -K) (c)
External Walls	0.21	0.30	0.70
Floors	0.18	0.25	0.70
Roofs	0.15	0.18	0.35

**Although U-value requirements (columns (a) and (b) Table 34) may be flexible, the U-value of any individual thermal element (wall, floor or roof) should not be worse than the limiting U-values set out in column c (Table 34) in order to ensure resistance to surface condensation and mould growth.*

¹⁹² Approved Document L1B for use in Wales: <http://wales.gov.uk/docs/desh/publications/140624building-regs-approved-document-l1b-fuel-power-en.pdf>

3 DAYLIGHT REQUIREMENTS

Use of daylight, the third topic of this study, is of great importance as it can lead to a significant reduction of energy demand caused by artificial lighting.

At the same time, access to daylight in a living and working space contributes significantly to the well-being and health preservation of occupants.

WHY IS DAYLIGHT IMPORTANT?

- 63% of the people rated natural light as the most important aspect of a home (survey: HOMEWISE, "Without space + light").
- Daylight improves visual and psychological comfort, and has a positive effect on people's performance, attentiveness, satisfaction and capacity to learn.
- Daylight alleviates Seasonal Affective Disorder (a form of depression).
- Exposure to bright light has been shown to be an effective treatment for sleep disorders.
- Daylight through windows is the key source to provide high levels of light, required to sustain the operation of the circadian system.

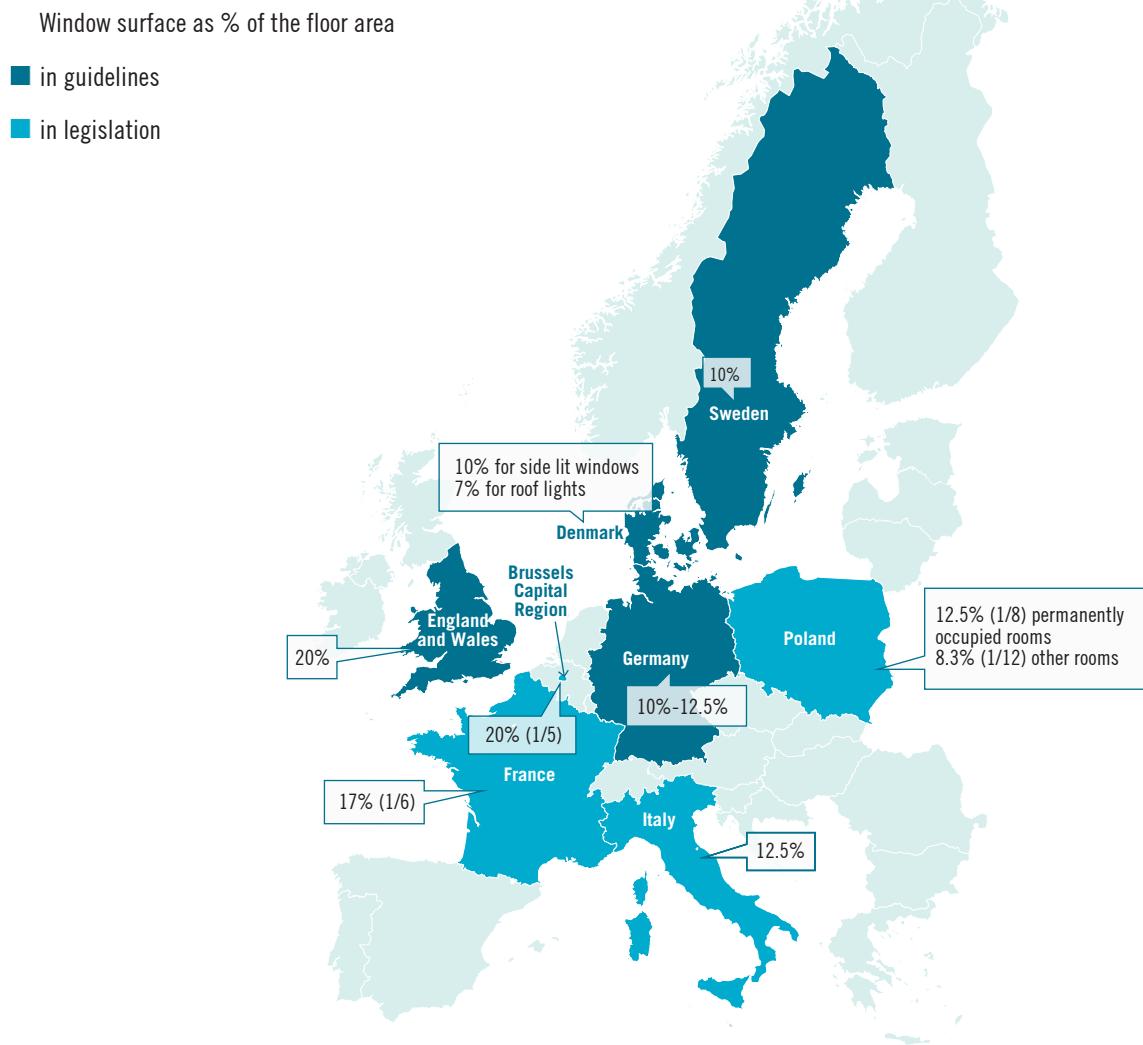
Source: http://www.lrc.rpi.edu/programs/daylighting/dr_health.asp

Summary of findings:

- The use of natural daylight to offset electric lighting has a huge energy saving potential¹⁹³.
- All countries include at least a basic reference to daylight in their building codes.
- Daylight requirements or recommendations in legislation mainly specify a minimum share of window/glazing area per floor area, indicate minimum levels of daylight or simply stipulate the need for sunlight access in buildings and for a view to the outside.
- Denmark is the only country requiring minimum solar gains in winter in cases of new buildings and major refurbishment.
- The Swedish law is unique as it recommends the use of daylight management systems for permanently installed luminaries.
- Only some building codes (Brussels, Denmark, Germany) highlight the importance of having a view to the outside as an important part of visual comfort.

¹⁹³ Energy Policy Toolkit on Danish Building code, LCTU

Map 7 -Daylight in legislation (Source: BPIE)



BRUSSELS-CAPITAL REGION

In Brussels, each dwelling must have at least one window providing a view to the outside without obstacles closer than 3 metres¹⁹⁴. Additionally, habitable spaces¹⁹⁵, with the exception of the kitchen, must have access to daylight. The net glazing surface area¹⁹⁶ in the habitable space must be minimum 1/5 of the floor surface area unless the glazing surface is located on the roof, in which case the minimum ratio is 1/12¹⁹⁷.

Apart from the above-mentioned requirements, there are no standards on lighting in residential buildings at the moment. Nevertheless, the Technical-Scientific Centre of Construction (Centre Scientifique et Technique de la Construction) suggested adapting Belgium's standard NBN 12464-1, about lighting in working places, to the needs of residential buildings and providing a reference technical document¹⁹⁸.

¹⁹⁴ Decree of 21 November 2006 (Regional Urbanism Regulation), title II, article 11. The view has to be allowed directly and in a horizontal way, referring to a point 1.5 meters above the floor.

¹⁹⁵ Habitable spaces are the ones destined to be continuously occupied by people and include for example: halls, dining rooms, living rooms, kitchens or bedrooms while hallways and toilets are considered as temporary occupied places (decree of 21 November 2006, title II, article 2, comma 1 and 2).

¹⁹⁶ "Superficie nette éclairante" excludes the framework (Decree of 21 November 2006, title II, article 2, comma 4).

¹⁹⁷ Decree of 21 November 2006, title II, article 10. Similar specifications are defined in article 3, comma 2 of the decree of 4 September 2003 defining the elementary requirements of dwellings according to the dwelling code ("Code du logement").

¹⁹⁸ Link to the reference document

http://www.cstc.be/homepage/download.cfm?dtype=publ&doc=eclairage_residentiel.pdf&lang=fr

The Belgium Institute for Lighting ("Institut Belge de l'Eclairage") realised also a guide for the not residential buildings

http://www.ibe-biv.be/media/pdf/IBE-BIV_Code_de_bonne_pratique_12464_1_FR_2007.pdf

Moreover, Bruxelles Environnement recommends:

- At least 50% (100% in the case of optimal comfort) of "traffic" areas ("zones de circulation") should be partially provided with natural lighting.
- At least 20% of glazing surface should be provided for all day and night areas.
- An optimum level of comfort should also include a visual perspective (taking into account as a minimum a view angle of at least 90°) of no less than 20m into the courtyard¹⁹⁹.

DENMARK

According to BR 10, Article 6.1, there should be an appropriate connection between window sizes, room proportions and surface properties, taking into account the influence of outdoor obstructions. This is also important to consider factors contributing to the visual environment, which include adapting the lighting requirement to the tasks performed in the area. Moreover, according to Article 6.5, habitable rooms must have sufficient daylight for the rooms to be well lit and, in general, they must have satisfactory lighting without causing unnecessary heat loads.

The instructions to assess if a residential room has adequate daylight are described in BR10 and consist of two methods. The first method is to assess the minimum ratio between the glazed area of all windows and the floor area of the room, while the second method is based on the calculation of Daylight Factors (DF).

According to BR 10, for side-lit windows, the daylight level can usually be accepted as sufficient if the window glazed area corresponds to a minimum of 10% of the floor area. For roof lights, the windows should correspond to no less than 7% of the floor area. In both cases, the light transmittance of the glazing should be no less than 0.75.

The above-mentioned 10% and 7% guidelines assume a normal location of the building, normal room layout and furnishing. If the window type is not known at the design stage, the glazed area can be estimated by multiplying the outer area of the frame by the factor 0.7. The glazed area must be increased proportionally to any reduction in light transmittance (for example solar control glazing) or reduced light access from the windows (for example nearby buildings).

Daylight may be deemed to be adequate in habitable rooms and kitchen when the calculation demonstrates that there is a daylight factor of 2% in half of the room. The daylight factor should be calculated in a grid placed 0.5m from the walls and covering the entire room. The spacing between calculation points shall be even and at most 0.5m. When determining the daylight factor, actual conditions must be taken into account, including the windows design, light transmittance and the nature of the room and of the surroundings. Moreover, according to BR10, rooms must be fitted with windows providing a view to the surroundings, as this is one of the most important factors for room comfort.

¹⁹⁹ <http://guidebatimentdurable.bruxellesenvironnement.be/fr/g-wel03-assurer-le-confort-visuel-au-moyen-de-la-lumiere-naturelle.html?IDC=117&IDD=4519>

FRANCE

In France, main rooms must have an opening area and transparent surfaces to the exterior. These surfaces can be separated from the exterior by another windowed surface (to allow heating from the sun or increase the acoustic insulation) if the volume created by the exterior and interior windowed/glass surfaces follow certain conditions:

- Has itself an opening surface to the exterior;
- Is designed to allow ventilation;
- Has no heating system;
- Is not a covered yard;
- Has a window surface area to the exterior of at least (excluding floor area) 60% for collective housing and 80% for individual housing²⁰⁰.

Furthermore, the windowed surface must not be less than 1/6 of the dwelling floor area²⁰¹.

In addition to natural lighting, the B_{bio} indicator, required by RT2012, includes the needs for electrical lighting. This B_{bio} indicator has to remain below a maximum value called $B_{bio_{max}}$, and is calculated according to the following formula:

$$B_{bio} = 2 \cdot E_{heating} + 2 \cdot E_{cooling} + 5 \cdot E_{lighting}$$

Energy needs for lighting are here given a higher weighting coefficient than heating and cooling.

At the same time, electrical consumption for lighting is also taken into account in the second energy indicator Cep (Consumption in primary energy) which has to remain below a maximum value Cep_{max} .

In the HQE environmental voluntary label, workplaces have to have a Daylight Factor higher than 2.5%.

For existing dwellings, no daylight requirements for single element installations or replacements apply in France²⁰².

GERMANY

Natural or artificial lighting is not included in the energy saving requirements for residential buildings. Guidance is provided by DIN 5034-1:2011-07 referring to a specific daylight factor, which is the ratio of the internal light level to the external light level.

Based on DIN 5034-1, the living areas' brightness produced by daylight is considered as sufficient for the well-being of occupants if the daylight factor is:

- On average 0.9%, horizontal, 0.85 m above the floor and in 1m distance to walls in the middle of the room and
- At least 0.75%, at the most unfavourable place.

Alternatively, to avoid complex calculations, a minimal share of a window's useful area can be applied based on a specific table from DIN 5034-1:2011-07, the indicated values fulfilling both daylight and view requirements. This may vary between 10% and 12.5% depending on the regional legislation of the federal states (Landesbauordnung-LBO).

In addition, taking into consideration the visual connection to the outside environment, DIN 5034 sets recommendations for the windows' location and size. Specifically, in order to ensure an adequate view to

²⁰⁰ Code de la construction, Article R*111-10

²⁰¹ Arrêté du 26 octobre 2010, Article 20

²⁰² In Arrêté du 3 mai 2007 (chapter VII), requirements regarding non-residential buildings.

the outside, the following requirements should be followed:

1. The bottom of the transparent glazing (h_{F_U}) should be no more than 0.95m above the floor.
Requirements regarding the fall height shall be taken into account;
2. The top of the transparent glazing of the window(s) (h_{F_D}) should be at least 2.20m above the floor;
3. The glazing width (or the sum of widths for all windows arranged side by side) shall be equal to at least 55% of the room width.

Moreover, the Standard includes recommendations for the minimum duration of exposure to sunlight in buildings. Specifically, it recommends that in at least one habitable room of a dwelling the exposure to sunlight should be at least 4 hours at equinox (vernal or autumnal). Moreover, in the winter period, at least one room per building unit needs to have 1 hour of sun on the 17th of January.

Germany has no specific requirements for the use of daylight in existing buildings. Indirect consequences might occur through the general requirement that the energy performance of existing buildings must not be changed for worse.

ITALY

In Italy, the daylight factor shall be no lower than 2% for each window and the total window surface area which can be opened shall be no lower than 12.5% of the total floor area²⁰³.

According to some regional law (e.g. in the Region of Lombardia²⁰⁴), the designers have to take into account the exploitation of daylight and its integration with artificial light while guaranteeing an appropriate level of visual comfort.

Local regulations define the health requirements of dwellings, including the orientation, the air ventilation and the daylight.²⁰⁵

There are no daylight requirements for the building stock at national level.

POLAND

The Polish legislation²⁰⁶ specifies the conditions for exposure to sunlight. Daylight requirements depend to a large extent on the room's function. In permanently occupied rooms, the insolation time should be at least 3 hours during equinox days (21st of March and 21st of September) between 7am and 5pm. For multi-family apartments, the limit of insolation time in at least one room is set at 1.5 hours, while in one-room apartments, no insolation time is required.

In addition, in permanently occupied rooms, the ratio window area to the floor area should be at least 1:8, and in any other room, where daylight is required, the ratio should be at least 1:12. The legislation foresees the exemption from the above-mentioned requirements, when:

1. The daylight is not necessary or is not desirable due to applied technology
2. There is a need for functional spaces in the underground facility or part of a building with no access to daylight.

²⁰³ Minister Decree Health of 5 July 1975, Article 5

²⁰⁴ Deliberation of Lombardia Regional Committee 8745 of 22 December 2008, Article 4

²⁰⁵ Royal Decree 1265 of 27 of July 1934, title III, chapter IV. Only part of the royal decree is still valid but nowadays the municipalities, through the building regulations, and local health agency, are responsible for buildings requirements (Decree of the President of the Republic 380 of 6 June 2001).

²⁰⁶ The Regulation of the Minister of Infrastructure dated 12 April 2002 on the technical conditions to be met by buildings and their location (Journal of Laws 2002 No. 75, item. 690, as amended)

Article 13 of the same regulation also specifies the conditions for distances between buildings in order to guarantee access to daylight:

- $D \geq H$ for obstructing objects no higher than 35m;
- $D \geq 35$ m for obstructing objects higher than 35m.

For downtown infill buildings, the distance (D) can be decreased by half.

Where: H is the obstructing height and is counted from: the lower edge of the lowest windows in the obstructed building to the level of the highest edge of the obstructing object.

SWEDEN

In Sweden, new buildings²⁰⁷ and modifications to existing buildings²⁰⁸ shall be designed in order to achieve satisfactory lighting conditions without the risk of injury or damage to human health. When sufficient levels of brightness and lightness (luminance) are achieved and no glare and distracting reflections occur, we can assume that the lighting conditions are satisfactory.

In new buildings, in rooms where people spend time, there should be at least one window with outside view giving the opportunity to monitor seasonal and daily variations²⁰⁹. Nevertheless, skylights cannot be the sole source of natural light in these rooms. Additionally, these crowded rooms should be designed and oriented so as to allow direct access to daylight²¹⁰ and to sunlight²¹¹.

According to the Swedish Standard SS 91 42 01, the glazed area in a room should be 10% of the floor area. That means a daylight factor of about 1%²⁰⁹. For rooms with conditions other than those specified in the Standard, the glazed area is calculated for a daylight factor of 10%.

The above-mentioned conditions for new buildings should also be followed for modifications to existing buildings, unless the implementation of the necessary measures damages the building's cultural, architectural or aesthetic value. On the contrary, for student residences ($<35\text{m}^2$) direct sunlight is not needed²¹⁰ and indirect daylight is only needed in the kitchen and in the common areas (living room, dining room).

UK (England & Wales)

According to the English and Welsh Approved Document(s) L1A, the Building Regulations do not specify minimum daylight requirements. Reducing the window area has conflicting impacts on the building's energy efficiency: reduced solar gains, but increased use of electric lighting. However, as a general guideline, if the area of glazing is much less than 20% of the total floor area, some parts of the dwelling may experience poor levels of daylight, resulting in increased use of electrical lighting.

The British Standard "Lighting for buildings. Code of practice for daylighting" (BS 8206-2:2008), provides recommendations for minimum daylight factors:

- Bedrooms: 1%
- Living rooms: 1.5%
- Kitchens: 2%

²⁰⁷ BFS 2014:3 - BBR 21, 6:31

²⁰⁸ BFS 2014:3 - BBR 21, 6:93

²⁰⁹ BFS 2014:3 - BBR 21, 6:33

²¹⁰ BFS 2014:3 - BBR 21, 6:322

²¹¹ BFS 2014:3 - BBR 21, 6:323

The aforementioned recommendations are also part of the assessment criteria set in the Code for Sustainable Homes, Technical Guide²¹². Specifically, the assessment criteria are:

- Kitchens must achieve a minimum average daylight factor of at least 2%;
- All living rooms, dining rooms and studies must achieve a minimum average daylight factor of at least 1.5%;
- 80% of the working plane in each kitchen, living room, dining room and study must receive direct natural light.

Moreover, the British Standard BS 8206-2:2008 foresees the following percentages of glazed areas to be implemented in order to secure a view for the room occupants.

Table 35 - Minimum glazed areas for view when windows are restricted to one wall

Depth of room from outside wall - max. (m)	Percentage of window wall as seen from inside - min. (%)
<8	20
≥8≤11	25
>11≤14	30
>14	35

NOTE: windows primarily designed to provide a view may not bring enough light

Furthermore, BS 8206-2:2008 requires that interiors should receive at least 25% of the annual probable sunlight hours (APSH)²¹³, with at least 5% of these being received between the 12th of September and 21st of March. The degree of satisfaction is related to the expectation of sunlight, and linked to a higher degree with the duration of the sunlight rather than its intensity.

For existing buildings, no binding requirements apply in England and Wales. Nevertheless, the Approved Document L1B for England contains a warning in the case of extensions: if the glazing area is much less than 20% of the total floor area, some parts of the extension and especially the part of the dwelling it covers may experience poor levels of daylight. Areas of glazing greater than 25% may be acceptable, especially if this is required to make the extension consistent with the external appearance or character of the host building.

According to the Welsh Approved Document L1B, the total area of windows and doors in the extension should not exceed the sum of:

- 25% of the internal floor area of the extension; plus
- The total area of any windows and doors which, as a result of the new extension, no longer exist or are no longer exposed.

In Wales, it is also advisable to ensure that the total area of windows and doors in the extension is no less than 20% of the internal floor area of the extension, as this would mean that the extension and the part of the existing building that it abuts are likely to experience low levels of daylight, resulting in increased use of electric lighting and consumption of fuel and power.

In the case of conversions and material change of use, where an existing window or door is enlarged or a new one is created the total area of windows and doors should be limited to no more than 25% of the total floor area of the building.

²¹²"Code for Sustainable Homes, Technical Guide": https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/5976/code_for_sustainable_homes_techguide.pdf

²¹³APSH: Long-term average of the total number of hours during the year that direct sunlight reaches the unobstructed ground

In England and Wales, the **Right to Light** is protected by a common law (Prescription Act 1832), which gives the owner of a building the right to receive light through defined openings in the buildings.

Specifically, according to the Prescription Act 1832, "when the access and use of light to and for any dwelling house, workshop, or other building shall have been actually enjoyed therewith for the full period of twenty years without interruption, the right thereto shall be deemed absolute and indefeasible, any local usage or custom to the contrary notwithstanding, unless it shall appear that the same was enjoyed by some consent or agreement expressly made or given for that purpose by deed or writing." The Right to Light²¹⁴ means that if a new building limits the amount of light coming in through a window and the level of indoor light falls below the accepted level, then this constitutes an obstruction. Unless the owner of the affected window waives his rights he would be entitled to take legal action against the landowner if he considers that his light is being blocked. However, the law recognises that some loss of light is acceptable and the fact that there is less light does not necessarily give a landowner a right to complain. There is the right to a certain amount of light not to all of the light that was once enjoyed.

Mathematical calculations are used to determine whether or not a development causes an infringement. Speed and accuracy rights to light calculations are undertaken using particular computer software²¹⁵.

²¹⁴ Right to Light: <http://www.planning-applications.co.uk/righttolight.htm>

²¹⁵ Rights of Light Calculations & Reports: <http://www.right-of-light.co.uk/calculation.php>

4 COMPLIANCE AND CONTROL

Summary of findings

- Compliance procedures are mainly focusing on structural analysis and energy performance aspects of new constructions, such as U-Values, right installation of heating equipment, airtightness, availability of EPCs, etc.
- Compliance with indoor air quality or thermal comfort standards is rarely checked by designated control bodies and if so, mainly at the design stage rather than by performing onsite measurements.

BRUSSELS-CAPITAL REGION

Bruxelles Environnement is the body in charge of compliance procedures. The Directorate for the Inspection of Dwellings checks compliance with the elementary requirements in dwellings²¹⁶ including the following six steps:

1. Development of a concept (overview of foreseen measures) on how minimum requirements will be met; this constitutes a so-called PEB (Performance Energétique des Bâtiments) proposal and is part of the application to receive a planning permit.
2. A PEB consultant has to be involved to prove the effectiveness of foreseen measures.
3. A technical dossier needs to be issued by an energy expert before construction begins²¹⁷.
4. Notify the beginning of work to Bruxelles Environnement²¹⁸.
5. A PEB declaration made by a PEB consultant at the end of the construction phase determines if the requirements are actually met and describes the steps that have been taken to comply with the PEB requirements²¹⁹. Similar to the PEB proposal, the format of the document is the same for new PEB units, deep renovations or simple renovations involving an architect, and if the proposal is established by Annex 3²²⁰ of the Decree of the 3rd of April 2014²²¹.
6. In the case of new dwellings, a PEB certificate is issued by Bruxelles Environnement²²².

In the event of non-compliance with procedures and/or PEB requirements, fines and penalties can apply.

For existing buildings, requests for an “urban permit” related to a PEB unit are accompanied by a PEB proposal provided by one of the following experts:

- PEB consultants in case of deep renovation of a unit (as in the case of a new PEB unit);
- Architects or PEB consultants, if charged by the declarer, in the case of a simple renovation;
- The declarer, in the case of a simple renovation and if the request doesn't require the support of an architect.²²³

²¹⁶ Website of the Directorate (decree of 4 September 2003 defines the scope of its tasks).

<http://www.logement.irisnet.be/qui-fait-quoi/que-fait-la-region/service-public-regional-de-bruxelles-direction-de-linspection-du-logement-1>

²¹⁷ <http://www.bruxellesenvironnement.be/Templates/Particuliers/Informer.aspx?id=11557&langtype=2060>

²¹⁸ Decree of 2 May 2013, Title 2, Article 2.2.8. The same actors mentioned in the PEB proposal are involved in the submission of the notification.

²¹⁹ Decree of 2 May 2013, Title 2, Article 2.2.10. Art 2.2.11. defines in how many days the PEB declaration has to be provided.

²²⁰ The decree amended the Decree of 19 June 2008 regarding building documentation. [http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?=&s_ql=\(text+contains+\(%27%27\)\)&rech=1&language=fr&tri=dd+A5+RANK&numero=1&table_name=loi&F=&cn=2014040335&caller=image_a1&fromtab=loi&la=F&pdf_page=2&pdf_file=http://www.ejustice.just.fgov.be/mopdf/2014/05/15_1.pdf](http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?=&s_ql=(text+contains+(%27%27))&rech=1&language=fr&tri=dd+A5+RANK&numero=1&table_name=loi&F=&cn=2014040335&caller=image_a1&fromtab=loi&la=F&pdf_page=2&pdf_file=http://www.ejustice.just.fgov.be/mopdf/2014/05/15_1.pdf)

²²¹ The government defines the content of the PEB proposal eventually according to the importance of the works, the size of the works and the use of the PEB unit according to the Decree of 2 May 2013, Title 2, Article 2.2.6). The decree of 3 April 2014 specifies different contents of the mentioned decree.

²²² <http://www.bruxellesenvironnement.be/Templates/Particuliers/Informer.aspx?id=11557&langtype=2060>

Decree of 2 May 2013, Title 2, Article 2.2.13

²²³ Decree of 2 May 2013, Title 2, Article 2.2.5. Additional cases are mentioned in this section.

For deep renovations and simple ones involving an architect, the content of the PEB proposal is established by Annex 1²²⁴ of the Decree of 3 April 2014 (as for new buildings). However, for simple renovations where an architect is not required, Annex 2 is used instead²²⁵.

Similar to the PEB proposal, the format of the PEB declaration for a simple renovation not requiring an architect is different from the case of new buildings; the format is established by Annex 4²²⁶ of the Decree of 3 April 2014²²⁷.

DENMARK

Building permits are approved by the local municipal authority, the main enforcement agent with regards to the building code. In order to get a permit, a developer has to demonstrate that the construction plans comply with the code, including energy efficiency requirements. Documentation for this must follow specific guidelines²²⁸. A building permit is required for new construction, including extensions and single-family houses. When construction has been completed, an energy performance review onsite is required. This must be conducted by an independent and certified auditor, who then issues the Energy Performance Certificate which is forwarded to the municipality. The building is legal only if it meets the energy performance requirements, so deficiencies must be corrected and corrections documented through a new energy performance review. Additionally, in order to prove that the building is in a proper state for occupancy, a certificate ("Ibrugtagningstilladelse") is issued by the local governmental authorities.

In addition, the municipal council may require documentation on airtightness. According to BR 10 Article 1.4(2), municipal councils are required to demand airtightness measurements in no less than 5% of the construction projects. For large-scale buildings, air changes through leakage may be experienced for individual building sections. For buildings to be approved according to the 2015 or 2020 requirements, the sample size must be 100%. Many municipalities have decided to apply this to all new buildings. Additionally, for rooms with special purposes, for example washing and drying rooms, saunas, storage rooms, lifts or car parks, the municipal council's approval is required for the ventilation design, taking into account the size and use of the room.

It becomes clear that if a new building does not comply with the regulation, the local municipal authority must request that conditions are improved. If this has no effect, it can lead to a police report, upon which prosecution authorities will take the matter to court. Provided that the court agrees with the authorities, the penalty is a fine, the size of which depends on the type and extent of non-compliance. The building owner must of course make sure that the conditions are legalised.

Another important enforcement mechanism, for new construction as well as for retrofits, is applied to construction products rather than to individual buildings. There are tests and certification schemes specifically regarding the energy efficiency of several construction components (e.g. windows, boilers, pumps, ventilation systems). Tests and certifications are carried out by independent laboratories. All in all, Danish enforcement is ensured through a limited administrative apparatus both at State and local levels.

²²⁴ Link to the annex [http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?=&sql=\(text+contains+\(%27%27\)\)&rech=1&language=fr&tri=dd+AS+RANK&numero=1&table_name=loi&F=&cn=2014040335&caller=image_a1&fromtab=loi&la=F&pdf_page=2&pdf_file=http://www.ejustice.just.fgov.be/mopdf/2014/05/15_1.pdf](http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?=&sql=(text+contains+(%27%27))&rech=1&language=fr&tri=dd+AS+RANK&numero=1&table_name=loi&F=&cn=2014040335&caller=image_a1&fromtab=loi&la=F&pdf_page=2&pdf_file=http://www.ejustice.just.fgov.be/mopdf/2014/05/15_1.pdf)

²²⁵ The government defines the content of the PEB proposal eventually according to the importance of the works, the size of the works and the use of the PEB unit according to the Decree of 2 May 2013, Title 2, Article 2.2.6). The decree of 3 April 2014 specifies different contents of the mentioned decree.

²²⁶ The decree amended the Decree of 19 June 2008 regarding building documentation. [http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?=&sql=\(text+contains+\(%27%27\)\)&rech=1&language=fr&tri=dd+AS+RANK&numero=1&table_name=loi&F=&cn=2014040335&caller=image_a1&fromtab=loi&la=F&pdf_page=2&pdf_file=http://www.ejustice.just.fgov.be/mopdf/2014/05/15_1.pdf](http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?=&sql=(text+contains+(%27%27))&rech=1&language=fr&tri=dd+AS+RANK&numero=1&table_name=loi&F=&cn=2014040335&caller=image_a1&fromtab=loi&la=F&pdf_page=2&pdf_file=http://www.ejustice.just.fgov.be/mopdf/2014/05/15_1.pdf)

²²⁷ The government defines the content of the PEB proposal eventually according to the importance of the works, the size of the works and the use of the PEB unit according to the Decree of 2 May 2013, Title 2, Article 2.2.6). The decree of 3 April 2014 specifies different contents of the mentioned decree.

²²⁸ The calculation of energy requirements has to follow the guideline SBi 213 "Bygningers energibehov" – in Danish. This guideline includes the calculation programme Be10.

The reasons for this include:

- A high level of information about the regulation. This is helped by the fact that requirements have evolved over many years with no radical shifts or change of direction;
- A general public understanding and positive attitude²²⁹.

FRANCE

Along with the application of RT 2012 and the strengthening of controls by the administration, building regulation controls (“contrôles des règles de construction”, CRC) are made each year on a sample of new constructions, the exact number of which is defined by the local authorities responsible for the control.

In general, compliance procedures are linked to building permit delivery and the finalisation of the construction. Short standardised reports about the thermal qualities of the building (“récapitulatif standardisé d'étude thermique”, RSET) are part of the application. The content has been defined in “l'arrêté du 26 octobre 2010” and includes:

- Administrative data of the building;
- Energy performance requirements and the thermal characteristics and requirements comprising the values of Bbio, Bbio_{max}, Cep and Cep_{max}²³⁰;
- The value of the building used in the calculations;
- The status of the building project vis-à-vis each requirement;
- The breakdown of needs and energy consumption of the building products, among other type of use and energy;
- Others.

A certificate of completion will be determined by a professional (architect, planner, certifying body etc.) who will verify:

- The three requirements results of RT 2012 (Bbio, Cep, Tic²³¹);
- Consistency between the short report for the building permit and the work actually done (energy production, airtightness, renewable energy, insulation etc.).

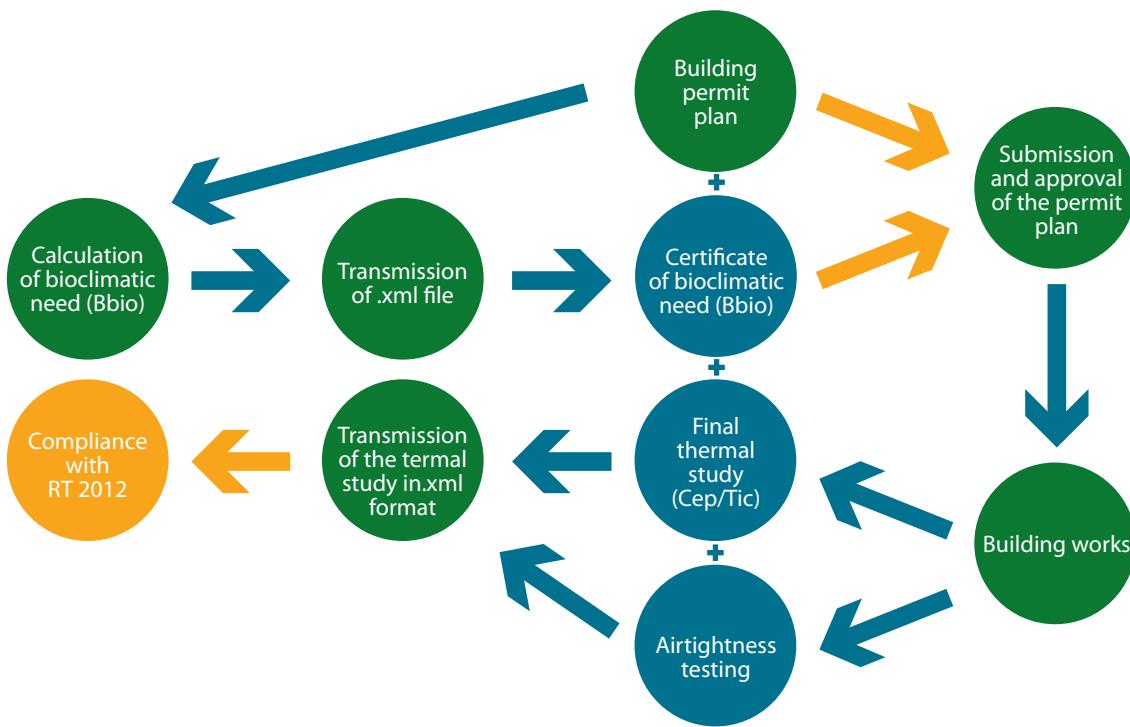
Specifically, the steps which are followed to show compliance with the RT 2012 are as follows:

²²⁹ Compare Policy tool kit

²³⁰ CEP: primary energy consumption, Bbio: bioclimatic needs. More details in Chapter Daylight requirements 3

²³¹ Tic: Indoor Conventional Temperature. More details in Chapter 2.1.1

Figure 5 - The stages of RT 2012 (Source: <http://aplushabitat.fr/coonstruire.htm>)



The client must provide the technical report of the building for five years following the declaration of completion. This summary will be made available to the following persons: a potential buyer, any person responsible for the compliance certification of the building with RT 2012 and/or a label of high performance, any inspector responsible for the monitoring of the construction rules application.

In the event of non-compliance, fines and penalties can apply.

Ventilation rates or indoor air quality requirements are not specifically addressed in the compliance check.

GERMANY

Even if most of the requirements apply nationwide, building codes and their compliance and control are officially the responsibility of the 16 regions (Länder). Checking for compliance is mostly delegated to the municipal authorities. Compliance with the minimum standards for thermal insulation (Wärmeschutznachweis) is part of the documentation when applying for a building permit. Once the construction is done, compliance with U-Values can be verified again. If an insulation material other than the planned one was used, it has to be checked that it is still in line with the requirements.

In the case of structural alterations to existing buildings that are within the scope of the Energy Saving Ordinance but do not require a building permit, the expert involved must confirm the compliance in a written document given to the building owner. This written confirmation must be kept for at least five years by the building owner and must be shown to the competent authority on request.

Infringements of the Energy Saving Ordinance may be punished by the authorities as an administrative offense with a fine of up to €50 000. An offense applies, for example, if the requirements for the energy characteristics in new buildings or renovations are not within compliance levels, if energy certificates are not provided (in time) or air conditioning systems are not inspected as they should be.

As ventilation rates according to DIN 1946 -6 are not legally binding, they are not part of the construction permit or compliance control process.

ITALY

The regional laws define all details pertaining to building permits and the cases in which they are required²³²; normally for new buildings and major refurbishments. An authorised body (e.g. the owner of the building) requests the building permit from the building service ("Sportello Unico per l'Edilizia") submitting inter alia the project drawings and a declaration of compliance (made by the designer)²³³.

National legislation requires a technical report (for energy efficiency requirements) to be provided together with the permit before the (building) work starts. The exact content of the technical report is defined in an additional decree²³⁴, and the proposed template also includes aspects related to ventilation and air quality (according to the level of compliance requested for the specific case) such as²³⁵:

- Planned indoor temperature and humidity considered in the project (such data are always provided);
- Calculated thermo-hygrometric characteristics (transmittance, humidity, surface weight) of the non-transparent elements (walls, floors, roof) compared to legal requirements;
- Calculated average daily air exchange rates for each different zone;
- Calculated exchange airflow in the case of mechanical ventilation;
- Design of airflow circulating in heat recovery systems (if available);
- Drawings of shadings and passive systems (always to be provided if available);
- Description of conditioning systems, possibly also including management devices for thermal regulation;
- Calculated thermal characteristics and airtightness of transparent surfaces;
- Evaluation of shading performances. Attenuation of thermal bridges (improvement measures and calculations);
- Calculated thermal transmittance of the walls dividing different dwellings.

After the end of the works, a "certificate of practicability" has to be requested from the relevant municipal office. It certifies compliance with the different requirements (i.e. related to health and energy efficiency). The certificate of practicability has to be requested by the person who has presented the building permit and who has to provide relevant documents such as:

- Declaration of compliance of the building (done by the applicant) with the project drawing, and compliance related to the drying walls ("asciugatura dei muri") as well as the healthiness of the building environment ("salubrità degli ambienti")²³⁶;
- Declaration of compliance of the conditioning systems (and other systems) and of systems testing²³⁷.

For existing buildings, the technical report associated with the building permit is also required for major refurbishments. However, the feasibility study on the installation of alternative systems for heating and cooling is only requested²³⁸ in the case of a refurbishment which involves at least 25% of the envelope surface area. In the technical report, the evaluation of shade systems is required for building modifications, including the new installation or refurbishment of thermal systems (but not in the case of replacement of the heat generator)²³⁹.

Usually minor modifications in existing buildings require a simple notification about the start of the works instead of a building permit (and the related documentation).

²³² Decree of the President of the Republic 380/2001, Article 10, comma 2.

²³³ Decree of the President of the Republic 380/2001, Article 20, comma 1.

²³⁴ Legislative Decree 192/2005, Art 8, comma 1. The technical report is no requested only in case of substitution of heat generator with a power lower than 50 kW (limit value defined in the Decree of the Ministry for the Economic Development number 37 of 22 January 2008).

²³⁵ Legislative Decree 192/2005, Annex E. The information contained in the paragraphs from number 5 to 9 are adjusted according to the level of compliance requested.

²³⁶ Decree of the President of the Republic 380/2001, Title 3, Chapter 3.

²³⁷ Compliance is specified in articles 113, 127 (compliance of system), 111 and 126 (test of systems) of the Decree of the President of the Republic 380/2001.

²³⁸ Legislative Decree 192/2005. Article 8, comma 1-bis.

²³⁹ Decree of the President of the Republic 59/2009, Article 4, comma 19 and 20.

POLAND

For new buildings, a building permit is required (before construction), as well as an occupancy permit (after construction). Exact procedures are described in the Construction Law (Dz.U. 1994 nr 89 poz. 414, amended).

For the "occupancy permit" to be issued, the following documents need to be submitted (Art. 57):

- Protocol from the inspection of the ducts (smoke, ventilation); the qualification of the person entitled to conduct the inspection is specified in the Construction act (i.e. craftsman, building engineers);
- Energy performance characteristics;
- The protocol from the control of the State Sanitary Inspection (i.e. especially for restaurants, office buildings, hospitals) and a fire-protection inspection;
- And many others.

In addition, before issuing the occupancy permit, the competent authority is required to undertake inspections. The post-executive control, or post-construction review of the site, is carried out by the County Building Supervision Inspectorate. The mandatory construction inspections will check compliance with the arrangements and conditions specified in the building permit and include different kind of checks.

If documents are not submitted, the occupancy permit might not be issued. In the case of negative inspection results, monetary penalties can be imposed on the investor and the permit might be refused.

For existing buildings, the building owners or managers are responsible for the building's good condition for aspects such as thermal insulation, energy saving, health and hygiene conditions. According to the construction law, owners and managers have to ensure proper maintenance of the building through periodic checks carried out by authorised persons; the frequency of the checks depend on the type of control.

Some checks involve indoor comfort aspects such as:

- At least one yearly check of the building technical conditions, including inspection of the ducts (ventilation and smoke);
- At least once every 5 years, a check of the building technical condition (mainly electric installations control);
- Boiler inspections (depending on size and fuel used):
 - every 2 years for boilers with a non-conventional source of fuel, with a minimum capacity >100kW;
 - every 4 years for boilers with a non-conventional source of fuel, with a minimum capacity between 20-100 kW and gas boilers.
- At least once every 5 years a check of the cooling system (>12 kW), its energy efficiency and an adjustment of the system parameters.

In addition, for all boilers (>20kW) in use for more than 15 years, further control should be conducted. It includes an assessment of energy efficiency and the size of the boiler, as well as the adjustment of system parameters.

All the periodic control results should be attached to the buildings documentation.

Anybody who performs the periodic checks without proper qualification, permission and the right to exercise an independent technical function is exposed to legal action, such as a monetary fine, restriction of liberty or imprisonment for up to a year. Fines can be issued in the case of poor quality of the control.

Sanctions specified in the provisions of the Construction Law may also be enforced to the owners and managers of a building. A fine of not less than 100 daily rates and/or restriction of liberty or imprisonment for a year can be imposed when the obligation to maintain a building in a proper condition (including periodic inspections) is not fulfilled, or when the safety of a building is not provided, etc.

SWEDEN

In Sweden, the compliance check implies that three levels of control have to be followed, all involving certified assessors. First, there is the Planning and Building System with the control plan, which foresees that a certified inspector has to verify if all items indicated in the control plan are properly fulfilled. The second assessor does the compulsory ventilation checks and finally, the energy expert issues an energy performance certificate.

The Building Board cannot allow energy checks to be undertaken regarding the Planning and Building System. However, if the Building Board finds out via the energy demand certificate that energy use is higher than allowed in the building code, they can act and ask the owner to correct it.

In Sweden, the compliance system is checked by local authorities. The person initiating the building project (future owner) is responsible for compliance. At the beginning of the project, the future owner applies for a building permit from the local authority. The local authority demands a control plan from the future owner, naming a special person assigned to control the project's fulfilment of different requirements.

Regarding energy issues, the local authority can demand calculations of energy balance from the future owner. After two years of running the building, the future owner can be asked to provide information on the operational rating. The authority can omit control of different requirements if the future owner is known to be a good builder. Nevertheless, the owner is still responsible. As part of the energy declaration of the building system, according to the EPBD, the previous or the new owner (if the building is sold) have to account for the operational rating after two years of using the building.

Materials and products should be verified by the developer. It is necessary to verify that prerequisites, project planning methods and calculations are relevant, properly applied and accurately recorded²⁴⁰.

Requirements concerning moisture condition should be verified during the design phase. However, moisture conditions may be affected during other phases. Therefore, for the moisture checks at the planning, design, construction and inspection phases, a guide concerning moisture processes can be used²⁴¹. Checking whether the material has not been damp-damaged during construction should be done by inspection, measurement, or documented analyses²⁴². Regarding the radon levels, energy certificates must include whether radon is measured and, if so, the value of the measurement must be reported²⁴³.

Testing, measuring or inspection of completed buildings depend on the building, and both the methods and results should be documented²⁴⁴.

²⁴⁰ BFS 2014:3 - BBR 21, 2:322

²⁴¹ BFS 2014:3 - BBR 21, 6:51.

²⁴² BFS 2014:3 - BBR 21, 6:51. Additional information on damp security at 6:53

²⁴³ Law (2006:985) on energy certification of buildings, article 9, comma 3.

http://www.riksdagen.se/sv/Dokument-Lagar/Lagar/Svenskforfatningssamling/Lag-2006985-om-energideklar_sfs-2006-985/

²⁴⁴ BFS 2014:3 - BBR 21, 2:321 (verification of the completed building).

UK (England & Wales)

When carrying out building works, compliance with the building regulations is checked by the Building Control Body (the local authority or an approved inspector)²⁴⁵.

The commissioning of the ventilation systems has to be realised in accordance with an approved procedure. Whenever building notice or full plans are required, the person carrying out the work has to provide to the Building Control Body the notification that the commissioning has been carried out no later than five days after the work has been completed; if the building works don't involve building notice, the notification may be provided within 30 days from the completion of the work²⁴⁶.

The person carrying out the work also has to provide sufficient information about the ventilation system (and its maintenance) to the owner or occupiers no later than five days after the work has been completed²⁴⁷.

The measurement of airflow rates is requested only in the case of a new dwelling (in accordance with an approved procedure); the results have to be properly recorded and notified to the Building Control Body no later than five days after the final test is carried out. If any measured value is less than the design value, adjustment should be made to correct the system, and if it is not possible, then a note to this effect should be made on the sheet²⁴⁸.

²⁴⁵ The Building (approved Inspectors etc.) Regulations 2010, No 2215": http://www.legislation.gov.uk/uksi/2010/2215/pdfs/uksi_20102215_en.pdf

²⁴⁶ http://www.planningportal.gov.uk/uploads/br/domestic_ventilation_compliance_guide_2010.pdf

²⁴⁷ Building Regulation, part 8, section 39 "Information about ventilation".

²⁴⁸ This may require the person with overall responsibility for the system to carry out remedial works to rectify the cause of the under-performance. The system will need to be re-tested to confirm that the design values have been met.

5 CONCLUSIONS AND RECOMMENDATIONS

Over the last decade, EU and national policies for buildings have called for stricter thermal insulation requirements for both new and existing buildings undergoing extensive renovation. This is a necessary strengthening of building policies as inter alia the climate and energy security threats are very serious and the EU's building sector is a major energy consumer and source of CO₂ emissions. Consequently, the need to improve the energy performance of buildings has led to a historical development of thermal regulations in many EU countries and especially in those from colder regions. Furthermore, securing proper indoor air quality and avoiding overheating during warmer seasons have become important aspects when designing a new construction or deeply renovating an existing building. Ventilation, humidity control, heat recovery, indoor temperature limitations, limitation of the indoor pollutant levels and CO₂ emissions have an increased importance in this new context and they should be appropriately regulated.

This study aimed to offer a brief overview of the main regulations related to indoor air quality, thermal comfort and daylight in eight EU countries and regions for both new and existing residential buildings. An overview of the main findings is presented in the following.

New residential buildings

Indoor air quality is recognised as an important aspect in the building codes in all focus countries of this survey. The benefits of securing proper indoor air quality, either for the well-being of inhabitants or for the safety and health of the building and its fabric, are also underlined in various forms in the building regulations of the studied countries.

Ventilation is included in all surveyed MS building regulations. In Denmark, France, Sweden and Brussels-Capital Region (BE) there are clear minimum requirements, while in Germany, Italy, Poland and the UK there are only recommended minimum ventilation rates. The indicators for minimum ventilation rates vary from one country to another and are generally different from EU standards. The most commonly used units are litres per second and cubic meters per hour while the air exchange rate is regulated based on the assumed number of occupants (e.g. Poland: 20 m³/h per occupant), on the type of the room (e.g. UK: Kitchen 13-60 l/s and WC 6 l/s), or on the floor area (e.g. 0.35 l/s per m²). Even though the use of the same metrics is less important, it seems that there is a need for further European harmonisation in order to facilitate a proper comparison across MS and an easier transfer of knowledge and practices among countries. Mandatory mechanical ventilation is in effect in two cases, i.e. for multi-family (Denmark) and high-rise buildings (Poland). For the other cases, there are recommendations for mechanical ventilation in two countries (Br-Region in Belgium and Germany), while in Italy and especially in warmer regions, natural ventilation is encouraged. It is worth mentioning the fact that the Danish regulation specifically asks ventilation systems to be easy to maintain even by the inhabitants. This should be considered as a good practice as ventilation systems need periodical maintenance to operate correctly over their lifetime. Maintenance of ventilation systems should be done systematically and should therefore be an easy and affordable procedure. Last but not least, it seems that most of the surveyed countries have to further improve their calculation tools to adequately address hybrid and demand-controlled ventilation in order to have comprehensive calculation methods to ensure that the ventilation needs are met.

Minimum efficiency requirements for *heat recovery systems* are in place in some countries (Sweden, Poland, Italy) when new mechanical ventilation systems are installed. *Airtightness* requirements differ largely across the EU. Six of the surveyed MS already have precise requirements in place. As for ventilation, indicators for airtightness requirements vary throughout Europe (e.g. volume per hour, litres per second per m²). Random airtightness tests are required in Denmark and France, but are voluntary in the other surveyed countries and are usually required only for applications to receive financial subsidies, or energy certification in the high classes. Regulations for heat recovery and airtightness, mainly introduced for energy efficiency reasons, have to be complemented by relevant ventilation requirements in order to secure proper indoor living conditions.

The *CO₂* concentration in fully occupied buildings – where inhabitants are the main pollutants – in relation to outdoor concentration is indicated by the European standard EN 15251. Requirements to limit CO₂ levels in residential buildings are in place in France, while in the UK, the levels are recommended. Limitations for *nitrogen oxide* are also in place in Denmark. The national implementation of EU construction products regulations and further national standards address the evaporation of unhealthy chemicals, however, this legislation is not considered for the purpose of this analysis.

Aspects of **thermal comfort**²⁴⁹ related to low temperatures or draught are often improved through measures primarily addressed at improving the energy performance of a building. However, there is an increasing risk of overheating to be addressed. Therefore, thermal comfort should be acknowledged in building regulations and the use of simple and efficient measures, e.g. solar shading, solar protective glazing and ventilative cooling²⁵⁰, should be encouraged. In all countries surveyed, there are requirements in place for the *thermal transmittance* of external building elements, but only few of them underline the co-benefits of thermal comfort.

Indoor air temperature is an indicator of thermal comfort in all countries surveyed and there are requirements and recommendations in place for lower and upper limits during winter and summer respectively. In a few countries such as France and the UK, operative temperature is also used to assess thermal comfort. Five out of eight countries require minimal temperatures in dwellings in winter (i.e. France, Germany, Poland, Sweden and the UK). Only Italy demands a lower limit in summer (max. cooling) and an upper limit in winter (max. heating).

Five countries within this survey (Br-Region/Belgium, Denmark, France, Germany and the UK) have overheating limitations (either mandatory or recommended), where overheating indicators differ by temperature and time limit. The extremes are found in the Brussels-Capital Region (> 25°C for 5%/yr) and the UK (> 28°C for 1%/yr), but only as recommendations in the latter case. Passive systems to avoid overheating are common in southern climates, but minimum requirements are mainly limited to solar shades while others such as ventilative cooling, use of building mass, natural ventilation, night time ventilation etc. are rarely considered. In Sweden, the building codes explicitly ask for the consideration of some passive solutions. The new Brussels-Capital Region regulations which will come in force from 2015 require a minimum share of 50% for passive systems.

Maximum *relative air velocity* limits are inconsistent in Europe; they range from 0.15 to 0.40 m/s (in summer) and from 0.15 to 0.25 m/s (in winter). Maximum values for air velocity in order to avoid draughts are required in Sweden and recommended in Denmark, Italy, Poland, the UK and Brussels (from 2015).

The use of **daylight** is an important element to achieve a good indoor environment in buildings, with a major impact on the health of inhabitants²⁵¹. Moreover, maximising the use of daylight in buildings offsets electric lighting and has a consistent energy saving potential. Acknowledging the importance of daylight use in buildings, all surveyed countries include at least a basic reference to it in their building

²⁴⁹ Thermal comfort is described as "that condition of mind which expresses satisfaction with the thermal environment" (British Standard BS EN ISO 7730)

²⁵⁰ "Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces". Source: <http://www.buildup.eu/>
communities/ventilativecooling

²⁵¹ Lighting Research Center, "Daylighting Resources-Health". Available at: http://www.lrc.rpi.edu/programs/daylighting/dr_health.asp#sad

codes. Daylight requirements or recommendations in MS legislations mainly specify a minimum share of window/glazing area per floor area, indicate minimum levels for daylight or simply stipulate the need for sunlight access in buildings and a view to the outside. As good practice, Danish building codes are the only ones requiring minimal solar gains in winter while the Swedish regulations recommend the use of daylight management systems for permanently installed luminaries. Only some building codes within the ones surveyed (i.e. Brussels-Capital Region, Denmark, Germany) highlight the importance of having a view to the outside as part of visual comfort.

Compliance procedures mainly focus on structural analysis and energy performance aspects during the design and construction of new buildings such as U-Values, right installation of heating equipment, airtightness, availability of EPCs, etc. Compliance with indoor air quality or thermal comfort standards is rarely checked by the designated control bodies and if so, mainly at the design stage rather than by performing onsite measurements.

Existing residential buildings

For existing buildings, **indoor air quality** related requirements, such as minimum ventilation rates, airtightness or limitation of pollutants, can hardly be found in the building codes analysed. Only recommendations of IAQ aspects can be found in most of the building codes. Energy efficiency improvements often apply without mandatory consideration of the influence in terms of building physics or indoor air quality. This lack of proper IAQ requirements to accompany the thermal and energy performance requirements has to be further considered as a priority. Among the surveyed countries, the Swedish building codes are unique at the moment in underlining potential conflicts between energy saving requirements and good indoor air quality in existing buildings, stipulating that in such cases priority should be given to the latter. Generally, renovation measures resulting in more airtight buildings are not accompanied by a compulsory assessment of ventilation needs. Therefore, in many such situations air change rates below the required values are reported. This is a serious shortcoming in building codes which has to be addressed through an improvement of the regulatory framework for renovation. Potentially, this aspect should be considered in the future recast of EU related legislation such as the EPBD.

When major renovation is undertaken, the most common requirement across surveyed countries concerns the **thermal transmittance** of building elements (U-Values), as required by the EPBD. Among the surveyed countries, only the southern ones (France and Italy) include shading requirements in cases of refurbishment.

Energy Balance requirements that include solar gains when assessing the energy performance of windows are included in the Danish and British building regulations. Considering solar gains together with the heat loss of a window provides a more comprehensive assessment of its energy performance.

Increased **thermal comfort** is often considered as a main driver for the decision of an owner-occupier to invest in renovation. However, thermal comfort results from improved energy performance are rarely captured by national and/or European legislation.

Introducing requirements for **daylight** use in existing buildings can be more challenging, as possible interventions to further increase daylight availability may be limited due to structural aesthetic reasons.

The Danish regulations stipulate requirements for a minimal solar gain in winter when replacing windows. No requirements have been identified across the surveyed building codes stipulating minimal daylight preservation when renovating a building, except in the UK where the regulation Right to Light is in place. This regulation secures that changes to neighbouring buildings must not reduce daylight availability in existing buildings.

As in the case of new buildings, **compliance** checks are only done on structural analysis and energy performance aspects, while no indoor air quality or thermal comfort verification procedures have been identified.

Indoor air quality and other aspects of thermal comfort have to be seriously considered when strengthening the energy performance requirements for buildings and building elements. Today, as identified in the eight focus countries, there are no clear and strict requirements in place for indoor air quality and thermal comfort. There is a need to emphasise thermal comfort aspects in order to have proper living and working indoor conditions.

The main findings of this study lead to several recommendations:

- Indoor health and comfort aspects should be considered to a greater extent in European building codes than is current practice. When planning new nZEBs or nZEB refurbishments, requirements for a healthy and pleasant indoor environment should be included. While indoor climate is mentioned in the EPBD, the importance of indoor air quality, thermal comfort and daylight has to be strengthened in a future recast. Such requirements should also be reflected in national renovation strategies as developed under Articles 4 and 5 of the Energy Efficiency Directive.
- In the EU and national legislation, stricter energy performance requirements should be complemented with appropriate requirements and recommendations to secure proper indoor air quality, daylight and thermal comfort. For instance, requirements for stricter insulation and airtightness should be completed by appropriate minimum requirements for indoor air exchange and ventilation. As there are several ways to obtain significant savings in energy consumption in buildings and at the same time improve the indoor climate, clear legislative provisions for conflicting situations will create certainty for planners and architects. At the same time, legislation should be technology-neutral.
- Unused potentials for energy savings should be further exploited in European and national legislation taking a system-approach to the building. This means that the building's envelope and its insulation, use of daylight, demand-controlled ventilation, heat recovery through mechanical ventilation systems, installations to avoid overheating such as ventilative cooling and solar shading (e.g. by overhangs, louvers and awnings) should be analysed and optimised in a systematic way in order to achieve the highest energy savings possible.
- Indoor air quality, thermal comfort and daylight indicators should be integrated in Energy Performance Certification as relevant information regarding the actual living conditions in the building.
- The development of a proper cost indicator and calculation formula to estimate the benefits of a healthy indoor environment should be considered and further integrated in the European methodology to calculate cost-optimal levels at a macroeconomic level.
- The co-benefits of a healthy indoor environment should be taken into account when assessing the macroeconomic impact of energy renovation measures (e.g. reduction of health service costs).
- Windows are elements of the building envelope and play an important role in the overall energy performance of the building. Therefore, thermal transmittance, daylight usage and solar gains should be considered in the overall energy performance of buildings, both for new and existing buildings undergoing energy renovation. Requirements for ventilation and to prevent overheating should be taken into account in the same context.

- Passive systems to avoid overheating are common in southern climates, but minimum requirements are mainly limited to solar shades. Additional measures, such as the management of glazing areas of the building envelope, dynamic external shading, consideration of solar gains and the use of building mass, natural and night time ventilation strategies, etc. have to be further covered within national and European legislation.
- The mandatory compliance tools for the evaluation of energy performance according to national EPBD implementation should to a larger extent reward and facilitate the use of energy efficient ventilation solutions and measures to prevent overheating.

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ANNEX 1: QUESTIONNAIRE

The data collection for this study was based on the following questionnaire, which at first stage was filled in by the BPIE team and at the later stage was reviewed by national experts.

LEGAL REQUIREMENTS AND DE-FACTO STANDARDS CONCERNING INDOOR AIR QUALITY (IAQ), THERMAL COMFORT AND DAYLIGHT FOR NEW AND EXISTING RESIDENTIAL BUILDINGS IN SELECTED EUROPEAN MEMBER STATES.

- QUESTIONNAIRE -

Country: <XXX>

Contact: <Name and institution>

GENERAL INFORMATION – NEW RESIDENTIAL CONSTRUCTION	
Name(s) of relevant legislation and/or standard(s) in local language covering IAQ, thermal comfort and daylight	<Please provide names and types>
URL(s) of relevant legislation and/or standard(s)	<www.xxx.xx>
Organisation(s) in charge of development (e.g. Ministry)	<XXX>
Implementation level (e.g. regional, national)	<XXX>
Exempted residential building types (if any)	<XXX>
Date of code enforcement (last update)	<XX.XX.XX>
Date of next update (if known)	<XX.XX.XX>

GENERAL INFORMATION – EXISTING RESIDENTIAL BUILDINGS (ONLY IF DIFFERENT FROM NEW CONSTRUCTIONS)	
Name(s) of relevant legislation and/or standard(s) in local language covering IAQ, thermal comfort and daylight	<Please provide names and types>
URL(s) of relevant legislation and/or standard(s)	<www.xxx.xx>
Organisation(s) in charge of development (e.g. Ministry)	<XXX>
Implementation level (e.g. regional, national)	<XXX>
Date of code enforcement (last update)	<XX.XX.XX>
Date of next update (if known)	<XX.XX.XX>

INDOOR AIR QUALITY & VENTILATION (IAQ) – NEW RESIDENTIAL CONSTRUCTION

Minimum requirements for Indoor air quality (IAQ) and ventilation

Ventilation rates/ Minimum Air exchange rate/ Airtightness	<Please provide number and unit, if applicable for different residential building types >
IAQ indicator (eg. limitation of certain pollutants, humidity)	<Please provide kind of indicator, including maximum value and unit, if applicable for different residential building types >
Minimum area of natural ventilation openings	<Please provide number and unit, if applicable for different residential building types >

Heat recovery (HR)

Do specific requirements for HR apply?	<If yes, which exactly?>
Do "De facto" standard(s) due to strict energy requirements apply?	<If yes , please explain briefly why>
Other aspects of ventilation limited by energy requirements?	<If yes , please explain briefly why >

Mechanical vs. natural ventilation

Are specific system types required, or do both have equal relevance and opportunities?	<If yes, which exactly and when do they apply?>
Is hybrid ventilation approached (combined natural and mechanical ventilation)? (e.g. summer/winter approach)	<If yes, how exactly?>

Compliance

Required documentation to show compliance	<Please briefly explain who has to deliver which information....
Which body is in charge and how are checks conducted? to which authority and what is the general procedure?>
What is the level of compliance?	<If known, please provide details>

INDOOR AIR QUALITY & VENTILATION (IAQ) – EXISTING RESIDENTIAL BUILDINGS (ONLY IF DIFFERENT FROM NEW CONSTRUCTIONS)

Minimum requirements for indoor air quality (IAQ) and ventilation

Ventilation rates/ Minimum Air exchange rate/ Airtightness	<Please provide number and unit, if applicable for different residential building types and case (trigger point) in which requirement applies>
IAQ indicator (eg. limitation of certain pollutants, humidity)	<Please provide kind of indicator, including maximum value and unit, if applicable for different residential building types and case (trigger point) in which requirement applies >
Minimum area of natural ventilation openings	<Please provide number and unit, if applicable for different residential building types and case (trigger point) in which requirement applies >

Heat recovery (HR)

Do specific requirements for HR apply?	<If yes, which exactly and when do they apply?>
Do "De facto" standard(s) due to strict energy requirements apply?	<If yes, please explain briefly why and for which case>
Other aspects of ventilation limited by energy requirements?	<If yes, please explain briefly why and for which case>

Mechanical vs. natural ventilation	
Are specific system types required, or do both have equal relevance and opportunities?	<If yes, which exactly and when do they apply?>
Is hybrid ventilation approached (combined natural and mechanical ventilation)? (e.g. summer/winter approach)	<If yes, how exactly?>
Compliance	
Required documentation to show compliance	<Please briefly explain who has to deliver which information....
Which body is in charge and how are checks conducted? to which authority and what is the general procedure?>
What is the level of compliance?	<If known, please provide details>

THERMAL COMFORT – NEW RESIDENTIAL CONSTRUCTION	
Requirements for summer situation (e.g. max hours above a certain temperature, thermal capacity, max. solar and internal gains, solar protection, requirements on glazed areas)	<Please provide kind of requirement, including maximum value and unit, if applicable for different residential building types >
Requirements for winter situation (e.g. requirements limiting the risk of too low temperatures, max. draught, max air velocities, any requirements on surface temperatures)	<Please provide kind of requirement, including maximum value and unit, if applicable for different residential building types>
Requirements on airflow	<If yes, please specify>
Requirements on humidity	<If yes, please specify>
(Passive) systems avoiding overheating (e.g. dynamic shading, ventilative cooling (intensive summer ventilation), etc.)	
Is there requirements to avoid overheating?	<If yes, please specify>
How is the potential of systems like shading, ventilative cooling etc. acknowledged in regulations?	<If yes, please specify>
How is the potential of these systems acknowledged in compliance tools?	<If yes and different from above , please specify>
Is it clear for designers how these systems can be used?	< If yes , please explain briefly why>

Compliance	
Required documentation to show compliance	<Please briefly explain who has to deliver which information....
Which body is in charge and how are checks conducted? to which authority and what is the general procedure?>
What is the level of compliance?	<If known, please provide details>

THERMAL COMFORT – EXISTING RESIDENTIAL BUILDINGS (ONLY IF DIFFERENT FROM NEW CONSTRUCTIONS)

Requirements for summer situation (e.g. max hours above a certain temperature, thermal capacity, max. solar and internal gains, solar protection, requirements on glazed areas)	<Please provide kind of requirement(s), including maximum value and unit, and case (trigger point) in which requirement applies >
Requirements for winter situation (e.g. requirements limiting the risk of too low temperatures, max. draught, max air velocities, any requirements on surface temperatures)	<Please provide kind of requirement(s), including maximum value and unit and case (trigger point) in which requirement applies>
Requirements on airflow	<If yes, please specify>
Requirements on air humidity	<If yes, please specify>

(Passive) systems avoiding overheating (e.g. dynamic shading, ventilative cooling (intensive summer ventilation), etc.)

Is there requirements to avoid overheating?	<If yes, please specify>
How is the potential of systems like shading, ventilative cooling etc. acknowledged in regulations?	<If yes, please specify>
How is the potential of these systems acknowledged in compliance tools?	<If yes and different from above , please specify>
Is it clear for designers how these systems can be used?	< If yes , please explain briefly why>

Compliance

Required documentation to show compliance	<Please briefly explain who has to deliver which information....
Which body is in charge and how are checks conducted? to which authority and what is the general procedure?>
What is the level of compliance?	<If known, please provide details>

DAYLIGHT – NEW RESIDENTIAL CONSTRUCTION

Minimum daylight requirements (e.g. Windows to be min. % of floor area, Daylight Factor (DF) or alike)	<Please provide kind of requirement (if any), including maximum value and unit, if applicable for different residential building types >
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Compliance

Required documentation to show compliance	<Please briefly explain who has to deliver which information....
Which body is in charge and how are checks conducted? to which authority and what is the general procedure?>
What is the level of compliance?	<If known, please provide details>

**DAYLIGHT – EXISTING RESIDENTIAL BUILDINGS
(ONLY IF DIFFERENT FROM NEW CONSTRUCTIONS)**

Minimum daylight requirements (e.g. Windows to be min. % of floor area, Daylight Factor (DF) or alike)	<Please provide kind of requirement , including maximum value and unit and case (trigger point) in which requirement applies>
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Compliance	
Required documentation to show compliance	<Please briefly explain who has to deliver which information....>
Which body is in charge and how are checks conducted? to which authority and what is the general procedure?>
What is the level of compliance?	<If known, please provide details>

ANY FURTHER COMMENTS OR REQUIREMENTS YOU WANT TO ADD:

< Please add your comments here>



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