Indoor air quality, thermal comfort and daylight policies on the way to nZEB – status of selected MS and future policy recommendations

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Abstract

Buildings are getting tighter and better insulated in order to reduce their energy needs caused by heat loss via transmission and uncontrolled air flows. Better insulated buildings also increase the risk of overheating, and therefore the prevention of overheating becomes increasingly important. At the same time humans need minimal air exchange rates for a healthy indoor climate and protection of the building fabric. There is also increasing awareness of the importance of daylight on health.

It needs integral planning and good building codes to adequately address these challenges. Projects already prove that buildings can be energy efficient and at the same time contribute to outstanding indoor air quality and comfort. The EPBD, 2010/31/EU calls the Member States (MS) to further improve the regulatory and policy frameworks in order to reach nearly zero-energy buildings and indicates that indoor climate conditions have to be considered when putting in place minimum energy requirements. However, there are currently no clear requirements for indoor climate conditions in buildings.

This technical paper about indoor air quality, thermal comfort and daylight requirements in 8 selected MS (BE –Brussels Region, DK, FR, DE, IT, PL, SE, UK – England and Wales) addresses a range of parameters of these topics that are vital for buildings and their inhabitants.

The results of the analysis show that all studied MS have at least a basic reference to IAQ included in their building codes. Minimum ventilation rates are required or recommended in all 8 MS and precise airtightness requirements are in place in 6 MS (BE, DK, FR, SE, PL, UK). Concerning thermal comfort indicators, indoor temperature requirements or recommendations range between 16 °C (PL) and 28 °C (FR) and recommendations about humidity are given in 6 MS (DE, PL, IT, SE, UK). All 8 MS include at least a basic reference to daylight in their building codes mainly referring to a minimum share of window area per floor area and minimum levels of daylight.

Based on the findings it can be concluded that indoor health and comfort aspects should be considered to a greater extent in the EU and national building codes.

Introduction

Air quality – be it indoors or outdoors – is one of the major environmental health concerns for Europe[1]. For that reason, and as people spend 60–90 %[2] of their life in indoor environments (houses, offices, schools, etc.), **indoor air quality** (IAQ) plays a very important role for the health of the population and particularly for vulnerable groups like babies, children and elderly people. According to the World Health Organization[3], in 2012, 99,000 deaths in Europe and 19,000 in non-European high income countries were attributable to household (indoor) air pollution.

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.

Indoor air quality refers to the quality of the air inside buildings and is related with 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 account[4]. 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 quality[5].

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 distracted[8]. Moreover, excess heat negatively affects the health of people suffering from cardiovascular diseases, diabetes, Parkinson's, Alzheimer's and epilepsy[9], whereas excess cold and mould in homes lead to asthma/respiratory illness and affects negatively the mental health of the occupants[10].

A good level of **daylight** is also an integral part of a proper indoor environment. A recent survey[11] showed that 63 % of the people rated natural light as the most important aspect of a home. The benefits of daylight are highlighted in numerous studies with one of the most recent ones[12] summarising them as:

- Economic and ecological, due to reduced energy consumption and CO_2 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.

The need to mitigate climate change and to reduce energy import dependency provides additional challenges for the design and operation of buildings, requiring to dramatically reduce the energy consumption and emissions associated with buildings. The building sector in the EU is responsible for more than one third of the energy consumption and a similar share of the CO_2 emissions associated with human activities. As a consequence, building policies are getting more demanding to improve the energy performance and to reduce CO_2 emissions. Consequently, buildings are getting air tighter and better insulated in order to prevent heat loss via transmission and uncontrolled air flows. The improvement of building air tightness through insulation should also mitigate factors that have a negative impact on the indoor air quality, such as mould and outdoor polluted air. In order to ensure good indoor climate and air exchange in buildings, a ventilation management system is required, for which both natural and mechanical solutions exist. Therefore, in addition to energy efficiency criteria, attention needs to be paid at all indoor comfort parameters, and building codes should impose appropriate minimum requirements to secure 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"[13]. Consequently, integral planning and good building codes are needed in order to adequately address these challenges. Best practise 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 and comfort[14]. But how do today's building codes address IAQ, thermal comfort and daylight? What are best practise approaches and where does legislation need improvement?

The EPBD asks EU Member States (MS) to significantly improve the regulatory and policy framework in order 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 to the European technical standards and to create evidence for potential future improvements.

Reducing energy demand and associated CO_2 emissions of buildings is imperative to mitigate climate change and to increasing energy security, but it is equally important to ensure proper indoor comfort. Therefore it is essential to ensure that indoor air quality and other aspects of comfort are being treated with the same level of importance as energy efficiency, so that energy renovation and comfort enhancement investments are mutually reinforcing.

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.

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

11. HOMEWISE, "Without space + light".

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

13.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.

14. Case studies available at the Active House Alliance website: http://www.activehouse.info/.

The aim of the paper

This paper 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 paper is to provide an overview of the regulatory framework for IAQ, and to highlight the importance of having appropriate requirements for thermal comfort, ventilation and daylight conditions. The paper provides concluding recommendations for further policy development relevant for IAQ. The assessment provided by this paper 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.

Main findings

This paper is based on the BPIE study "Indoor Air Quality, Thermal Comfort and Daylight – Analysis of residential building regulations in eight EU Member States". The data collection for this study was based on a questionnaire that addressed all the above mentioned topics and at first stage was filled in by the BPIE team and at the later stage was reviewed by national experts. An overview of the main findings are presented below.

NEW RESIDENTIAL BUILDINGS

Indoor air quality

Indoor air quality[15] is recognised as an important aspect in the building codes in all focus countries of this paper. The benefits of securing a proper indoor air quality, either for the well-being of inhabitants or for 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 buildings regulations in all the 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 are only recommended minimum ventilation rates. The indicators for minimum ventilation rates vary from one country to another and are generally different from the 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 m^3/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 m^2). 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 the EU 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 residential (PL) buildings. For the other cases, there are recommendations for mechanical ventilation in two countries (Br-Region, DE), while in Italy and especially in warmer regions natural ventilation is encouraged. It is worth mentioning the fact that Danish regulation specifically asks that the ventilation systems have to be easy to be maintained even by the inhabitants. This should be considered 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 for adequately addressing hybrid and demand controlled ventilation in order to have comprehensive calculation methods to ensure that the ventilation needs are met.

Increasing the air exchange rate to improve IAQ may increase energy consumption, but this may be compensated by **heat recovery**. However, requirements for heat recovery are rarely found in national building codes for dwellings and the EPBD Recast does not even mention it as an option to be considered. Minimum efficiency requirements for heat recovery systems are in place in some countries (Sweden, Poland, Italy) when new mechanical ventilation systems are installed.

Building **airtightness**, which describes the resistance of the building envelope to inward or outward air leakage, is a crucial aspect for a better energy performance of buildings. Although it is now included in many energy performances related regulations (e.g. in Belgium, Denmark, France, Germany, Swede, 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, UK) and others with guidelines for the 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. 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 CO_2 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 for limiting CO_2 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 such as is the case in Denmark. National implementation of European's construction products directives and further national standards address evaporation of unhealthy chemicals, however, this legislation is not considered for the purpose of this analysis.

Thermal comfort

Aspects of thermal comfort[16] related to low temperatures or draught are often improved with measures that are primarily addressed to improve the energy performance of a building. However, there is an increasing risk of overheating which has

15. Indoor Air Quality is the environmental characteristics inside buildings that may affect human health, comfort or work performance." Source: IAQ scientific findings resource bank.

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

Table 1. Ventilation standards in dwellings (Source: BPIE).

Country and Standard Reference	Whole Building Ventilation Rates	Living Room	Bedroom	Kitchen	Bathroom + WC	WC only	Standard
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 25 m^3/h (limited to 72 m^3/h)	Open kitchen Minimum 75 m^3/h (exhaust)	Minimum 50 m^3/h (limited to 75 m^3/h)	Minimum 25 m^3/h	Requirement
Denmark (BR10)	Min. 0.3 $l/(s \cdot m^2)$ (supply)	Min. 0.3 $l/(s \cdot m^2)$ (supply)		20 l/s (exhaust)	15 l/s (exhaust)	10 l/s (exhaust)	Requirement
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	Requirement
Germany (DIN 1946-6)	15–285 m^3/h			45 m^3/h (nominal exhaust flow)	45 m^3/h (nominal exhaust flow)	25 m^3/h (nominal exhaust flow)	Recommendation
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		Recommendation
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 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	Recommendation
Sweden (BFS2014:13 – BBR21)	Supply: min 0.35 $l/(s \cdot m^2)$ floor area						Requirement
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)	Recommendation
EN 15251	0.35–0.49 $l/(s \cdot m^2)$	0.6–1.4 $l/(s \cdot m^2)$		14–28 l/s	10–20 l/s	7–14 l/s	European standard

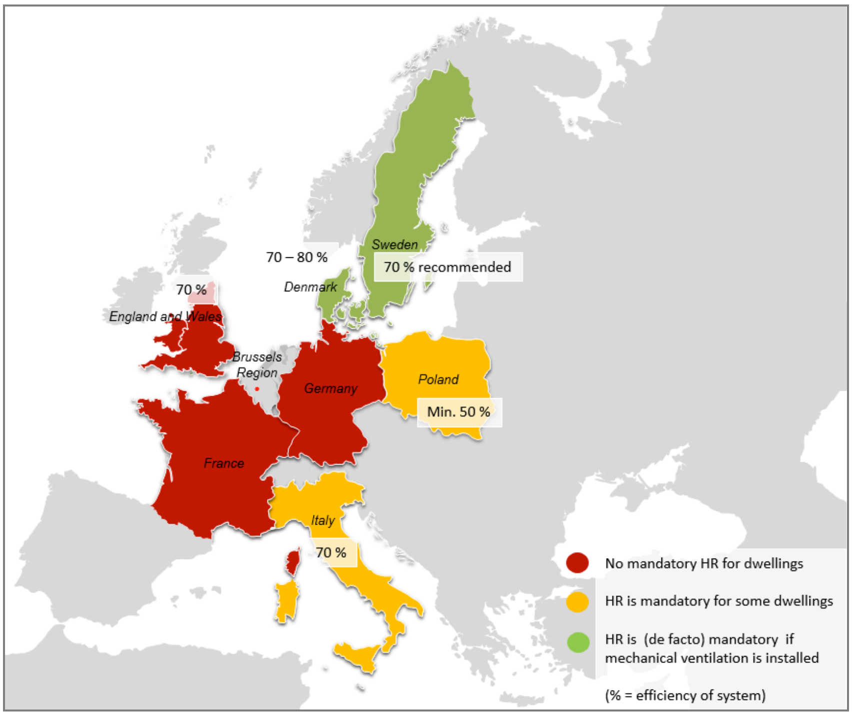

Figure 1. Heat recovery (HR) requirements in Europe (Source: BPIE).

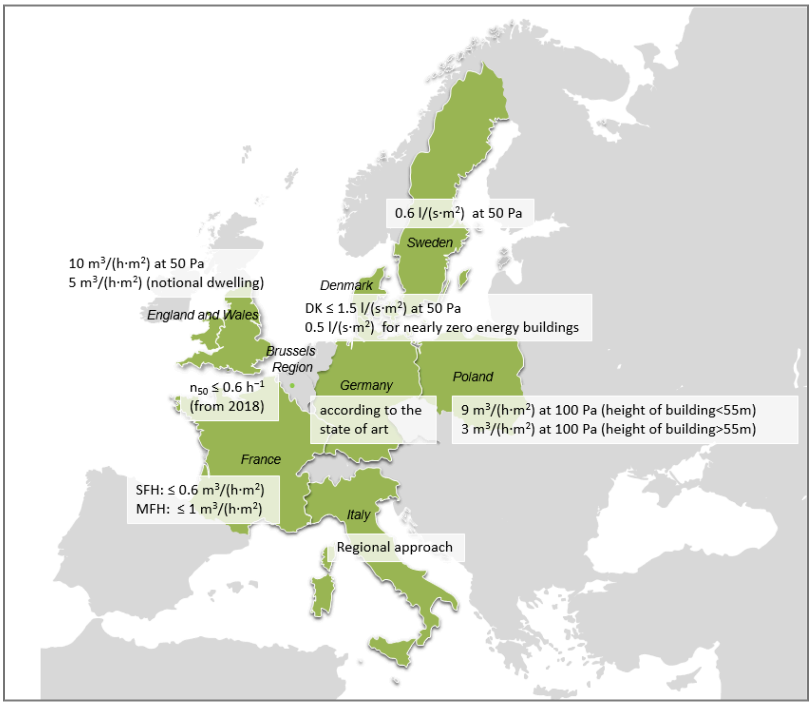

Figure 2. Airtightness requirements in Europe (Source: BPIE).

to be addressed[17], as buildings are getting tighter – through the addition of insulation, airtight windows, etc. – in order to avoid energy losses and air leakages. In high insulated buildings, internal temperatures can often be maintained by heat gains from sources other than the heating system and if heat gains are significantly greater than the losses then overheating can occur[18]. 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[19] should be encouraged. In all surveyed countries there are requirements for thermal transmittance of external building elements in place, but only few of them underline the co-benefits of thermal comfort.

Indoor air temperature is an indicator for thermal comfort in all surveyed countries and there are requirements and recommendations in place for lower and upper limit during winter and summer respectively. In few countries such as France and the UK, operative temperature is also used for assessing thermal comfort. Five out of eight countries require minimal temperatures in dwellings in winter (i.e. France, Germany, Poland, Sweden, 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 UK) have introduced limitations of overheating in their buildings codes, where overheating indicators differ by temperature and time limit. The extremes are found in Brussels Region (> 25 °C for 5 %/yr) and UK (> 28 °C for 1 %/yr), but only as 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, use of building mass, natural ventilation, 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.

Humidity is of particular concern in residential ventilation as most of the adverse health effects and building disorder (condensation, moulds) are related to humidity. Recommendations concerning the humidity (in order to avoid water condensation or too dry air) are given in Germany, Poland, Italy, Sweden and UK (soft reference).

Maximum relative **air velocity** limits are inconsistent in Europe; they range from 0.15 to 0.30 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 and, from 2015, in Brussels Region.

Daylight

The use of daylight is an important element for reaching a good indoor environment in building, with a major impact on health of inhabitants[20]. Moreover, maximising the use of natural 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 EU MS legislations mainly spec-

17. Department for Communities and Local Government, "Investigation into Overheating in Homes, Literature Review". Source: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7604/2185850.pdf.

18. "Reducing Overheating – a designer's guide", Energy Saving Trust. Source: http://www.rebelenergy.ie/ce129.pdf.

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

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

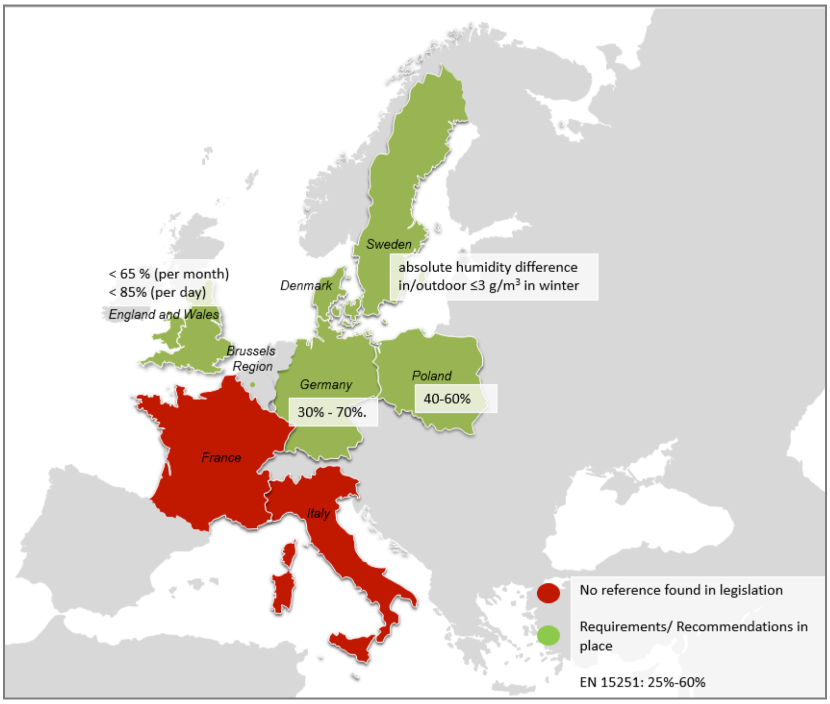

Figure 3. Overview of (de facto) humidity standards in Europe (Source: BPIE).

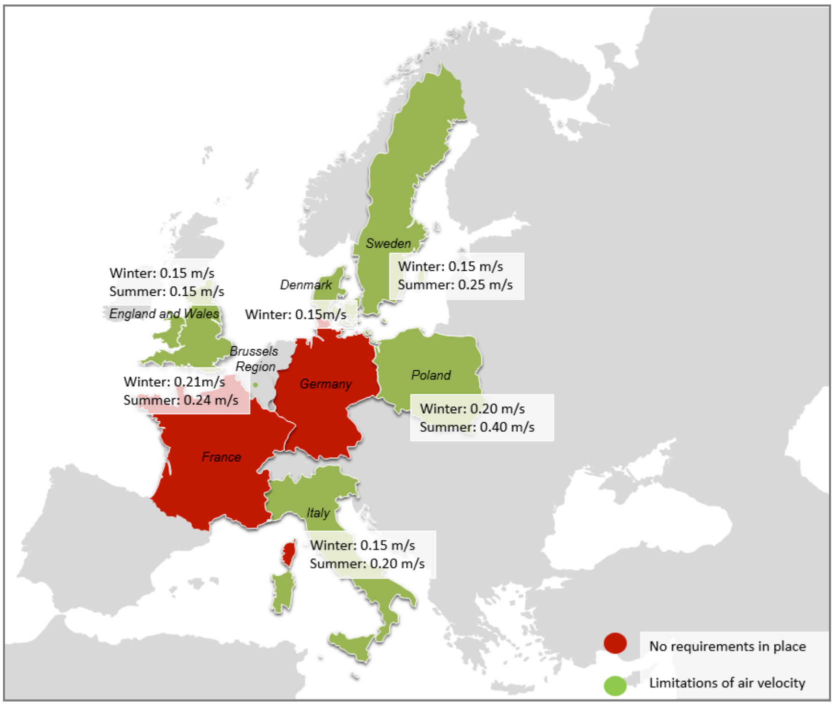

Figure 4. Maximal allowed air velocities in Europe (Source: BPIE).

ify 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. As good practice, Danish building codes are the only 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 surveyed ones (i.e. Brussels Region, Denmark, Germany) highlight the importance of having the view to outside as part of visual comfort.

Compliance

Compliance procedures are mainly focusing on structural analysis and energy performance aspects at design and construction of new buildings such as U-Values, right installation of heating equipment, air tightness, 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 on-site measurements.

EXISTING RESIDENTIAL BUILDINGS

Indoor air quality

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 of 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. 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.

Thermal comfort

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.

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 surveyed countries, only the southern ones (France and Italy) include shading requirements in case of refurbishment. Energy Balance requirements that include solar gain 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.

Furthermore, some countries require minimal (winter) and maximal (summer) temperatures in existing buildings in order to guarantee a minimum level of comfort. Such case is Germany, where 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.

Daylight

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.

Compliance

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.

Recommendations

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.

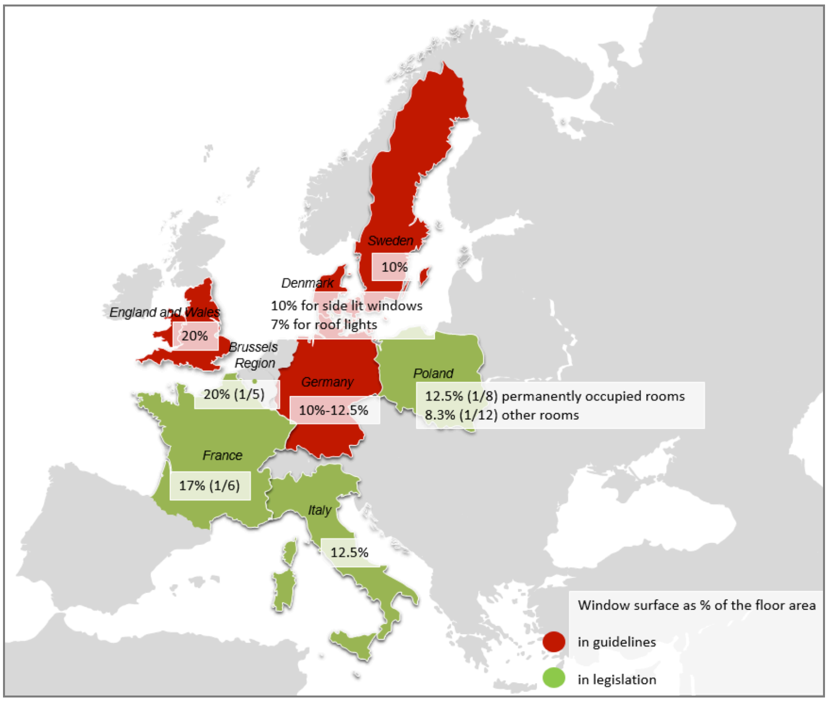

Figure 5. Daylight in legislation (Source: BPIE).

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. The main findings 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 have 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 further energy savings should be further exploited in European and national legislation taking a systems 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 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 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 are playing an important role in the overall energy balance 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 management of glazing areas of the building envelope, consideration of solar gains and 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 evaluation of energy performance according to national EPBD implementation should to a larger extent award and facilitate the use of energy efficient ventilation solutions and measures to prevent overheating.

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Germany

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Italy

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