Analysis of indoor air quality & thermal comfort parameters in building regulations in 8 member states

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ABSTRACT

It is estimated that people spend 60-90% of their life in indoor environments. Therefore, it is obvious that indoor air quality (IAQ) and thermal comfort are of highly importance for the health and wellbeing of the population. Consequently, buildings should be designed to ensure proper indoor conditions. Furthermore, the need to mitigate climate change and to reduce energy import dependency, provides additional challenges for the design and operation of buildings and requires a dramatic reduction in their energy consumption and emissions. Based on that, the Energy Performance of Buildings Directive (EPBD, 2010/31/EU) asks EU Member States (MS) to significantly improve their regulatory and policy framework to ensure that minimum energy performance requirements will be met. At the same time, the EPBD, acknowledging the important role of IAQ, 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”.

Projects and voluntary standards for very low energy buildings already prove that buildings can be energy efficient and at the same time contribute to outstanding IAQ and thermal comfort. But how do today’s building codes address these topics?

The overall aim of the paper is to provide an overview of the regulatory framework for IAQ and thermal comfort and to highlight the importance of having appropriate requirements for the parameters linked with these topics. The parameters that are studied in this paper are: ventilation rates, airtightness, indoor air pollutants, mechanical and natural ventilation, indoor temperatures, humidity and air velocity. 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).

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 with regard to humidity are given in 6 MS (DE, PL, IT, SE, UK).

For existing buildings, indoor air quality related requirements (ventilation rates, airtightness, etc.), can hardly be found in the analysed building codes. Regarding thermal comfort, even though it is often considered as a main driver for the decision of an owner/occupier to invest in renovation, it is rarely captured by national and/or European legislations.

Based on the findings of the paper, it can be concluded that indoor health and comfort aspects should be considered to a greater extent in the European and national building codes than it is current practice.

KEYWORDS

Indoor air quality, thermal comfort, residential buildings, building regulations

1 INTRODUCTION

Indoor air quality (IAQ) refers to the quality of the air inside a building. Its importance for people's health, comfort and ability to work is self-evident taking into consideration that people spend 60-90% of their life in indoor environments (homes, offices, schools, etc.) (DG SANCO, 2011). In 2012, 99000 deaths in Europe and 19000 in non-European high income countries were attributable to household (indoor) air pollution (World Health Organization, 2014).

Thermal comfort is described by the British Standard BS EN ISO 7730 as "that condition of mind which expresses satisfaction with the thermal environment" and according to the Health and Safety Executive (Health and Safety Executive) is strongly linked to environmental factors such as air temperature and humidity as well as to personal factors (clothing insulation, metabolic heat). 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 distracted (Green Education Foundation).

Referring to IAQ and thermal comfort aspects, the Energy Performance of Buildings Directive (EPBD, 2010/31/EU) 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". Consequently, holistic planning and all-encompassing building codes are necessary in order to adequately deal with these challenges. But how do today's building codes address these topics?

The aim of this paper is to provide a comprehensive overview of the regulatory framework for IAQ and thermal comfort parameters in residential buildings in selected member states (MS) and to highlight the importance of having appropriate requirements for these parameters.

2 INDOOR AIR QUALITY AND THERMAL COMFORT PARAMETERS

2.1 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 (Table 1).

Table 1: Ventilation standards in dwellings (BPIE, 2015)

Country	Whole Building Ventilation Rates	Living Room	Bedroom	Kitchen	Bathroom + WC	WC only
Brussels (requirements)	3.6 $m^3/(h \cdot m^2)$ floor surface area	Minimum 75 m^3/h (limited to 150 m^3/h)	Minimum 25 m^3/h (limited to 72m^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
Denmark (requirements)	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)
France (requirements)	10-135 m^3/h (depending on room number and ventilation system)			Continuous: 20 – 45 m^3/h		Minimum 15 m^3/h
Germany (recommendations)	15-285 m^3/h (from 30 m^2 to 210 m^2)			45m^3/h (nominal exhaust flow)	45 m^3/h (nominal exhaust flow)	25 m^3/h (nominal exhaust flow)
Italy (recommendations)	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 (recommendations)	20 m^3/h for each permanent occupant	20 -30 m^3/h for each permanent occupant (for public buildings)	30 m^3/h to 70 m^3/h without windows	50 m^3/h	30 m^3/h
Sweden (requirements)	Supply: min 0.35 $l/(s \cdot m^2)$ floor area				
UK (recommendations)	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 $l/(s \cdot m^2)$	0.6 – 1.4 $l/(s \cdot m^2)$	14 -28 l/s	10- 20 l/s	7-14 l/s

In **Brussels-Capital Region**, in case 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” (Table 1), except some adjustments that are specified in the Decree of 21 December 2007. Bruxelles Environnement, the public administration for environment and energy in the Brussels-Capital Region, recommends that windows should be designed to allow hygienic ventilation and rapid discharge of indoor pollution.

In **Denmark**, the Building Regulation 2010 (BR10) clearly addresses the importance of indoor air quality and ventilation. Apart from the specific ventilation rates (Table 1), the BR10 states that 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.

According to Article R*111-9 of the **French** Code of Construction and Housing, air exchange rates and the expulsion of emissions have to guarantee that air quality does not constitute a danger for the occupants and certain airflow requirements must be followed (Table 1).

The **German** Energy Saving Ordinance (EnEV 2014) requires all new buildings to be built airtight according to the state-of-the-art, 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 if additional mechanical ventilation is needed. The non-binding standard DIN 1946-6 “Ventilation of dwellings” provides more guidance on minimum ventilation rates (Table 1).

Italy follows a regional approach concerning building regulations: local health agencies and the municipalities are responsible for building requirements according to the Decree of the President of the Italian Republic No. 380 of 6 June 2001. Based on the Standards listed in Legislative Decree 192/2005 (Table 1), the national implementation of the EPBD, in the case of natural ventilation 0.3 vol/h are used in the design phase. Moreover, the Standards suggest:

- An exchange rate of 4 vol/h for bathrooms
- A flow of external air of 0.011 m^3/s per person for an occupancy level of 0.04 persons/m^2 in dining rooms and bedrooms

In **Poland**, mechanical or natural ventilation must ensure appropriate air exchange for premises designed to accommodate people. According to the legislation Art 149.1, for residential premises, the ventilation rates shall not be lower than 20 m^3/h for each permanent occupant. Moreover, based on the Polish Norms PN-B-03430:1983/Az3:2000 (Table 1), 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 the ventilation rates should not be lower than 20 m^3/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 m^3/h per occupant

The **Swedish** Building Code, BFS 2014:3 - BBR 21, states that “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". Therefore, ventilation systems shall be designed for a minimum airflow of 0.35 $l/(s{\cdot}m^2)$ in the cases of both new buildings and alternations of buildings, and the outdoor airflow must not be lower than 0.10 $l/(s{\cdot}m^2)$ of floor area when the space is unoccupied and 0.35 $l/(s{\cdot}m^2)$ when the space is occupied.

In the **UK (England and Wales)**, according to the Building Regulations 2010, "there shall be adequate means of ventilation provided for people in the building". The "Approved Document F1 – Means of ventilation" provides guidance about compliance and may be accepted as reasonable provision for compliance. Among others, the approved document proposes that the following ventilation rates should be followed:

Table 2: Ventilation rates that should be followed in England and Wales

<table>
<tr><th colspan="6">Extract ventilation rates</th></tr>
<tr><th>Space type</th><th colspan="2">Intermittent extract rate / Minimum rate</th><th colspan="2">Continuous extract / Minimum high rate</th><th>Continuous extract / Minimum low rate</th></tr>
<tr><td>Kitchen (l/s)</td><td colspan="2">30 adjacent to the hob; 60 elsewhere</td><td colspan="2">13</td><td rowspan="4">Total extract rate should be at least the whole dwelling ventilation rate given in the following table</td></tr>
<tr><td>Utility rooms (l/s)</td><td colspan="2">30</td><td colspan="2">8</td></tr>
<tr><td>Bathroom (l/s)</td><td colspan="2">15</td><td colspan="2">8</td></tr>
<tr><td>Sanitary accommodation (l/s)</td><td colspan="2">6</td><td colspan="2">6</td></tr>
<tr><th colspan="6">Whole dwelling ventilation rates</th></tr>
<tr><td>No of bedrooms (l/s)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Whole dwelling ventilation rate [a,b] (l/s)</td><td>13</td><td>17</td><td>21</td><td>25</td><td>29</td></tr>
</table>

a. The minimum ventilation rate should not be less than 0.3 l/s per m^2 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.

2.2 Airtightness

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 BE, DK, FR, DE, SW, UK) in practice there are major differences in the way it is taken into account (Figure 1).

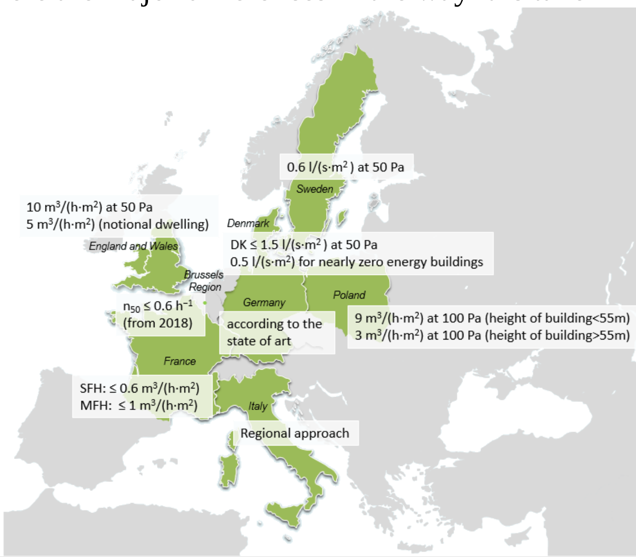

Figure 1: Airtightness requirements in Europe (BPIE, 2015)

According to the Decree of 21 December 2007, in **Brussels-Capital Region** from 2018, the individual dwelling's PEB (Performance Energétique des Bâtiments) units require an airtightness of maximum 0.6 volume per hour, while before 2018, there is no requirement on airtightness.

In **France**, for individual buildings, the airtightness has to be equal or lower than 0.6 $m^3/(h \cdot m^2)$ and for multi-family residential buildings, the airtightness has to be equal or lower than 1 $m^3/(h \cdot m^2)$. The Thermal Regulation RT 2012 requires mandatory airtightness tests for all new dwellings.

In **Germany**, leakages in exterior building elements have to be avoided according to the Energy Saving Ordinance 2014 and airtightness has to be according to the state-of-the-art (DIN 4108-7). Therefore, the air leakage rate (n_{50}) must not exceed 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} (ETHICS Project, 2008).

Italy has no requirements on airtightness at national level, but some regions do. For example, 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 dwellings.

In **Poland**, since 2014 there are requirements (Regulation of the Minister of Infrastructure, 12 April 2002) stating that:

- 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 $m^3/(m^2 \cdot h)$ in relation to the length of the contact line or 9 $m^3/(m^2 \cdot h)$ 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 $m^3/(m^2 \cdot h)$ in relation to the length of the contact line or 3 $m^3/(m^2 \cdot h)$ in relation to the surface area, which corresponds to class 4 of the Polish standard for air permeability

In **Sweden**, according to BFS 2011, the air leakage rate through the building envelope shall not be higher than 0.6 $l/(s \cdot m^2)$ (at 50 Pa). Specifically, for single-family homes ($<50m^2$) if this requirement as well as an average heat transfer coefficient less than 0.33 $W/m^2 \cdot K$ are satisfied, no requirement for maximum energy use ($kWh/m^2/year$) has to be fulfilled.

In the **UK (England and Wales)**, the dwelling complies with the requirements if the measured air permeability is not worse than the limit of 10 $m^3/(h \cdot m^2)$ at 50 Pa. At the same time, the notional dwelling specification sets the airtightness level at 5 $m^3/(h \cdot m^2)$ 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 $m^3/(h \cdot m^2)$ at 50 Pa".

2.3 Mechanical and natural ventilation

For a good indoor climate and air exchange in buildings, a ventilation control system is required, for which both natural and mechanical solutions exist. From the studied countries, mandatory mechanical ventilation has been identified for two cases: multi-family buildings in Denmark and high-rise residential buildings in Poland, while 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).

In **Brussels-Capital Region**, both mechanical and natural ventilation systems can be installed. Regarding ventilation in dwellings, the Decree of 21 September 2007 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). Furthermore, there is a distinction between continuous ventilation and intermittent/periodic ventilation, which is needed in case of overheating or pollutant activities and requires the presence of openings 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 (Bruxelles Environnement (a), 2014) suggest introducing passive systems for cooling. In order to provide a good quality for indoor air, it is also suggested to introduce a single flow CMV over natural ventilation, although double flow CMV is suggested for an optimum level of indoor air (Bruxelles Environnement (b) , 2014).

In **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. On the other hand, apartments in multi-storey buildings must be mechanically ventilated.

In **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 allowed. Specifically, for overseas departments (Guadeloupe, Guyana, etc.) natural ventilation has to be prioritised for dwellings and new parts of dwellings, as mentioned in Article R162-4 of the Code of Construction and Housing.

In **Germany**, as the reference building is a non-binding description, mechanical ventilation systems are not obligatory, but indirectly recommended by the government (EnEV 2009 Anlage 1 Tabelle 1 Zeile 8).

In **Italy**, the Decree of the President of the Republic 59/2009 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 refurbishment. Nevertheless, mechanical ventilation is mandatory for new construction and deep renovations in at least 105 regional building regulations all over Italy (ONRE, 2013).

The **Polish** Regulation of the Minister of Infrastructure (April 12, 2002) states that 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.

In **Sweden**, the required airflow of 0.35 $l/(s \cdot m^2)$ can be ensured via mechanical or natural ventilation. Boverket, the National Board of Housing, Building and Planning, published the handbook “Självdrags-ventilation”, which according to the Swedish Building Code (BFS 2014:3 - BBR 21) can be used for guidance by developers, planners and building committees. The demands are functional, so authorities do not mind hybrid ventilation as long as an airflow of 0.35 $l/(s \cdot m^2)$ can be ensured.

In the **UK (England and Wales)**, the ventilation strategy adopted in Approved Document F suggests natural ventilation, mechanical ventilation system or a combination of both. 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.

2.4 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.

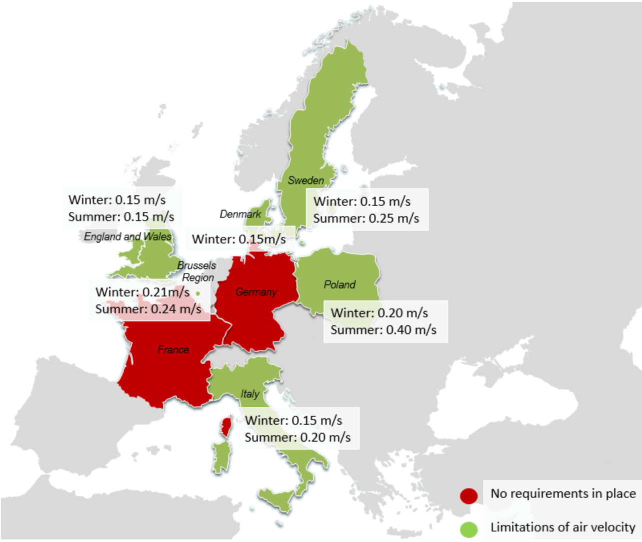

Figure 2: Maximal air velocity in Europe (BPIE, 2015)

According to the recommendations from **Brussels** Environment (Bruxelles Environnement (a), 2014), 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.

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

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

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.

The **Polish** Standard PN-B-03421:1978 specifies the comfort indoor parameters (Table 3) taking into account the physical activity of occupants.

Table 3: Indoor comfort parameters in Poland

	Winter	**Summer**
Low metabolic rate		
Indoor temperature	20-22ºC	23-26ºC
Airflow	0.2 m/s	0.3 m/s
Average rate of metabolism		
Indoor temperature	18-22ºC	20-23ºC
Airflow	0.2 m/s	0.4 m/s
High rate of metabolism		
Indoor temperature	15-18ºC	18-21ºC
Airflow	0.3 m/s	0.6 m/s

According to the **Swedish** Buildings Code (BFS 2014:3 – BBR 21), 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 year.

In the **UK (England and Wales)**, 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 year (Brelih & Seppänen, 2011).

2.5 Humidity

Humidity is of particular concern in residential ventilation as most of the adverse health effects and building disorder (condensation, moulds) are related to humidity. From the studied countries recommendations concerning humidity (in order to avoid water condensation or an air too dry) are given in Brussels-Capital Region, Denmark, Germany, Poland, Sweden and the UK (soft reference).

In **Brussels – Capital region**, elementary requirements, defined at Decree of 4 September 2003, related to the healthiness of IAQ have to be fulfilled, for example the limitation of humidity causing mould or damage to the walls. **France** and **Italy** have not adopted specific requirements on humidity levels. In **Denmark**, non-binding recommendations for relative humidity are specified in DS 474, Code for Indoor Thermal Climate. In **Germany**, according to the non-binding DIN EN 13779, the minimum and maximum indoor relative humidity ranges from 30 to 70%. In **Poland**, there are specific requirements to avoid water condensation (Regulation of the Minister of Infrastructure, 12 April 2002) such as the fact that the temperatures in the AC system should be adjusted so there is no condensation on the surfaces. Apart from that, the Polish Standard PN-B-03421:1978 specifies the comfort indoor parameters taking into account the physical activity of the occupants (Table 4).

Table 4: Comfort parameters related to humidity in Poland

Metabolic rate	**Winter**			**Summer**		
	Relative humidity		Max	Relative humidity		Max
	Optimal	Minimal	airflow	Optimal	Maximal	airflow
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%	0.2 m/s	40-60%	70%	0.6 m/s

Air humidity and moisture safety are major concerns of the **Swedish** Building Code (BFS 2014:3). Maximum moisture conditions are defined as an upper limit for which such negative effects do not happen and in winter, the difference in absolute humidity between indoor and outdoor should not be higher than 3 g/m^3. In the **UK**, according to the Approved Document F, the moving average relative humidity in a room during the heating season should be less than the values defined in the following table.

Table 5: Indoor air relative humidity

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

2.6 Minimal and maximal temperature requirements

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 (Figure 3).

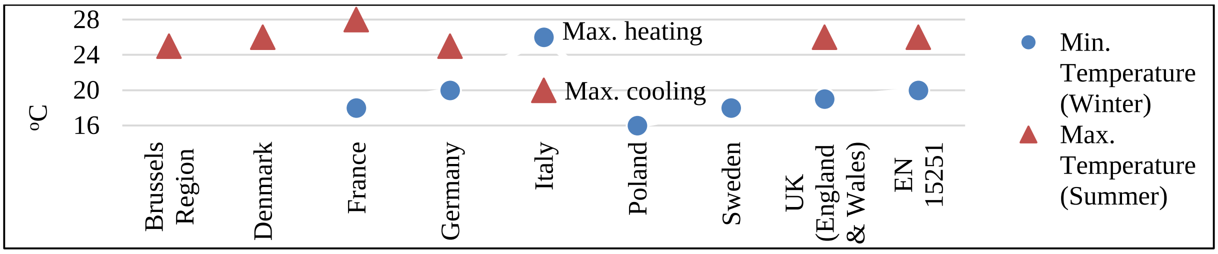

Figure 3: Temperature requirements in Europe (BPIE, 2015)

In **Brussels-Capital Region**, overheating is defined as temperature of more than 25ºC and has to be limited to 5% of the time during the year (Decree of 21 December 2007). In **Denmark**, according to the DS 474 Code for Indoor Thermal Climate, appropriate indoor temperatures have to not exceed 26ºC for more than 100 hours and 27ºC for more than 25 hours. In **France**, heating equipment in all housing must maintain a minimum of 18°C at the centre of the housing parts, while the maximum comfort temperature is 28ºC when a mechanical system is used. In **Germany** the recommended indoor air temperature is limited at 25°C, 26°C and 27°C for climatic regions A, B and C respectively and according to DIN 4701-10, the temperature in apartments should be able to reach at least 20°C and 22°C in bathrooms. In **Italy**, minimal and maximal temperatures are required in order to limit the waste of energy for cooling and heating. Therefore, according to Article 3 of the Decree of the President of the Republic 74/2013, cooling systems have to be limited to 26°C and heating systems to 20°C. In **Poland**, the indoor temperature cannot be lower than 16ºC and buildings should be designed and constructed in such a way that they reduce the risk of overheating in the summer (Regulation of the Minister of Infrastructure, 12 April 2002). According to the **Swedish** Building Code (BFS 2014-3 – BBR-21), buildings and their installations must be designed to guarantee a satisfactory thermal comfort. Based on that, the recommended minimal operative temperature for the average dwellings is 18°C. In the **UK**, 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. Moreover, according to the Chartered Institution of Building Services Engineers, the operative (maximum) temperature should not exceed 25°C in living areas and 23ºC in bedrooms.

2.7 Indoor air pollutants

Beside CO_2 concentration and humidity, 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. 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 (<1000ppm), while in the UK there are recommended levels (800 - 1000 ppm). 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.

2.8 Indoor air quality and thermal comfort requirements in existing 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 (BPIE, 2015). 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. Regarding thermal comfort, even though it is often considered as a main driver for the decision of an owner-occupier to invest in renovation, thermal comfort parameters are rarely captured by national and/or European legislations.

3 CONCLUSIONS

Indoor air quality is recognised as an important aspect in the building codes in all focus countries of this survey. Furthermore, thermal comfort aspects are often captured by national legislation. However, as identified in the eight focus countries of this paper, there are no clear and strict requirements to cover these topics. Therefore, indoor air quality and thermal comfort aspects have to be seriously considered when strengthening the energy performance requirements for buildings and building elements. Towards this goal:

- In the EU and national legislation, stricter energy performance requirements should be complemented with appropriate requirements and recommendations to secure proper indoor air quality and thermal comfort. For instance, requirements for stricter insulation and airtightness should be completed by appropriate minimum requirements for indoor air exchange and ventilation.
- Indoor air quality indicators should be integrated in Energy Performance Certificates as relevant information regarding the actual living conditions in the building.
- The development of a proper cost indicator and a 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.
- 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).

4 ACKNOWLEDGEMENTS

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