VENTILATION RATES AND IAQ IN EUROPEAN STANDARDS AND NATIONAL REGULATIONS

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ABSTRACT

This paper presents some results from the Work Package 5 in the HealthVent project supported by the European Commission. One of the objectives of the project has been to review and critically evaluate the existing requirements on ventilation and IAQ defined in national building codes and European standards. The project's focus has been set on ventilation rates, pollutants, noise, temperature and draft in dwellings, offices, schools and kindergartens. This paper presents a summary of the values given in European regulations and results of comparisons. The up-to-date data in national legislation and codes were collected from 16 European countries with questionnaires, which were sent to project partners and trusted experts on ventilation. The requirements on ventilation rates were found to be given in different units, therefore test cases of real-life design situations were introduced to compare the data on a basis of a common unit. The results show that the ventilation rates given in the regulations are inconsistent and very heterogeneous. The ventilation rates in test cases range from 0.23 to 1.21 h^{-1} in dwellings and 4.2 to 41.7 l/s for local exhaust rates. The ventilation rates per person in test cases of classroom, playroom, and office range from 4 to 25 l/s. Big differences were also found in pollutant levels. Limit CO levels range from 3.0 to 12.5 mg/m^3 and formaldehyde levels from 10 to 100 $\mu g/m^3$. Minimum winter air temperature requirements were found in the range of 15 to 21°C, maximum summer air temperatures from 25 to 28°C, maximum air velocity in summer from 0.15 to 0.30 m/s and in winter from 0.15 to 0.25 m/s. Limit maximum noise levels were also found scattered, from 26 to 40 dB(A) in sleeping rooms and 30 to 50 dB(A) in other investigated room types. In conclusion, the evaluation of the data showed that values in the European local regulations, standards, and those practised locally, are very inconsistent. Moreover, several values in regulations were found to be looser than the recommended values published in European standards and WHO guidelines, thus allowing lower ventilation rates and higher pollutant levels than recommended. Results indicate that there is a considerable need on the European level to harmonize the ventilation and IAQ regulations and adjust them to the values provided in standards and guidelines.

KEYWORDS

ventilation rates, pollutants, indoor air quality, noise levels, thermal environment

INTRODUCTION

Every citizen has a right to indoor air quality that does not endanger his health [1]. Europeans spend on average over 90% of their time indoors – at home, in the office, in school, in kindergarten, etc. In order to assure a healthy and comfortable indoor environment and quality for all citizens as building occupants, the key parameters must be controlled and take into account air pollutants, thermal environment, and acoustic environment.

The building structure and materials as well as other sources in buildings contaminate the indoor air. Besides that, 20 to 100% of the concentrations of outdoor air pollutants are transferred to the inside of the building, adding to the pollution generated by the building itself. Considering the amount of time people spent inside and the concentrations of indoor pollutants, the buildings are the most important factor in air pollution exposure and associated health effects. Ventilation is used to bring outdoor air to the occupied indoor zone and to remove or dilute indoor-generated pollutants. Ventilation rate, as the flow of outdoor air to a space, is one of the most important factors affecting indoor air quality.

In order to achieve a sufficiently comfortable thermal environment in buildings, the following main physical parameters influence a person's sensation of warmth: air temperature, mean radiant temperature, relative air speed, and humidity. In practice, a combination of all listed parameters influences human perception of comfort. Temperature is usually the most important environmental variable affecting thermal comfort. A recommended range of temperature depends mostly on a person's activity and clothing.

An acoustic environment should be free of any unwanted sounds because it causes annoyance to the occupants. The unwanted sound is usually defined as noise. Ventilation and other mechanical systems in buildings must be designed so that the noise level does not cause annoyance to the building's occupants. In a building, a balance must be sought between the noise produced by the building services and the noise coming from the activities taking place within the building. For example, a higher level of noise from the building services may not be disturbing for the occupants in a space with a high level of activity noise. The criteria for the acceptable indoor noise are usually given as maximum A-weighted noise levels or as equivalent continuous A-weighted noise level.

In this paper, we present some of the results from the work performed under Work Package 5 in the HealthVent project[1], supported by the European Commission. The objective of the HealthVent project is to develop health-based ventilation guidelines for the EU. Members of the project group are experts from different disciplines from 9 European countries. One of the objectives of the project was to review and critically evaluate the existing requirements on ventilation and IAQ defined in building codes and European standards. The project's focus was set on ventilation rates, pollutants, noise, temperature and relative air movement in dwellings, offices, schools and kindergartens.

METHODS

The work focused on national regulations and practice in European countries. To overcome the language barriers and to collect data from as many countries as possible, the task of collecting data was performed with a special questionnaire, which was sent to project partners and trusted experts on ventilation in several European countries. The questionnaire comprised of 10 questions and sub-questions. The respondents were asked to provide values of ventilation rates, pollutant limits, noise levels, etc., which can be found in the national regulations. In case if no such values existed in the regulations, they were asked to provide values which are most widely used in practice (from standards, guidelines, etc.). In the responses they had to mark if the provided value is mandatory or voluntary to use.

The returned questionnaires revealed that the ventilation rate criteria are given using various units depending on a country, which do not allow direct comparisons. Criteria are expressed as flow rate per number of persons, flow rate per floor area, flow rate per number of rooms, fixed flow rate per room type, number of air changes per hour, or combination of different units. In order to compare ventilation rates criteria, we developed several test cases, which represent real-world situations. The test cases were developed for two different dwellings, a kitchen, a toilet, a bathroom, a school classroom, a kindergarten playroom, and an office. The

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[1] HealthVent project website: www.healthvent.eu

details of the test cases are shown in Tables 1 and 2. Using the details from the tables, we compared the ventilation rates in dwellings on the base of air changes per hour, ventilation of kitchens, bathroom, and toilet as ventilation rate per room, and ventilation of classroom, playroom, and office as air flow rate per person.

Table 1. Properties of the test dwellings

Properties	**Dwelling case 1**	**Dwelling case 2**
floor area	50 m^2	90 m^2
ceiling height	2.5 m	2.5 m
main rooms	2: 1 living, 1 sleeping	4: 1 living, 1 sleeping, 2 children
kitchen	1 x 10 m^2 with window and electric stove	1 x 15 m^2 with window and electric stove
toilet	1 x 2 m^2	1 x 2 m^2
bathroom	1 x 5 m^2	1 x 5 m^2
persons	2	4

Table 2. Properties of the test rooms

Properties	**Kitchen**	**Toilet**	**Bathroom**	**Classroom**	**Playroom**	**Office**
area	10 m^2	2 m^2	5 m^2	50 m^2	50 m^2	12 m^2
ceiling height	2.5 m	2.5 m	2.5 m	2.8 m	2.8 m	2.8 m
persons	1	1	1	25	25	1

RESULTS

Respondents in 16 countries returned the questionnaire. A list of the countries and their abbreviations, which are used in the charts, are shown in Table 3.

Table 3. Country abbreviations used in charts

BG	Bulgaria	**DE**	Germany	**LT**	Lithuania	**PT**	Portugal
CZ	Czech Republic	**GR**	Greece	**NL**	Netherlands	**RO**	Romania
FI	Finland	**HU**	Hungary	**NO**	Norway	**SI**	Slovenia
FR	France	**IT**	Italy	**PL**	Poland	**UK**	United Kingdom

Ventilation rates

The results show that values are very inconsistent among European countries. Figures 1 and 2 show ventilation rates[2], which were calculated using the input data from Tables 1 and 2. The lowest ventilation rate in dwellings is 0.23 h^{-1} and the highest 1.21 h^{-1}. Large differences can also be seen in the cases of local exhaust rates, where the highest rates can be up to five times higher than the lowest rates. The ratio is therefore similar to the one of air changes in dwellings, where it is almost 1 to 6. Observing ventilation rates in the cases of classroom and playroom, one can distinguish two groups of countries with similar values. The first group has ventilation rates of around 10 l/s per person. It is formed by the following countries: Finland, Germany, Hungary, the Netherlands, Norway, Slovenia and UK. The second group has rates of around 4 l/s per person and is formed by the following countries: Bulgaria, Czech Republic, France, Greece, Italy, Lithuania, Poland and Romania. Both Nordic countries are in the group with higher ventilation rates, which is predominantly formed by the countries from the North and West of Europe. No countries from the Southern Europe are in that group. The ventilation rates in offices cannot be so obviously divided into two groups, because rates are much more scattered. Two ventilation rates that stand out are from Germany and Hungary, which are calculated according to EN 15251. The region-based conclusions are therefore not possible in the office case.

[2] Ventilation rate in this document is taken as the flow of outdoor air to space

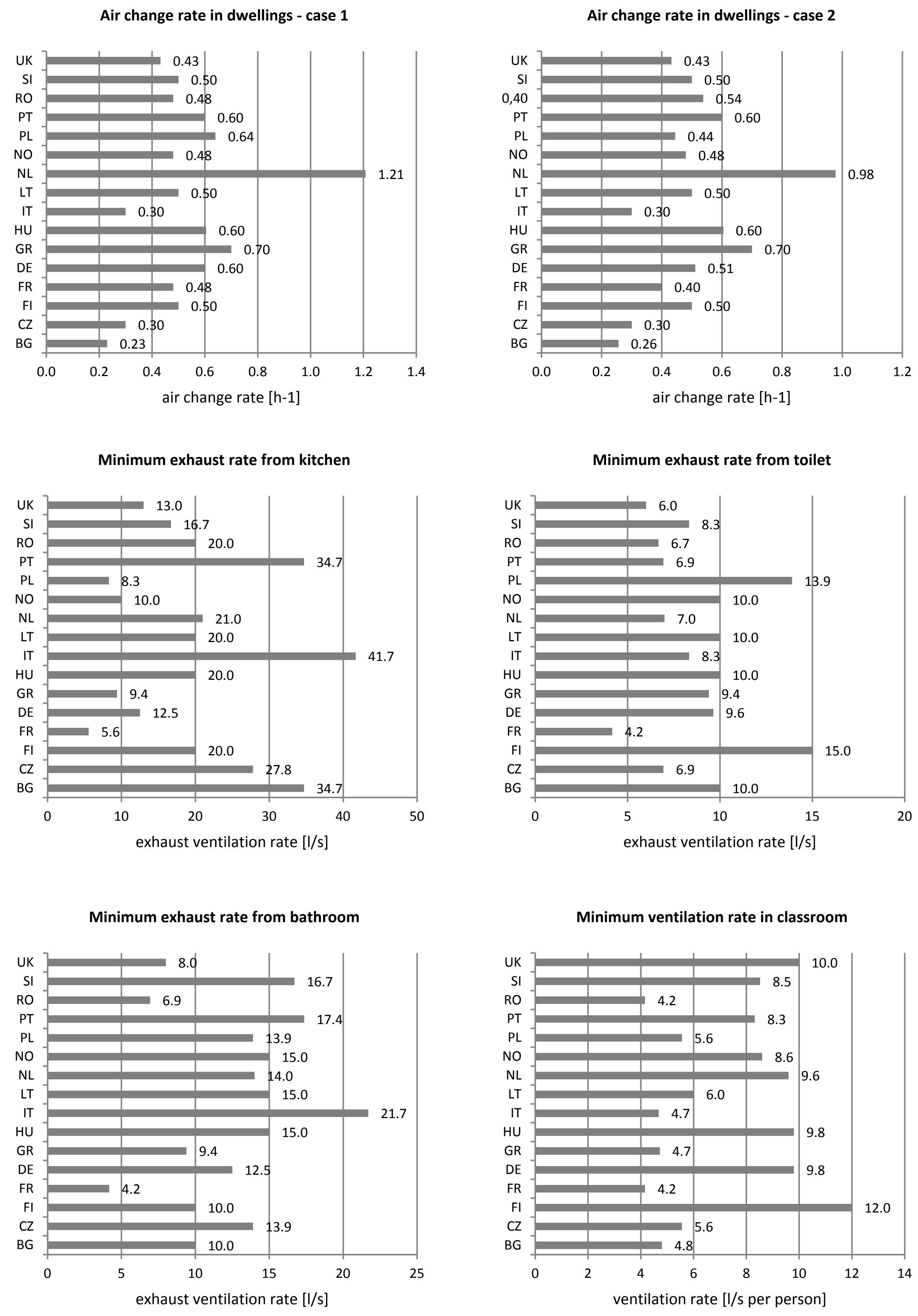

Figure 1. Comparison of ventilation rates in the test cases of dwellings, kitchen, toilet, bathroom and classroom

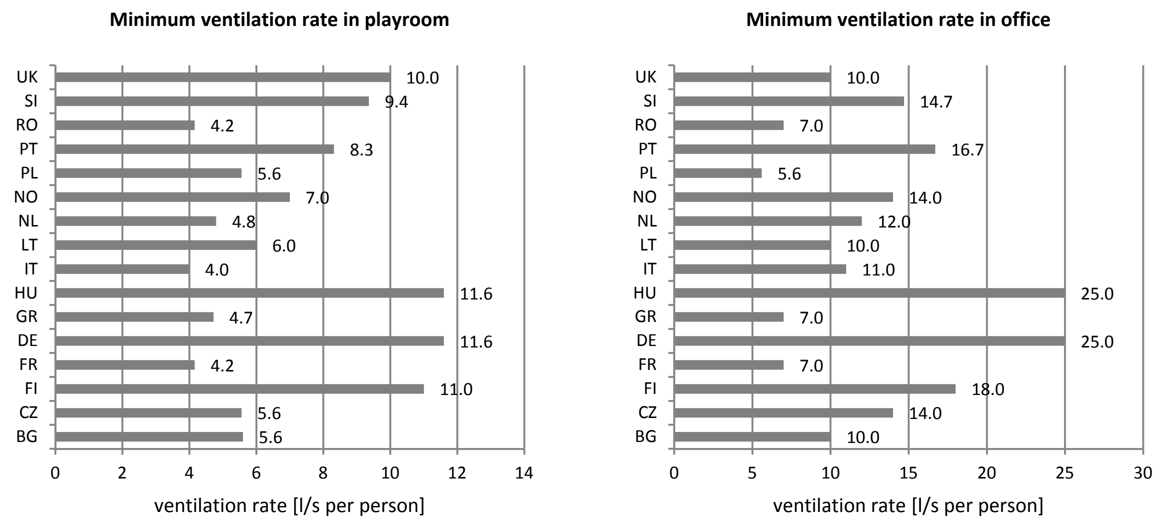

Figure 2. Comparison of ventilation rates in the test cases of kindergarten playroom and office

Indoor pollutants

The required limit levels of selected pollutants are shown in Table 4. The table also includes the WHO suggested values to serve as a comparison [2, 3]. The comparison of all values is difficult, because the limits are given as a maximum or average concentration in a given time. Only 6 out of 16 countries have requirements on limit indoor pollutant levels in non-industrial buildings. Limit levels of only two pollutants are found in the regulations of all the 6 countries: carbon monoxide (CO) and formaldehyde (HCOH). The range of CO limit levels is wide, from 3 to 12.5 mg/m^3. The WHO recommended limit is 7 mg/m^3, therefore the limit of 4 countries exceeds that value. Formaldehyde limit values range from 10 to 100 µg/m^3 and all values are equal to or below the WHO recommended value of 100 µg/m^3. Limit values of other pollutants are not included in the regulations of all countries and their ranges are also wide.

Table 4. Indoor pollutant limit levels

	WHO	FI	LT	NO	PT	RO	SI
Ammonia[µg/m^3]	-	20	40	-	-	-	50
Asbestos	-	0 fb/cm	0.1 mg/m^3	0.1 fb/cm	-	-	-
CO[mg/m^3]	7$^{\#2}$	8	3	10$^{\#5}$	12.5	6$^{\#3}$	10
CO_2[ppm]	-	1200	-	1000	1000	-	1670
Formaldehyde[µg/m^3]	100	50	10	100$^{\#3}$	100	35$^{\#3}$	100
NO_2[µg/m^3]	40	-	40	100$^{\#4}$	-	-	
Ozone[mg/m^3]	0.1$^{\#5}$	-	0.03	-	0.2	-	0.1
PM_{10}[µg/m^3]	20	50	50	-	150	-	100
Radon[Bq/m^3]	-	200$^{\#1}$	-	100	400	140$^{\#6}$	400
Styrene[µg/m^3]	-	1	2	-	-	-	-

#1 – annual average #3 – 30 min average #5 – 8 h average fb – fibre
#2 – daily maximum #4 – 1 h average #6 – instant max

Thermal environment

Figure 3 shows two charts that display the limit values of indoor temperature and relative air velocity in any type of the investigated room types. The temperature limits for summer vary from 25 to 28°C and in winter from 18 to 21°C. Temperature limits that are most commonly found in the regulations are 26°C for summer and 20°C for winter. The lowest low limits of air temperatures are imposed on kindergartens. In the UK, spaces can have a maximum air temperature of 28°C for maximum 1% of the annual occupied hours. Some countries do not have any requirement for limitation of maximum air temperature, but they all have limitation of minimum air temperature. Maximum relative air velocity limits are also inconsistent. They range in summer from 0.15 to 0.30 m/s and in winter from 0.15 to 0.25 m/s. In most of the countries the relative air velocity does not depend on the air temperature. The limit values of air humidity follow the pattern of temperatures and air velocities and are slightly more consistent. Limit levels of humidity are expressed as relative humidity (%) or absolute humidity (g/kg$_{dry\ air}$). Lower limits are constantly at 30% while higher limits are 70% in all cases except one, where it is 75%. The humidity level is given in terms of absolute humidity to limit the highest amount of water in the air and is in both cases the same, i.e. 12 g of water per one kg of dry air.

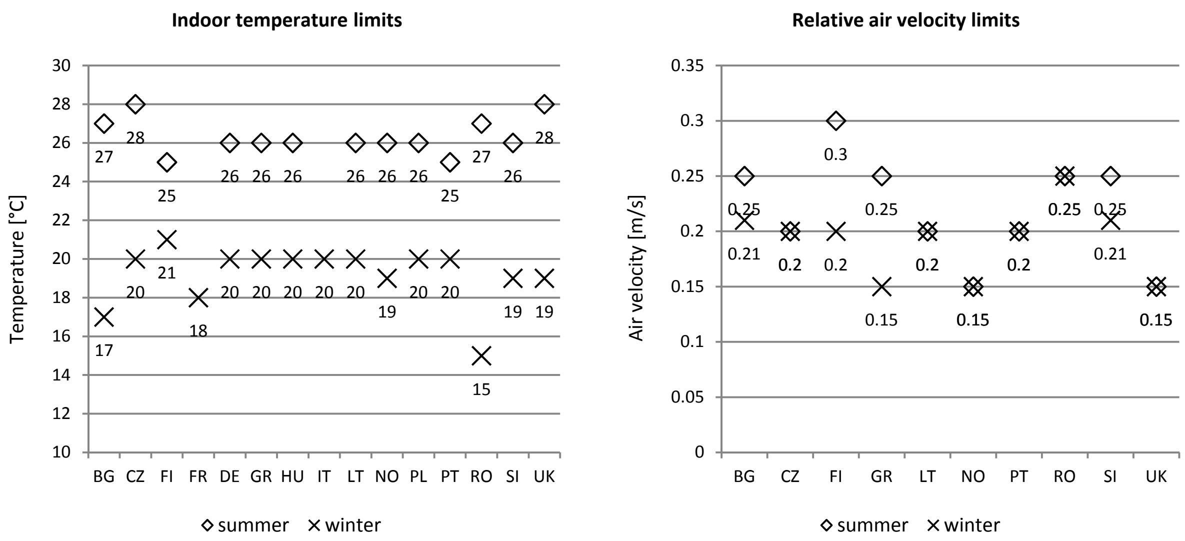

Figure 3. Indoor temperature and relative air velocity limit values

Noise environment

Charts on Figure 4 display limit noise values. Noise limits are expressed with three different criteria which are not directly comparable. The values are most often given as maximum A-weighted noise levels (L_{AFmax}), followed by equivalent continuous A-weighted noise level (L_{eq}), and least often as noise rating (*NR*) curves. The limit maximum noise levels range from 26 to 40 dB(A) in sleeping rooms and from 30 to 50 dB(A) in other investigated room types. The limit equivalent noise levels range from 28 to 35 dB(A) in sleeping rooms and from 25 to 45 dB(A) in other room types. It seems that in average, the equivalent levels are usually 5 dB lower than the instantaneous levels. Differences min – max are big in all cases, for maximum and equivalent levels. For comparison, European Standard EN 15251 [4] recommends the following limits of maximum noise level: living room 32 dB(A), bedroom 26 dB(A), small offices 35 dB(A), landscape offices 40 dB(A), classrooms 35 dB(A), playrooms 40 dB(A).

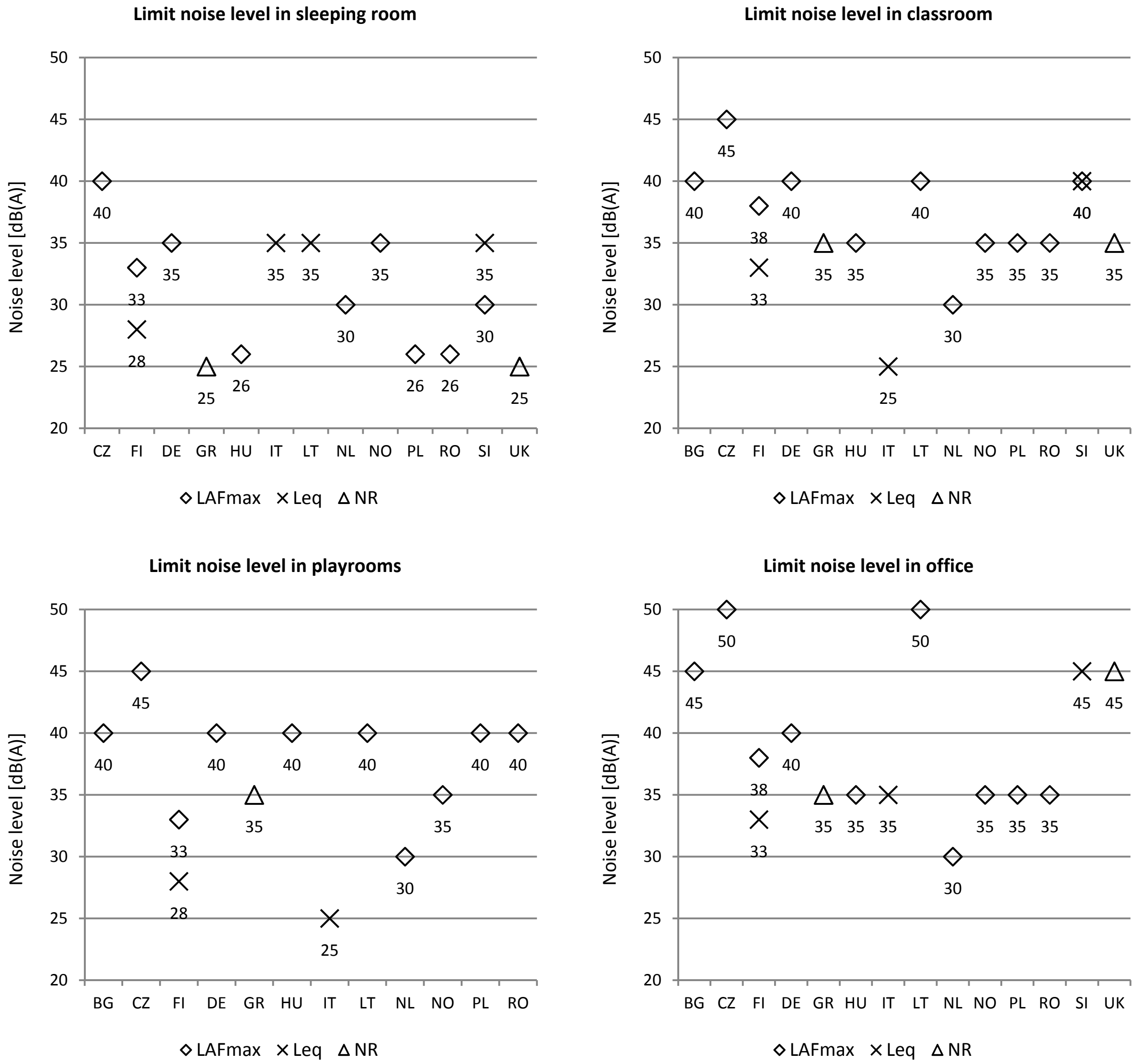

Figure 4. Noise limit levels in sleeping room, classroom, playroom and office

DISCUSSION

The data was collected from 16 countries from all parts of Europe, thus giving a good coverage of regions with different building practice and climate. Although the respondents are experts on ventilation, a certain measure of uncertainty exists regarding the accuracy of the data in the received questionnaires. Due to the language barriers, and limited resources, all data could not be verified. The data presented in this paper are informative and should not be used for the design of ventilation.

Different boundary conditions, which are used to calculate the ventilation rates, show that countries have taken different approaches to define them in regulations. This is further confirmed with the wide range of air change rates and ventilation rates, which were calculated with the data from the test cases. Such wide ranges suggest that countries did not have a common theoretical background for the determination of the required ventilation rates. Approximately one third of countries have requirements for the ventilation of dwellings, which result in air change rate lower than 0.5 h^{-1}.That is in contrast with the health-based recommendations of minimum air change rate of 0.5 h^{-1} [5]. The ventilation rates in classrooms, playrooms and offices are also in contrast with health-based recommendations, because the resulting ventilation rates are often below 10 l/s per person. In the extensive review of studies that investigated the association of ventilation rates with human responses, Seppänen et al. [6] showed that almost all the studies included in the review found that the ventilation rates below 10 l/s per person had been associated with a significantly worse prevalence or value of one or more health perceived air quality outcomes. This is further confirmed by Sundell et al. [5], who in the review of literature shows that the ventilation rates up to 25 l/s per person are associated with reduced adverse health symptoms, and that the number of symptoms increases with lower ventilation rates.

The limit levels of pollutants are often higher than those recommended by the WHO, and missing in the regulations of several countries. The ranges of values are wide, which indicates that the countries do not use common theoretical background to determine the limit values. Minimum requirements for pollutant levels in non-industrial buildings should be included into the regulations of all European countries.

The temperature limit of the lowest winter temperature of 15°C is too low from the health and comfort point of view. The summer maximum temperature limit of 28°C is too high from the perspective of performance, which is higher if the temperatures are lower. All regulations should include temperature limits, which respect comfort and productivity aspects, and may be adapted to local climate conditions. The requirements for relative air velocity usually do not take into account the air temperature. Dissatisfaction due to draught is not only a function of mean air speed, but also of local air temperature and fluctuations of air velocity. The regulations should therefore limit maximum values of air velocity in relation to air temperature.

The noise limit levels are higher than the recommended by the European standards in the majority of the countries. The limits for bedrooms are particularly critical, and significantly too high in almost all the countries. The noise criterion, expressed as equivalent noise level, is more appropriate for the industrial environment than for the environment of non-industrial buildings. If given, it should be supplemented with the limit maximum noise level. The noise limit levels should be harmonized across the national regulations. The maximum noise level should be preferably used as a criterion, supplemented by the equivalent levels if necessary.

CONCLUSION

A review of the European regulations for ventilation rates, indoor air quality and noise showed that the values in regulations are inconsistent and vary greatly according to country. Almost all of the regulated parameters included in the review are already defined in European Standards, which were accepted in the CEN voting process by national bodies. Nevertheless, the values found in the standards and those in the regulations are not harmonized. The inconsistency on the national level between the EN standards and regulations, as well as on the European level from country to country, causes problems to designers and industry, and increases the construction cost. Besides that, the current practice is in contrast with the efforts of unification and standardization of the European common market. Clearly, a common European guideline is needed, which would serve as a basis for national European regulations. The guideline should include ventilation rates, technical properties, and other parameters related to the performance of ventilation.

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