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Revision of EN15251 standard related to criteria for the indoor environment.

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Abstract
EN15251 specifies indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. This standard has now been available for 5 years and must be revised. The paper presents several issues to be discussed in the planned revision. The presented issues are dealing with the thermal environment (when to use adaptive model and criteria for personalized systems), indoor air quality (ventilation effectiveness, air cleaning, adapted/non-adapted occupants, and personalized ventilation), acoustic (introduction of categories), lighting (introduction of categories, daylight factor) and finally occupant behaviour.

Keywords: Thermal comfort, indoor air quality, ventilation, illumination, acoustic, criteria.

Introduction
Energy consumption of buildings depends significantly on the criteria used for the indoor environment (temperature, ventilation and lighting) and building (including systems) design and operation. Indoor environment also affects health, productivity and comfort of the occupants. Recent studies have shown that costs of poor indoor environment for the employer, the building owner and for society, as a whole are often considerable higher than the cost of the energy used in the same building. It has also been shown that good indoor environmental quality can improve overall work and learning performance and reduce absenteeism. In addition uncomfortable occupants are likely to take actions to make themselves comfortable which may have energy implications. An energy declaration without a declaration related to the indoor environment makes no sense. Thus there is a need for specifying indoor environmental criteria for design, energy calculations, performance and operation of buildings.

EN15251 specifies how design criteria can be established and used for dimensioning of systems. The standard how to establish and the main parameters to be used as input for building energy calculation and long term evaluation of the indoor environment. Finally the standard identifies parameters to be used for monitoring and displaying of the indoor environment as recommended in the Energy Performance of Buildings Directive.

The standard is now up for review and there is a wish also to adopt this standard at the ISO level. The revision must be based on experience gathered from application of the standard both in the field and by more theoretical studies.

Thermal Environment
The following issues must be discussed during the revision of the standard.

- Clear differentiation between the adapted and PMV-PPD approach
- Personalized systems
- Local thermal comfort parameters

Adapted versus PMV-PPD approach
The use of the standard has shown it is needed to make it clearer when the adapted concept can be used (residential buildings, passive cooling). When comparing the two concepts in more

temperate climates like Copenhagen it can be seen (Figure 1) that the adapted approach specifies lower room temperatures in early and late summer. For sedentary occupation the requirements for mechanical condition buildings (PMV-index) is an operative temperature range in winter 20-24°C and summer 23-26°C, which is shown in figure 1 with the blue and yellow squares. The adapted approach in 15251 shows a little more variations (running mean outside temperature) than ASHRAE-55 (monthly average outside temperature). The maximum temperature during summer is almost the same for the two approaches. During the summer period (May-October) the adapted approach do however specify room temperatures lower than 26°C and thus a stricter requirement.

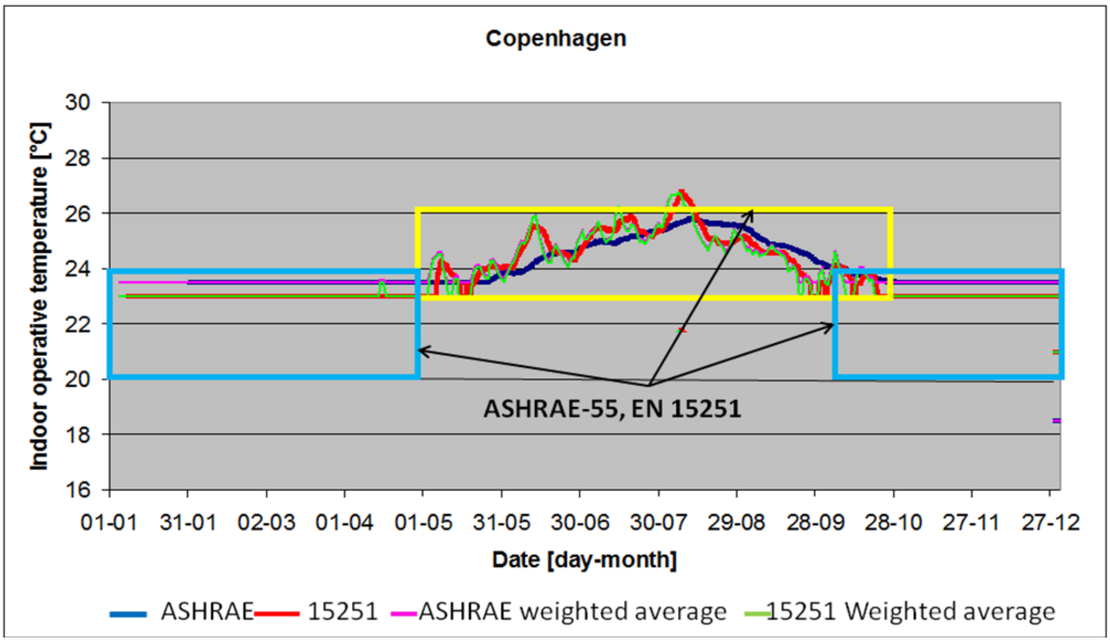


Figure 1: Recommended requirements for the indoor operative temperature based on the adapted approach and PMV-index from ASHRAE-55 and EN15251.

In the present standard the PMV-PPD approach is mainly presented by giving recommended temperature intervals for the different categories of thermal environment. More emphasis should be put on how to use the PMV-PPD index in a more flexible way i.e. taking into account the cooling effect of increased air velocity.

Personalized systems

During the last decade several systems for providing a high quality personal indoor environment have been studied and tested. Also several products/systems are now available on the market. The existing standards with criteria for the indoor environment (thermal, air quality, noise , light) are all based on criteria for the whole occupied zone (ISO EN 7730, EN15251, ASHRAE-55, ASHRAE-62.1). Can these criteria be directly applied also to a personal system, where the occupants try to meet their own preferences? If the occupants have a personalized system is it then possible to relax on the requirements to the general environment? These are some of the issues that will be discussed in the revision of the standard. Based on the many studies found in the literature on personalized systems for control of thermal comfort, air quality, lighting and noise a set of criteria for the personalized environment should be established. At the same time recommended changes in the existing criteria for the general environment should be made. Personalized indoor environmental systems can provide the occupant with an individual control of thermal comfort, perceived air quality, illumination and masking of noise. In general for illumination and noise you can use the same criteria for a personalized environment as for a general environment. Most personalized systems blow air towards the occupant (Figure 1) This set-up will mainly influence the perceived air quality and increase cooling due to an increased air velocity and may be lower air temperature of the supply air. But also the classification of the Indoor environment will be influenced due to better CO_2-level within the

Personalized Environmental zone. As shown in Figure 2 a personalized system may divide the space in two zones, one close to the occupant and a general zone. The question is if it should be allowed to relax the indoor environmental criteria for the general zone if a personalized system is available. The increased ventilation effectiveness should allow a decrease of the supply ventilation rate. This can be taken into account by correcting the required ventilation rates in the standard tables (based on complete mixing) with the ventilation effectiveness (see below).

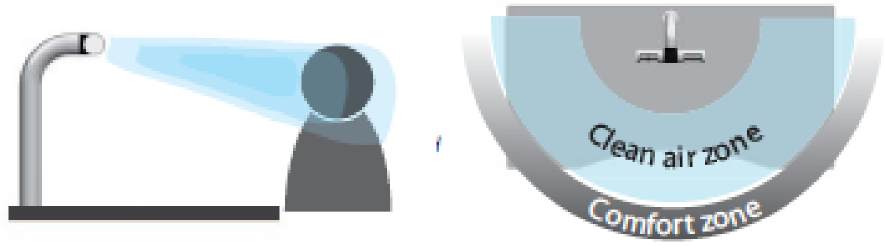


Figure 2: Typical set-up of personalized ventilation system.

Local thermal comfort parameters

In the present standard local thermal comfort parameters like asymmetric radiant temperature, draught, vertical air temperature differences and surface temperatures are not included as these parameters may not have a direct influence on the energy consumption in buildings. They do however have an influence on the design and dimensioning og buildings and HVAC systems and then also on the energy consumption.

Indoor Air Quality and Ventilation

The standards approach to indoor air quality is to specify a recommended level of ventilation (outside air), depending on number of occupants in the space and a contribution depending on the floor area of the space. There is however a need for some clarification and new concepts regarding these issues:

- Ventilation for Non-adapted or adapted occupants
- Use of increased CO2 level as IAQ indicator
- Air cleaning as substitute for outside air
- Ventilation effectiveness
- Personalized ventilation

Ventilation for non-adapted or adapted occupants.

For the prescriptive method, a minimum ventilation rate per person and a minimum ventilation rate per square metre floor area are required. The two ventilation rates are then added. The person-related ventilation rate should take care of pollution emitted from the person (odour and other bio effluents) and the ventilation rate based on the person's activity and the floor area should cover emissions from the building, furnishing, HVAC system, etc.

The design outdoor airflow required in the breathing zone of the occupied space or spaces in a zone, i.e., the breathing zone outdoor airflow (V_{bz}), is determined in accordance with the equation:

$$V_{bz} = R_p P_z + R_a A_z \qquad (1)$$

Where:

A_z = Zone floor area: the net occupied floor area of the zone m^2,

P_z = Zone population: the greatest number of people expected to occupy the zone during typical usage.

R_p = Outdoor airflow rate required per person: these values are based on adapted occupants in EN15251 and un-adapted in ASHRAE-62.1.

R_a = Outdoor airflow rate required per unit area.

In the standard different methods for calculating the recommended ventilation rate are included. As a minimum it must be ventilated to dilute the bio effluents from the occupants (people component, R_p, see **table 1**). These rates are in EN15251 specified for three categories of indoor

air quality, based on the prediction that a certain percentage of visitors will find the air quality unacceptable. The design levels are thus adequate for people who walk into a space. It is debatable if this should always be the case. People adapt very quickly to the odour (bio effluents) in a space while there is less adaption to emissions from building materials and tobacco smoke (odour and irritants, [2]). To provide an acceptable perceived air quality for occupants (who have adapted to the air quality for at least 15 min.) it is estimated that one third of the ventilation rate is sufficient i.e. for category II 2, 5 instead of 7 l/s per person. The ASHRAE Standard 62.1 for ventilation and indoor air quality defines ventilation levels for adapted persons (occupants). In addition, the minimum recommended ventilation is increased with a building-related ventilation rate, in order to take into account the emissions from the building and its systems (see **Table 1**). There is, however no general agreement on whether the contribution from the building should be added in full. Several studies indicate this is the best approximation, but it may not be valid for all types of pollutants. Here it is the contribution to the odour and irritation (perceived air quality) which must be taken into account. So it can be argued that they all influence one organ (the nose) and so should be added. When the health risk is considered a simple addition can be made for the same chemical component; but not for different chemical components if they influence different body organs.
Table 1 shows the required ventilation rates from standard EN15251 compared to ASHRAE 62.1.

Table 1 Smoking free spaces in commercial buildings according to ASHRAE 62.1 and EN15251

Type of building/ space	Occupancy person/m^2	Category EN	Minimum ventilation rate, i.e. for occupants only l/s person		Additional ventilation for building (add only one) l/s·m^2				Total l/s·m^2	
			ASHRAE R_p	EN	EN Very low-pollut.	EN Low-pollut.	EN *Not* low-pollut.	ASHRAE R_a	EN Low Pol.	ASHRAE
Single office	0,1	I	2,5	10	10	1,0	2,0	0,3	2	0,55
		II		7	7	0,7	1,4		1,4	
		III		4	4	0,4	0,8		0,8	
Landscaped office	0,07	I	2,5	10	10	1,0	2,0	0,3	1,7	0,48
		II		7	7	0,7	1,4		1,2	
		III		4	4	0,4	0,8		0,7	
Conference room	0,5	I	2,5	10	10	1,0	2,0	0,3	6	1,55
		II		7	7	0,7	1,4		4,2	
		III		4	4	0,4	0,8		2,4	
Classroom	0,5	I	3,8	10	10	1,0	2,0	0,3	6	2,2
		II		7	7	0,7	1,4		4,2	
		III		4	4	0,4	0,8		2,4	

There are quite big differences between the European recommendations and those listed by ASHRAE. One major reason is that ASHRAE requirements are minimum code requirements, where the basis for design is adapted people, while the European recommendations are for un-adapted people (visitors). Who should we ventilate for? For people just entering the room (un-adapted) or for people already occupying a room (adapted)? Here the philosophy adopted by ASHRAE 62.1 and EN15251 differs. But should it really be one or the other? In a conference room, auditorium or lecture room most people enter at the same time. It then takes some time before the odour level has reached an unacceptable level and meanwhile people adapt. In this case it may be appropriate to require a ventilation rate based on adapted persons. There may be other spaces where you would design for un-adapted people, e.g. in a first class restaurant, offices, and department stores. It seems logical that more differentiated criteria could be used.

Use of increased CO_2 level as IAQ indicator

In the standard are also listed a CO2 criteria for three categories; but the values are not consistent with the required ventilation rates listed in Table 1. Knowing the CO2 production from the occupants it is possible to calculate the increased CO2 level compared to outside, which corresponds to the total ventilation rates (see Table 2).

Table 2. Equivalent increase in CO2 levels indoor for the total ventilation rates specified in Table 1.

		Very low-polluting	low-polluting	Not low-polluting
Type of room or building	Category	ΔCO_2 [ppm]	ΔCO_2 [ppm]	ΔCO_2 [ppm]
Single office	I	375	280	190
	II	560	400	265
	III	930	695	465
Landscape office	I	310	220	140
	II	465	310	195
	III	745	530	340
Conference room	I	510	465	400
	II	735	665	570
	III	1265	1160	995
Auditorium	I	480	465	440
	II	690	665	625
	III	1195	1160	1090
Restaurant	I	495	465	415
	II	715	665	590
	III	1235	1160	1030
Class room	I	510	465	400
	II	735	665	570
	III	1265	1160	995
Kindergarten	I	430	400	350
	II	620	570	500
	III	1070	995	870
Retail store	I	260	195	160
	II	365	275	225
	III	615	470	380

Air cleaning as a substitute for outside air

Air cleaning is not taken into account at all in EN15251, while ASHRAE 62.1 by using the analytical procedure allows some credits for air cleaning. There is an increased interest in the development of air cleaning equipment. This may be an acceptable way of reducing the amount of outside air, saving energy and still have an acceptable indoor air quality. However, better test methods for air cleaners are required, because at present the test is usually based on chemical measurements and the resulting effect on odour or perceived air quality is not taken into account. It is also very important to specify which kind of "pollutants" should be used when testing. Some air cleaners may work well on VOC's (emission from materials) but have zero or even a negative effect if the source is people (bio effluents). There is an increasing development of methods and products for gas phase air cleaning including both adsorptions filters and air cleaners using a chemical reaction to remove certain gasses (PCO-Photo Catalytic Oxidisation). CEN-ISO and ASHRAE are developing standard test methods, which will measure the air cleaning efficiency or the equivalent amount of outside air called Clean Air Delivery Rate, CADR

If we work with classes one option could be that even with air cleaning you must have a level of ventilation corresponding to the lowest class. With air cleaning you can then reach a higher class without increasing the amount of outside air. It is therefore recommended that the standard specifying indoor air quality as a certain ventilation rate open up for the possibility to partly use air cleaning as a substitute for outside air.

One serious problem is how to ventilate if a building is located in an area with poor outside air quality or if there is a time of the day (e.g. rush hour) when the outside air quality is unacceptable. In some cases it might even be better to reduce ventilation under these circumstances. For testing gas phase air cleaning a known gas is used to simulate pollution (i.e. toluene to simulate VOC's). The concentration is measured before and after the air cleaner. The air cleaning efficiency is calculated as:

$$\varepsilon_{clean} = (C_U - C_D)/C_U \cdot 100 \qquad \%$$

where ε_{clean} = air cleaning efficiency
C_U gas concentration before air cleaner
C_D gas concentration after air cleaner

The criteria for the ventilation rates shown in Table 1 are mainly based on perceived air quality PAQ, which is measured by a human test panel. It is therefore also important to be able to test the air cleaning efficiency in relation to the perceived air quality. The air cleaning efficiency can be expressed as:

$$\varepsilon_{PAQ} = Q_o/Q_{AP} \cdot (PAQ/PAQ_{AP} - 1) \cdot 100 \qquad \%$$

where

ε_{PAQ} air cleaning efficiency for perceived air quality
Q_o ventilations rate in l/s
Q_{AP}
PAQ perceived air quality without the air cleaner, decipol
PAQ_{AP} perceived air quality without the air cleaner, decipol

The Clean Air Delivery Rate is calculated as:

$$CADR = \varepsilon_{PAQ} \cdot Q_{AP} \cdot (3{,}6/V) \qquad h^{-1}$$

where

$Q_{AP}\cdot$ air flow through the air cleaner l/s
V volume of the room m^3.

If the air cleaner has been tested based on chemical measurements it should then be allowed to reduce the pollution contribution due to the building in Table 1 with a factor based on the measured air cleaning efficiency:

$$q_{b,clean} = \varepsilon_{clean} \cdot q_b \qquad l/s \text{ per } m^2$$

If the efficiency is 50% the contribution from the building in Table 1 is then reduced to half, which means the building category can be changed from low-polluting to very low polluting.

Ventilation effectiveness

The ventilation rates specified in the standards (**Table 1**) are the required rates at breathing level in the occupied zone. The required ventilation rate at the room supply diffusers are calculated as:

$$\text{Total ventilation rate } V = V_{bz} / \varepsilon_v \qquad (2)$$

Where :

V_{bz} = *breathing zone ventilation*

$$\varepsilon_v = \frac{C_e - C_s}{C_i - C_s} \qquad (3)$$

Where:

ε_v = Ventilation effectiveness

C_e = Pollutant concentration in extract air

C_s = Pollutant concentration in supply air

C_i = Pollutant concentration at breathing level

The ventilation effectiveness depends on the air distribution efficiency and the type and position of the pollution source(s), so this value is not only a system characteristic. In most cases it is assumed that the pollutant emission is uniform, so the ventilation effectiveness is the same as the air distribution effectiveness. For a fully-mixed ventilation system the value is 1 and the ventilation rates in **Table 1** can be used for the design of the supply grills. The ventilation effectiveness or air distribution efficiency is a function of the position and type of supply and return grills, and depends on the difference between supply and room temperature and on the total amount of airflow through the supply grill. The air distribution effectiveness can be calculated numerically or measured experimentally. Typical examples of ventilation effectiveness/air distribution effectiveness are shown in **Figure 3**.

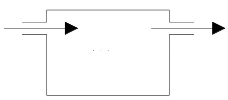
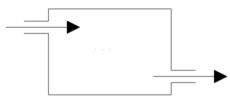
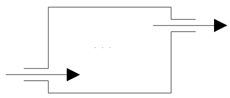
Mixing ventilation		Mixing ventilation		Displacement ventilation		Personalized ventilation	
							
T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T room °C	Vent. effect. -
< 0 0 - 2 2 - 5 > 5	0,9 - 1,0 0,9 0,8 0,4 - 0,7	< -5 -5 - 0 > 0	0,9 0,9 - 1,0 1	<0 0-2 >2	1,2 - 1,4 0,7 - 0,9 0,2 - 0,7	-6 -3 0	1,2 - 2,2 1,3 - 2,3 1,6 - 3,5

Figure 3. Typical examples of ventilation/air distribution effectiveness

The air distribution effectiveness takes into account the air distribution in a space, but does not take into account how effectively the outside air is transported through the ducts to the space. If the system has any air leakage, the amount of ventilation air must be increased. This is not dealt with in EN15251, but is mentioned in ASHRAE 62.1.

The rates given in the Tables are based on full mixing and in practice the ventilation effectiveness is very seldom taken into account. One complication is that some systems may have a different ventilation effectiveness summer and winter. If the supply temperature is lower than room temperature the ventilation effectiveness is normally 1 or higher, but if the ventilation system is used for heating in winter the ventilation effectiveness could be as low as 0.5, and the ventilation rates should really be doubled. More information and a greater emphasis on this factor are required

To use ventilation effectiveness can be one way of taking into account personalized ventilation; but we need also to look at issues like acceptance of higher air velocities and less strict requirements to the general environment if the person is equipped with a personal system.

Illumination

The criteria in EN 15251 are only specified at one level of luminance. The following additional criteria for daylight factor (Table 3) and seasonal affective disorder (SAD, Table 4) should be discussed for inclusion in the standard.

For rooms that are used during the day (work places, living rooms, dining rooms, kitchens, or child's play rooms) the minimum daylight factor is:

Table 3. Recommended criteria for the daylight factor.

	I	II	III
Daylight factor	> 5% on average	> 3% on average	> 2% on average

Residential buildings

To reduce the prevalence of SAD (Seasonal Affective Disorder; "winter depression"), higher light levels are particularly important during winter. For minimum one of the main habitable rooms in residential buildings direct sunlight should be available from fall to spring equinox.

Table 4. Recommended criteria for SAD (Seasonal Affective Disorder).

	I	II	III
Direct sunlight availability, percentage of probable sunlight hours[1]	> 10%	> 7,5%	> 5%

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Acoustic

The section on acoustic needs to be revised. Again it would be recommendable if experts could suggest different categories of requirements.

Occupant behaviour

The occupant behaviour will have a significant influence on the energy consumption in buildings. In dynamic computer simulations of indoor environment and energy consumption in buildings certain occupant behaviour (temperature set-point, time of occupancy, solar shading etc.) significantly influences the results. Therefore there is a need to specify some "standard" patterns of occupant behaviour. An example from EN ISO 13790 is shown in Table 5.

Conclusions

EN15251 is the first European standard that includes criteria for the four indoor environmental factors: Thermal comfort, air quality, lighting, and acoustic. This standard has been widely used in practice and several scientific papers have been published dealing with issues related to the standard.

The present paper has highlighted some of the issues that must be discussed in the future revision of the standard.

References

ASHRAE Standard 55-2007. Thermal environment conditions for human occupancy. ASHRAE, Atlanta.

ASHRAE-62.1(2010) Ventilation for acceptable indoor air quality, Atlanta, GA, American

Society of Heating, Refrigerating and Air-Conditioning Engineers.
EN 15251 (2007) Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics. CEN, Brussels
EN 7730 (2005) Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal
EN ISO 13790, Energy performance of buildings – Calculation of energy use for space heating and cooling

Table 5. Input parameters for occupant related parameters from EN ISO 13790

Building type	a	b	c	d	e	f	h	g	i) Other types				
Building category / Input data	single-family houses	apartment blocks	offices	education buildings	hospitals	restaurants	trade services	sports facilities	Meeting halls	Industrial buildings	Warehouse	Indoor swimming pool	Unit
Internal temperature in winter	20	20	20	20	22	20	20	18	20	18	18	28	°C
Internal temperature in summer	26	26	26	26	26	26	26	26	26	26	26	28	°C
Area[1] per person (occupancy)	60	40	20	10	30	5	10	20	5	20	100	20	m^2/P
Average heat flow per person	70	70	80	70	80	100	90	100	80	100	100	60	W/P
Metabolic gain per conditioned floor area[1]	1.2	1.8	4.0	7.0	2.7	20.0	9.0	5.0	16.0	5.0	1.0	3.0	W/m²
Presence time per day (monthly average)	12	12	6	4	16	3	4	6	3	6	6	4	h
Annual electricity use per conditioned floor area[1]	20	30	20	10	30	30	30	10	20	20	6	60	kWh/m^2
Internal part of electricity use	0,7	0,7	0,9	0,9	0,7	0,7	0,8	0,9	0,8	0,9	0,9	0,7	-
Outdoor airflow rate per conditioned floor area[1]	0,7	0,7	0,7	0,7	1,0	1,2	0,7	0,7	1,0	0,7	0,3	0,7	$m^3/(h \cdot m^2)$
Outdoor airflow rate per person	42	28	14	7	30	6	7	14	5	14	30	14	m^3/(h·pers.)
Heat for hot water per conditioned floor area[1]	10	20	10	10	30	60	10	80	10	10	1,4	80	kWh/m^2

[1] These figures refer to the gross conditioned area, calculated with external building dimensions.
This area includes all conditioned space contained within the thermal insulation layer. For example, internal unheated (but indirectly heated) staircase is included, but the cellar is not