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COMPARISON OF THE STANDARDIZED REQUIREMENTS FOR INDOOR CLIMATE IN OFFICE BUILDINGS

Bachelor's Thesis
Building Services Engineering

December 2012

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DESCRIPTION

MIKKELIN AMMATTIKORKEAKOULU Mikkeli University of Applied Sciences	**Date of the bachelor's thesis**
Author(s) Kazderko Mikhail	**Degree programme and option** Double Degree Program Building Services Engineering

Name of the bachelor's thesis

Comparison of the standardized requirements for indoor climate in office buildings

Abstract

The subject of this thesis is a comparison of different normative documents and the corresponding requirements for indoor climate in office buildings.

International, European, Russian and Finnish standards were chosen as sources of the material for description and comparison of the modern requirements to indoor environment. They include: International standard ISO 7730, Technical report CR 1752, European standards EN 13779 and EN 15251, Russian national standard GOST R EN 133779 and SNiP 41.01.2003, National Building Code of Finland D2 and LVI 05-10440 Classification of indoor environment 2008.

The aim of this work is to find out the differences or similarities between the foregoing groups of standards. In addition the compliance of indoor climate conditions in real office room with the standardized requirements is verified in this thesis. Two methods are used for an achievement of these purposes. These methods are a comparison of the valid requirements and measurements of some parameters in real office.

Conclusion describes the results of theoretical comparison and practical measurements. In whole all considered standards prescribe almost similar requirements. In spite of insignificant differences they do not contradict one another. The measured indoor climate parameters meet the requirements of the vast number of all considered standards.

Subject headings, (keywords)
Indoor climate, thermal conditions, air movement, air quality

Pages	Language	URN
37	English	

Remarks, notes on appendices

Tutor	Employer of the bachelor's thesis
Mika Kuusela	

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DEFENITIONS

clothing insulation

resistance to sencible heat transfer provided by a clothing ensemble. It is expressed in the clo unit or in $(m^2 \cdot K)/W$; 1 clo = 0,155 $(m^2 \cdot K)/W$.

draught

unwanted local cooling of the body caused by air movement and temperature.

draught rate (*DR*)

percentage of people predicted to be dissatisfied due to draught.

metabolic rate (*M*)

rate of energy production of the body. It is expressed in the mey unit or in W/m^2;
1 met = 58,2 W/m^2.

operative temperature (θ_0)

uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment

predicted mean vote (PMV)

index that predicts the mean value of the thermal sensation votes of a large group of persons on a 7-point scale.

predicted percentage of dissatisfied (PPD)

index that predicts the percentage of a large group of people likely to feel thermally dissatisfied for the body as a whole, i.e. either too warm or too cool.

turbulence intensity (*TU*)

ratio of the standard deviation of the air velocity to the mean air velocity

ventilation rate

magnitude of outdoor air flow rate to a room or building either through the ventilation systemor infiltration through building envelope

1 INTRODUCTION

Standard is a normative document containing the generally accepted set of rules for different fields of human activity. Functions of standards include the improvement of product, work and service quality and also the assurance of life safety and human health.

There are following standardization levels in accordance with limitations of the competence:

- International standardization. ISO is the main standardizing authority.
- Interregional standardization. This level involves a number of independent nations or unions such as EU, CIS, etc.
- National standardization. It is standardization within one country.
- Rules, norms and guidelines in the field of standardization. In addition, different classifiers of technical, economical or social information may be concerned to this level.
- Standards of organizations. There are branch, local and factory standards. It is the lowest standardization level.

Countries seek to harmonize the national standards and release the international standards. These arrangements make it possible to simplify the maintenance of export production and facilitate the product promotion to foreign markets.

Standards concerning the indoor environment will be considered in this work. Normative documents of different countries and different standardization levels are chosen for the most complete comparison. All of them are divided into four groups: International, European, Russian and Finnish standards. The basic requirements of each group of standards will be described in the theoretical part of this thesis. As a result, there will be conclusion about differences or similarities between each group of standards.

Given standards establish technical requirements to the designing of the indoor environment in different types of buildings. But this thesis concentrates on considering the basic requirements to the indoor environment only for office buildings. The set of concerned requirements includes the requirements to thermal conditions, air motion properties and air quality. These basic requirements prescribe the normative values for the following parameters: operative temperature, air velocity, draught rate, air flow rate and carbon dioxide concentration.

Some characteristics of office premises should be determined before the beginning. There are some generally accepted assumptions. Occupants are in office premises from 8 a.m. to 6 p.m. during weekdays. The foregoing requirements should be met during this time. The activity of the occupants is sedentary (1,2 met). The clothing insulation is 0,5 clo in summertime and 1,0 clo in wintertime. The operative temperature is equal to the air temperature. The turbulence intensity is 40% for the mixing ventilation in the occupied area. Finally, smoking is not allowed.

After the theoretical consideration of the requirements of different standards, verification of a compliance of indoor environment parameters in real office room with these requirements will be done.

2 AIMS AND METHODS

2.1 Aims

The main aim of this thesis is to find out the differences or similarities of valid normative documents from different countries. Chosen standards prescribe the indoor environment parameters and design criteria of ventilation systems for office buildings. During the process of this consideration certain requirements for indoor environment in office premises will be compared.

The set of parameters chosen for a comparison includes indoor temperature conditions, air velocity and draught rate, air quality and the permitted CO_2 concentration level. These parameters are the most important for public premises. Therefore their comparison will make it possible to make an objective assessment of certain requirements of each standard.

Also the compliance of indoor climate conditions in real office room with the requirements from different standards will be verified. It will be done using measurements of basic parameters in the given office and further comparison between derived values and required values.

2.2 Methods

For an achievement of aims of this work two methods will be used. These methods are the comparison of valid normative documents from different countries and measuring the indoor environment parameters in real office room.

The first method may be characterized as a description of each category of standards, consideration of requirements from each standard and further finding similarities or differences in requirements.

Method of measurements consists in readout of measuring devices situated in the given premise. For measurements in this work the typical office room for two working persons was chosen. This room is situated on the first floor of X-building, which is one of new buildings of Mikkeli University of Applied Sciences. Air temperature at three levels of height (0,1 m, 1,1 m and 2,1 m) and the CO_2 concentration level were chosen as measurable parameters. Values of these parameters are measured for one week. In addition supply and exhaust air flow rates will be estimated on basis of types of the devices and measured pressure drops. Consideration of results of these measurements will be done in following chapter dealing with measurement data.

3 THE REQUIREMENTS OF THE INTERNATIONAL STANDARDS

Main international normative documents for indoor environment are the international standard ISO 7730 and the Technical Report of European Committee for Standardization called CR 1752. The requirements of international standards differ from the requirements of European standards. Therefore separate chapters deal with each of them.

3.1 Indoor environment categories

Before considering the requirements of the standards, the variety of different office premises should be classified by the type of indoor environment. The international standard ISO 7730 and the Technical Report of European Committee for Standardization called CR 1752 should be referred for the most complete disclosure of this classification.

These documents are based on international system of ranging the indoor environment in buildings. This classification contains three categories of environmental quality shown in Table 1. Category A conforms to a high level of environmental conditions, category B to a medium level and category C to a moderate level. These categories can be selected for different parameters of environment in premises such as thermal conditions, the air quality or acoustical conditions.

Table 1. Categories of thermal environment. /1/

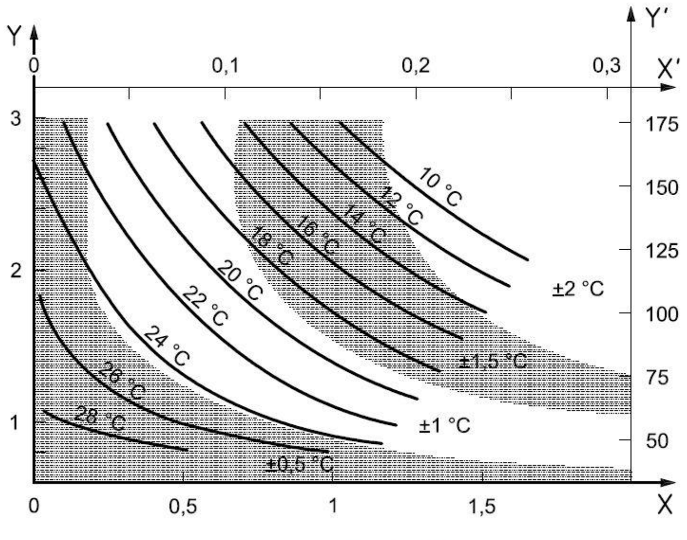
Category	Thermal state of the body as a whole		Local discomfort			
				PD, %, caused by		
	PPD, %	PMV	DR, %	Vertical air temperature difference	Warm or cool floor	Radiant asymmetry
A	< 6	-0,2 … +0,2	< 15	< 3	< 10	< 5
B	< 10	-0,5 … +0,5	< 20	< 5	< 10	< 5
C	< 15	-0,7 … +0,7	< 25	< 10	<15	< 10

Given international classification will be used when further consideration of thermal conditions, conditions of air motion, air quality and other parameters of indoor environment for a space. Parameters from Table 1 will be described in next chapters.

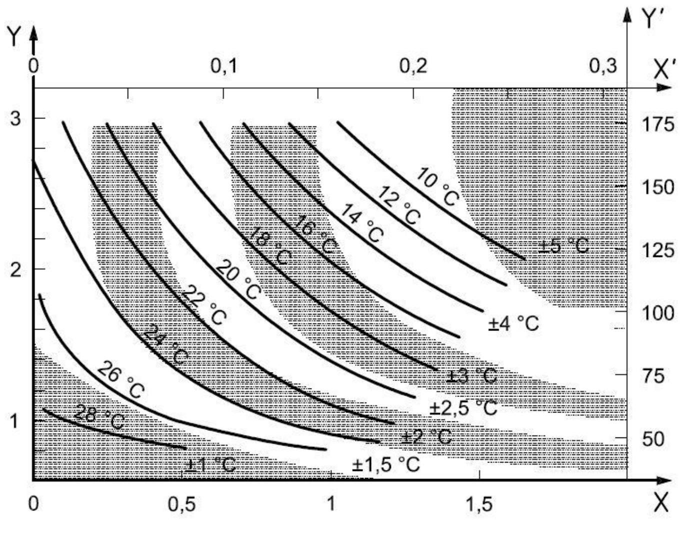
3.2 Thermal conditions

When considering the thermal environment in public premises, some international sources should be discussed. First of them is international standard ISO 7730. This normative document takes into account thermal and other factors that can cause dissatisfaction. These factors are called local discomfort. Thermal acceptability in offices, sitting rooms and other public rooms also should be ensured according to ISO 7730.

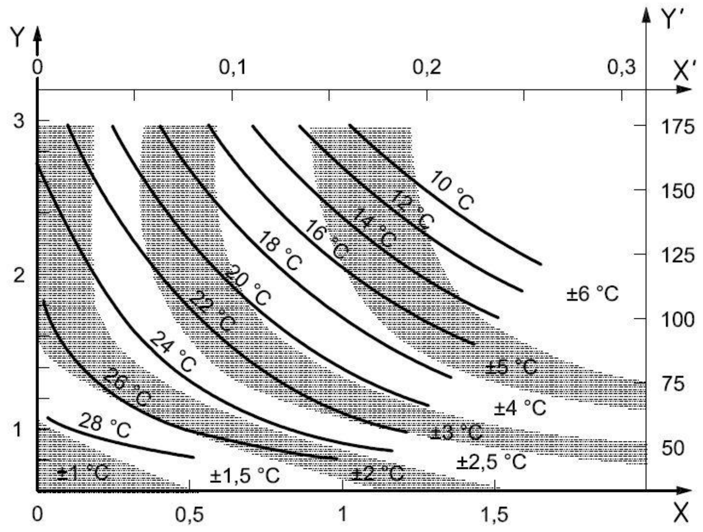
Clothes and physical activity of people belong to the most important factors influencing the thermal acceptability. Clothing insulation and metabolic rate are initial data for designing of indoor environment. The diagrams presented in the Figure 1 give optimum values of the operative temperature for the three categories of indoor environment as function of clothing insulation and physical activity of people.



Category A: PPD < 6 %



Category B: PPD < 10 %



Category C: PPD < 15 %

Key

PPD is a predicted percentage dissatisfied, %

X is a basic clothing insulation, in clothing units, (clo)

X’ is a basic closing insulation, in clothing units, $m^{2}\cdot{}^{o}C/W$

Y is a metabolic rate, in metabolic units, (met)

Y’ is a metabolic rate, in metabolic units, W/m^2

Figure 1. Optimum operative temperature as function of clothing and activity. /1/

In addition to foregoing values of operative temperature, standard ISO 7730 normalizes values for the local thermal discomfort factors. Values of vertical air temperature difference are shown in Table 2. Permitted range of floor temperature is presented in Table 3. Finally, radiant temperature asymmetry is shown in Table 4. All these parameters correspond to three categories of indoor environment.

Table 2. Vertical air temperature difference between head and ankles. /1, 2/

Category	Vertical air temperature difference*, ˚C
A	< 2
B	< 3
C	< 4
* 1,1 and 0,1 m above floor	

Table 3. Range of floor temperature. /1, 2/

Category	Floor surface temperature range, ˚C
A	19…29
B	19…29
C	17…31

Table 4. Radiant temperature asymmetry. /1, 2/

Category	Radiant temperature asymmetry, ˚C			
	Warm ceiling	Cool wall	Cool ceiling	Warm wall
A	< 5	< 10	< 14	< 23
B	< 5	< 10	< 14	< 23
C	< 7	< 13	< 18	< 35

Another international normative document is the Technical Report CR 1752 meant for designing of ventilation systems for different buildings. It contains design criteria for the indoor environment. Temperature requirements from CR 1752 are practically identical to data from ISO 7730. For example, parameters from Tables 2, 3 and 4 have absolutely identical values in both documents. But the Technical report defines parameters for offices more precisely.

Following design assumptions are determined for cellular office /2/

- The occupancy is 0,1 person per m^2 floor
- The cooling load caused by occupants, machines, illumination, solar radiation etc. is 50 W/m^2 floor.

As a result of review of international requirements to parameters of thermal environment for office premises, thermal design criteria for three types of indoor environment should be presented. They are shown in Table 5. These values are applicable for different office premises such as cellular offices or landscape offices. Physical activity for this case is 70 W/m^2.

Table 5. Operative temperature for office premises. /1, 2/

Category	Operative temperature, °C	
	Summer (cooling season)	**Winter** (heating season)
A	24,5 ± 1,0	22,0 ± 1,0
B	24,5 ± 1,5	22,0 ± 2,0
C	24,5 ± 2,5	22,0 ± 3,0

3.3 Air velocity and draught rate

Permissible value of mean air velocity depends on the draught rate (it means the percent of persons dissatisfied with draught), air temperature and turbulence intensity. Description of this correlation is given in international regulations ISO 7730 and CR 1752.

According to international standards, draught rate (*DR*, %) is calculated from the following equation /1, 2/

$$DR = (34 - \theta_a) \cdot (v - 0{,}05)^{0{,}62} \cdot (0{,}37 \cdot v \cdot TU + 3{,}14) \qquad (1)$$

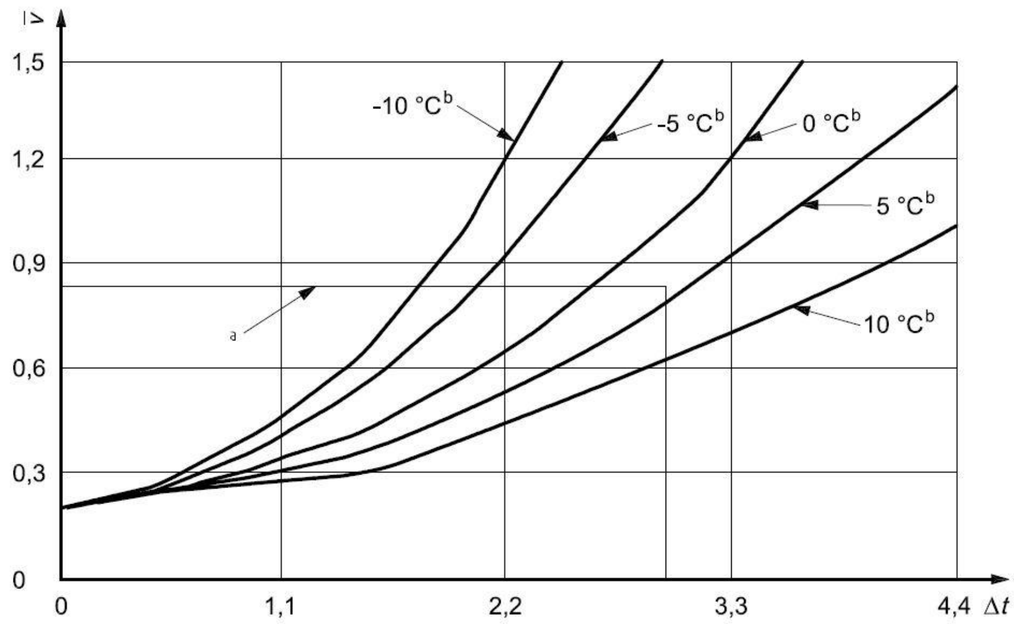
where

θ_a is the local air temperature, 20…26°C

v is the local mean air velocity, < 0,5 m/s (but not less than 0,05 m/s)

TU is the local turbulence intensity, 10…60% for mixed distribution of air flow (if unknown, 40% may be used)

Also ISO 7730 regulates how the increased temperature can be offset by increasing of air velocity. In summer season it is permitted to exceed the comfort level of temperature, if it is provided to also increase the air velocity. The amount by which the temperature may be increased is shown in Figure 2. Correlations of the air temperature and air velocity are expressed by the curves in this figure. Initial temperature on these graphs is 26°C and initial air velocity is 0,20 m/s. Figure 1 shows the air velocity that is necessary for typical clothing (0,5 clo) and sedentary activity (1,2 met) in summertime. /1/



Key

Δt is the temperature rise above 26°C

$\bar{v}$ is the mean air velocity, m/s

a is limits for light, primarily sedentary, activity (Δt < 3°C, $\bar{v} < 0{,}82$ m/s)

b is the difference between the average radiance temperature (θ_r) and the air temperature (θ_a), °C

Figure 2. Air velocity required to offset increased air temperature. /1/

This figure gives to understand that the higher the difference between the average radiance temperature and the air temperature, the more effective elevation of air velocity at increasing heat loss.

Technical Report CR 1752 also requires applying Equation (1) for estimation of draught. But there are slightly different parameters. Values of the local mean air velocity change between 19…27°C instead of 20…26°C. And there are no limitations for values of the local mean air velocity.

Permitted mean air velocity is shown in Figure 3 and in Table 6. There are three international categories of the thermal environment: A (when *DR* = 15%), B (when *DR* = 20%) and C (when *DR* = 25%). There is mean air velocity as a function of the local air temperature and the turbulence intensity. The range of the turbulence intensity is 30…60% for spaces with mixed distribution of air flow. It can be lower for spaces with displacement ventilation or without mechanical ventilation. /2/

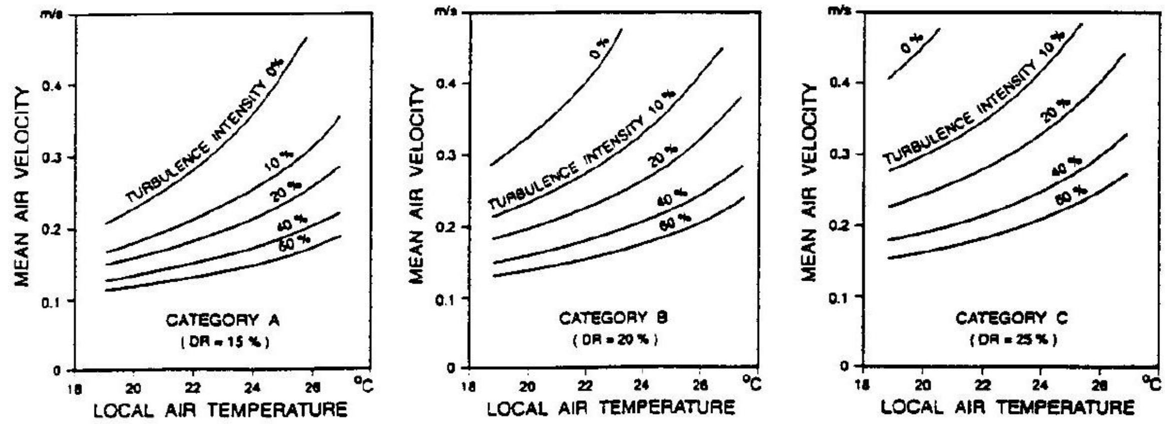


Figure 3. Permitted mean air velocity as a function of the local air temperature and the turbulence intensity for three categories of the thermal environment. /2/

Table 6. Maximum mean air velocity for office premises. /2/

Category	**Maximum mean air velocity,** m/s	
	Summer (cooling season)	**Winter** (heating season)
A	0,18	0,15
B	0,22	0,18
C	0,25	0,21

3.4 Air quality

Two parameters will be considered in this work as air quality design criteria. These parameters are the permitted carbon dioxide concentration and the required ventilation rate.

Carbon dioxide is gas contained in air. The high concentration of carbon dioxide has a negative influence on health of people. The main source of carbon dioxide in public premises is the occupants. In other words the CO_2 concentration depends on the number of occupants in the room and their physical activity.

Because of absence of reference to this question in the standard ISO 7730, the requirements of the Technical Report CR 1752 will be considered in this chapter. According to them office premises have 0,07 occupants per 1 m^2 of floor /2/. Technical Report gives the pollution load as 19 l/h(occupant) of carbon dioxide when sedentary activity in offices /2/. In addition it should be noted that ”if sedentary occupants are assumed to be only source of pollution, the CO_2 concentration above the outdoor level corresponding to the three categories is A: 460 ppm, B: 660 ppm and C: 1190 ppm” /2/. It is shown in Figure 4 graphically.

The given curve presents the percent of dissatisfied persons as a function of the CO_2 concentration above outdoors. The outdoor concentration of carbon dioxide is usually about 700 mg/m^3 (350 ppm). /2/

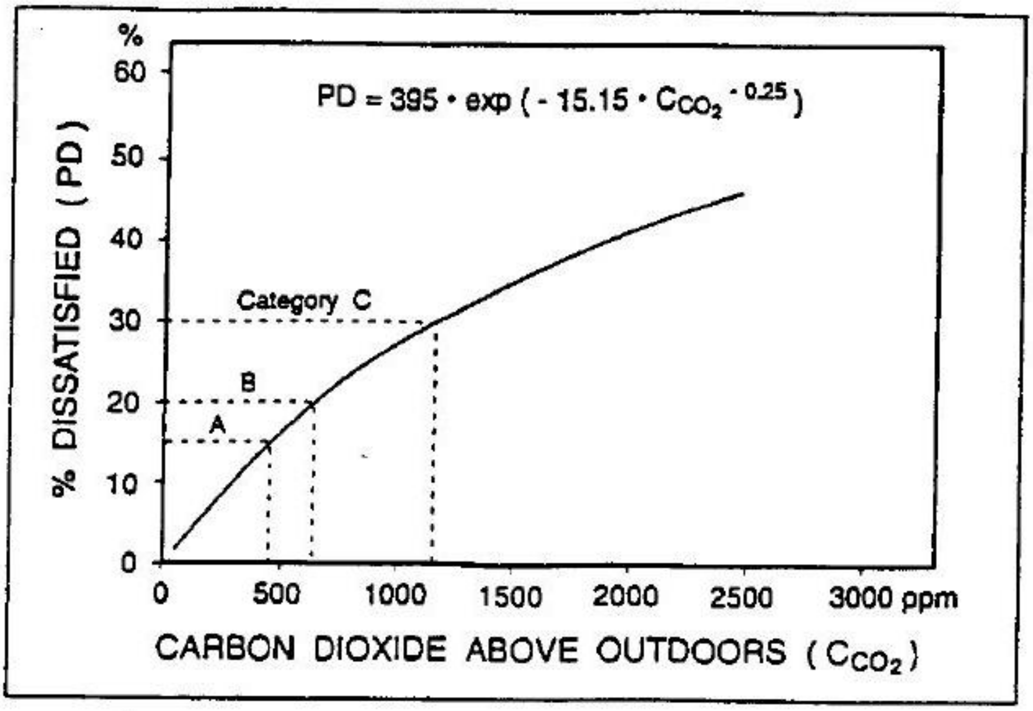


Figure 4. Carbon dioxide as an function of human bioeffluents. /2/

Another parameter considered in this chapter is the ventilation rate. In accordance to CR 1752, this parameter has two values: the ventilation rate required for comfort and the ventilation rate required for health. Both values should be calculated separately. The highest values should be used for the designing. Technical Report contains the detailed calculations of the required ventilation rate, but only results will be pointed out in this work. These results are presented in Table 7.

Table 7. Required ventilation rate per unit floor area for office premises. /2/

Category	Required ventilation rate, l/s(m² floor)	
	For comfort	For health
A	2,0	1,0
B	1,4	0,7
C	0,8	0,4

Besides of foregoing values there are other values relating to the number of occupants and the percent of smokers among them. This values are given in Table 8.

Table 8. Required ventilation rate per occupants for office premises. /2/

Category	Required ventilation rate, l/s(occupant)			
	No smoking	20% smokers	40% smokers	100% smokers
A	10	20	30	30
B	7	14	21	21
C	4	8	12	12

4 THE REQUIREMENTS OF THE EUROPEAN STANDARDS

There are two interrelated normative documents called standards EN 13779 and EN 15251. These European standards have been applied in European Community for last years. All countries of Europe which are members of European Committee for Standardization have approved their national normative documents according to EN 13779. These standards were developed by Technical Committee CEN/TC "Building ventilation" functioned on basis of British Standard Institute (BSI).

New European standard EN 13779 has a basic character and contain "guidance especially for designers, building owners and users, on ventilation, air-conditioning and room-conditioning systems in order to achieve a comfortable and healthy indoor environment in all seasons with acceptable installation and running costs" /3/.

4.1 Indoor environment categories

European standard EN 13779 is based on classification applied to the indoor air in the occupied zone. This classification is given in Table 9. In whole, European standards use a lot of type of classifications such as classification by extract, exhaust or outdoor air. But this thesis considers only classification by requirements to the indoor air.

Table 9. Basic classification of indoor air quality. /3/

Category	Description
IDA 1	High indoor air quality
IDA 2	**Medium indoor air quality**
IDA 3	Moderate indoor air quality
IDA 4	Low indoor air quality

Another European standard EN 15251 contains the same classification, but, as signed there, categories may be named different. For a comparison, description of categories from this document is presented in Table 10.

Table 10. Basic classification of indoor air quality. /4/

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

As seen from given tables, description of indoor environment categories is almost identical. And it should be noted that when considering of the typical office building category II (IDA 2) should be taken into account mainly.

4.2 Thermal conditions

Heat exchange of human body by radiation depends on temperature of ambient surfaces. On the other hand heat exchange by convection depends on temperature and velocity of air flow.

As stated in European standard EN 13779, the most of non-residential buildings have a low velocity of air flow (< 0,2 m/s) and little difference between the air temperature and the average radiance temperature in the room (< 4^{o}C). For determination of the operative temperature this standard requires to use the following equation /3/

$$\theta_0 = \frac{\theta_a + \theta_r}{2} \qquad (2)$$

where

θ_0 is the operative temperature at a given location in the room, ^{o}C

θ_a is the air temperature in the room, ^{o}C

θ_r is the average radiance temperature of all surfaces (walls, floor, ceiling, windows, radiators, etc.) for a given location in the room, ^oC.

When the fixing of operative temperature values for determined premises, European standard EN 13779 refers to standard EN 15251. This standard treats the question about thermal conditions more amply. As stated above, all buildings are divided into four categories by thermal states of the body as a whole. This dividing is shown in the Table 11.

Table 11. Examples of recommended categories for design of mechanical heated and cooled buildings. /4/

Category	Thermal state of the body as a whole	
	PPD, %	Predicted Mean Vote
I	< 6	-0,2 < PMV < +0,2
II	**< 10**	**-0,5 < PMV < +0,5**
III	< 15	-0,7 < PMV < +0,7
IV	> 15	PMV < -0,7; or +0,7 < PMV

According to standard EN 15251, normalized values of the operative temperature for office premises are presented in the Table 12.

Table 12. Example of recommended design values of the indoor temperature for typical office premises (1,2 met). /4/

Category	Operative temperature, °C	
	Minimum for heating (winter season), 1,0 clo	Maximum for cooling (summer season), 0,5 clo
I	21,0	25,5
II	**20,0**	**26,0**
III	19,0	27,0

4.3 Air velocity and draught rate

European standard EN 15251 does not include consideration of draught. But EN 13779 refers to the international standard ISO 7730. Because of this fact, all requirements for air velocity and draught stated in the chapter about international standards should be met when the designing in accordance to European regulations too.

4.4 Air quality

First of all it should be observed that European standard EN 13779 describes typical values for human occupancy. Design assumption for floor area is 10 m^2 per person for typical office room /3/. Besides them, typical ranges and design values of CO_2 concentration are given in Table 13.

Table 13. Carbon dioxide level in office rooms. /3/

Category	CO_2-level above level of outdoor air, ppm	
	Typical range	Default value
IDA 1	< 400	350
IDA 2	**400 – 600**	**500**
IDA 3	600 – 1000	800
IDA 4	> 1000	1200

Design values of the ventilation rate are also given in EN 13779. Rates of outdoor air per unit floor area are shown in Table 14. And rates per person are presented in Table 15.

Table 14. Required ventilation rate per unit floor area for office rooms. /3/

Category	Required ventilation rate, l/s(m^2 floor)	
	Typical range	Default value
IDA 1	-	-
IDA 2	**> 0,7**	**0,83**
IDA 3	0,35 – 0,7	0,55
IDA 4	< 0,35	0,28

It should be noted, that values of ventilation rate per unit floor area are not determined for category IDA 1 because this method is not sufficient for this category. And all this values are based on a running time of 50% and room height up to 3 m. With shorter running time and for higher rooms the ventilation rate should be higher.

Table 15. Required ventilation rate per person for office rooms. /3/

Category	Required ventilation rate, l/s(occupant)			
	Non-smoking area		Smoking area	
	Typical range	Default value	Typical range	Default value
IDA 1	> 15	20	> 30	40
IDA 2	**10 - 15**	**12,5**	**20 – 30**	**25**
IDA 3	6 – 10	8	12 – 20	16
IDA 4	< 6	5	< 12	10

In accordance to standard EN 15251 the values of air flow rate do not depend on season. But occupancy, emissions from building materials, indoor activities and processes have an influence on the ventilation rate.

Concerning the foregoing parameters, EN 15251 prescribes the same required values of ventilation rates and carbon dioxide concentration as EN 13779.

5 THE REQUIREMENTS OF THE RUSSIAN STANDARDS

In Russia the basic normative document for the designing of ventilation systems in office buildings is the national standard of Russian Federation called GOST EN R 13779-2007 “Ventilation for non-residential buildings”. This document is created on basis of European standard EN 13779. But it contains some differences from original source because of national features.

Another Russian normative document called SNiP 41.01.2003 contains a variety of requirements to heating, ventilation and air conditioning systems for different types of buildings.

5.1 Indoor environment categories

Russian national standard uses the same classification as its European origin source. This classification may be found in Table 6. In contrast to the national standard, SNiP 41.01.2003 does not contain any classification of the indoor environment. In this document requirements for all parameters of indoor air are described for the premises not divided by categories.

5.2 Thermal conditions

When considering of indoor environment parameters for the designing, first of all Russian national standard sets typical values of clothing insulation and metabolic rate. They are shown in Table 16.

Table 16. Typical values of clothing insulation and metabolic rate for office buildings. /5/

Parameter	Typical range of values	Typical design value
Clothing insulation, clo	in summertime: 0,5...0,7	in summertime: 0,5
	in wintertime: 0,8...1,0	in wintertime: 1,0
Metabolic rate, met	1,0...1,4	1,2

There should be observed that when determination of the operative temperature value, it should be used the Equation (2). This formula is also prescribed in European standard EN 13779.

For non-residential buildings the optimal value of the operative temperature is +24,5°C in summertime and +21,5°C in wintertime /5/. If it is possible, the project should allow for parameters and characteristics of a given building. Also temperature requirements can depend on local climatic conditions influencing on the thermal acceptability. Therefore, local regulations are priority. If they do not establish other parameters, it should be used data from the Table 17. As a rule, agreed values of operative temperature should be accomplished at a height of 0,6 m in the middle of the room.

Table 17. Operative temperature values in office premises. /5/

Season	Typical range of operative temperature values, °C	Typical design operative temperature value, °C
Winter heating season	19…24	21*
Summer cooling season	23…26	26**
*- the minimum value during a day ** - the maximum value during a day		

Despite the fact that national standard of Russian Federation is based on European standard EN 13779, Russian standard GOST R EN 13779-2007 confines itself to normalization of the range of operative temperature values only for winter and summer seasons.

5.3 Air velocity and draught rate

Unless otherwise provided, air temperature in the room can be determined by use of data from Table 18 which is true when the draught rate is 10…20% and the turbulence intensity is 40% for the mixed air flow.

Table 18. Values of the local air velocity. /5/

Local air temperature, °C	Typical range of values of local mean air velocity, m/s	Typical design value of local mean air velocity, m/s (when *DR* = 15%)
20	0,10…0,16	0,13
21	0,10…0,17	0,14
22	0,11…0,18	0,15
24	0,13…0,21	0,17
26	0,15…0,25	0,20
Comment – It is permitted to use exceeding values, if there is an air flow control or intensive ventilation during limited intervals.		

When the determining of the draught rate both international standards should be referred because of use of the same formula – the Equation (1). Values of the local mean air velocity also change between 19…2 ^{o}C instead of 20…26^{o}C and there are no limitations for values of the local mean air velocity as in CR 1752. /5/

5.4 Air quality

The minimum values of the outdoor air flow rate are specified in SniP 41.01.2003 for different types of buildings. The outdoor air flow rate is 40 m^3/h (11 l/s) per person for public and office premises with natural ventilation and 60 m^3/h (17 l/s) per person for the same buildings without natural ventilation. /6/

In accordance to GOST R EN 13779-2007 the typical range of floor area per person is between 8…12 m^2 for usual office room. At the same time the design value of floor area per person is 10 m^2. /5/

The requirements of Russian national standard to air flow rate are the same as the requirements of European standard EN 13779 presented in Table 15. These requirements applies to office premises where the metabolic rate of the occupants is 1,2 met. Limitations for CO_2-level from Table 13 are also equal to the requirements of Russian national standard.

6 THE REQUIREMENTS OF THE FINNISH STANDARDS

In Finland the basic normative document for ventilation is the National Building Code D2 published in 2003. Besides them, there is another helpful document called LVI 05-10440. It is a document containing target values, design guidance and product requirements for construction and building design. In essence, this document is not a standard prescribing mandatory requirements. But it contains a set of instruction and guidelines to be useful and convenient during the design of building construction and building services. Therefore this document also deserves attention.

6.1 Indoor environment categories

There are two classifications. First of them is a standard system approved in international normative documents. On the other hand, classification from LVI 05-10440 is a subsidiary Finnish system intended to make the designing more convenient.

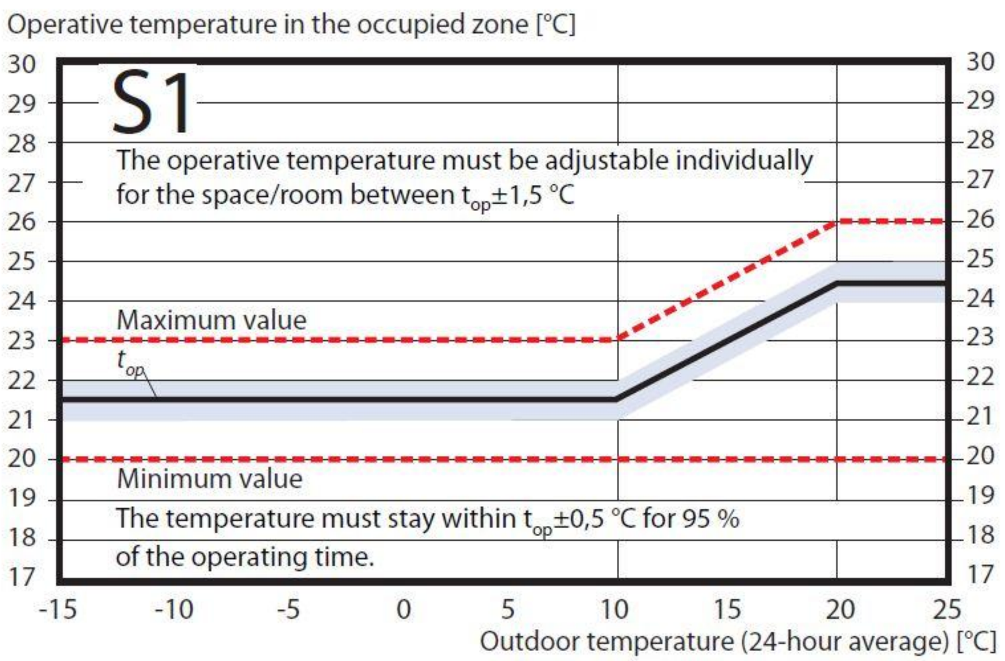
In accordance to LVI 05-10440, the classification can be subdivides into three categories. They are called as S1, S2 and S3. Category S1 (Individual Indoor environment) is notable for the most exacting requirements to air quality and other indoor conditions. There are no sources of potential health hazard such as impurities or harmful microorganisms. Conditions of this category are the most comfortable, because there should be no draught or overheating. The next category S2 (Good Indoor environment) gives not so high requirements for the indoor climate of building. Also there are no sources of health hazard and other disturbing factors. Overheating is possible in summertime, but draught is also not detected. Temperature conditions are quite good. Finally, category S3 (Satisfactory Indoor environment) means that temperature conditions and quality of air meet the minimum requirements given by normative documents. Also it should be noted that a different category can be selected for different type of parameters or different seasons. /7/
Given classifications will be used when further consideration of thermal conditions, conditions of air motion, air quality and other parameters of indoor environment for a space. In some cases it is convenient to refer to both classifications.

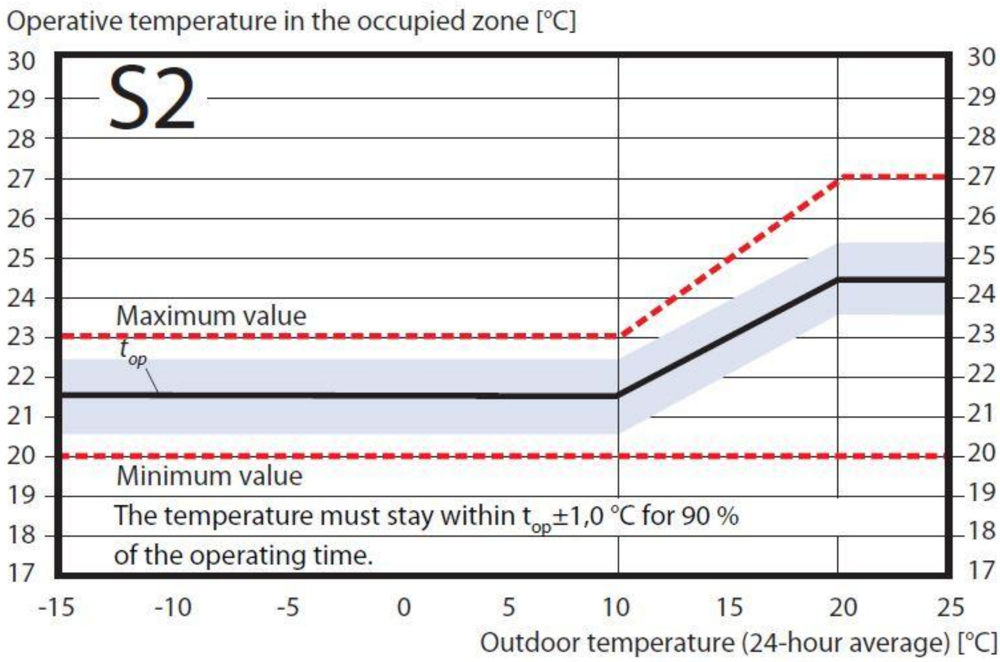
6.2 Thermal conditions

According to D2 it should be noted a following point: ”Design temperature for the heating season that is normally used for room temperature in the occupied zone is 21°C. The design temperature for the summer season that is normally used for room temperature in the occupied zone is 23°C.” /8/

Besides that, D2 regulate a maximum temperature in the occupied zone. It should not normally be more than 25°C during period of occupancy. Only in case the average outdoor air temperature over a maximum period of five hours is higher than 20°C, the room air temperature may exceed this value by a maximum of 5°C. These values also apply to office and other public places where the room temperature design value is 21°C. /8/

In addition to D2 Classification of Indoor Environment LVI 05-10440 was published in 2008. This document gives more detailed guidelines for target values of operative temperature. These recommended values are shown in Figure 5 graphically.





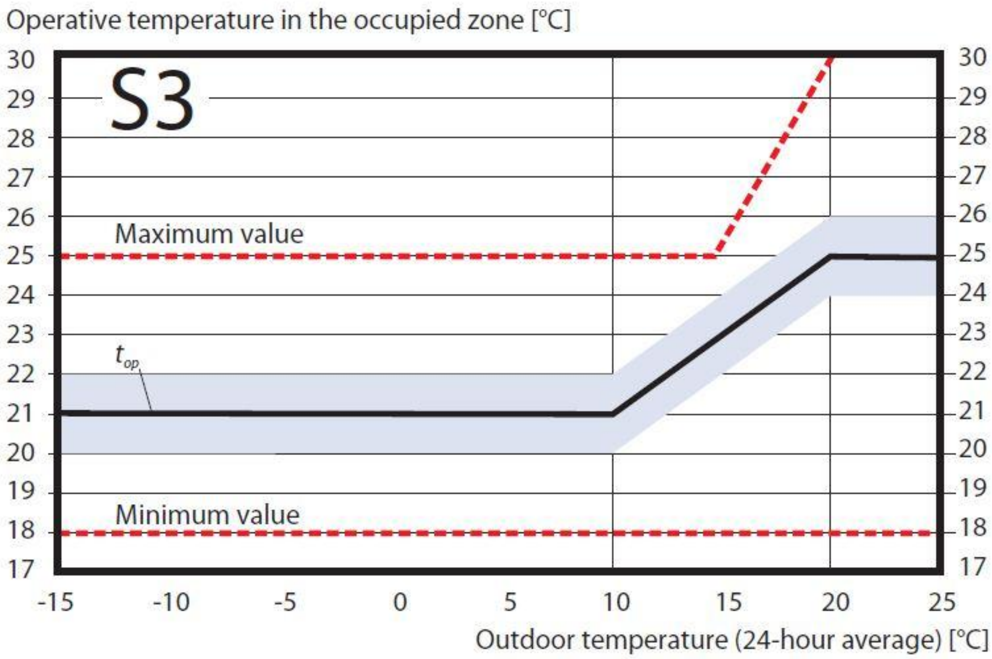


Figure 5. Target values of the operative temperature for three categories of buildings. /7/

6.3 Air velocity and draught rate

According to D2 the permitted air velocity in office premises has the following values: 0,2 m/s for winter season and 0,3 m/s for summer season. These values are determined in accordance to the operative temperatures defined in D2. /8/
Also the draught curves presented in Figure 6 should be taken into account. They can be useful when evaluation of air velocities given rise to discomfort at different temperatures in the room.

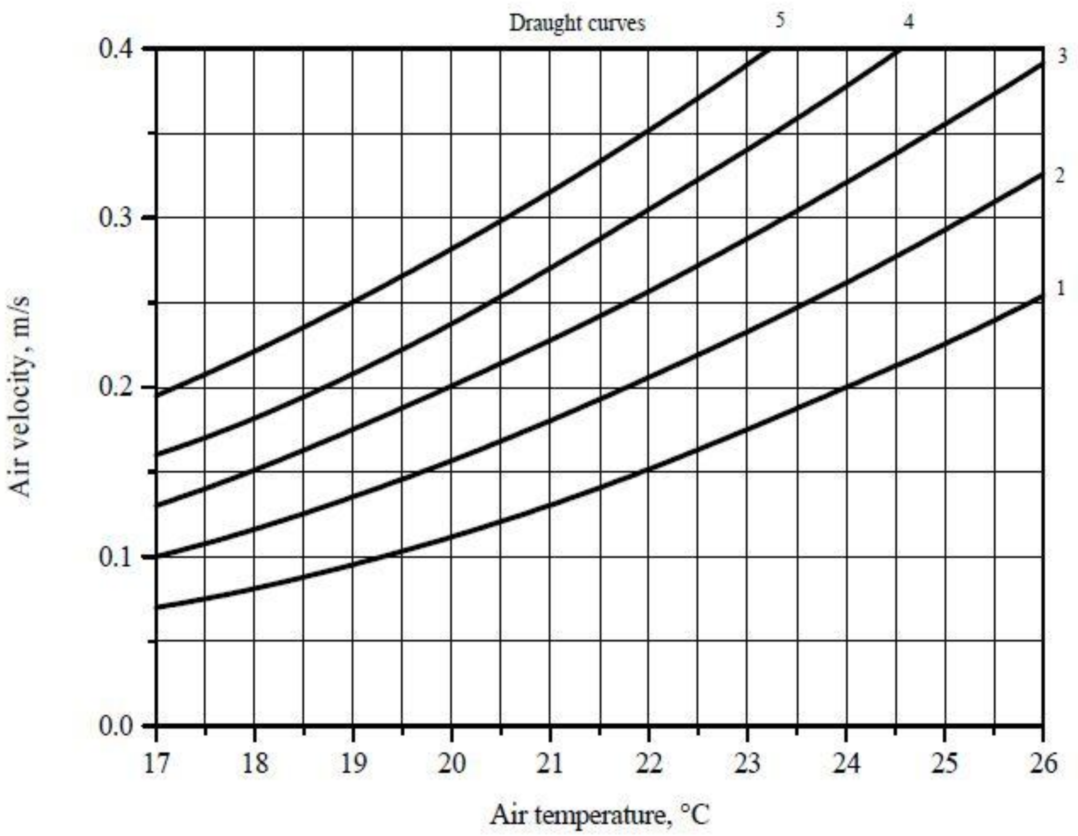


Figure 6. Draught curves described the relationship between air temperature and air velocity that causes discomfort. /8/

Also the guidance LVI 05-10440 does not recommend exceeding the maximum permitted values of air velocity in the room. These limiting values are presented in Table 19 for different seasons with different values of the indoor air temperature.

Table 19. Target values for air velocity. /7/

Category	Air velocity, m/s		
	θ_a = 21°C (wintertime)	θ_a = 23°C	θ_a = 25°C (summertime)
S1	< 0,14	< 0,16	< 0,2
S2	< 0,17	< 0,2	< 0,25
S3	0,2	-	0,3

6.4 Air quality

The maximum CO_2-level permitted by D2 is usually 2160 mg/m^3 (1200 ppm) for indoor air /8/. This value corresponds to period of occupancy and normal weather conditions. The equal limitations for three categories of the indoor environment are given by LVI 05-10440 and shown in Table 20.

Table 20. The permitted values of CO_2 concentrations for office premises. /7/

Category	Carbon dioxide concentration, ppm
S1	< 750
S2	< 900
S3	< 1200

Considering design values of air flow rates D2 gives detailed guidelines for different types of buildings during the period of occupancy. In different cases normalized air flow rate can be determined by the area of the premise or the number of occupants. It depends on type of the premise.

For office and similar rooms the normalized parameter is outdoor air flow rate determined by the area of the room. Normalized value of this parameter is 1,5 l/s per 1 m^2 of the floor. /8/

LVI 05-10440 also prescribes the required values of outdoor air flow rate in office buildings. There are values determined by the area of space and the numbers of occupants. These required values are shown in Table 21. Also it should be observed that the required floor surface is 12 m^2 per person for offices with normal space efficiency. /7/

Table 21. The design values of outdoor air flow rate for office space with normal space efficiency. /7/

Category	Outdoor air flow rate	
	l/s per person	l/s per m^2
S1	16	1,5
S2	13	1,5
S3	-	1,5

7 COMPARISON OF THE REQUIREMENTS

This chapter deals with the comparison of the requirements of the foregoing groups of standards. Differences and similarities will be found out between these groups. After that it will be possible to make a conclusion about the exactness of given requirements.

The operative temperature is the first parameter which will be considered. Comparison of the design values from different groups of standards is presented in Table 22.

Table 22. The design values of the operative temperature for office premises.

Group of standards	Category of buildings	Operative temperture, ˚C			
		Summer season		Winter season	
		Typical range	Default value	Typical range	Default value
International	A	23,5…25,5	24,5	21,0…23,0	22
	B	23,0…26,0	24,5	20,0…24,0	22
	C	22,0…27,0	24,5	19,0…25,0	22
European	I	-	25,5	-	21
	II	-	26	-	20
	III	-	27	-	19
Russian		-	26	-	21
Finnish D2		-	23	-	21
Finnish classification	S1	20…26	24,5	20…23	21,5
	S2	20…27	24,5	20…23	21,5
	S3	18…30	25	18…25	21

From this table it is clear that the requirements of the given standards are generally similar. But also there are some features. In contrast to International and Finnish standards, European and Russian standards prescribe only design value of the operative temperature without the typical range of this parameter. In addition there is no division of the required values by category of buildings in Russian standards. Also it should be noted that the highest requirements are stated in International and Finnish standards because of the most exact values for each category of buildings. At the same time European and Russian standards have relatively mild requirements to the operative temperature.

The second compared parameter is the maximum mean air velocity. Data from the standards are given in Table 23.

Table 23. The maximum values of the mean air velocity for office premises.

Group of standards	Category of buildings	Maximum mean air velocity, m/s	
		Summer season	Winter season
International	A	0,18	0,15
	B	0,22	0,18
	C	0,25	0,21
European	I	0,18	0,15
	II	0,22	0,18
	III	0,25	0,21
Russian		0,2	0,14
Finnish D2		0,3	0,2
Finnish classification	S1	0,2	0,14
	S2	0,25	0,17
	S3	0,3	0,2

The permitted mean air velocity has the different values for summer and winter seasons. In wintertime the maximum value of the mean air velocity is lower than in summertime. As in the case of thermal conditions in Russian standards the values of air velocity are not subdivided by categories of buildings. At the same time International and European standards have the equal requirements for this parameter. It should be observed that their requirements to the air velocity during summertime are the highest among the considered regulations. But in spite of lower requirements to the air velocity during summertime, Russian and Finish standards are notable for the highest requirements to this parameter during the wintertime.

Finally, the required ventilation rate and the permitted carbon dioxide concentration are the last parameters which will be considered in this work. These two parameters are concerned to the air quality. Therefore they can be combined in one table. It is shown in Table 24. Values of the required air flow rate are divided into two types in this table. First type is the values per unit floor area. Second type is the values per person.

Table 24. The required ventilation rate and the permitted CO_2-level for office premises.

Group of standards	Category of buildings	Required ventilation rate: per unit floor area, l/s(m^2 floor)	Required ventilation rate: per person, l/s(occupant)	Permitted CO_2-level, ppm
International	A	1	10	460
	B	0,7	7	660
	C	0,4	4	1190
European	I	-	20	350
	II	0,83	12,5	500
	III	0,55	8	800
Russian	I	-	20	350
	II	0,83	12,5	500
	III	0,55	8	800
Finnish D2		1,5	-	1200
Finnish classification	S1	1,5	16	750
	S2	1,5	13	900
	S3	1,5	-	1200

First of all it should be noted that the requirements to air quality from European and Russian standards are equal because the national standard of Russian Federation refers to European standard in this case. The value of the required air flow rate per person is more priority than the value per unit floor area. It is safe to say about this fact because of absence of the required value per unit floor area for the first category of buildings. At the same time their requirements to the air flow rate per person and the permitted concentration of carbon dioxide are the highest among the given standards. On the other hand the highest permissible CO_2-level relates to Finnish standards. But the lowest required air flow rate is stated in the International regulations.

8 MEASUREMENTS OF THE INDOOR CLIMATE PARAMETERS

Real office room was chosen for the measurements of some indoor environment parameters on this work. This premise is situated on the first floor of X-building of Mikkeli University of Applied Sciences. There are two working persons. The square of this office is 19 m^2. Plan of the given room is shown in Figure 7.

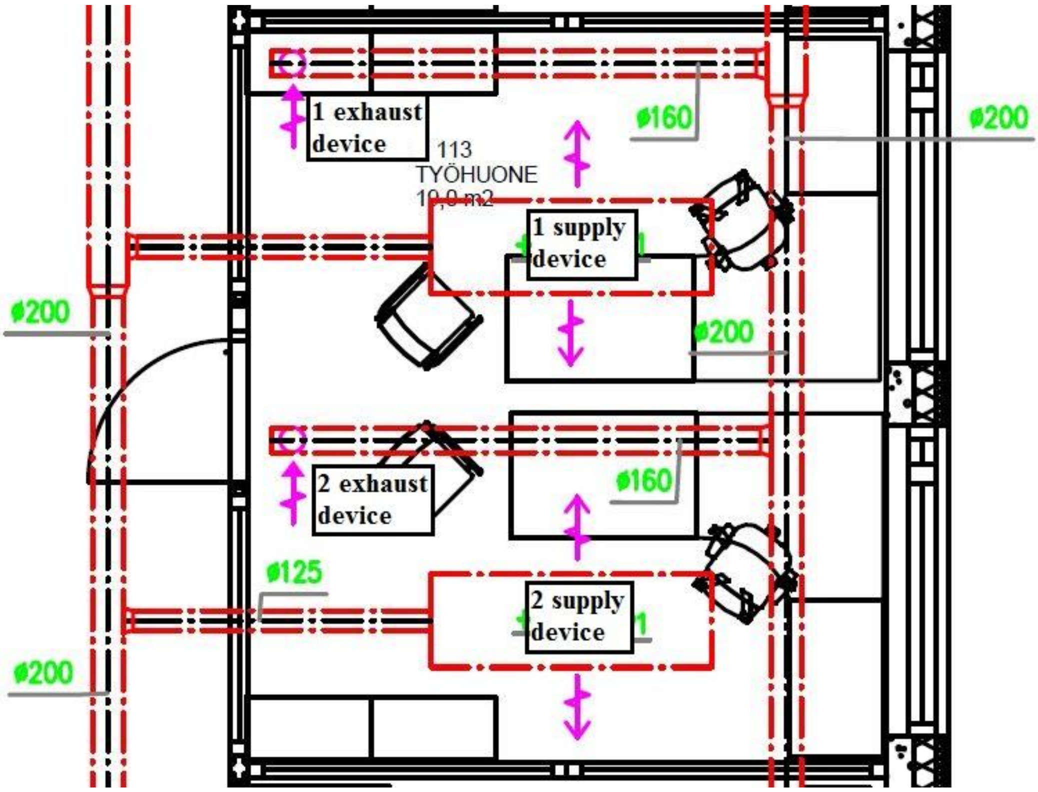


Figure 7. Plan of the office room where measurements were done.

Three parameters of the indoor environment were measured for this work. They include the air temperature, carbon dioxide concentration and supply and exhaust air flow rates. In this chapter the results of these measurements will be presented. Also there will be a comparison between findings and the required values of given parameters.

For a start supply and exhaust air flow rates will be determined in the given office. As shown in Figure 7, there are two supply and two exhaust devices. For determining the air flow rates types of the devices and pressure drops should be known. For measurement of pressure drops the micromanometer with “hook”-sensor are used. Further the methodology of air flow rate calculation is presented for the supply device and for the exhaust device.

Type of the supply devices is Lindab Pilot. Length of the device is 1,8 m. Diagrams which are necessary for determining the air flow rates are given in Figure 8. The numbered lines correspond to the step indicators showing the position of each regulating screw of the device. In the given case the position of regulating screws is 5. On the basis of these data and the known pressure drop, the air flow rate can be found.

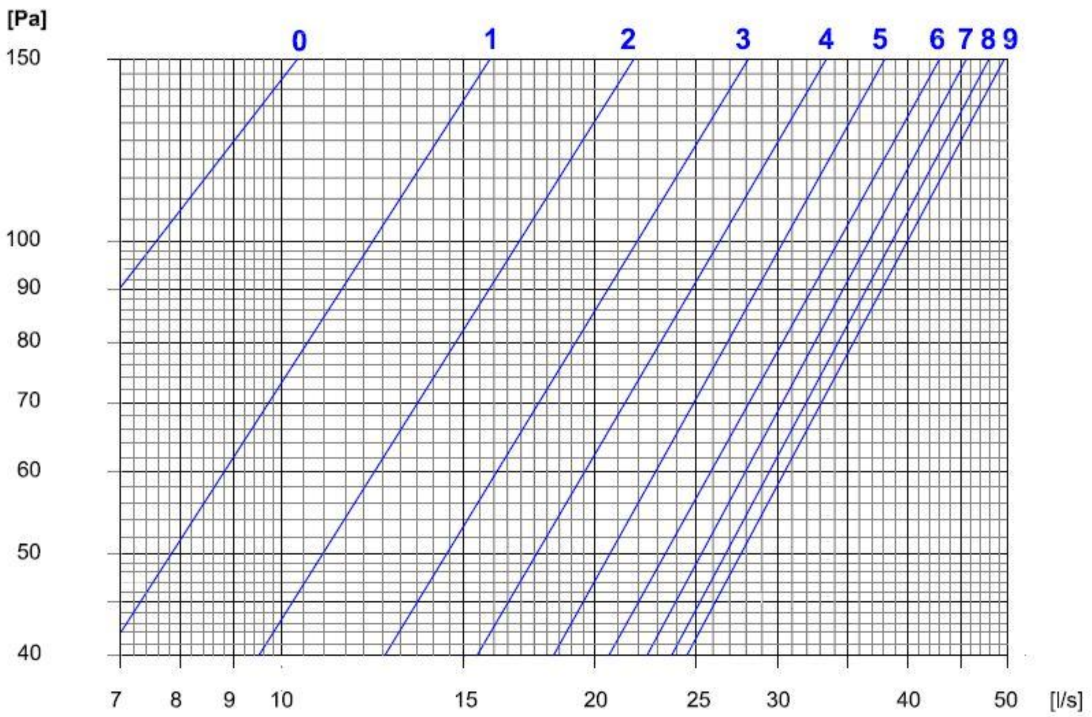


Figure 8. Air-flow pressure-difference relations for different installation-specific settings of the supply device Lindab Pilot 1,8 m. /9/

The given ventilation system works in adaptive mode. Thereby air flow rate depends on different parameters of the indoor environment such as carbon dioxide level and the room temperature. Therefore pressure drops should be measured in two different cases. First case is a normal operating regime when two working persons are in office room. And second case is when the office room is empty. After these measurements it is possible to estimate supply air flow rates in both cases. The results are presented in Table 25.

Table 25. Supply air flow rates in the given office room.

Operating regime	Number of the device	Pressure drop, Pa	Air flow rate, l/s	Summary air flow rate, l/s
2 persons are in the office	1	81	27	56,4
	2	94	29,4	
The office is empty	1	40	18,3	35,6
	2	36	17,3	

The area of the room is 19 m^2. There two persons. Thereby the results of measurements which should be compared with the standardized requirements is 28,2 l/s per person or 3 l/s per unit floor area. The results significantly exceed the required values of supply air flow rate from all considered standards.

In addition exhaust air flow rate should be determined for more exact estimation of the air quality. The air flow rate can be calculated using the following equation /10, p. 7/

$$q_v = k \cdot \sqrt{\Delta p_m} \tag{3}$$

where

q_v is the air flow rate, l/s

k is the coefficient dependent on type of the device

Δp_m is the pressure drop, Pa

Type of the exhaust devices is Fläktwoods KSO-160. For determining the air flow rate pressure drop and coefficient *k* should be found. Coefficient *k* depends on type of the device and parameter *a* which characterizes a degree of flow capacity of the exhaust device. Physical meaning of the parameter *a* and pressure drop is demonstrated in Figure 9. And value of the the parameter *a* can be found from Table 26.

Table 26. *a* – *k* relations for exhaust device KSO-160. /10, p. 45/

KSO-160 a	k
-10	2,0
-5	2,8
0	3,6
5	4,4
10	5,3
15	6,2

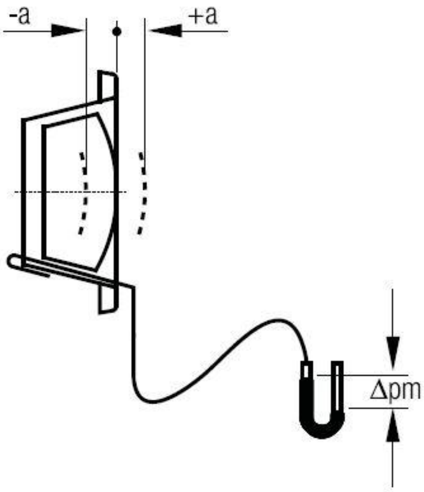


Figure 9. Pressure drop and parameter *a* for exhaust devices. /10, p. 45/

For the exhaust device №1 parameter *a* is -1. On the basis of this value coefficient *k* is 3,44 as followed from the interpolation of data in Table 26. For the exhaust device №2 parameter *a* is -1,5. By analogy coefficient *k* is 3,36. Using these coefficients and measured values of pressure drop exhaust air flow rates can be found from the equation (3). Following values are calculated:

- for the exhaust device №1 when two persons are in the room

$$q_{v1} = 3{,}44 \cdot \sqrt{104} = 35{,}1 \quad \text{(l/s)}$$

- for the exhaust device №2 when two persons are in the room

$$q_{v2} = 3{,}36 \cdot \sqrt{115} = 36{,}0 \quad \text{(l/s)}$$

- for the exhaust device №1 when the room is empty

$$q_{v1} = 3{,}44 \cdot \sqrt{63} = 27{,}3 \quad \text{(l/s)}$$

- for the exhaust device №2 when the room is empty

$$q_{v2} = 3{,}36 \cdot \sqrt{56} = 25{,}1 \quad \text{(l/s)}$$

Thereby the summary exhaust air flow rate is 71,1 l/s when two persons are in the office room and 52,4 l/s when the room is empty. This fact indicates that the total exhaust air flow rate is higher than the total supply air flow rate in the given office when both operating regimes of the ventilation system. But it should be noted that the differences between supply and exhaust air flow rates during the same operating regimes are approximately equal. This difference is 14,7 l/s in the case when two persons are in the premise. And when the room is empty, the difference is 16,8 l/s. In other words measurement results indicate that ventilation system reduces air flow rates of all devices proportionally when people leave the room.

Next parameter measured in the given office room is the air temperature. It is one of the most important factors influencing on the indoor comfort in buildings. The air temperature was measured by data loggers during one week. Three devices were used for measurements in this work. They were located in the office room at three different heights: 0,1 m, 1,1 m and 2,1 m. Data loggers measured the air temperature in this room uninterruptedly during seven days. Results of these measurements are presented in Figure 10.

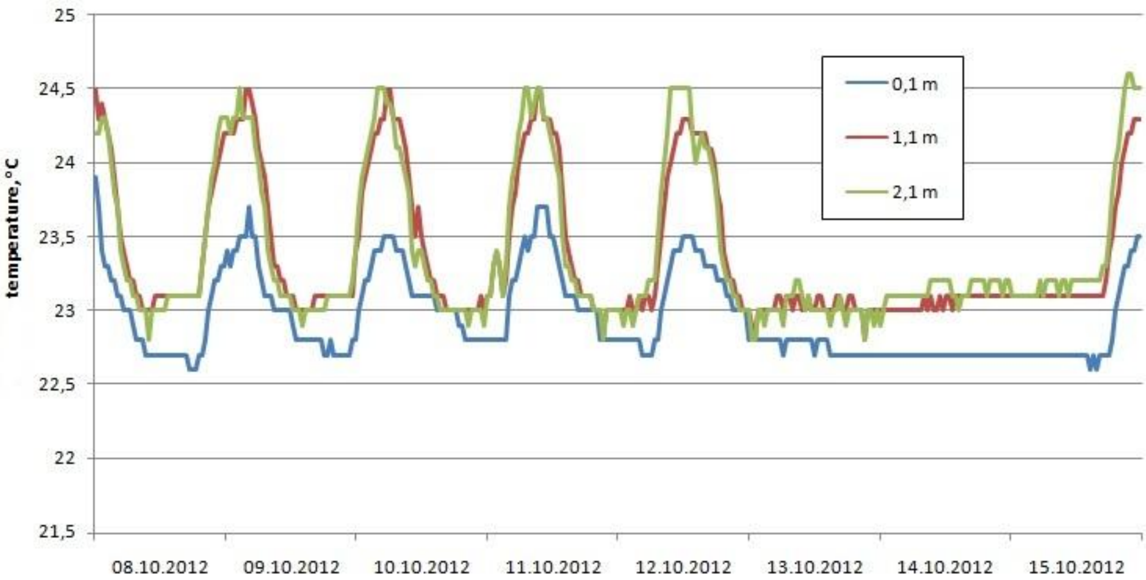


Figure 10. Measured air temperature on three height levels of the office.

The obtained result indicates that the air temperature depends on the occupancy in the room. As shown in the graphs, values of the air temperature during work time are much higher than during non-working time. At the same time temperature at the lowest height is significantly lower than at the other levels. Generally, it is possible to conclude that the obtained results correspond to the reality.

Values of the air temperature at height 1,1 m should be taken into account for a comparison with the valid standardized requirements because sedentary activity of people takes place at the same height level in the office. These values correspond to the red line in Figure 10. The maximum value of the air temperature at this height is 24,5^{o}C during a week. On the other hand the minimum value is 22,8^{o}C. These values should be compared with the required values of the operative temperature from Table 22 for summer season because this week was in the beginning of October. After a comparison it should be conclude that the thermal conditions in the given office room meet the requirements of all considered standards.

Finally, the measured level of carbon dioxide concentration will be estimated on basis of the standardized requirements. Values measured during one week are shown in Figure 11 graphically.

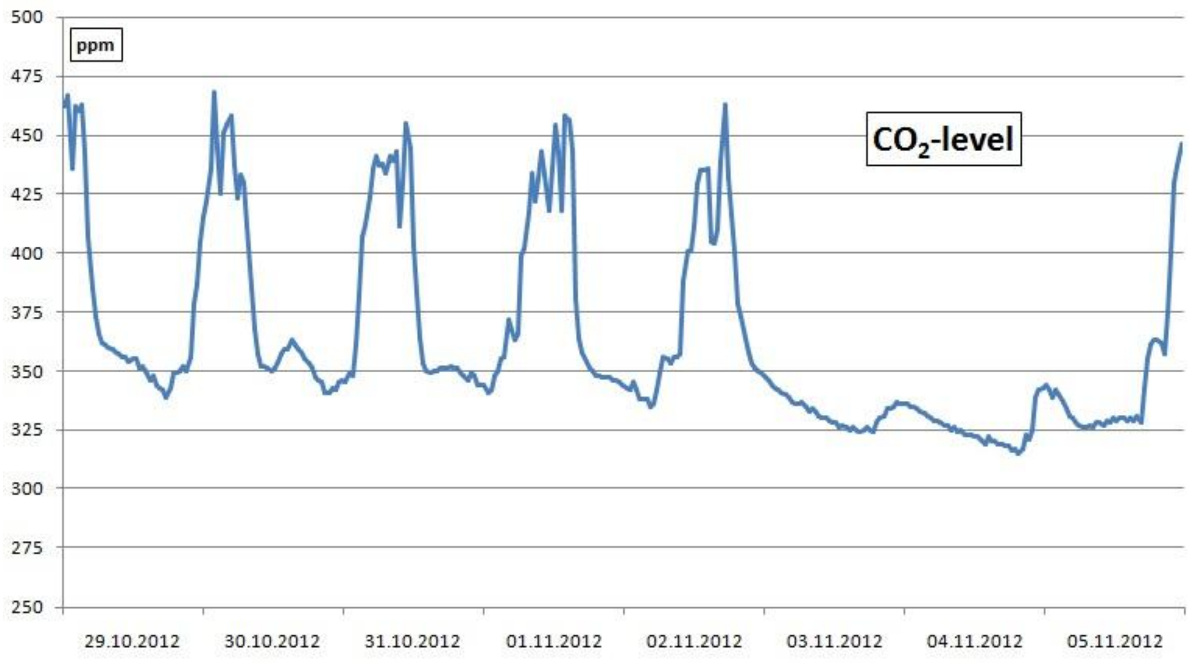


Figure 11. Measured CO_2 concentration in the office room.

There is the same dependence as in the case of the air temperature. Carbon dioxide concentration sharply increases at the beginning of working time and just as sharply reduces when people leave the office room. These concentration jumps do not take place during the weekend.

The maximum measured value of CO_2 concentration level is 468 ppm during considered week. This value should be compared with the permitted value of CO_2-level. Also the minimum measured value is 315 ppm, but it is not so important for a comparison with the requirements. However, the maximum measured value does not meet the requirements stated in International, European and Russian standards for the first category of buildings. But it meets the requirements of all standards for the second category of buildings. In additional it should be noted that the given office room can be attributed to the first category of buildings according to the Finnish standardized requirements.

9 CONCLUSION

As a conclusion it should be noted that the aims assigned in the given work were achieved. The most important standardized requirements for the indoor climate were described and analyzed in the theoretical part of the thesis. International, European, Russian and Finnish requirements were compared. The results of a comparison are presented in the respective chapter. Moreover this thesis includes the practical part where the compliance of some indoor climate parameters in the real office room with foregoing requirements was verified. The results of the measurements and their analysis are described in the chapter dealing with these measurements.

In whole it is possible to summarize that the requirements of all considered standards are similar in many respects. And in spite of insignificant differences they do not contradict one another. As for the indoor environment parameters measured in the real office room, they meet the requirements of the vast number of all considered standards. Therefore it is possible to believe that the work is completed successfully.

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