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Improvement of indoor climate in an educational building

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Abstract

Educational buildings are places where young and adult people stay for a long period of time. Harmful and unhealthy conditions can be a reason of health issues. Therefore, the productivity of students decreases and they are not able to adopt and remember all information. Nowadays, many old educational buildings have some problems with poor indoor air quality. The healthy and comfortable indoor conditions heavily depend on the design and operation of the ventilation system as well as its maintenance. The existing ventilation systems in most of the old buildings are natural exhaust ventilation and do not comply with actual standards.

The main aim of this Bachelor's thesis was to study existing problems with indoor air quality in a given educational building and to make recommendations to solve these issues. For that purpose, some measurements of environmental characteristics such as temperature, relative humidity and exhaust air volume flow were done in the two classrooms of university in Saint Petersburg (Russia) during the classes with many students. Some theoretical backgrounds about productivity and indoor air quality and its connection were investigated. Moreover, the Finnish and Russian recommendations and guidelines concerning in-door air quality were discussed and compared.

Furthermore, the measured data was analyzed taking construction and design of the given classrooms into account. The results of measurements were presented and compared with Finnish and Russian Standards to find out if the indoor air quality in the classroom satisfied these requirements. In addition to this, potential solutions to improve indoor environment were discussed and described.

The indoor air temperature in both classrooms in the given building exceeded limitations required by Russian and Finnish guidelines. In order to provide acceptable indoor air quality and thermal conditions, the exhaust air flow rate in both classrooms should be increased. The split-ductless air conditioning system is common equipment which is used for air recirculation to provide a room with heated or chilled air. It is the most suitable system for the given classrooms because it is simple, flexible and relatively cheap. However, a unit ventilator should be used to provide the best indoor conditions.

Subject headings, (keywords)

Indoor climate, educational building, indoor environmental quality, productivity, HVAC systems

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CONTENTS

1 INTRODUCTION

People spend most of their time inside the buildings which were constructed to protect occupants against any unfavourable outside conditions and to provide them with healthy, safe and comfortable conditions for their activities. Building construction and renovation are changing in order to create a high-quality indoor environment. They are becoming more improved to meet the people's needs.

Educational buildings are places where young and adult people stay for a long period of time. Studying is a very intensive and complicated process which requires a lot of mental work. It is hard to study in the classroom where there are poor indoor air quality and unacceptable thermal conditions. Moreover, harmful and unhealthy conditions can be a reason of health issues such as allergic and asthmatic reactions, sick building syndrome complaints, eye or nose and throat irritation. Students are more exposed to the health issues due to fatigue and their age so they are very sensitive to a poor quality of indoor environment. Therefore, the productivity of students decreases and they are not able to adopt and remember all information.

Nowadays, many old educational buildings have some problems with poor indoor air quality because it was not considered the first priority when the buildings were constructed. The healthy and comfortable indoor conditions heavily depend on the design and operation of the ventilation system as well as its maintenance. The existing ventilation systems in most of the old buildings are natural exhaust ventilation and do not comply with current standards. Thus, it is becoming an actual and serious problem which needs to be solved.

According to several studies the improvement of the indoor environment increases productivity. If the money invested in designing, operation and maintenance of the building will result in decreased health complaints and increased productivity then this investment is highly cost-effective. It is the most efficient method to assure comfort, productivity and healthy conditions to occupants.

The environmental parameters inside the building that can affect the productivity and health of occupants are indoor air quality, thermal conditions, lightning, vibration and

acoustic factors. In this thesis only the thermal conditions and indoor air quality are considered and investigated as the main factors which influence productivity.

2 AIMS

The main aim of this Bachelor's thesis is to study existing problems with indoor air quality in a given educational building and to make recommendations to solve these issues. For that purpose, some measurements of environmental characteristics such as temperature, relative humidity and exhaust air volume flow are going to be done in the two classrooms of university in Saint Petersburg during the classes with many students.

Firstly, some theoretical backgrounds about productivity and indoor air quality and its connection will be investigated. In order to achieve the main aim, the most important environmental parameters which affect the indoor air quality will be studied. These parameters have a significant influence on the health and productivity of occupants. Moreover, the Finnish and Russian recommendations and guidelines concerning indoor air quality will be discussed and compared.

Furthermore, the measured data will be analyzed taking construction and design of the given classrooms into account. The results of measurements will be presented and compared with Finnish and Russian Standards to find out if the indoor air quality in the classroom satisfies these requirements. Moreover, the connection between the indoor air quality and the occupancy will be figured out.

In addition to this, potential solutions to improve indoor environment will be discussed and described. To make recommendations, the most suitable technical solutions, equipment and designing solutions which can improve indoor air quality will be presented.

3 LITERATURE REVIEW

3.1 Productivity

Productivity is a complicated notion which is used in different fields of activity to express the efficiency of production. The common definition is an amount of output per unit of input used in the process. The unit of input can be a time unit. Thus, if it is possible to step up output for the same time period then the productivity of the process increases. For example, if a student solves more tasks, assimilates more information or reads quicker per time unit then his learning performance improves.

There are four principal factors which have an influence on productivity: environmental, social, personal and organizational /1, p.11/. They consist of different aspects such as indoor environmental comfort, organizational structure, work or studies commitment, relationship with others and even gender or age of a person. The effect of these factors and the importance of each of them depend on the person. For example, some people are more affected by noise or different sounds in the room and cannot focus on the given task. However, other people listen to music to increase their concentration.

High productivity is very important for employers as well as for workers (engineers, teachers) and students. Firstly, it is possible to earn more money if there are more products (output). The profit depends on the duration of the production process and the quality of output. It is much cheaper to improve the work environment rather than employ more people. Comfortable work environment reduces the cases of absenteeism because it will not have any harmful effect on the employee's health.

It is absolutely significant to improve the productivity because the productive person will achieve great success. It should be done by creating the comfort work environment. One of the most important aspects which affect productivity is the indoor environment quality. It strongly influences everybody in the building. Creating comfortable indoor environment is difficult to do, though. Every person has his own perception of indoor conditions and it might differ from other's. However, the majority of people should be provided with comfortable indoor environment.

3.2 Indoor environment factors

The indoor environmental quality (IEQ) is a combination of different parameters such as indoor air quality and climate, visual comfort, thermal comfort and acoustic comfort /2, p.4/. Buildings are built to protect people against unfavorable outside conditions. However, indoor environment inside the building may cause dissatisfaction, discomfort and even sickness. According to some studies a comfortable indoor environment improves productivity and performance of people who live, work or study in it.

There are some factors which have impact on the indoor environmental quality and they can be divided into the four groups: building, building services, outdoor conditions and human activities. It is shown in Figure 1 that HVAC system, building materials and outdoor air pollution affect the indoor environment. It is possible to achieve acceptable quality of the indoor environment if the building and its services are well-designed and there is a proper maintenance. Hence, it is important to take into consideration all the factors which are show in Figure 1 when there are some problems with indoor environment in the old or even new building which were found and are going to be fixed.
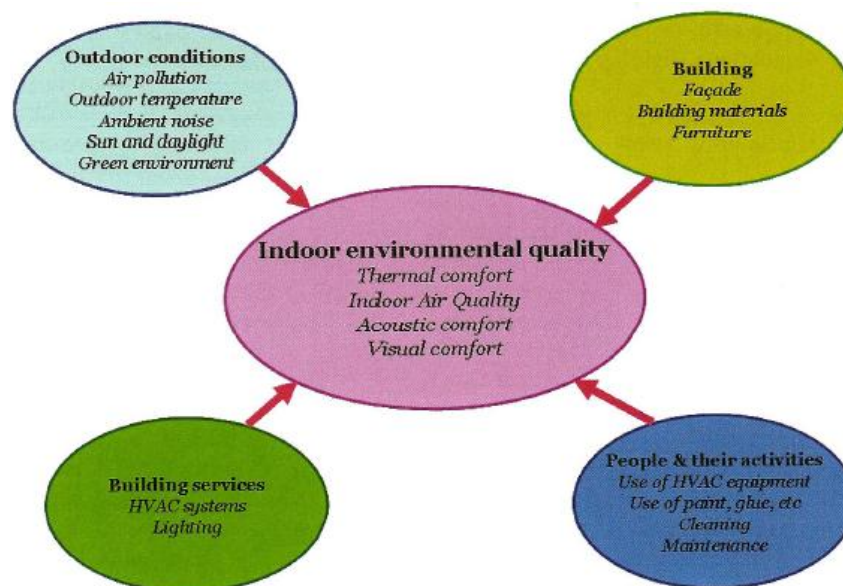
FIGURE 1. Factors which have impact on indoor environmental quality. /2/.

The microclimate of a room is a state of internal environment which has a direct effect on human body. The optimal indoor environment provides comfort and keeps thermal and functional condition of people on normal level during their occupation period. Long-term effect of adverse indoor conditions can be a reason of health impairment. For example, heat radiation and high humidity may have a harmful influence on cardiovascular system and respiratory system of human body. /2, p.5./ These effects can be short-term or long-term. Poor indoor environment can be a reason of complaints about health issues or uncomfortable conditions which may lead to a decreasing productivity or ability to learn and even increase a number of disability leave or direct and indirect medical costs. Therefore, it can cause the increased costs and charges.

Typical reasons of complaint about thermal discomfort are high or low indoor air temperatures, uneven thermal radiation, draughts and cold floors. They may cause a significant effect on human's health such as common cold, fatigue and headache. For example, if someone is exposed to high indoor air temperature for a long period of time then it leads to intensive sweating to discharge the overheating and fast fatigue.

Indoor air quality takes into consideration different types of indoor air pollutants with regard of relative humidity and indoor air temperature. Carbon monoxide, carbon dioxide, ozone, nitrogen oxides, formaldehyde, sulfur oxides, dust and volatile organic compounds (VOCs) are the most common indoor air pollutants. /3, p.248./ Moreover, sometimes the concentration of carbon dioxide (CO_2) which is a gas that people breathe out is used as parameter of indoor air quality to show the efficiency of the room ventilation. The duration of exposure, the number of particles per unit volume of air (concentration) and the way how pollutants get into the human's body (with the air or food) will influence on the harmful health effect. The poor indoor air quality might result in throat or eye irritation, headache, fatigue, complaints about dry air. Furthermore, it can cause some serious problems with health such as asthma attacks, carbon monoxide poisoning and catching an infection (cold or flu). /2, p.5./ Acceptable indoor air quality is defined as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction"/4/.

Acoustic discomfort is usually caused by noise from building services, from other room or outside. It distracts the mind of a person, decreases the concentration and the clearness of speech. Visual comfort is possible to achieve by good adequate lightning. As a result, it will be easier to read and work at the computer. Moreover, it will lead to reduction of eyestrain, headache or neck problems.

3.3 Relationship between productivity and indoor environment quality

Productivity in educational buildings such as schools or universities can be expressed as learning performance. As it was mentioned above, there are several factors which influence on that. However, the most important one for that type of buildings is the indoor environment quality because it affects not only on productivity but also student's health. For instance, children in schools do not have strong immunity and resistance to illnesses because they are still growing and physically developing.

There are many different studies and investigations which show that the indoor environment in educational buildings which are located in different countries is poor /5,p.53-64 ; 6, p.437-446/. There is a huge number of people who often attend schools and universities. It is absolutely important that the ventilation in these buildings is capable to remove the pollutants from students such as CO_2, dust or moisture and the excess heat loads to keep the indoor air quality on acceptable level. Therefore, the building, its services and systems must be designed correct to provide good indoor environment.

Different studies have shown that the students' learning performance is better in classrooms with a good indoor environment. It has been demonstrated that the indoor air temperature and thermal comfort, relative humidity, ventilation rate, indoor air quality (IAQ) and carbon dioxide (CO_2) concentration have significant effect on people's productivity.

Comfortable thermal conditions may be a ground for optimal mental work. Recently, various investigations about relationship between air temperature and productivity have been made. They were carried out for the productivity of office work in office buildings. However, the results can be assumed to be the same for educational build-

ings because it is the same connection between air temperature and productivity changes. The one significant analysis which was based on the studies of third parties was made by Seppänen and others in 2006. /7/ The result of this meta-analysis is shown in Figure 2. It demonstrates that the average productivity (so called relative productivity in this case) decreases by approximately 2% per degree Celsius if the temperature exceeds 25 °C. Moreover, the highest productivity can be achieved at the temperature of around 22°C
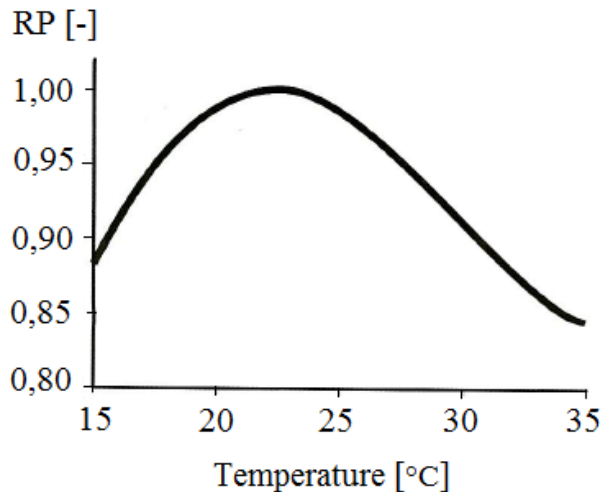
FIGURE 2. Effect of indoor air temperature on relative productivity (RP) in office work. /2/.

Ventilation systems are designed to create comfortable thermal conditions and good indoor air quality in buildings. Changes of ventilation air flow rate could improve the productivity of mental work. There are several studies about connection between ventilation rates and learning performance which were made by Bako-Biro et al. in 2007 /8/, Wargocki et al. in 2005 /9/, Shaughnessy et al. in 2006 /10/ and Gids in 2007 /11/. They are summarized in Figure 3. The results show that the learning performance significantly reduces if the ventilation air flow rate is below 4 dm^3/s per person. However, high air flow rate particularly in a cold climate can be a reason of a discomfort and can decrease the learning performance due to unnecessary heat losses and, as a result, getting cold faster.
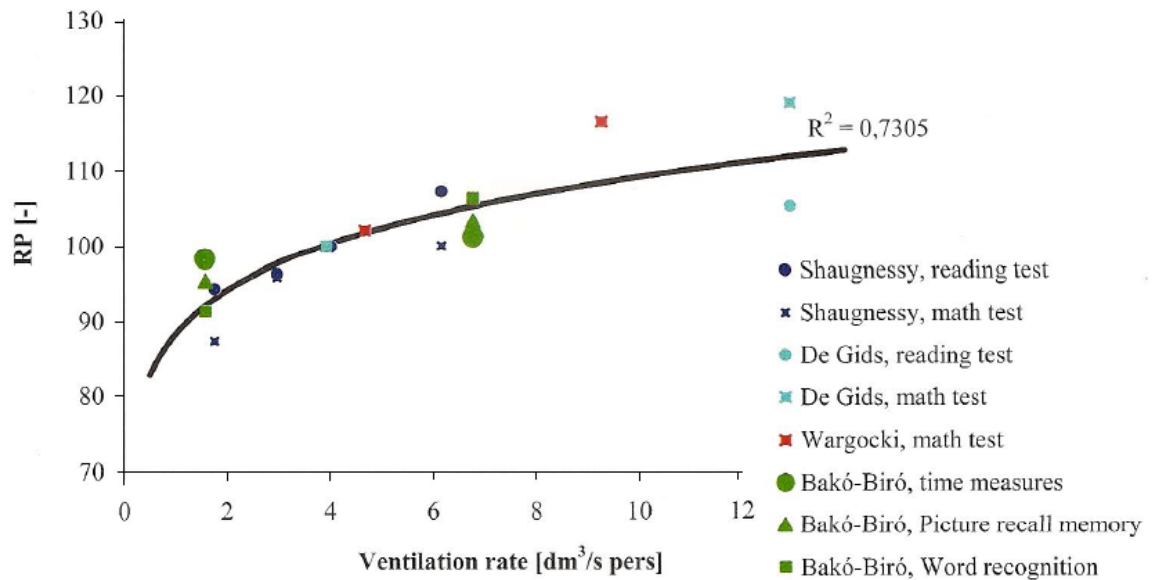
FIGURE 3. Association between ventilation rates and learning relative performance (RP). /2/.

The indoor air temperature and relative humidity, indoor air quality and air distribution pattern strongly depend on ventilation air flow rate. The type of ventilation system and its air distribution devices designate the air flow rate. The correct designed ventilation system will ensure efficient operation, optimal indoor climate and will dilute and remove harmful air contaminants.

Another research based on 15 cross-sectional and 5 experimental investigations among 350 buildings and more than 30000 participants revealed that sick building syndrome symptoms are more often registered at ventilation rates that are lower than 10 dm^3/s per person. Furthermore, they can be reduced by 35% for each 5 dm^3/s per person increase in ventilation air flow rate /12/.

There is a high risk of catching a respiratory infection if there are a lot of people near each other. Hence, classrooms without proper ventilation system are dangerous for health because there is a poor indoor air quality. Students can spread a disease through the air by sneezing or coughing. Sickness strongly affects human's health and his productivity. Firstly, the sick student will be absent some lessons or lectures. Therefore, he might not understand missed study material. Secondly, if the person feels ill during the classes his concentration and ability to perceive will decrease. Hence, the student's learning performance will decrease as well. The studies of groups including

Li et al. in 2007 /13/ which were based on literature review revealed the importance of ventilation to remove airborne infection. It showed that adequate fresh air flow rate supplied to the classrooms will decrease the risk of catching infectious diseases.

The high carbon dioxide (CO_2) concentration may also be a reason of reduced learning performance. The primary source of this contaminant is a human's breath. Usually a person inhales about 18 liters of oxygen and discharges about 14,4 liters of CO_2 per one hour /14/. The quality of air is considered to be good if the CO_2 concentration is 400-600 ppm (parts per million). The concentration of carbon dioxide above this level can be a reason of complaints about discomfort and even some health problems. For instance, if the concentration of CO_2 is 800 ppm or more then it will cause a headache, reduced mental concentration, fatigue. Shendell et al. /15/ conducted a research in 2004 which recorded the student attendance and carbon dioxide level in over 400 American schools. It demonstrated that the number of absent students is 10-20% bigger in school where the carbon dioxide concentration was approximately 1000 ppm higher than in the fresh outdoor air.

The productivity of students is also affected by indoor air humidity. Air consists of different gases and water vapour. The air humidity can be defined by three parameters. The first one is a dew point which indicates the maximum possible amount of water vapour that can be in air at specific temperature. The second parameter is absolute humidity. It shows the mass of water vapour in a given air volume. The third parameter is a relative humidity. Relative humidity is a ratio, expressed as a percent, between current partial pressure of water vapour and saturated water vapour pressure at a certain temperature. Actually, it is mainly used to describe the air humidity condition and the guidelines provide the certain values of relative humidity. The outdoor air humidity and the number of persons in a room strongly affect the indoor air humidity. Human's body uses evaporative cooling as a main way to remove excess heat. Intensity of this mechanism depends on the air temperature and air humidity. High air humidity will slow down the evaporation from skin and lungs. It might irritate a person and decrease his productivity. If the relative humidity is very low (below 30% RH) then the person may feel dryness of skin or itchy eyes. The comfortable conditions may occur when the relative humidity is 30-70 %, however, the optimal value is 50-60% /16/.

People mostly complain about discomfort caused by air temperature and ventilation air flow rate while lightning and noise have less harmful effect on human's well-being. The reason is that the air temperature and ventilation rate strongly depend on the building and its building services. There is almost nothing that people can do to change these parameters. However, the lightning and noise can be easily controlled and fixed by users. Therefore, the air temperature and ventilation air flow rate must be regulated in guidelines and checked in every building. Appropriate actions should be taken to solve the problem if needed.

3.4 Requirements for indoor climate

In this chapter the guidelines and requirements for the different parameters of indoor climate are overviewed. The optimal values for indoor air temperature, relative humidity, CO_2 concentration and ventilation air flow rate which are used by construction designers in Russia and Finland will be defined. The comparison of these values will be made and the difference will be shown.

3.4.1 Russian requirements for indoor climate

There are several state standards of microclimate parameters of indoor enclosures for different types of buildings in Russia. Requirements for residential and public buildings which includes educational buildings are presented in the GOST 30494-96 "Residential and public buildings. Microclimate parameters for indoor enclosures.". According to this standard the values of indoor climate parameters depend on the functional type of building and differ for warm and cold seasons of the year. The educational buildings which are used for learning purposes (universities, schools and daycare centers) are classified as a 2nd category of buildings. /17/

Indoor air conditions are divided into 3 classes: optimal, admissible, harmful. This classification considers health condition, comfort and productivity. /18/ Each class has certain values of indoor air parameters and different effect on health or performance.

The optimal and admissible air conditions do not harmfully affect human's health during the occupational period. However, only the optimal air condition provides good

indoor climate and the highest productivity. Some people might feel discomfort or short-term dissatisfaction if there are admissible air conditions but in general the parameters of indoor climate are on the acceptable to majority of occupants level.

The harmful condition is defined by specific values which may cause harmful effect on human's health during the occupational period. There is a chance that people might get serious sickness and health issues. Moreover, this condition causes productivity to reduce because poor indoor climate is a reason of discomfort.

In accordance with Russian law, it is restricted to work or study under the harmful condition. The main aim is to protect people from conditions which can harm someone's health and to provide acceptable environment for different activities. Hence, any harmful conditions should be revealed and fixed as soon as possible. /18/

The optimal indoor conditions are the most preferable. Especially public and educational buildings should be designed in a way that they can provide occupants with indoor air parameters that positively impact on comfort, health and productivity. The Russian standard GOST 30494-96 defines the parameters for this class of indoor air conditions. The optimal values for indoor air temperature, relative humidity of indoor air, air velocity and air flow rate are shown in Table 1.

TABLE 1. Indoor climate parameters of optimal indoor condition for the 2nd category of buildings. /17, 19/.

Season	Indoor air temperature, °C	Relative humidity of indoor air, %RH	Air velocity m/s	Ventilation air flow rate, m^3/h/person
warm	23-25	30-60	$\leq 0,3$	40 (11 l/s/person)
cold	19-21	30-45	$\leq 0,2$	40 (11 l/s/person)

The warm season of the year corresponds to the time period when the average outdoor air temperature during one day is +8 °C or more. If the average outdoor air temperature during one day is +8 °C or less then it is a cold season. The outside temperature influences on the indoor climate, therefore there is a difference in the parameters for warm and cold period of the year.

According to "Set of rules. Heating, ventilation and conditioning" SP 60.13330.2010 /19/ the minimum value of volume of supplied outdoor air in public buildings is 40 m^3/h (11 dm^3/s) per one person. This ventilation air flow rate should provide satisfactory indoor air quality and thermal comfort in the occupied zone. The minimum value of air flow rate is also shown in Table 1.

The parameters of indoor climate for admissible conditions are obtained from the standard GOST 30494-96 /17/. They are presented in Table 2. There are not any requirements of ventilation air flow rate for the admissible conditions, though. Therefore, it can be assumed that the minimum value for this parameter is the same as for the optimal indoor conditions.

TABLE 2. Indoor climate parameters of admissible indoor condition for the 2nd category of buildings. /17, 19/.

Season	Indoor air temperature, °C	Relative humidity of indoor air, %RH	Air velocity, m/s	Ventilation air flow rate, m^3/h/person
warm	18-28	30-65	$\leq 0,5$	40 (11 l/s/person)
cold	18-23	30-60	$\leq 0,3$	40 (11 l/s/person)

The admissible values of indoor climate parameters are commonly used if there is no possibility to achieve the optimal condition due to difficulties in technological and construction process or it is economically unfavorable. However, in order to provide good indoor climate the optimal values should be used. Moreover, the optimal indoor conditions will ensure good learning performance for students, as it was discussed above.

The Russian standards do not define the requirements for CO_2 concentration in public and residential buildings. For practical purposes, according to GOST 30494-96 four classes of air quality in a room are used: high air quality (IDA 1), medium air quality (IDA 2), acceptable air quality (IDA 3), poor air quality (IDA 4). Typical values of CO_2 concentration produced by occupants above outdoor air concentration are shown

in Table 3. These values correspond to different investigations and research results and can be used for ventilation air flow rate calculations /17, p.20/.

TABLE 3. Carbon dioxide concentration in public and residential buildings. /17/.

Class of air quality	CO_2 concentration in a room in addition to outdoor air CO_2 concentration, ppm	
	Typical range	Typical value
IDA 1	≤ 400	350
IDA 2	400-600	500
IDA 3	600-1000	800
IDA 4	> 1000	1200

3.4.2 Finnish requirements for indoor climate

Two main documents are used as regulations and guidelines of indoor climate in Finland: National Building Code (NBC) of Finland D2 "Indoor climate and ventilation in buildings" /20/ and LVI 05-10440 Classification of indoor environment 2008 /21/. The Classification supplements the National Building Code and does not overrule it.

The NBC is the official document which defines the requirements for indoor climate parameters and ventilation that have to be complied. It gives different values that provide comfortable and healthy conditions inside the building. These guidelines must be applied to buildings which are designed for the all year long usage or during the winter season.

The Classification of indoor climate provides design and target values for the better indoor climate. It can be used by the owners of building, contractors, designers and manufacturers of construction materials or equipment for new buildings and also for renovation. These requirements take into consideration past engineering experience and the latest research results and they are stricter than official NBC. However, the Classification is advisory in nature.

According to National Building Code D2 /20/ the designed air temperature in the occupied zone during heating season should be 21°C. For the summer season the designed air temperature in the occupied zone should be 23°C. Moreover, the temperature in the occupied zone shall not exceed 25°C during the occupancy period.

The D2 establishes regulations for relative humidity as well. It says that the humidity of indoor air should be kept on specified level for the designed use of the building. Condensation of water vapor on structures or in the ventilation system is forbidden to prevent moisture damage and harmful health effects.

Concentration of different impurities in indoor air such as gases, microbes and particles should be on the level which will not have any harmful effects to human's health and it will not decrease his comfort. According to D2, the maximum admissible concentration of carbon dioxide in indoor air is 1200 ppm during the occupancy period.

The ventilation air flow rate is defined in National Building Code per one person and per one area unit (m^2). The outdoor air flow in classrooms shall be 6 dm^3/s per person or 3 dm^3/s per 1 m^2. The air velocity should be less than 0.20 m/s during the heating season and 0.30 m/s during the summer. Moreover, it is recommended to design ventilation system to be controllable according to the current demand.
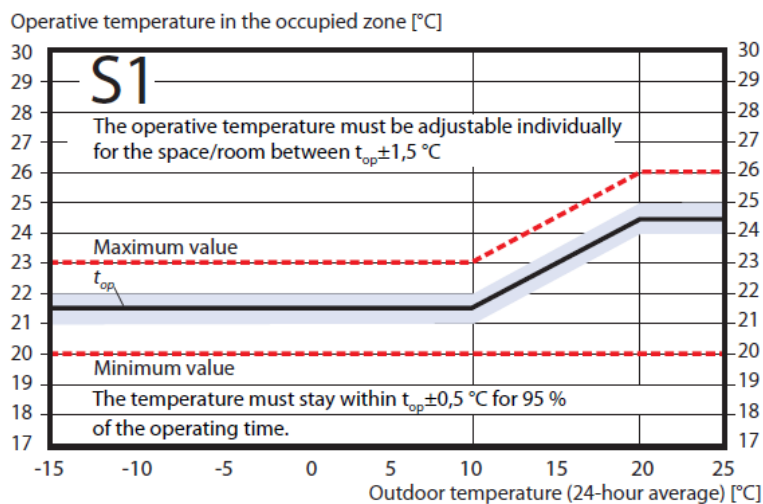
Classification of indoor climate subdivides indoor climate into three categories: S1 (individual indoor environment), S2 (good indoor environment) and S3 (satisfactory indoor environment). It gives a verbal description for each category and defines certain values for parameters of indoor climate such as thermal conditions and acoustic conditions, air quality, illumination. The main features of these categories are demonstrated in Table 4.

TABLE 4. Features of the indoor climate categories. /21/.

Parameters	Category		
	S1	S2	S3
Indoor air quality	very good	good	minimum require- ments which are prescribed by the building codes
Odours	no detectable odours	no disturbing smells	
Sources of impurities	no sources	no sources	
Thermal environment	comfortable	good	
Draught	not possible	not possible	
Overheating	not possible	possible during summer	
Acoustic conditions	very good	good	
Illumination	good	good	

Each category has its own regulations of operative temperature. It indicates the combined effect of radiation and convection. Operative temperature approximately equals to the average value of the air temperature and the radiation temperature. Sensation of warmth is affected by indoor air temperature and surface temperatures. It should be taken into account when the building is being designed.

It is necessary to admit that the optimal operative temperature (t_{op}) strongly depends on outdoor air temperature (t_u). Hence, it varies for different season of the year. For example, the target values for operative temperature for S1 category are shown in Figure 4. The guidelines for different parameters from Classification of indoor climate for classrooms are presented in Table 5.

FIGURE 4. Target values for operative temperature for S1 category. /21/.

TABLE 5. Guidelines for different parameters from Classification of indoor climate for classrooms. /21/.

Parameters		Category		
		S1	S2	S3
Operative temperature t_{op}, °C	$t_u \leq 10$ °C	21,5	21,5	21
	$10 < t_u \leq 20$ °C	$21,5+0,3*(t_u-10)$	$21,5+0,3*(t_u-10)$	$21+0,4*(t_u-10)$
	$t_u > 20$ °C	24,5	24,5	25
Minimum value of t_{op}, °C		20	20	18
Maximum value of t_{op},°C		$t_{op}+1,5$	$t_u \leq 10$ °C: $t_{op}+1,5$	$t_u \leq 15$ °C: 25
			$10 < t_u \leq 20$ °C: $23 + 0,4 * (t_u-10)$	$t_u >15$ °C: $t_{umax} + 5$
			$t_u > 20$ °C: 27	
CO_2 concentration, ppm		<750	<900	<1200
Ventilation air flow, dm^3/s	per person	11	8	6
	per m^2	5,5	4	3
Relative humidity, %		> 25 (in winter)	-	-

Classification of indoor climate has stricter regulations for carbon dioxide concentration than National Building Code D2. The relative humidity is defined only for the winter season in the S1 category. In comparison with D2, the Classification requires to calculate the necessary ventilation air flow according to standard EN 15251:2007 (method B.1) /22/ by the following formulas:

for S1 category   outdoor air flow = 10 (dm^3/s)/person + 0,5 (dm^3/s)/floor-m^2

for S2 category   outdoor air flow = 7 (dm^3/s)/person + 0,5 (dm^3/s)/floor-m^2

3.4.3 Comparison of requirements for indoor climate

The same indoor climate parameters have different required values in Russian and Finnish guidelines which were investigated above. Mostly the difference is not so considerable. The documents in Russia and Finland have separated requirements for cold and warm seasons. Therefore, they can be easily compared. The analysis of the Rus-

sian standard GOST 30494-96 /17/ and Set of rules SP 60.13330.2010 /19/, Finnish National Building Code D2 /20/ and Classification of indoor climate 2008 /21/ is shown as a summary in Table 6.

TABLE 6. Comparison of Russian and Finnish guidelines for indoor climate. /17, 19, 20, 21/.

Indoor climate parameters	Russia	Finland	
	GOST 30494-96 SP 60.13330.2010	National Building Code D2	Classification of indoor climate 2008
Requirements for cold season			
Temperature, °C	19-21 (admissible 18-23)	21	S1: 21,5 S2: 21,5 S3: 21,0
Relative humidity, %	30-45 (admissible 30-60)	-	S1: > 25 (winter) S2: - S3: -
Air flow rate, dm^3/s	11 per person	6 per person or 3 per m^2 in class-room	S1: 10 per person and 0,5 per m^2 or 11 per person S2: 7 per person and 0,5 per m^2 or 8 per m^2 S3: 6 per person or 3 per m^2
CO_2 concentration, ppm	- (< 1400)	< 1200	S1: < 750 S2: < 900 S3: < 1200
Requirements for warm season			
Temperature, °C	23-25 (admissible 18-28)	23	S1: 21,5-24,5 S2: 21,5-24,5 S3: 21,0-25,0
Relative humidity, %	30-60 (admissible 30-65)	-	S1: - S2: - S3: -
Air flow rate, dm^3/s	11 per person	6 per person or 3 per m^2 in class-room	S1: 11 per person and 0,5 per m^2 or 5,5 per m^2 S2: 8 per person and 0,5 per m^2 or 4 per m^2 S3: 6 per person or 3 per m^2
CO_2 concentration, ppm	- (< 1400)	< 1200	S1: < 750 S2: < 900 S3: < 1200

Table 6 demonstrates that guidelines for the indoor air temperature on both countries are almost the same: approximately 21°C during the cold season and approximately 23°C during the warm season. However, Classification of indoor climate has specific

requirements which take into consideration the outdoor air temperature. They are shown in Table 5. Hence, these requirements define changeable values of indoor air temperature according to different outdoor temperature.

According to the Russian and Finnish standards, the relative humidity should not be too high. Classification of indoor climate has no requirements for relative humidity during the warm period of time, though. Moreover, in compliance with Finnish guidelines, the ventilation air flow rate can be calculated based on the number of persons or based on the floor area. Russians guidelines define constant air flow rate (11 dm^3/s).

According to the Russian standard GOST 30494-96 /17/ there are no strict limitations of carbon dioxide concentration. However, if it is assumed that the poor indoor quality (class IDA 4) is strongly inadmissible and the outdoor CO_2 concentration is supposed to be 400 ppm, then it is possible to conclude that the maximum possible CO_2 concentration in indoor air is 1400 ppm according to Table 3.

3.5 Potential solutions to improve indoor environment

3.5.1 General consideration and design criteria

Educational buildings such as universities are generally used from September to July. Thus, they are designed and provided only with ventilation and heating but without cooling during the summer. In order to provide students with acceptable indoor environment for their studies indoor air quality, comfortable thermal conditions and low sound level are required. Therefore, it is necessary to have suitable HVAC systems for every particular case considering outdoor climate.

University buildings not always but usually have some typical areas such as classrooms, libraries, administrative rooms, computer rooms, auditoriums, laboratories. For each area there are different requirements for indoor environment and design criteria.

It is important to take into consideration indoor and outdoor design conditions when the HVAC systems are designed. Thermal loads of spaces are affected by outdoor conditions such as outdoor air temperature, relative humidity, solar radiation and wind

which depend on the climate zone and the orientation of the building. Indoor air quality, noise levels and thermal comfort are related to indoor conditions. Indoor air contaminants produced by occupants or building materials should be removed by sufficient supply outdoor airflow rates provided by ventilation systems.

For classrooms, ventilation and heating systems should be installed for any climate. Air conditioning should be considered in hot and humid climates. In order to avoid some issues related to low or high relative humidity and provide students with comfortable thermal conditions the humidity control should be considered. Recommended design guidelines for the humidity in occupied spaces are shown in Table 6.

The old educational buildings usually have a natural exhaust ventilation system. It is based on the effect of wind and difference of the air density which is caused by temperature difference. Therefore, the outdoor temperature and weather conditions influence the air flow rate. Moreover, the available pressure difference is small. That kind of system was used in the construction design of public and residential buildings long time ago. On the one hand the natural exhaust ventilation is a silent and simple system which does not require maintenance. However, airflows in these systems are very weather-depended and there is a possibility that the air may flow in wrong direction. The natural exhaust ventilation is relatively ineffective and there is no heat recovery nor airflow control. Moreover, the windows are used quite often to supply some fresh air into the room. They are opened for a short period of time but it causes a lot of discomfort for occupants especially during the winter. Therefore, nowadays that system does not meet the people's needs and cannot provide rooms with acceptable indoor air conditions.

In spite of the disadvantages natural ventilation through windows opening could be used in addition to mechanical ventilation. It could be an energy-efficient solution to provide required thermal comfort. It is necessary to choose a correct place for the openings of natural ventilation and suitable sizing to provide the required airflow rates.

Thermal load calculations heavily affect the dimensioning of the HVAC equipment. Designing values for outdoor air temperature, indoor air temperature and relative hu-

midity, outdoor airflow rates, occupant density and acceptable noise levels are significantly important for HVAC systems design and heat load calculation. Moreover, the thermal load from lightings which is 20-25 W/m^2 for classrooms, thermal load produced by each person which is up to 100 W and total vapour production which is up to 50 g/h per student should be taken into account /2, p.67/. In addition to this, HVAC systems must be flexible because the thermal loads depend on the university schedule and total occupancy for each room. Furthermore, the overall supply airflow rate must be able to manage the total heat loads; the general values for the HVAC systems design for temperature conditions are 5-6 volumes per hour for classrooms and 6-8 volumes per hour for auditoriums /2, p.67/.

### 3.5.2 HVAC systems and equipment in education buildings

It is important to consider new and old existing buildings separately. The price for expensive equipment which is going to be installed in old building can turn out uneconomical investment. Moreover, sometimes it is not possible to install some complicated HVAC systems in existing building due to its design and construction. However, in new buildings that problem could be taken into account and solved.

Generally, only heating and ventilation systems are installed in schools which are located in cold outdoor climate. Air conditioning systems or whole-year dehumidification equipment must be installed in hot and humid outdoor conditions. HVAC equipment for evaporative cooling could be used in hot and dry climates.

HVAC systems can be described by two classification modalities: centralized, decentralized systems, or a combination of both and all-air, water, air-and-water systems and direct-expansion systems /2, p.68/.

For large educational buildings and group of buildings the centralized systems are preferable. The primary central heating and cooling system provides hot or chilled water which is transferred to the secondary system to supply designed coils of fan-coil systems or air handling units (AHU) with heating or cooling power.

Air-and-water systems such as fan-coils and outdoor air or dedicated outdoor air system (DOAS) which is shown on Figure 5 are not recommended to be used in classrooms because students can spoil that equipment. Therefore, it accumulates a bacteria and dust, so it must be maintained very often. However, that type of systems can be used in educational building if it is mounted in a special socket in outside walls. Moreover, it is possible to use cheaper equipment such as a unit ventilator which has an outdoor air inlet but it has a minor air quality improvement and the same disadvantages as fan-coils. The prevalent and low-cost air-and-water system which is used for heating especially in cold climate consists of radiators and outdoor air gap. However, that kind of air-and-water systems cannot provide a classroom with cooling power. In temperate climate the systems with radiant panels can be installed in classrooms. They are more expensive and complicated then the radiators but they can be supplied both with hot or cold water for heating and cooling.
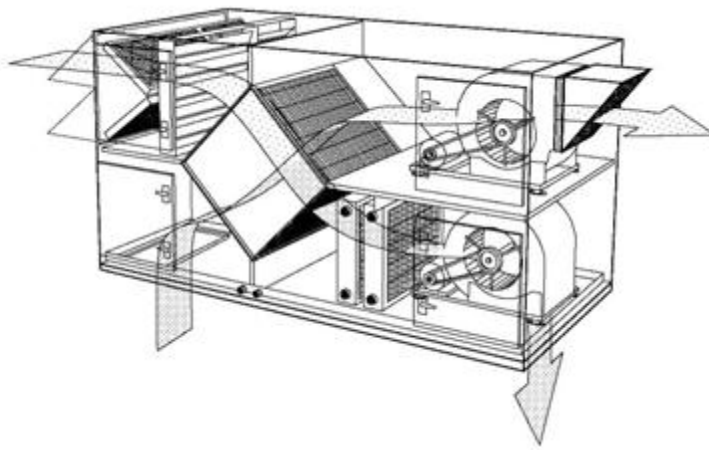
**FIGURE 5. Dedicated outdoor air system (DOAS). /23/.**

All-air systems are used for both single and multiple zones. In first case, each system operates for each thermal zone but in the other case several individually controlled thermal zones are served by one system. Therefore, spaces with the same operating schedule and occupancy should be grouped in different thermal zones. All-air systems with variable air volume (VAV) and all-air systems with zone reheat coils are typical solutions for multiple zone systems. The VAV systems can achieve economic operation and energy efficiency. The demand controlled air flow provides occupants with comfortable indoor conditions at low energy consumption.

Decentralized systems are special systems which are not connected to a central plant. They do not utilize hot or chilled water from central heating and cooling system. Direct-expansion coils are generally used as cooling coils. There are several commonly used decentralized systems: direct-expansion systems, rooftop single-zone zone packaged air conditioners, water source or ground source heat pumps, packaged air handling units.

Direct-expansion systems which are also known as split-ductless air conditioning systems are generally used only for recirculation of indoor air. They can operate for a single or several zones. Split system consists of two main units: inside heat exchanger (evaporator) and outside heat exchanger (condenser and compressor). That type of systems can supply chilled or heated air to the room. Moreover, they are small and flexible systems because the outside unit can be mounted further away from the inside unit. However, split systems are expensive and require frequent maintenance.

Rooftop single-zone packaged air conditioners or Packaged Single Zone (PSZ) are used to serve single thermal zone of a building. The scheme of that type of decentralized system is shown on Figure 6. This is a prefabricated unit and it consists of cooling and heating coils, air-cooled condensers, compressors, dampers, supply and exhaust fans, filters, controls. PSZ operates with both outdoor fresh air and exhaust air for recirculation. It is possible to change the unit's configuration and add some other modules such as enthalpy wheel for heat recovery.
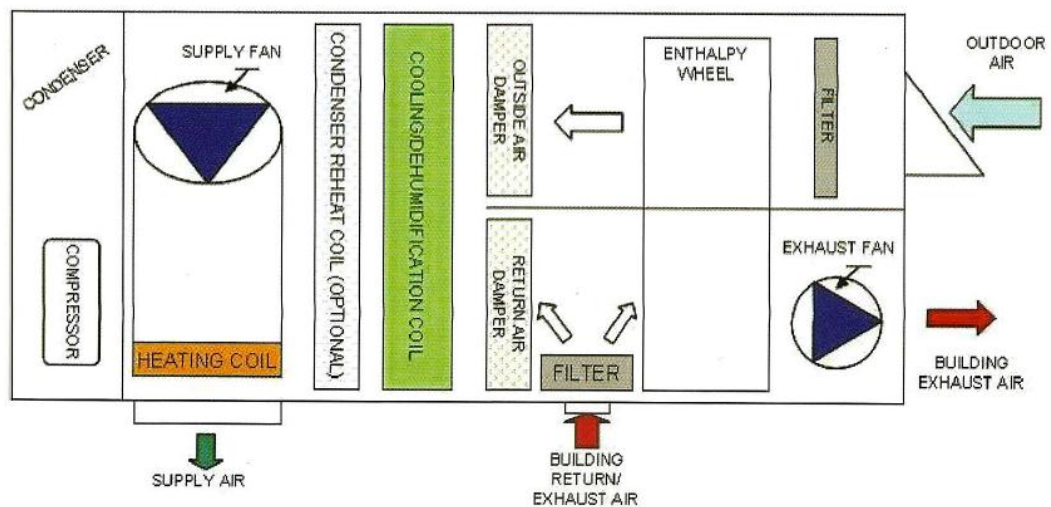
FIGURE 6. Scheme of rooftop single-zone packaged air conditioner with enthalpy wheel and condenser reheat coil. /2/.

Ground source heat pump (GSHP) consists of heat pump unit and water pipes placed into the ground or rock. It extracts heating power during the winter and cooling power during the summer from the ground because it has almost constant temperature all the time. That system discharges thermal energy from the room to the ground in summer time and uses it for pre-heating of outdoor air in winter time. Hence, the system can be in balanced operation of a long time.

The most suitable HVAC systems for different areas of educational building are shown on Table 7. Cooling coils for centralized systems are served with chilled water but for decentralized systems direct-expansion (DX) coils are used. It is important to take into account that ventilation is obligatory for all areas to provide rooms with needed outdoor airflow rates in order to achieve acceptable indoor air quality.

TABLE 7. Suitable HVAC systems for typical areas of educational building. /2/.

| Area | Cooling / heating systems | | | | | | | | | | Only heating |
| | Centralized systems | | | | Decentralized systems | | | | | | |
	SZ	VAV	Reheat	Fan-coil	PSZ	SZ split, or multi-split	P-VAV	P-reheat	WSHP (WLHP)	GSHP	
Classrooms	X	XX	XX	X	X		XX	XX	X	X	X
Administrative areas	X	X	X	X	X	XX	X	X	X	X	
Libraries	X	XX	XX	X	X	X	XX	XX	X	X	
Laboratories	X	X	X	X	X	X	X	X	X	X	
Cafeteria	X				XX	XX					
Kitchen	X				X	X					
Toilets and locker rooms											XX
Gymnasium	XX	X	X		XX		X	X			
Auditorium	XX	X	X		XX		X	X			
Ventilation	AA	AA	AA	BB	AA	BB	AA	AA	BB	BB	BB

In Table 7 there are several markings and abbreviations: XX means the most suitable type ; SZ – all-air system for Single Zone; Reheat - multizone all-air system with re-heat coils; SZ split – split system for Single Zone; P-VAV - multizone Packaged all-air system with Variable Air Volume; P-reheat – multizone Packaged all-air system with zone reheat coils; WSHP – Water Source Heat Pump; AA – ventilation require-ments are already satisfied by the all-air system; BB – ventilation requirements must be satisfied by means of a dedicated primary air system or DOAS.

4 METHODS

4.1 Investigation of indoor climate in classrooms in the educational building

The educational building of university in Saint Petersburg was built in 1973. There are a lot of classrooms, teachers' facilities, computer classrooms, some laboratories and administrative rooms on 5 floors of the building. It is constructed of ceramic solid brick. The overall height of the structure is 24.8 m; heated area - 11180.8 m^2; heated volume - 43605.08 m^3 and the total area of the exterior walls is 14155.6 m^2. Heat supply source is the disctrict heating network. Heating system is a direct two-pipe vertical hot water system with the lower connection to the service pipe. The building has a natural exhaust ventilation system.

This building has not been renovated, hence heating and ventilation systems are original. Therefore, cooling system is not installed and the designing temperatures for heating system are not changed in order to improve the energy effiency.

4.1.1 Overview of the classrooms

The case study classrooms 1 (Figure 9) and 2 (Figure 10) are situated next to each other on the 4th floor of the educational building. They are used for lectures or calculation and design courses. The classroom 1 has 22 desks for 44 students and the classroom 2 has 35 desks for 70 students. The classrooms have only natural exhaust ventilation system, so the air changes through the leakages and openings of windows and doors. Figure 7 and Figure 8 show the classrooms where the measurements were done.

FIGURE 7. Overview of the classroom 1.
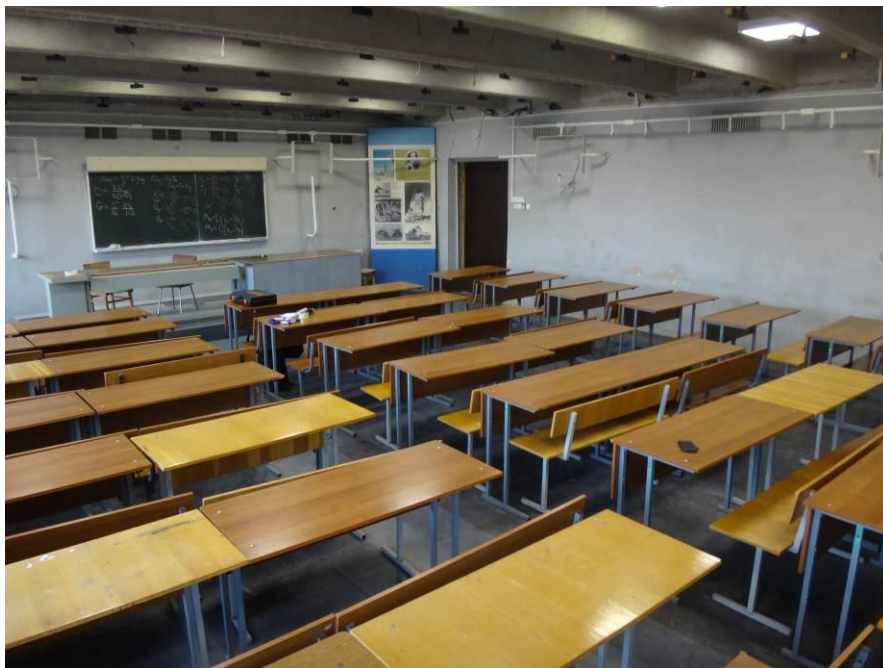
FIGURE 8. Overview of the classroom 2.

The area of the classroom 1 is 73,1 m^2. There are 3 windows; 3 column radiators and lamps produce heat load in the classroom. The exhaust air is extracted by 7 terminal devices (grills): the area of 3 grills is 0,1125 m^2 each, the area of 2 grills is 0,175 m^2 each, the area of 2 grills is 0,0575 m^2 each. The volume flows through these devices are different.
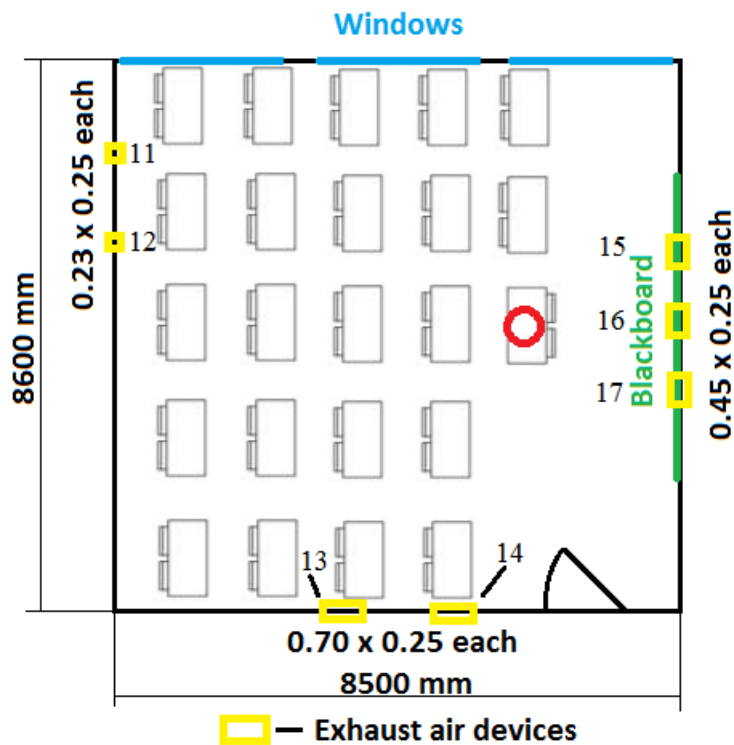
FIGURE 9. Scheme of the classroom 1.

The area of the classroom 2 is 98,9 m^2. There are 4 windows; 4 column radiators and lamps produce heat load in the classroom. The exhaust air is extracted by 8 terminal devices (grills): the area of 5 grills is 0,1125 m^2 each, the area of 3 grills is 0,093 m^2 each. The volume flows through these devices are different.
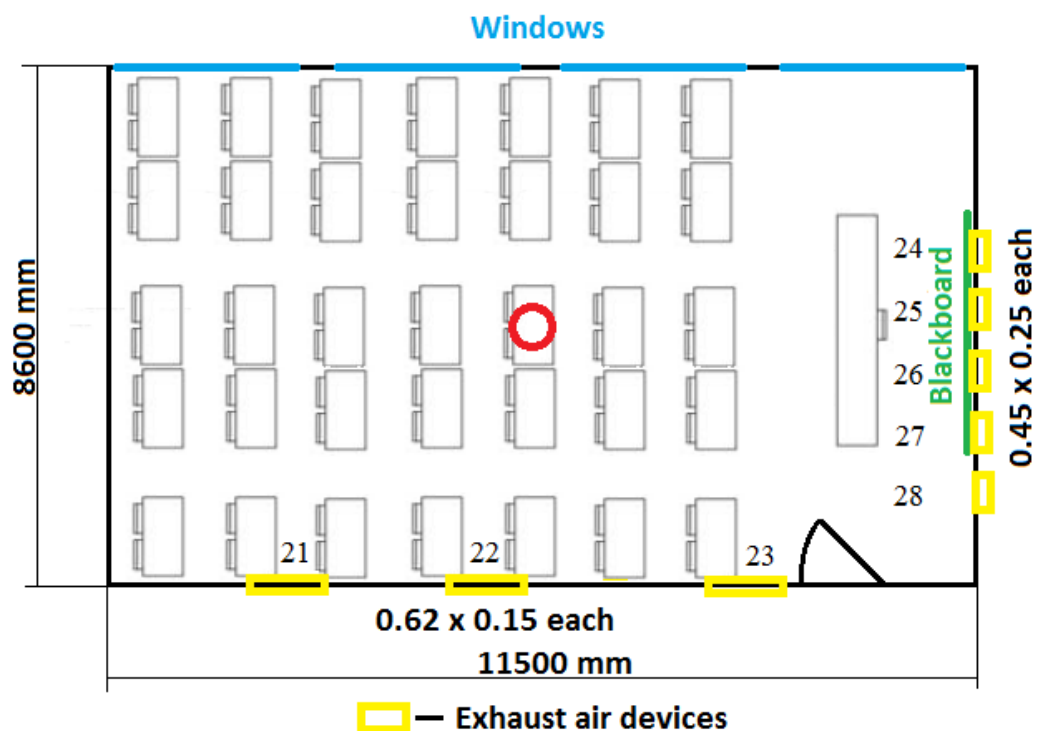

FIGURE 10. Scheme of the classroom 2.

4.1.2 Measurement of temperature and relative humidity

Relative humidity and temperature of indoor air were measured on October 24th started at 10.00 AM and lasted until 16.00 PM. During that period of time there were some lectures which were attended by many students. The CEM DT-172 Temperature and Humidity Dataloggers (Figure 11) were used for continuous measurements during 6 hours. The interval of measurements for these dataloggers was set to 2 minutes and they were programmed with compatible software on PC. Each datalogger was placed on the desk in the center of the classroom at the height of 1 m. The location of the devices is shown on Figure 9 and Figure 10 as a red circle. After the monitoring was done the measured data was saved in the memory of that datalogger. Then the measured data was downloaded to a PC and analyzed in Microsoft Excel software.

FIGURE 11. CEM DT-172 Temperature and Humidity Datalogger. /24/.

4.1.3 Measurement of air flow rates

The case study building has only natural exhaust ventilation system. Air volume flow rate was calculated with the help of the measured velocity of air flow for each exhaust air device in the classrooms. The measurements were done on the same day as temperature and relative humidity monitoring but only once after the lectures were finished. The classrooms have several rectangular exhaust air grills with different sizes. The locations of these devices and their dimensions are shown on Figures 9 and 10. The Testo 435 instrument with thermo anemometer was used for air flow measurements and it is shown on Figure 12. There was no opportunity to use a special capture hood with Testo 435 to get more precise data. Therefore, the velocity of air flow was measured in five points of the exhaust air device to get the average values.

**FIGURE 12. Testo 435 instrument and CEM DT-172 Datalogger.**

5 RESULTS AND DISCUSSION

5.1 Thermal conditions and air flow rates in the classrooms

The indoor air temperature and relative humidity strongly depends on the outdoor conditions and occupancy. The indoor climate guidelines define the values of the different parameters for cold and warm season separately. According to the weather forecast the outdoor air temperature on October 24th was 2°C and relative humidity was 68%. Table 8 shows the time and occupancy when the measurements were done. That information is needed to analyze measured data of temperature and relative humidity.

TABLE 8. Number of students in the classrooms.

Classroom	Time period of lessons		
	10.00-12.00	12.00-14.00	14.00-16.00
1	20	24	33
2	11	21	21

Temperature and relative humidity values were obtained in a table format which was transformed into the graphs. The measured data for these two important indoor climate parameters in two classrooms is shown in Figures 13 and 14.
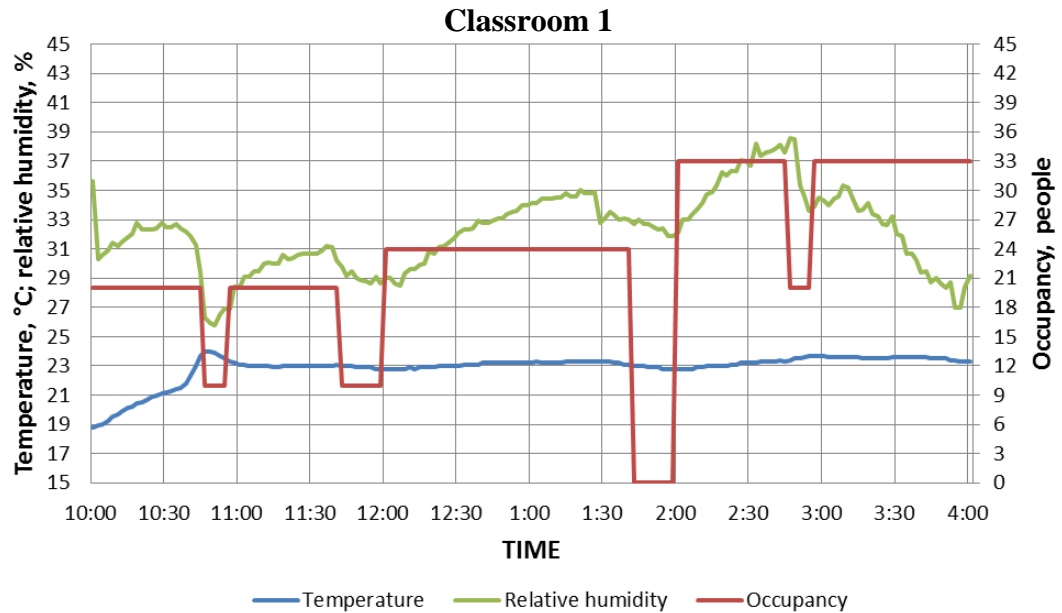
FIGURE 13. Measured temperature and relative humidity in classroom 1.
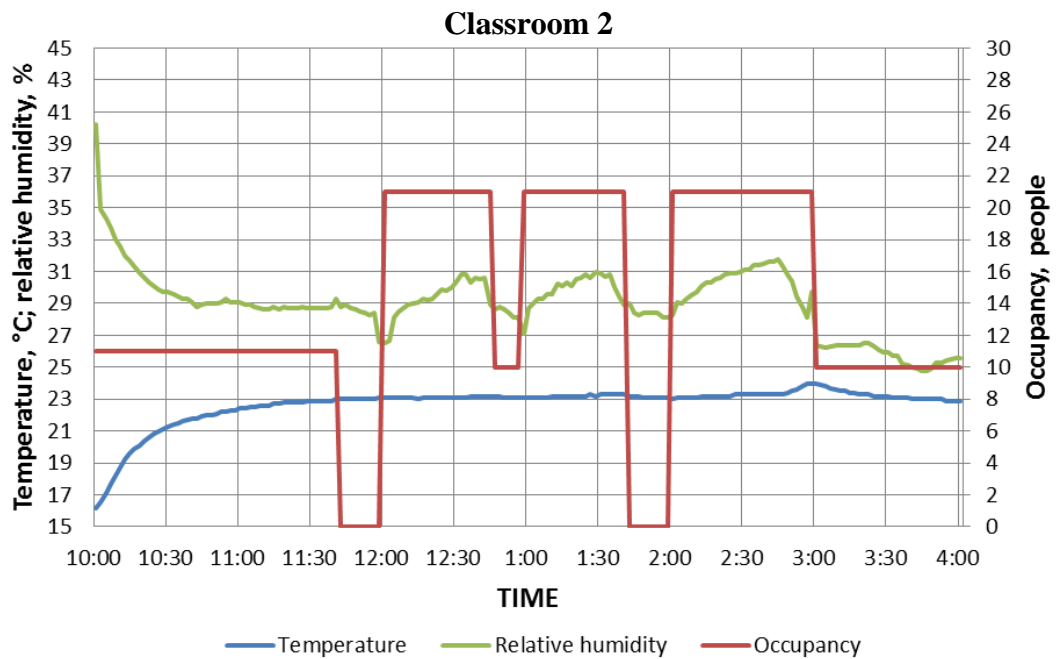
FIGURE 14. Measured temperature and relative humidity in classroom 2.

Very low indoor air temperature and relatively high relative humidity in the beginning of the monitoring should not be taken into consideration. These values were measured when the CEM DT-172 Datalogger had not adapted to the indoor temperature.

These two graphs show that the indoor air temperature in both classrooms is almost constant during the classes. Moreover, even during the break or when the classrooms were closed between the lessons the temperature remained on the same level but the number of students was changing. For instance, the door of the classroom 1 was opened during 3.00-4.00 PM time period. However, it did not affect on the indoor air temperature. It can be assumed that the exhaust ventilation system and the transferred to corridor heated air compensated the excess heat load due to poor air tightness inside the building.

The results of the measurements show that the average indoor air temperature in the classroom 1 was 23,2 °C and in the classroom 2 23,1°C. According to Russian standards /17,19/, the temperature should be 19-21°C for optimal indoor condition and National Building Code of Finland D2 /20/ requires that the temperature should be 21°C. Therefore, the indoor air temperature in both classrooms exceeded the requirements and these guidelines were not met. However, the measured temperature satisfies Russian requirements for admissible indoor condition which allow 18-23°C temperature range.

On the other hand, the relative humidity was not constant during the given time period. It changed accordingly to occupancy. When the number of students became smaller during the breaks the relative humidity level slightly decreased. Furthermore, it was increasing during the classes because people discharge water vapour as well as heat.

According to the measured data, the average relative humidity in the classroom 1 was 32,4%, the minimum value was 27% and the maximum value was 38,6%. In the classroom 2 the average relative humidity was 28,7%, the minimum value was 24,8% and the maximum value was 31,8%. These values almost comply with Russian and Finnish guidelines. According to these requirements, relative humidity in classrooms should not exceed 45% and the minimum possible value is 30%. Therefore, the rela-

tive humidity in the classroom 1 is on normal level but the relative humidity in the classroom 2 should be increased.

As it was mentioned above, ventilation air flow rate was calculated with the help of measured velocity of air flow for each exhaust air device. Firstly, the samples were taken in 5 different points for each device as it is shown as red dots on Figure 15.
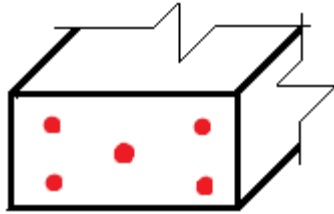
FIGURE 15. Points for measurements.

Then the average velocity of air flow for each device was calculated. After that, it is possible to calculate the ventilation air flow using the following equation:

$$q_v = v \cdot A$$

where

q_v is the air volume flow, m^3/s;

v is the average velocity of air flow, m/s;

A is the area of the exhaust air device, m^2.

For example, the exhaust air device has following dimensions: 0,23x0,25 m and the calculated average air velocity is 0,36 m/s. Then the air volume flow for this device is:

$$q_v = v \cdot A = 0,36 \; m/s \cdot (0,23 \; m \cdot 0,25 \; m) = 0,0207 \; m^3/s = 20,7 \; dm^3/s$$

The sum of air volume flow of each exhaust air device will define the ventilation air flow rate for the classroom. It is important to take into account that this ventilation air flow rate is the supply outdoor air rate. However, the case study building has only natural exhaust ventilation system. It is very difficult to accurately dimension this type of ventilation system. It is assumed that the supply ventilation air flow and exhaust air flow are equal. The results of the air flow measurements and calculations are demonstrated in Table 9 and in Table 10.

TABLE 9. The results of the air flow measurements and calculations in classroom 1.

	Dimensions of exhaust air device						
	0,23 m x 0,25 m		0,70 m x 0,25 m		0,45 m x 0,25 m		
Marking	11	12	13	14	15	16	17
Average air velocity, m/s	0,36	0,54	0,29	0,33	0,18	0,24	0,18
Exhaust air flow, m^3/s	0,0207	0,03105	0,05075	0,05775	0,02025	0,027	0,02025
Exhaust air flow, dm^3/s	20,7	31,05	50,75	57,75	20,25	27,0	20,25
The sum of ventilation air flow in classroom 1: $q_{v, total}$ = 227,75 dm^3/s ≈ 228 dm^3/s							

TABLE 10. The results of the air flow measurements and calculations in classroom 2.

	Dimensions of exhaust air device						
	0,62 m x 0,15 m			0,45 m x 0,25 m			
Marking	21	22	23	24	25	26	27	28
Average air velocity, m/s	0,24	0,27	0,29	0,45	0,39	0,44	0,27	0,27
Exhaust air flow, m^3/s	0,02232	0,02511	0,02697	0,05062	0,04387	0,0495	0,03037	0,03037
Exhaust air flow, dm^3/s	22,32	25,11	26,97	50,62	43,87	49,50	30,37	30,37
The sum of ventilation air flow in classroom 2: $q_{v, total}$ = 279,13 dm^3/s ≈ 279 dm^3/s								

There are 22 desks for 44 students in the classroom 1. Therefore, the ventilation system should be designed for 45 persons. According to Russian standards, the ventilation air flow should be 11 dm^3/s per person. Hence, required air flow is 495 dm^3/s. National Building Code of Finland D2 defines that the air flow in the classroom should be 6 dm^3/s per person or 3 dm^3/s per one m^2 of floor area, so the required ventilation air flow is 270 dm^3/s and 219,3 dm^3/s correspondingly. However, outdoor air

flow rates are determined primarily on the basis of the number of occupants. Classification of indoor environment 2008 suggests that the ventilation air flow should be 11 dm^3/s per person as well as Russian standards. Furthermore, according to these guidelines, the required ventilation rates should be calculated by following formulas:

for S1 category: q_v = 10 (dm^3/s)/person+0,5 (dm^3/s)/floor-m^2

$$q_v = 10 \cdot 45 + 0,5 \cdot (8,6 \cdot 8,5) = 486,55 \ dm^3/s$$

for S2 category: q_v = 7 (dm^3/s)/person + 0,5 (dm^3/s)/floor-m^2

$$q_v = 7 \cdot 45 + 0,5 \cdot (8,6 \cdot 8,5) = 351,55 \ dm^3/s$$

Table 9 shows that the total measured exhaust air flow is 228 dm^3/s. Therefore, it does not meet Russian and Finnish standards for ventilation air flow except of the NBC D2 requirements for air flow per one m^2 of floor area. It can be concluded that there is insufficient exhaust air flow rate in the classroom 1 and it cannot provide 45 persons during the cold season with comfortable indoor climate. Moreover, it can be assumed that the indoor air quality is poor due to inadequate air flow rates.

The classroom 2 has 35 desks for 70 students. Hence, the ventilation system should be designed for 71 persons. According to Russian standards, the required air flow is 781 dm^3/s. National Building Code of Finland D2 defines that the air flow in the classroom should be 426 dm^3/s or 296,7 dm^3/s. It should be taken into account that outdoor air flow rates which are determined primarily on the basis of the number of occupants are more important. Furthermore, according to Classification of indoor environment, the required ventilation rates should be calculated by the following formulas:

for S1 category: q_v = 10 (dm^3/s)/person+0,5 (dm^3/s)/floor-m^2

$$q_v = 10 \cdot 71 + 0,5 \cdot (11,5 \cdot 8,6) = 759,45 \ dm^3/s$$

for S2 category: q_v = 7 (dm^3/s)/person + 0,5 (dm^3/s)/floor-m^2

$$q_v = 7 \cdot 71 + 0,5 \cdot (11,5 \cdot 8,6) = 546,45 \ dm^3/s$$

Table 10 shows that the sum of measured exhaust air flows is 279 dm^3/s. Therefore, it does not comply with Russian and Finnish standards for ventilation air flow. However, the NBC D2 requirements for air flow per one m^2 of floor area are very close to the actual air flow. Hence, the exhaust air flow rate is insufficient in the classroom 2 and it

cannot provide 71 persons during the cold season with comfortable indoor climate. It can be assumed that the indoor air quality is poor as well as in the classroom 1 due to inadequate air flow rates.

However, the classrooms were not occupied with the maximum number of students. During the measurements the maximum occupancy of classroom 1 was 33 persons and occupancy of classroom 2 was 21 persons. Therefore, it is possible to recalculate the required air flow rates for actual numbers of students according to the same guidelines and formulas which were used above. Then, the results of these calculations can be compared to the measured values.

According to Russian standards, the ventilation air flow in classroom 1 should be 363 dm^3/s to provide 33 persons with comfortable indoor climate. The air flow determined on the basis of number of students should be 198 dm^3/s according to the NBC D2. Moreover, to meet the requirements of Classification of indoor environment the ventilation rates should be calculated by the following formulas:

for S1 category: $q_v = 10$ $(dm^3$/s)/person+0,5 $(dm^3$/s)/floor-m^2

$$q_v = 10 \cdot 33 + 0,5 \cdot (8,6 \cdot 8,5) = 366,55 \text{ } dm^3/s$$

for S2 category: $q_v = 7$ $(dm^3$/s)/person + 0,5 $(dm^3$/s)/floor-m^2

$$q_v = 7 \cdot 33 + 0,5 \cdot (8,6 \cdot 8,5) = 267,55 \text{ } dm^3/s$$

The ventilation air flow in classroom 2 should be 231 dm^3/s to provide 21 persons with satisfactory indoor climate according to SP 60.13330.2010 /19/. According to the National Building Code of Finland D2 the air flow determined on the basis of number of students should be 126 dm^3/s. Furthermore, to meet the requirements of Classification of indoor environment the ventilation rates should be calculated by the following formulas:

for S1 category: $q_v = 10$ $(dm^3$/s)/person+0,5 $(dm^3$/s)/floor-m^2

$$q_v = 10 \cdot 21 + 0,5 \cdot (11,5 \cdot 8,6) = 259,45 \text{ } dm^3/s$$

for S2 category: $q_v = 7$ $(dm^3$/s)/person + 0,5 $(dm^3$/s)/floor-m^2

$$q_v = 7 \cdot 21 + 0,5 \cdot (11,5 \cdot 8,6) = 196,45 \text{ } dm^3/s$$

These recalculations show that the sum of calculated air flows in classroom 1 which is 228 dm^3/s does not meet Russian standards and Classification of indoor environment. However, the ventilation air flow in classroom 1 does comply with NBC D2 requirements based on number of occupants and even slightly exceeds the required values. On the other hand, the sum of calculated air flows in classroom 2 (279dm^3/s) meets the Russian and Finnish standards and guidelines but significantly exceeds the required values. It can be justified by low number of occupants (21 students out of 71) in large classroom.

Overall, the indoor air temperature in both classrooms in the educational building in Saint Petersburg exceeds limitations required by Russian and Finnish guidelines. However, this indoor climate parameter meets the requirements for admissible thermal condition of GOST 30494-96. The measured relative humidity in the classroom 1 satisfies standards of both countries but the relative humidity in the classroom 2 should be increased. In order to provide acceptable indoor air quality and thermal conditions, the exhaust air flow rate in both classrooms should be increased because it does not meet the Russian and Finnish requirements. If these problems are fixed, the students' productivity and well-being will improve.

5.2 Recommendations to improve indoor climate in the classrooms

As it was discussed above, thermal conditions and exhaust air flow rates in the classrooms 1 and 2 do not comply with official guidelines. The case study building has old heating system as well as old natural exhaust ventilation system because it was constructed in 1973. Apparently, this building needs to be reconstructed or its systems should be improved to create good indoor climate and to protect occupants' health from harmful effect of poor indoor environmental quality.

The educational building is generally used from September to July. Therefore, it was designed only with exhaust ventilation system and heating system. Equipment for cooling is not installed because it is not necessary to provide cooling during the summer when the building is not in ordinary use. Renovation of this educational building must be done considering that the new or reconstructed HVAC systems advisably should be flexible for each room and according to the university schedule. In that case,

the excess of heat load will be removed and the indoor air quality will be on acceptable level. As it is shown in Figure 13 and Figure 14 the indoor air temperature in classrooms is quite high but on admissible level. Certainly, it might improve if the heating system will be renovated. However, that will not solve the problem with very low ventilation air flow rates in this building. It may be assumed that the renovation of existing ventilation system will improve indoor air quality and will reduce the indoor air temperature to the required level.

Theoretically, there are many types of HVAC systems and equipment that can be used for reconstruction purposes. Some complicated or expensive systems may be efficient and suitable choice for new buildings because they provide very good indoor climate and save some energy. However, the price for these systems is very high and it is economically unfavourable for old building such as case study building. For instance, it will be very difficult to find money to build central heating and cooling system for several buildings of that university in Saint Petersburg, even though the centralized systems are preferable for group of buildings. Furthermore, some HVAC systems cannot be installed due to its design and construction.

Firstly, it is suggested to replace old windows and doors with new modern ones. Now the classrooms are not air tight enough and there are a lot of leakages. They may be a reason of low indoor air temperatures during the winter. Moreover, it will be possible to create stable indoor conditions which will be easier to change and control. The second suggested measure is a cleaning of ventilation air ducts. It is necessary to remove dust and other harmful particles from the ducts so they cannot pollute indoor air. In addition to this, that measure should be done when the existing ventilation system is being renovated or the new equipment is being installed.

The unit ventilator which is shown in Figure 16 can be used as a cheap and simple equipment for indoor climate improvement. It consists of outdoor air inlet, air filters, air fans and heating coils. This equipment can be installed under the windows in given classrooms because there is a space which can be used. Moreover, the heated water which is supplied to the existing radiators can be used for heating coils or the electric heating coil can be used. The supplied fresh outdoor air with needed temperature will provide the space with comfortable thermal conditions and air quality. According to

the catalog of Daikin Classroom Unit Ventilators /26/, the classrooms can be provided with the required ventilation air flow. The equipment produced by this company has nominal airflow of 472 dm^3/s, 590 dm^3/s and even 708 dm^3/s which is enough to satisfy the Russian and Finnish guidelines.
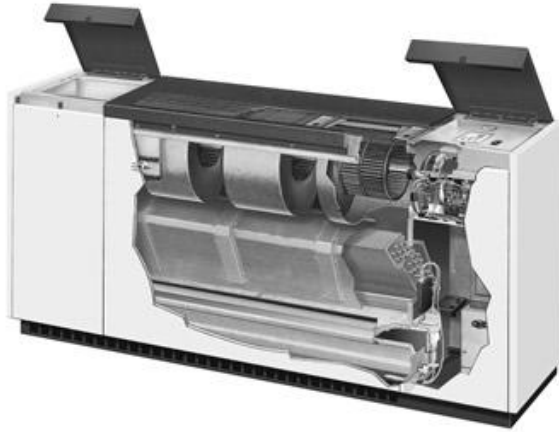

FIGURE 16. A unit ventilator. /25/.

The simpler and cheaper way to slightly improve the indoor climate in classrooms 1 and 2 is installing of radiators and outdoor air opening in the outer wall. It is a widely distributed and low-cost air-and-water system. This equipment is generally used for heating purposes in cold climate. The modern radiators with thermostatic radiator valve will efficiently supply needed heat for space and small amount of fresh air. It might not be enough to provide the classrooms with needed ventilation air flow but anyway it will improve the indoor climate.

It is possible to install an exhaust air fan on the roof in the existing air ducts. The scheme of the exhaust ventilation system of case study building is shown in Figure 17. Apparently, this fan will serve the same classrooms on different floors. Therefore, this solution can be relatively effective because it will improve the indoor air quality in several classrooms instead of one. This measure will increase the exhaust air flow rate to the required values. Moreover, it is desirable to install silencers and dampers on ventilation inlets so the ventilation system can be easily balanced.
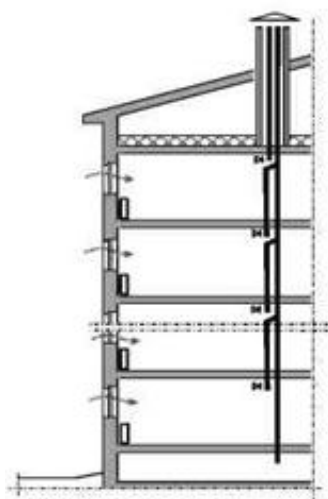
FIGURE 17. Scheme of the exhaust ventilation system of case study building.

Moreover, it is possible to consider the variant when the air fan can be installed in the existing air ducts to supply the outdoor air in the classrooms instead of removing the exhaust air. The clean air ducts, proper air filters and installed electric air heaters can make this solution viable. For instance the exhaust air device №13 and №14 in the classroom 1 and exhaust air device №21, 22, 23 in the classroom 2 can be changed to supply air outlets. However, in this case to satisfy the minimum requirements of NBC D2 the air velocity in the duct should be 1,54 m/s in the classroom 1 and 1,53 m/s in the classroom 2. Therefore, it is necessary to extend the existing ventilation air ducts with new ones under the ceiling. It will allow to install extra supply air devices for even distribution of outdoor air in the classrooms so the requirements for air velocity will be met.

Furthermore, the rooftop single-zone packaged air conditioners which are shown in Picture 6 can be used. This is a complicated prefabricated unit which can provide necessary exhaust and supply air flow rates with needed temperature and relative humidity. However, this system is an expensive solution which requires extra estimation and calculations. That equipment might be too heavy for the building's constructions and therefore cannot be installed on the roof. Moreover, it has the same disadvantages as the extra supply and exhaust air fans. Thus, these two solutions may be difficult to implement but it will provide comfortable indoor conditions.

The most common way in Russia to improve the indoor climate is installation of split-ductless air conditioning system which is shown in Picture 18. This direct-expansion

system is generally used for recirculation of indoor air. It can provide heated or chilled air to the classroom. Some administrative rooms and some computer classrooms in the case study building have this air conditioning system. It is possible to install one multi-split system to serve the classroom 1 and 2. There will be no difficulties during the installation of this air conditioning system because it is flexible and small. However, it can only provide acceptable thermal conditions. Comfortable indoor climate can be achieved if fresh air will be supplied through the opened window during the break and heated by split-ductless air conditioning system after that. This equipment cannot supply outdoor air, hence, the guidelines for ventilation air flow rate will not be met.

FIGURE 18. Split-ductless air conditioning system. /27/.

6 CONCLUSION

Nowadays, people are giving more attention to their health and productivity. They stay inside the buildings during the work time, their studies or being at home. Poor indoor climate may be a reason of discomfort and health issues. Hence, buildings should provide a good indoor environment to satisfy people's needs. A lot of young and adult people spend their time inside the educational buildings. Studying is an intensive occupation which is becoming absolutely difficult if there are poor and unacceptable indoor conditions.

In this Bachelor's thesis, it is discussed that a lot of old educational buildings cannot provide good indoor climate. The design and operation of the HVAC system strongly affect thermal conditions and indoor air quality in classrooms. Some parameters of indoor climate do not comply with the Russian and Finnish standards sometimes.

Several studies which were mentioned in this thesis report that the productivity and learning performance strongly depends on indoor environmental quality. The most important environmental parameters were studied. Moreover, official Russian and Finnish standards concerning indoor climate were investigated and compared to each other.

In order to achieve the main aim of Bachelor's thesis, indoor air temperature, relative humidity and exhaust air flow rate was measured in the classrooms 1 and 2 of educational building in university in Saint Petersburg. The measured data was shown and analyzed. These measurements demonstrated that there are some problems with indoor climate. The measured air temperature was 2°C higher than it is defined in guidelines. The measured ventilation air flow rate was lower than the Finnish and Russian standards require.

There were some limitations and possible errors in the discussed measurements and calculations. It was not possible to use more advanced devices and accessories like a special capture hood, so the measured data maybe not very accurate. The measurements of velocity of air flow for each device were not a continuous measurements (monitoring) so the measured values do not take into account that the air velocity could had been changing during the day. Moreover, the locations of temperature and humidity dataloggers maybe were not the most appropriate to show the average values of indoor air temperature because window radiation, door and students' location have significant effect on measuring device. Furthermore, the inaccuracy of dimensions' measurements influences on the discussed calculations of ventilation air flow rates.

Furthermore, in this Bachelor's thesis, possible solutions which can improve the indoor quality and thermal conditions were discussed and described. The most suitable equipment, designing solutions and necessary measures were figured out and presented as recommendations. The split-ductless air conditioning system is common equip-

ment which is used for air recirculation to provide a room with heated or chilled air. It is the most suitable system for the given classrooms because it is simple, flexible and relatively cheap way to improve the indoor climate. However, a unit ventilator should be used to provide the best indoor air quality and thermal conditions.

Overall, many old buildings have some problems with indoor climate. It is becoming a serious and sometimes complicated issue. In order to provide to people comfortable and healthy indoor conditions during their activities inside the building this problem needs to be solved.

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