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Productivity and Indoor Climate

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DESCRIPTION

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Productivity and Indoor Climate

Abstract

The subject of this Thesis is indoor climate and productivity. During last 20 years this subject is studied by different scientists more and more. Studies are usually concerning influence only one parameter of indoor climate on productivity. Some of studies investigated relationship between indoor climate and productivity in economical aspect. This Thesis studied combination action of parameters indoor climate on productivity. The aims of this Thesis are to learn which parameters of indoor climate have an effect on productivity, and to perform a small investigation of the effects on productivity.

For investigation of effects of indoor climate on productivity two groups of students was chosen. These two groups had exam on the same day and in one classroom. Air was not refreshed between exams. Therefore indoor climate for the first group was better than for the second. Based on this fact exam results of the first group could be better than for the second, but obtained exam results of the second group were a little higher than for the first one. It means that indoor climate was not only factor, which affects students' productivity. Literature review confirmed this, too.

This investigation was conducted in 3 stages. The first stage was measuring parameters of indoor climate and indoor air quality (CO_2 level) during 2 exams. Later they were compared with requirement values, which give guidelines by Russia and Finland. The second stage was analysing answers in indoor climate questionnaires, which were filled in by students. The third stage was comparison of obtained results from measuring parameters of indoor climate, answers from questionnaires and students'exams results. Some aspects of productivity like personal and environment was assessed by questionnaires and measurements, but by no means this study can be regarded as comprehensive. However, it gave invaluable experience and insights to the author of this Thesis report.

Subject headings, (keywords)

Indoor Climate, Productivity, Student performance, Indoor air quality

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CONTENTS

I. INTRODUCTION

Nowadays, people from all over the world are interested in increasing productivity of themselves and other people who surround them. Worldwide interest of it do not only relate with people who work and their employers, but also with people who study. Factors which affect productivity are material-technical (level of innovativeness, level of development of technology and so on), organizational and economic (determined by the level of organization of labor, production and management), socio-psychological and indoor climate in which the work or study proceeds /1, p.998/. These factors have a complex effect on increase or decrease in productivity. If worker has low productivity then a company may have low level of competitiveness. And if student do not pay enough attention to lectures or has difficulties in concentration then he needs more time for performing different kinds of tasks which are related with his study. In modern rhythm of life it is not desirable.

Recently there have been a lot of complaints in buildings concerning indoor climate. Significant part of them relate to thermal comfort and indoor air quality. Thereby people sense discomfort on their workplaces. Such type of discomfort may be caused by fluctuating of temperature, relative humidity, concentration of carbon dioxide (CO_2) and air flow rates. It takes more time for man to adapt to changing conditions of ambient environment and begin to work or study normally. So as you can see, discomfort on workplace may decrease productivity.

The main targets of this bachelor thesis is to study what kind of indoor climate parameters affect productivity, how they do it and to perform small investigation of the effects of indoor climate on productivity.

The bachelor thesis starts with general information about productivity and what factors affect it. In this part, an overview of recommendations concerning indoor climate and indoor air quality in public buildings in guidelines of Russia and Finland was done. Then comparison of guidelines is presented. Also in this part overview of major findings of international research projects on the relationship between indoor climate and productivity were done.

Second part of thesis tells about investigations of relationship between indoor climate and productivity, which scientists of Finnish Institute of Occupational Health had done, aims, methods and results. Small investigation in a classroom with two groups of participants was performed in Mikkeli University of Applied Sciencies. Methods, measuring equipment and results of it are presented.

The last part compares obtained results from measurements, exam results of students and questionnaires, which students filled in after investigation. It gives information about factors which could affect students' productivity. After that comparison of results from small investigation in classroom and major findings of international research projects on the relationship between indoor climate and productivity were made.

II. THEORETICAL BACKGROUND

2.1 What is productivity?

Productivity is a complex conception which is studied in different disciplines. The main definition of this word which is given from the dictionary is quantity of output which is made by workers in time units. Thereby productivity is ability of people to enhance their work output through increase in the quantity of the product or service they deliver /2/. Actually, on the one hand, productivity is a measure of efficiency, and on the other hand, it is an indicator of economic development of company or even country /1, p.998/.

Productivity depends on 4 main factors: personal, social, organizational and environmental. (Figure 1) These factors include gender and age of a person, previous experience, knowledge, what kind of work a person do, workplace environment, social communication an so on. Of course all these factors more or less affect it. In general it depends on a person: his well-being, ability of performs, motivation, job satisfaction, technical competence.

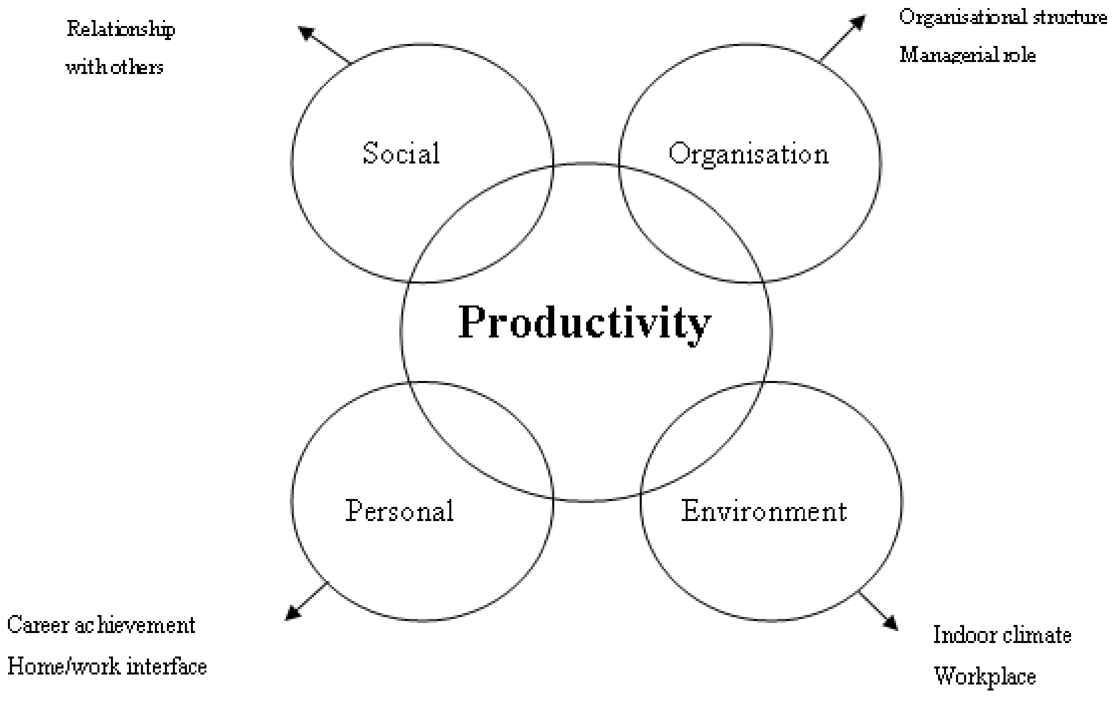

FIGURE 1. Factors which affect productivity. /3, p. 11./

Persons who are most interested in high productivity are employers, engineers, designers, construction managers. But why do they need and want to increase productivity? What kind of benefits will they have?

The first benefit is monetary, i.e. ratio between input and output (product) in money's worth and how much profit the company will have. If a person will work hard and fast then he will do a lot of work and company will have more profit.

The second one is the quality of work performance. Of course, education, experience and ability of person to make creative project are positive impact on it. The third benefit is health of a worker. Employers are interested in worker's health, because if worker has less problems with health (fewer low-level health issues like tonsillitis, flu and so on, which are appeared at least twice a year) then cases of absenteeism will be reduced. So company will have less economical losses and the work performance of a person will be almost on stabile level. One of the reasons of problems with health is indoor environmental conditions of workplace. "The quality of indoor environment has a significant effect on the health and productivity of employees and other occupants" /3, p 107/. "Any environmental condition that decreases individual performance (either quantity or quality), increases absenteeism, or reduces turn over, is more expensive (or costly) for organization. Consequently, a poor indoor environment decreases organizational productivity both by reducing revenue and by increasing costs." /2./

The last one is satisfaction of job. In this case different kind of workers' complains, which can be related with bad indoor environment or workplace in the beginning and organizational structure of a company in the end, will reduce. Benefits, on which productivity affects, are shown on Figure 2.

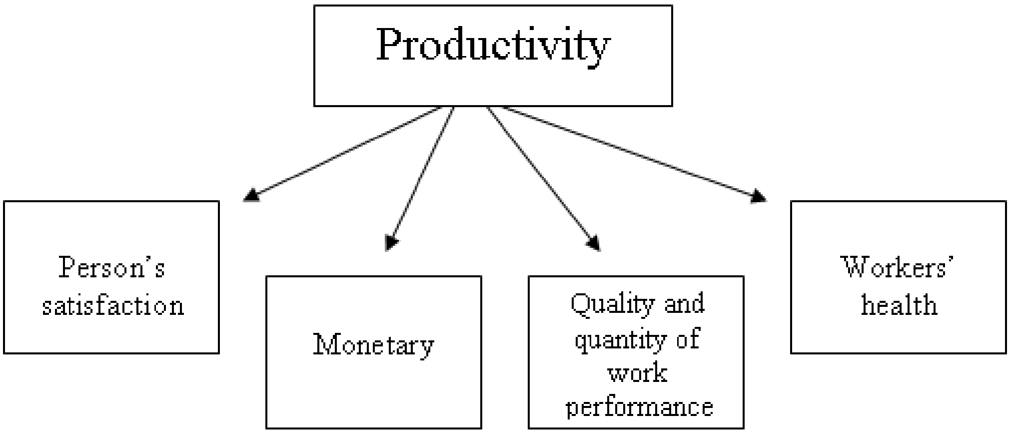

FIGURE 2. Benefits, on which productivity affects

As you can see, indoor climate plays an important role in productivity. "Intervention to ensure a healthy working environment should always be the first step towards improving productivity"/3, p.7/. One of the ways to increase productivity is to improve indoor climate of workplace. But it is not easy to do. "There are very large individual differences in the tolerance of sub-optimal thermal and environmental conditions. Even if the average level of a given environmental parameter is appropriate for the average worker, large decrements in productivity may still be taking place among at least tolerant."/3, p.7./

2.2 Parameters of indoor climate which affect productivity

As mentioned earlier, there are a lot of factors which affect productivity. One of them is related with indoor climate of occupied zone, others are related with psycho-emotional state of the person and psycho-emotional states in which this person works and knowledge skills of a person and resources or tools which person use during his work. In this chapter an overview of factors of indoor climate which affect productivity is given.

The first main parameter of indoor climate is temperature of air. When value of this parameter is too high or too low person feels thermal discomfort, consequently it can lead to deterioration of person's health. As a result temperature of indoor air has a direct impact on well-being of a man and productivity. For example, high temperature of air, which stays for a long time, leads to fast fatigue of worker and overheating of his body with big amount of sweating even if other parameters of indoor air like humidity and air flow rate are constant. Such combination leads to attention decreasing, sluggishness, so it might be a reason of accident.

The second parameter of indoor climate is humidity of air. Air always contains certain amount of water vapor. There are three indicators of humidity. One of them is dew point. It is characterized by maximum amount of water vapor which air with certain temperature can consist. The second one is absolute humidity. It is characterized by actual amount of water vapor contained in the air. The third one is relative humidity, which is used in guidelines. Relative humidity is percentage ratio between absolute humidity and maximum amount of saturated water vapor at the certain temperature of air. The main sources of humidity in the working place are a man's body and level of outside air humidity. The amount of water vapor from the body depends on temperature of indoor air and what work does man do. If there is air which is over-saturated with water vapor then evaporation from skin and lungs of a man is complicated. It can lead to sharp deterioration of well-being of a man and reduce his productivity. Otherwise if relative humidity is too low (for example 20 %RH) then person feels dryness of mucous membrane and upper respiratory tracts. The optimal value of relative humidity is 30 – 70 % RH, but it does not guarantee well-being of a man inside the room /4/. Guidelines in different countries gave acceptable values for temperature, relative humidity and velocity of air /7, 12/.

The third parameter is air flow rate. It has significant impact in creating and maintaining good indoor climate in the working place. Poor ventilation system is usually related with too low values of air flow. If there is no air flow around the man's body a thin fix shell is made, which is quickly saturated by water vapor. Such type of shell has temperature of man's body and it reduces process of heat transfer from man's body to ambient environment. But slight air flow can improve this situation /5/. For example, if temperature of ambient environment is lower than temperature of man's body than heat losses from body rise with increasing air flow. In this case we should increase relative humidity of air thereby to reduce evaporation from man's body or to increase temperature of air for maintain comfortable indoor climate. At the same time excessive air flow rate especially in cold environment can lead to increasing heat losses and fast cooling of a man's body can occur. We should select values of air flow rate in relationship with work activities of a man. Air flow rate has significant impact on indoor climate, temperature and relative humidity, and air distribution inside the room. Air flow rate depends on type of air distribution devices, air flow rate and what kind of ventilation system we had.

Air flow rate, efficiency of ventilation, and concentration and chemical composition of indoor contaminants affect quality of indoor air. Adequate and effective ventilation prevents creating of favorable conditions for growth of mold, bacteria and other harmful microorganisms. It removes or (in cases when it is impossible because of technology of work or other factors) dilutes indoor air contaminants and body effluents such as carbon dioxide, sources of which can be presented in occupied zone. Also effective ventilation is a key for maintaining good indoor climate.

The fourth parameter is level of carbon dioxide (CO_2). One of the main sources of CO_2 is man's breath. Under normal conditions man approximately consumes 19 l per hour of oxygen and releases 16 l of CO_2. Released air contains level of CO_2 100 times more than in clean outdoor air. Clean outdoor air contains level of CO_2 300 ppm – 400 ppm. Air with such type of concentration of CO_2 is considered ideal for well-being of man. Quality of air is good if level of CO_2 is 400 ppm – 600 ppm. Excess of CO_2 in the air has bad influence on well-being of man. Some complains which are concerned indoor air quality are appeared when concentration of CO_2 is equal 600 ppm – 800 ppm. More often they are appeared when level of CO_2 fluctuated from 800 ppm to 1000 ppm. After 1000 ppm common discomfort, headaches, fatigue, migraine, problems with attention are occurred, also amount of errors which man make increase. Serious problem with health are occurred when concentration of CO_2 is above 2000 ppm. Such concentration affects workers' attention in work and amount of done errors. Also excess of CO_2 can be a reason of elaboration of sick building syndrome. /5./

Robertson's study "Health effects of increase in concentration of carbon dioxide in the atmosphere" shows that people started to sense decreasing of indoor air quality in the level of 600 ppm. If its level started to increase people sense one or a few classic symptoms of SBS./6, p. 1608./

All these factors of indoor climate affect well-being of a man and productivity. Thus, we should investigate all these factors at the same time, because if one factor changes we should change others for maintaining good indoor climate.

2.3 Indoor climate and requirements for it in different countries

In this chapter an overview of guidelines, which designers of Russia and Finland use during their work is made. Requirements for indoor climate which are presented in guidelines and values of these requirements will be determined. After that comparison of them will be made.

2.3.1. Russian requirements for indoor climate

GOST 30494-96. "Residential and Public buildings. Microclimate parameters for indoor enclosures." /7/ establishes requirements for indoor air parameters of residential and public buildings. Parameters of indoor air should be established according functional purpose of this building and season of the year (cold, warm). According this document building which is used for learning process (daycare centers, schools, universities and so on) is related to 2nd category of buildings. The second category includes such tasks as constant walking, the movement of small (1 kg) articles or things standing and sitting. /7./

There are 4 types of indoor air conditions. The classification is based on principle of well-being of man and his productivity. The terms of indoor air conditions are optimal, allowable, harmful and dangerous. /8./

Optimal indoor air conditions are characterized by such combination of parameters of indoor air that does not risk man's health during working time. There is no general or local thermal discomfort under this type of conditions, consequently it is possible to maintain a high level of productivity.

Allowable conditions of indoor air are characterized by such combination of parameters that there is no cause of changes in thermal comfort of man during the work shift. It can lead to thermal discomfort. Thermal conditions of man's body are relatively stabile, there is observed temporarily decreasing of productivity during work shift, but there is not any injuring of health during all period of labour activity.

Harmful conditions of indoor air are characterized by such combination of parameters of indoor climate that they provoke general or local thermal discomfort of man and decrease man's productivity during the working shift. There is no any guarantee to conserve man's health during his labour activity and after its end.

Dangerous conditions of indoor air are characterized by such combination of parameters of indoor climate that they provoke injuring of man's health and appearing of death risk in short time (less than 1 hour).

According to laws of Russian Federation it is not allowable to work in harmful and (or) dangerous indoor air conditions. The purpose of the norms is to protect people from this kind of indoor climate conditions.

As mentioned earlier, indoor air conditions have to be optimal, because it provides local and general thermal comfort for persons. There is no any deviation in well-being of man, so it creates the preconditions for high level of productivity. That is why such type of indoor air conditions is preferred in working place. Parameters of optimal level of indoor air conditions are shown in the Table 1.

TABLE 1. Characteristics of optimal level of indoor air parameters for the 2nd category of building /7, 9/.

Seasons	Indoor air temperature, ^{0}C	Relative humidity of indoor air, RH%	Air flow rate, dm^3/s per person
warm	23 - 25	30 - 60	11,11 (40 m^3/h per person)
cold	19 - 21	30 - 45	11,11 (40 m^3/h per person)

This table shows relations between thermal conditions and air flow rate during the year and optimal level of indoor air parameters (temperature, relative humidity).

There are two seasons of the year as you can see from the Table 1. The main difference between cold and warm season is average outdoor air temperature during 1 day. In first case (cold thermal conditions) it is equal + 10 ^{0}C and less, and in the second it has to be more then + 10 ^{0}C. Thus, it is not possible to determine exactly the thermal conditions of the year previously, because they depend on the year.

Concerning air flow rates AVOK Standard 1-2004 "Residential and Public buildings. Air Change Rate"/9/ establishes minimum values of outdoor air change rates, which provides in occupational zone required quality of indoor air and there is minimum possible injure to man's health /9/. According this document minimum value of air change rate in classroom is also presented in Table 1.

If we compare allowable level and optimal level of indoor air parameters then the first one is less attractive for student. It is determined in case when it is impossible to support optimal level. It can be result of technology requirements or technically and economically justifiable reasons. It should be also mentioned that when allowable level of indoor air parameters takes place, productivity decrease. It arises from general and local thermal discomfort of man's body and deterioration of his health.

Parameters of allowable level of indoor air conditions for buildings in 2nd category should not exceed values, which are given in the Table 2. Also this table shows relation between indoor air parameters and thermal conditions during the year.

TABLE 2. Characteristics of allowable level of indoor air parameters for the buildings in 2 category /7/.

Seasons	Indoor air temperature, ^0C	Relative humidity of indoor air, RH% (should not exceed)
warm	18 – 28	65
cold	18 – 23	60

Level of CO_2 in Russia in occupational environment for premises which are located in public and residential buildings is lacking. According to SNIP 41-01-2003 "Heating, Ventilation and Air conditioning"/10/ and SanPin 2.1.2.1002 – 00 "Hygienic requirements for residential buildings and premises" /11/ indoor air quality is the same as outdoor air quality, in the area where this building is built /10,11/.

2.3.2 Finnish requirements for indoor climate

There are two main guidelines for indoor climate in Finland. They are the National Building Code of Finland D2 "Indoor Climate and ventilation in buildings" /12/ and Classification of

Indoor Climate 2008 /12/. These documents complement each other in order to maintain good indoor climate in occupational zone.

National building Code D2 establishes requirements for indoor climate in order to maintain healthy, safety and comfortable indoor climate in the occupied zone under all normal weather conditions and operational situations /12/.

According to D2 /12/ design temperature for heating season in occupied zone is 21 ^{0}C and designed temperature for the summer season is 23 ^{0}C. However, temperature of the room should not be greater than 25 ^{0}C during the period of occupancy /12/.

The maximum level of carbon dioxide in the building which is given by Finland's National Building Code D2, Part 2.3 Air Quality gives:

> " 2.3.1
> Buildings shall be designed and constructed in such a way that the indoor air does not contain any gases, particles or microbes in such quantities that will be harmful to health, or any odors that would reduce comfort.
> 2.3.1.1 The maximum permissible indoor air carbon dioxide content in usual weather conditions and during occupancy is usually 2,160 mg/m^3 (1200 ppm)." /12, p 9./

For classrooms outdoor air flow rate is determined on of number of occupants basis. For classrooms outdoor air flow is 6 dm^3/s per person. /12./

Classification of Indoor climate 2008 specifies target and design values for indoor climate and supports the work of developers, designers, equipment manufacturers, contractors, and maintenance personnel. This classification is based on current knowledge of health and comfort. Values of parameters of indoor climate are more rigorous than required by authorities /13/.

According this classification there are 3 categories of indoor environment. They are S1 (individual indoor environment), S2 (good indoor environment) and S3 (satisfactory indoor environment). Characteristics of these categories are shown in Table 3 "Categories of indoor environment and their characteristics"

TABLE 3. Categories of indoor environment and their characteristics /13/.

Category / Parameters	S1	S2	S3
Indoor air quality	very good	good	minimum requirements set by the building codes
- Odour	no detectable odours in the environment	no disturbing smells in the environment	
- Sources of impurity	no sources of impurities	no sources of impurities	
Thermal environment	comfortable	good	
- draught	no	no	
- overheating	no	possible on summer days	
Acoustic conditions	very good	good	
Lighting conditions	good	good	

As you can see, these categories are classified by principle of indoor climate condition. The main difference between these categories is that in the first case the user of the space can regulate thermal conditions by himself, in the second case in summer season can occur overheating of the space and in the third case indoor environment and indoor air quality meet minimum requirements.

The requirements for operative temperature (t_{op}) are different in these three category. Operative temperature is an average value of radiant temperature of surfaces and ambient air temperature. Operative temperature affects man’s thermal sensation. For example, when it is above or close to 24 ^{0}C man’s body tolerates higher air velocity than when this temperature is equal to 21 ^{0}C. Sensibility to draught increases when the temperature is below the optimal operative temperature.

It is important to notice that the value of operative temperature depends on outdoor air temperature (t_u, ^{0}C). More detailed relationship is shown in Table 4. Also other requirements for indoor climate which are present in Classification of indoor climate 2008 are shown in Table 6.

TABLE 4. Requirements for indoor climate present in Classification of indoor climate 2008 /13/.

Parameters \ Category	S1	S2	S3
Operative temperature, ^0C			
$t_u \le 10\ ^0C$	21,5	21,5	21
$10 < t_u \le 20$ °C	$21{,}5 + 0{,}3 * (t_u – 10)$	$21{,}5 + 0{,}3 * (t_u – 10)$	$21 + 0{,}4*(t_u – 10)$
$t_u > 20\ ^0C$	24,5	24,5	25
minimum value	20	20	18
maximum value	t_{op} +1,5	$t_u \le 10$ °C: t_{op}+1,5	$t_u \le 15$ °C: 25
		$10 < t_u \le 20$ °C: $23 + 0{,}4 * (t_u – 10)$	t_u >15 °C: t_{umax} + 5
		$t_u > 20$ °C: 27	
Level of CO_2, ppm			
values	<750	<900	<1200
Air flow, m^3/s (for classroom)			
per person	11	8	6
per m^2	5,5	4	3
Relative humidity, RH%			
values	> 25 (in winter)	-	-

Thus, from the Table 4 you can see that Classification 2008 shows more rigorous requirements for level of CO_2 (for each category it is different). As for relative humidity it is determined only by category S1. Another situation we have with determining of air flow in comparing with D2. According to Classification of indoor climate 2008 to achieve category S1 for indoor environment we should use for calculation of air flow following formula:

$$\text{outdoor air flow} = 0{,}5\ dm^3/s*\text{floor-}m^2 + 11 dm^3/s*\text{person}$$

and for achieving S2 category of indoor environment:

$$\text{outdoor air flow} = 0{,}5\ dm^3/s*\text{floor-}m^2 + 8\ dm^3/s*\text{person}$$

2.3.3 Comparison of requirements for indoor climate

After analyzing of guidelines of two countries, it can be said that for the same parameters of indoor climate there are different requirements. In some cases the difference is significant, in another is not. More detailed results of comparison of requirements for indoor climate between Russia and Finland are shown in the Table 5.

TABLE 5. Comparison of requirements for indoor climate

Parameters of indoor air	Russia	Finland	
	GOST 30494-96 & AVOK Standard 1-2004	National Building code D2	Classification of Indoor climate 2008
Cold season			
Temperature, ^0C	19-21	21	S1: 21,5 S2: 21,5 S3: 21,0
Humidity, RH%	30-45	-	S1: > 25 (in winter) S2: - S3: -
Air flow rate, dm^3/s	11 per person	6 per person or 3 per m^2 in class-rooms	S1: 11 per person and 0,5 per m^2 or 5,5 per m^2 S2: 8 per person 0,5 per m^2 or 4 per m^2 S3: 6 per person or 3 per m^2
Level of CO_2, ppm	-	1200	S1: < 750 S2: < 900 S3: < 1200
Warm season			
Temperature, ^0C	23-25	23	S1: 21,5 S2: 21,5 S3: 23,0
Humidity, RH%	30-60	-	S1: - S2: - S3: -
Air flow rate, dm^3/s	11 per person	6 per person or 3 per m^2 in class-rooms	S1: 11 per person and 0,5 per m^2 or 5,5 per m^2 S2: 8 per person 0,5 per m^2 or 4 per m^2 S3: 6 per person or 3 per m^2
Level of CO_2, ppm	-	1200	S1: < 750 S2: < 900 S3: < 1200

As you can see from the Table 5, there is not any requirement for humidity in Finland (only for category S1 (in winter)), in Russia it has ranges from 30 to 60 RH%. Levels of CO_2 in buildings in Finland establish by regulation guidelines, but in Russia are lacking such type requirements for indoor air. Air flow rate in both countries can be determined by the amount of occupants. There is difference between amounts of supply air. For example in Russia this value is equal 11 dm^3/s per person and in Finland D2 it is 6 dm^3/s per person. However, if we need to achieve category of indoor environment like S1 and S2 we should calculate air flow rate with taking into account amount of persons and floor area. Indoor air temperature in Russia (19-21 ^0C in cold season and 23-25 ^0C in warm) is approximately equal indoor air temperature in Finland (21 ^0C in cold season and 23 ^0C in warm).

2.4 Major findings of international research projects on the relationship between indoor climate and productivity

There are several international studies made on productivity and indoor climate. Some of them concentrated on the influence of only one parameter of indoor climate to productivity, others included several parameters of indoor environment. Many studies show that indoor environment conditions have significant influence on health and productivity. The most famous investigators of this field are O. Seppänen (Helsinki University of Technology), P. Wargocki, D. Wyon and P.O.Fanger (International Centre for Indoor Environment and Energy, Technical University of Denmark), and W.J. Fisk and M.J. Mendell (Lawrence Berkeley National Laboratory Environmental Energy Technologies Division Indoor Environment Department Berkeley, USA).

Effects of temperature to productivity is one of the most studied fields. More than 31 studies are related with it. It became so because a lot of indoor environment complaints concern thermal conditions. The main goal of research studies in this field was to develop relationship between air temperature and productivity. Researches had focus on changing temperature range from 18 ^0C to 30 ^0C and determining work performance by implementation various type of tasks, which participants should do during the experiments. As a result, a significant influence on the performance in typewriting, factory work, signal recognition, time to respond to signals, learning performance, reading speed and comprehension, multiplication speed, and word memory was identified if there were changes of air temperature in a few degrees Celsius during the work period /14, p. 29/.

More details on how temperature influences productivity is shown in study of Olli Seppänen, William J. Fisk, QH Lei, which was about the effect of temperature on task performance in office environment. The goal was to develop the best possible quantitative relationship between temperature and work performance for use in cost benefit calculations related to building design and operation. The base of this study was other studies about temperature and productivity, which have objective indicators that are likely to be relevant in office type work. The percentages of work performance change per increase degree of temperature were calculated from all studies and then the measured work performance with temperature was statistically analyzed. Comfortable temperature for office type work when the highest productivity is determined is around 22 ^{0}C. If temperature of air is below 22 ^{0}C (21^{0}C-22^{0}C), productivity decrease. If temperature increases up to 23 ^{0}C - 24 ^{0}C, productivity starts to decrease. This relationship is presented in Figure 3. For example, at the temperature of 25 ^{o}C the performance is only 98.1% of the maximum i.e. the reduction in performance is 1.9%”./15, p. 24./

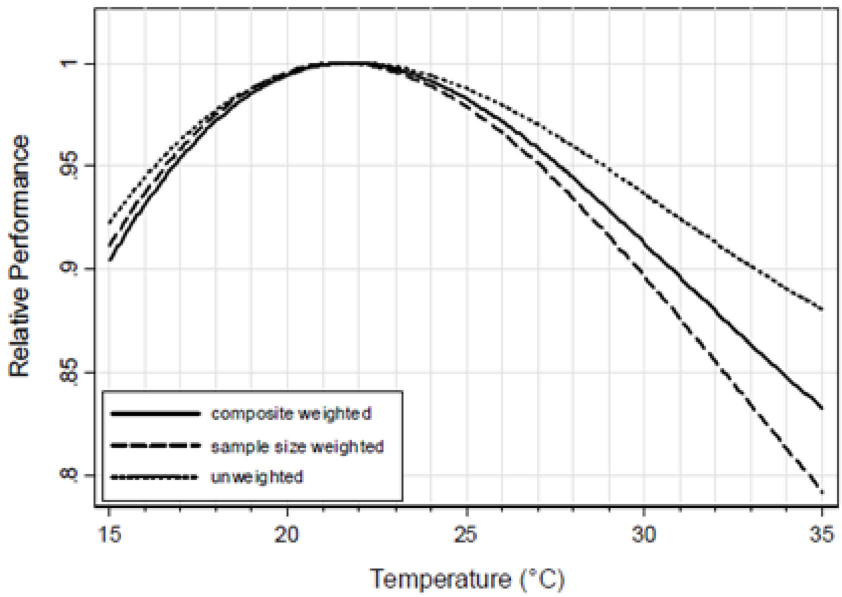

FIGURE 3. Normalized performance vs. temperature. Maximum performance is set equal to 1. /15, p. 24./

The comfortable (or optimum) temperature depends on nature of the task and a person, who will do this task that is why it is complicated to determine. The value of optimum temperature will vary among individuals and over time, so in this way individual control of temperature would increase productivity. /14, p.29./

Productivity can be reduced by 5% to 15% even if thermal conditions within the thermal comfort zone, the main reason of it may be the impact of poor air quality /16, p.13/. Poor indoor air quality is caused by inadequate ventilation, in turn it can be a reason of contaminant accumulation from indoor and outdoor sources in building. Increasing indoor air quality (by increasing ventilation rate, which decrease contamination load) improves work performance like text typing, addition and proof-reading. This fact was confirmed by study of Pawel Wargocki, David Wyon and Ole Fanger about productivity and air quality in offices. Due to this study relationship between air quality and performance and also between productivity and ventilation rate was identified. Productivity of typing will increase by 1.8%, of addition by 1.5% and of proof-reading by 2.8% for every 2 times increase of ventilation rate /17, p.636/. Concerning productivity and indoor air quality, productivity will increase with 1,5 % when percentage of dissatisfied persons with indoor air quality decrease 10% /17, p. 640/.

Moreover, during this study was found out that if indoor air quality in offices improve above minimum standards then also productivity will improve as well as economic benefits of providing indoor air of higher quality /17, p.639/. The minimum category of indoor air quality is C category. As you can see from Table 6, if we will upgrade indoor air quality from category C to category B then the amount of persons who are dissatisfied of air quality decrease and productivity will increase. For example for text typing it will increase by 1,4%, for addition 1,1% and for proof-reading 2.3%. These results are presented in Table 6.

TABLE 6. Relative increase in performance of office work by upgrading to a higher category of air quality in an office. /14, p.639/

Air quality (CEN CR 1752)		% increase in performance relative to category C		
Category	% dissatisfied	text typing	addition	proof-reading
C	30	—	—	—
B	20	1.4	1.1	2.3
A	15	2.1	1.6	3.4

More detailed information about influence ventilation rate, CO_2 concentrations and air quality is shown in the study of Seppänen, Fisk and Mendell, which combine 41 studies in this field. This study investigates association between these three parameters in non-residential and nonindustrial buildings (primarily offices) with health and other human outcomes. During this study there was identified that with increasing in ventilation rate from 0 dm^3/s per person to 10 dm^3/s per person will improve indoor air quality and will decrease occupant symptoms like fatigue, irritation of noise, shortness of breath and so on. And increasing in ventilation rates from 10 dm^3/s per person till 20 dm^3/s per person further increase indoor air quality and reduce occupants symptoms. /18, p.248./

Indoor CO_2 concentrations study identified that if concentration is below 800 ppm then the risk of occupants' symptoms decreases significantly /18, p.226/. CO_2 concentration in range down to 500 – 600 ppm (corresponding to steady state ventilation rates of 34.7 - 20.8 l/s per person) is associated with improving in indoor air quality /18, p.239/.

According to study of Wargocki and Wyon about effects of HVAC on student performance, air quality and temperatures in classrooms are important factors in the learning process /19, p. 28/. This study shows that increasing the outdoor air supply rate and decreasing indoor temperature significantly improved productivity of children and reduce errors, which they usually do. During the study it was found out that if outdoor supply air increase in 1 time then productivity in schoolwork will improve in terms of speed by 8% and if air temperature decrease by 1 ^0C then productivity improve in terms of speed by 2% /19, p.26/. In this study CO_2 concentration was used like indicator of actual effective ventilation rate indoor, because during the experiment teachers were allowed to open door and windows in order to improve indoor air quality /19, p24/.

The actual ventilation rates depend on frequency and length of opening of doors or windows /19, p. 24/. In this case indoor CO_2 concentration was considered as an indicator of ventilation rate per occupant. This type of indicator can be poor, because indoor CO_2 concentration will have fluctuations with time even if number of occupants and ventilation rates are constant /18, p.229/. Therefore more reliable indicator of the ventilation rate is the difference between indoor and outdoor CO_2 concentration /18, p.243/.

III. AIMS

There are three main aims of this Bachelor's Thesis. The first aim is to learn which parameters of indoor climate have an effect on productivity. Learning of relationship between indoor climate and productivity was based on firstly theoretical part, what kinds of investigations have been done before and secondly practical part, in which small investigation about this relationship was performed. After that comparison of results which were gotten in literature review and results of small investigation will be done.

The second aim is to visit a laboratory in which the relationship between indoor climate and productivity is studied. The visit was carried out to get familiar with research work about productivity which was done by scientists of this laboratory, methods which were used to study productivity, location of equipment for measuring thermal conditions and indoor air quality (level of CO_2) and results which were gotten. On basis of this investigation it was clear how to perform a small investigation about productivity and indoor climate.

The third aim is to perform a small investigation of the effects of indoor climate on productivity. The measurements were carried out to monitor thermal conditions (temperature and relative humidity of air), indoor air quality (level of CO_2) and level of productivity during whole measuring period. When results of measurements will be obtained, comparison of them and the values which are given in guidelines of Finland and Russia will be done. On basis of two guidelines conclusion about acceptability or unacceptability of indoor climate conditions in investigated room will be made. After that the level of productivity in certain indoor climate will be assessed and combination actions of parameters of indoor climate affect productivity also will be determined.

IV. METHODS

4.1. Visit to Finish Institute of Occupational Health

Influence of indoor environment to productivity is studied in Finish Institute of Occupational Health (FIOH), in Indoor Environment Laboratory which is located in west part of Finland in Turku. The purpose of this visit was to see how scientists make research work about productivity in real life, what kind of methods they use, how laboratory looks like.

Now scientists of this Institute study how indoor environment in open plan office can affect productivity. Factors of indoor environment which are studed are effect of different interior decorating, noise which can occur in office during the work time from air conditioning and ventilation systems and office workers, temperature and relative humidity of air and CO_2 level inside the room and air flow rates. For this study a special room, which looks like ordinary open plan office, was built in laboratory (Figure 4). The regulation of such parameters like noise, temperature, air flow rates are easy to do.

FIGURE 4. Open plan office in the laboratory of FIOH.

The total area of this room is 82 m^2. It is divided up into 12 sections, but at the moment only 8 persons can participate and 1 tutor who give instructions to participants during experiment and monitor experiment. Work place of each participant contains a table, chair, PC and folder with instructions.

For studying influence of noise to productivity in laboratory there are 4 reproducers (Figure 5), which are located in each corners of the room. They make certain level of noise which can appear inside office during the work time (calls, conversations between office workers and so on). Only 8 persons can take participation in acoustic study. During acoustic study human voices are always used, there are no sounds of ringing phones, people walking and etc. Program for reproduction such kind of noise was made by FIOH engineers themselves with help of different kind of radio program. /20./

FIGURE 5. Reproducer, which make noise during experiment.

For studying influence color to productivity two colors are used. They are neutral color (grey - blue) and bright color (bright green). When there is study in neutral conditions carpets, curtains, and plants do not present in interior design. Study with bright color condition are provided by adding curtains, posters, plants and changing color of all furniture (desks, chairs, scarp boards) and removable wall panels to interior with help of engineers of FIOH. Repeating measurements are provided twice with participants in one color condition. First time these measurements do when all environmental conditions meet requirements of standards. Second time measurements do when environmental conditions are realistic (sometimes they are outside the categories of standards) with or without subject design. After that study with another group of participants and in other interior design are provided in the same way. Then the interior design comparison is done between groups and designs. In every case there are different versions of tasks which participants have to do, but the order of versions is counterbalanced. /20./

For studying influence thermal conditions and indoor air quality (CO_2 level) to productivity there are several instruments which are located inside the room. CO_2 sensors are located in 2 opposite corners inside the room. During previous experiments was determined that 2 location for CO_2 sensors is enough, because concentration of CO_2 level is almost the same (there is no big deviations of CO_2.) in volume of the room. Thermal conditions inside the room are regulated automatically by special computer program. Therefore it is easy to design and maintain certain thermal conditions. Supply air to the volume of the room is distributed by 6 chilled beams. /20./

Productivity in each study is measured by using objective and subjective methods. Objective method is based on determining productivity by carry out different type of tasks (For example in pilot study /21/ are used N-back test, memorize test and some filler tasks.). All tasks are performed by participants in PC. Tasks require reading comprehension, learning and long-term memory. Usually tasks performance is divided into 2 parts. During the first part participants carry out simple tasks and adapt to indoor environment. During the second part participants perform different levels of difficulty of tasks and from this point productivity is started to be define. The levels of difficulty of tasks do not change during the time and always are in counterbalance. Productivity in N-back test is assessed like error rate, with which participant made errors in test, and reaction time, during which participant performed this task. Duration of experiment is 2 hours. Subjective method is based on assessment workload, indoor environment by man himself. Questionnaires and rating scale are usually used in this method. Using of subjective method help to understand how man himself senses in certain type of environment conditions. Using both methods give full information about work environment and productivity./21./

4.2. Investigation of indoor climate and productivity in a classroom

There are a lot of factors which affect productivity. In this small investigation only some of them have been studied. Factors which have been studied and how they were studied are presented in Table 7.

TABLE 7. Investigated factors of productivity in this study

Factors of productivity	How they were investigated?
Social	Not tested
Organization	Not tested
Personal	Some aspects were asked in the questionnaire
Environment	Some perceptions were asked Some parameters were measured

Environmental factor were studied more carefully than others. For its investigation and effect on productivity questionnaires and measurements were used.

To study the influence of indoor climate parameters to productivity there were 2 groups of students, who had the same course with one teacher. Both groups had an exam in the same room, but at different time. First exam started at 11.15 and finished at 13.30. Exam for the second group of students started at 13.45 and was finished 15.45. Therefore measuring period started in 25 minutes before the 1^{st} exam and was finished 30 min after the end of the 2^{nd} exam. Temperature, relative humidity and level of CO_2 inside the room were determined every 5 minutes by the help of 2 data loggers EBI 20 and device TSI IAQ Calc. Air flow rate was constant and was measured by Swema Air 125 Hood and Swema Air 300. After exam all students received questionnaires about indoor environment during the exam which they filled immediately. Influence of indoor climate parameters to productivity were assessed with exam results, questionnaires about indoor environment and measuring results.

4.2.1. Overview of the classroom

A classroom which was chosen for the study is located at the 2^{nd} floor in building A on the main campus of Mikkeli University of Applied Science. This building was built in 1995. Any reconstruction works of the building and ventilation system were not done during whole operational period. In fact there is 16 years old building with exhaust and supply mechanical ventilation system. The chosen room in building A profiles on providing lectures and some extra training courses. Figure 6 show the room where investigations have been done.

FIGURE 6. Investigated classroom.

The area of this room is 86 m^2. Ventilation inside the room is achieved with 3 supply air distribution devices (in Figure 8 they are blue), 5 exhaust air distribution devices (in Figure 8 they are red) and 1 supply air terminal device for air mixing (in Figure 5 it is black). Some of these devices were made by Stifab Company (1 supply air terminal unit) and others were made by Flaktwood (5 exhaust and 3 supply air distribution devices). Supply air deliver by ducts from air handling unit which is located inside the technical room in the attic of A – building. Locations of air distribution devices are presented in Figure 7.

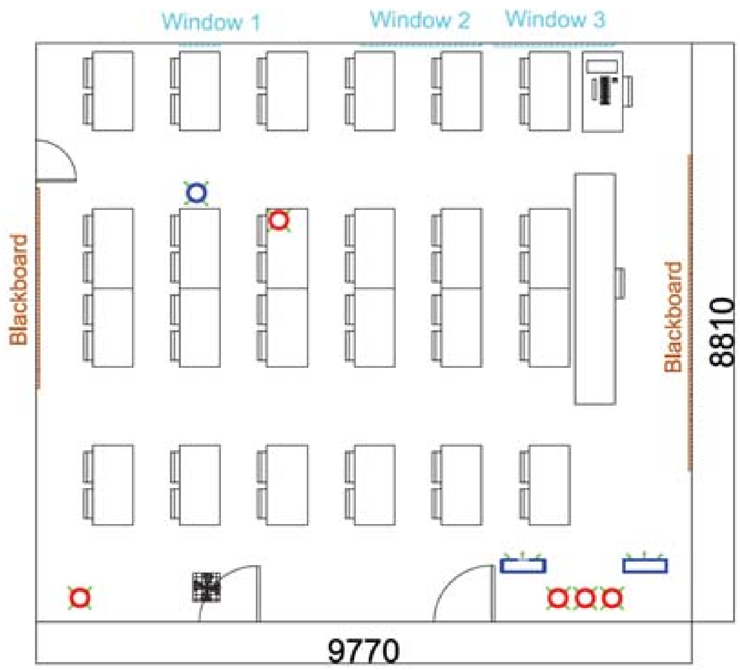

FIGURE 7. Locations of air distributions devices.

Thermal load during the period of occupancy are produced by radiators, projector, lamps, computer and occupants themselves.

4.2.2. Temperature and relative humidity

Temperature and relative humidity of air were measured by 2 data loggers EBI 20 (Figure 8) in two locations in the room at the height of 1.1 m. The locations of data loggers were in the center of the room and near the blackboard. The measuring period was 6 hours 25 minutes from 10.50 pm to 16.15 pm. The data loggers were programmed with PC and they measured temperature and humidity every 5 minutes. All the data was saved in the memory of data loggers. The data loggers were compared before the measuring started and the differences in the results are taken into account. The measuring results are modeled in Excel and are shown in the graphic form.

FIGURE 8. Data logger EBI 20 profiles for measuring temperature and relative humidity of air./22/

4.2.3. Carbon dioxide level

CO_2 concentration inside the room was measured by TSI IAQ Calc (Figure 9) at the height of 1.1. m in the center of the room. This location was chosen because concentration of CO_2 is almost equal in each point of the room and there is less possibility to breath in front of the sensor of the equipment. The measuring period was the same from 10.50 till 16.15. Every 5 minutes the value of CO_2 concentration was saved in the memory of this equipment. Then received data were read by program WinLog in PC. The measuring results also are modeled and are shown in the graphic form.

FIGURE 9. TSI IAQ Calc profiles for measuring CO_2 concentration. /23/

Also by help of TSI IAQ Calc level of CO_2 of outside air was measured at the same day. Before measuring of CO_2 level started TSI IAQ Calc was calibrated.

4.2.4. Location of measuring equipment

Locations of 2 data loggers EBI 20 and TSI IAQ Calc are presented in Figures 10 and 11. They are shown with red circles 1 and 2. In the point number 1 there are two measuring device TSI IAQ Calc and data logger and one more data logger is near blackboard. In Figure 11 there is presented real condition during the measuring period and in Figure 11 it is shown in schematic form. Also locations of air distribution devices are shown on Figure 11.

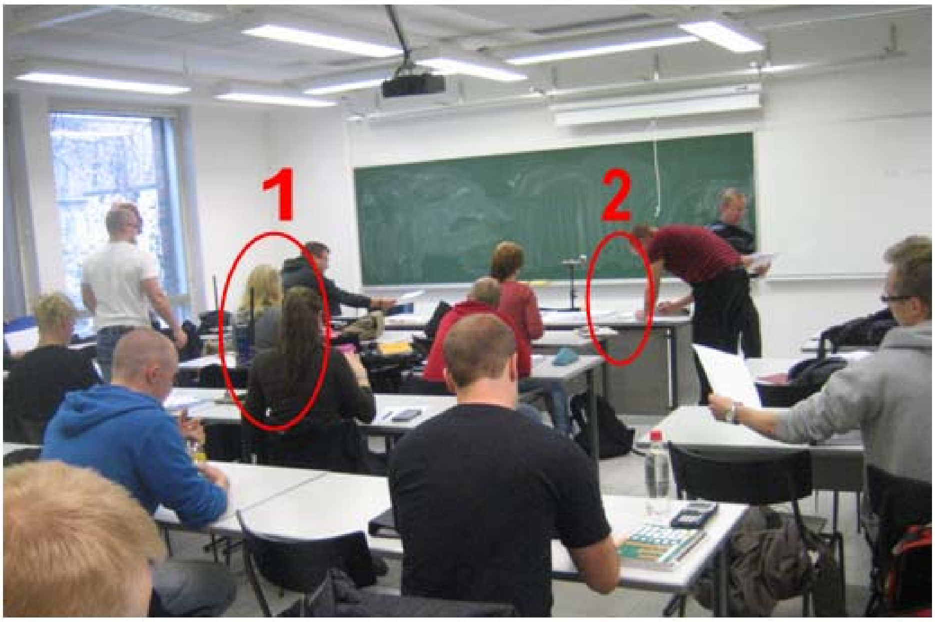

FIGURE 10. Location places of measuring devices during experiment.

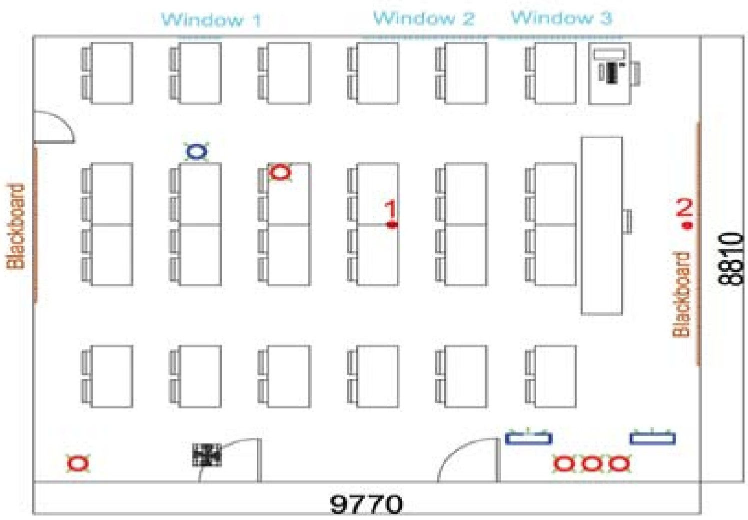

FIGURE 11. Schematic plan of the location places of measuring devices.

4.2.5. Measuring of air flow rate

Air flow rate was measured by Swema Air 125 Hood and Swema Air 300 twice before the 1st exam and after the 2nd exam. These equipments were chosen for measuring because of different configuration of supply and exhaust distribution devices. There are 5 exhaust and 1 supply air distribution devices, which are round, inside the class and air flow through these devices were measured by Swema Air 125 Hood. Swema Air 125 Hood was connected to air distribution device (Figure 12).

FIGURE 12. Measuring air flow by Swema Air 125 Hood.

By help of Swema Air 300 was measured pressure in supply air distribution devices, which have rectangular form. (Figure 13) Air flow rate through this device was calculated by formula.

FIGURE 13. Measuring pressure in supply air distribution device by Swema Air 300

4.2.6 Questionnaire

The base for making questionnaire was "FIOH questionnaire concerning indoor air quality on the workplace" /24/. It consists from some background information, questions about class environment, general information about course, which is specify productivity, present symptoms, that possibly could be connected with bad indoor air, and some past illnesses. Some questions about stress situation before exam, sleeping well at last night and time for studying before exam were examined in questionnaire, because of success in an exam is affected by many personal factors. The total number of participants was 41 persons. In the first group there were 18 persons and in the second group 23 persons. Example of the questionnaire with all questions is shown in appendix 1.

V. RESULTS

5.1. Studies at the Finnish Institute of Occupational Health

During the study about work performance and indoor climate which was done by scientists of Finnish Institute of Occupational Health 21 female and 14 male subjects were tested in different thermal conditions (21 ^{0}C, 25 ^{0}C and 29^{0}C) during 3 days. The main aim of the study was to assess how thermal conditions affect cognitive performance and thermal comfort. For this study open plan office was built in the laboratory. Each work place is separated from other workplaces by screens with 1.30 height and contains a table, computer, chair and folder with instructions. /21/

Each experiment lasted for 2 hours. The first 30 minutes was used for person's acclimatization to thermal conditions and for practicing tasks. After an hour productivity was measured objectively by performance of 2 cognitive tasks (N-back task and memory task) and was measured subjectively twice (in the beginning and end of the experiment) by filling questionnaire. N-back task is a task where 4 set of 100 letters on a computer screen are appeared (1 letter in 1 second) and participant have to respond to each letter by clicking button "YES" or "NO" on his mouth according to instructions which were given by tutor. During performance of N-back task its performance increase with each set. For example, in first set participant should respond on appearing letter "X" on his computer screen by clicking "YES" or "NO": in the second task participant should identify presented letter in the task with the one letters which will be appeared during the performance of this task in the screen of computer (one trial back); in the third and fourth tasks amount of letters between first letter and following letters, which participant have to respond, increase to two and three trial back. During performance of this task reaction time and amounts of errors which participants have done are measured. And what about memory task participants got text about specific theme, which they should read during 5 minutes and memorize facts. After 20 minutes participant should write in 5 minutes all fact about this specific theme which he memorized in Word document. And then amount of correct facts will be counted. /21/

Questionnaires were used to assess thermal comfort, symptoms, motivation and disturbance which were caused by light, noise and odors.

During this experiment was determined that high temperature was only one factor which disturbed participants. High temperature affected on task performance in N-back task. When air temperature was equal 29 ^{0}C there were more errors than when air temperature was 21 ^{0}C or 25 ^{0}C. Significant difference between task performance in 21^{0}C and 25^{0}C was not identified. Temperature did not affect memory task. Females sense thermal conditions between 21^{0}C and 25 ^{0}C significantly colder than males, even if they have the similar clothes. /21/

5.2. Results of investigation in a classroom

Measuring of indoor climate factors and indoor air quality (CO_2 level) were done 04.11.11 in a classroom. Results of measuring are modeled in Excel (Appendix 2) and are shown in graphic form below.

5.2.1. Temperature and relative humidity of air

The temperature of air increased during almost the whole measuring period. However, temperature in the center of the classroom was a little higher than near the blackboard. Comparing results from two data loggers fluctuation of values of temperature was approximately ± 0,3 ^{0}C at the same time. Therefore the temperature of air was roughly equal in each part of the classroom. At the beginning of measurements temperature of air was 20.1 ^{0}C – 20,2 ^{0}C (it was minimum value of air temperature during measuring period) and at the end it 24,7 ^{0}C - 24,9 ^{0}C as you can see from Figure 14. The maximum value of temperature was 26,5 ^{0}C at 15.40. This was registered by data logger which location was in the center of the classroom. Time period of temperatures' measuring was divided into two periods. Duration of each period coincided with duration of each exam. In Figure 14 these periods are shown with red lines. The average temperature during the 1st exam (1st period of measuring) was 22,4 ^{0}C and during the 2nd exam (2nd period of measuring) was 25,2 ^{0}C.

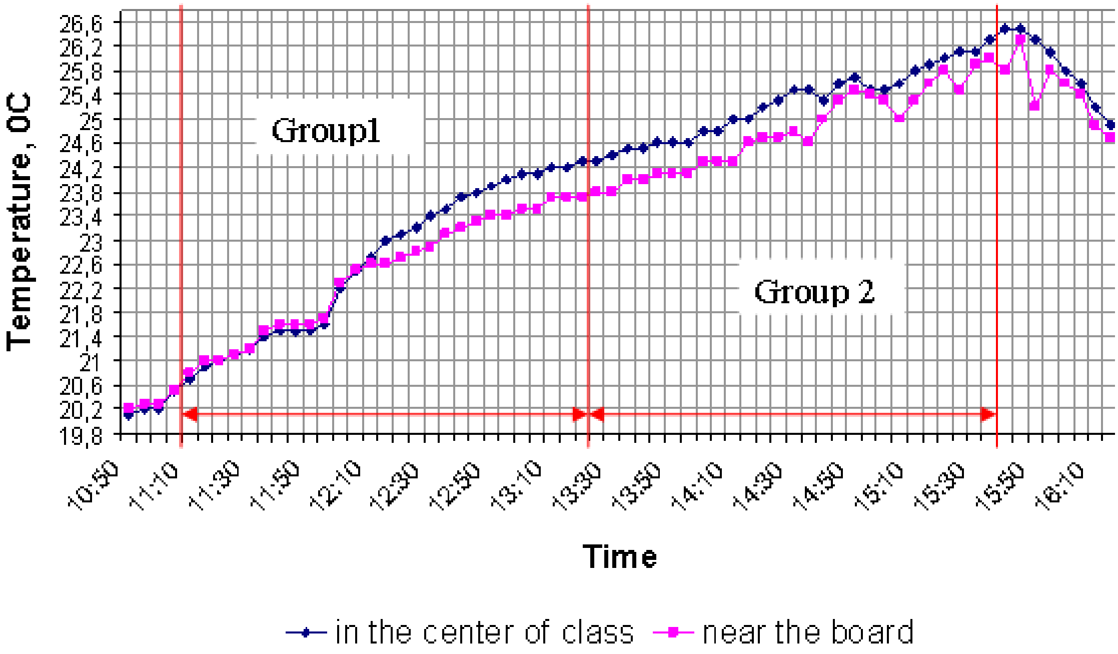

FIGURE 14. Temperature measurements during exam.

The same situation as with temperature we can see with relative humidity of air. During whole measuring time values of relative humidity in the center was a little more than near the blackboard. But difference between readings from data loggers was not so significant, therefore the relative humidity of air was roughly equal in each part of the classroom. Average value of relative humidity during whole measuring period is 38,7 %RH. At the beginning of measurements relative humidity of air was 40 %RH – 40,2 %RH. Then it started to increase fast. The first maximum value of relative humidity 44 RH% was achieved at 11.05. After that relative humidity decreased slowly to the first minimum values 37 %RH (data logger in the center of the classroom) and 36 %RH (data logger near the blackboard) at 12.05. During this period of measurements readings from data loggers had difference of ≈ 1% RH between each other in comparing with other measuring periods. Then it increased until 37,7 RH% and got stabile from 12.25 till 14.45. At this period of measurements there are small fluctuations between two data loggers' readings (± 0,1 %RH). From 14.50 till 15.30 relative humidity started to increase again and there we can see the second maximum value 42,7 RH% at 15.30. After that it decreased during 15 minutes and were achieved 35,9 %RH (data logger in the center of the classroom) and 34,9 %RH (data logger near the board). It was the second minimum value of relative humidity at 15.45. At the end of measuring period value of relative humidity was 36.9 %RH – 37,2 %RH. More detailed you can see it in Figure 15.

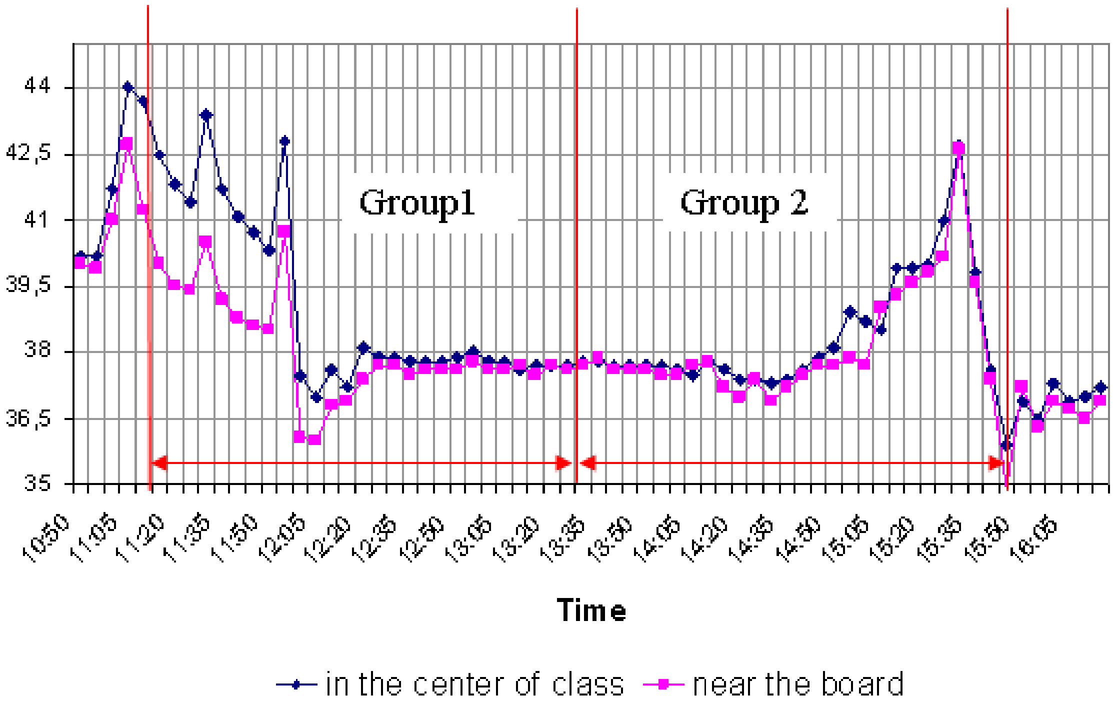

FIGURE 15. Relative humidity measurements during exam.

5.2.2. Air flow and CO_2 level

Concentration of CO_2 increased slowly during whole measuring period. The minimum value of it was 450 ppm at the beginning of experiment and the maximum value was 1325 ppm at 16.05 (almost in the end of measuring period). The average level of CO_2 inside the room was 983 ppm during whole measuring period. The average CO_2 for the 1st exam was 769 ppm and for the 2nd exam was 1197 ppm. More detailed measuring of CO_2 is presented in graphic form in Figure 16 and in table in Appendix 2.

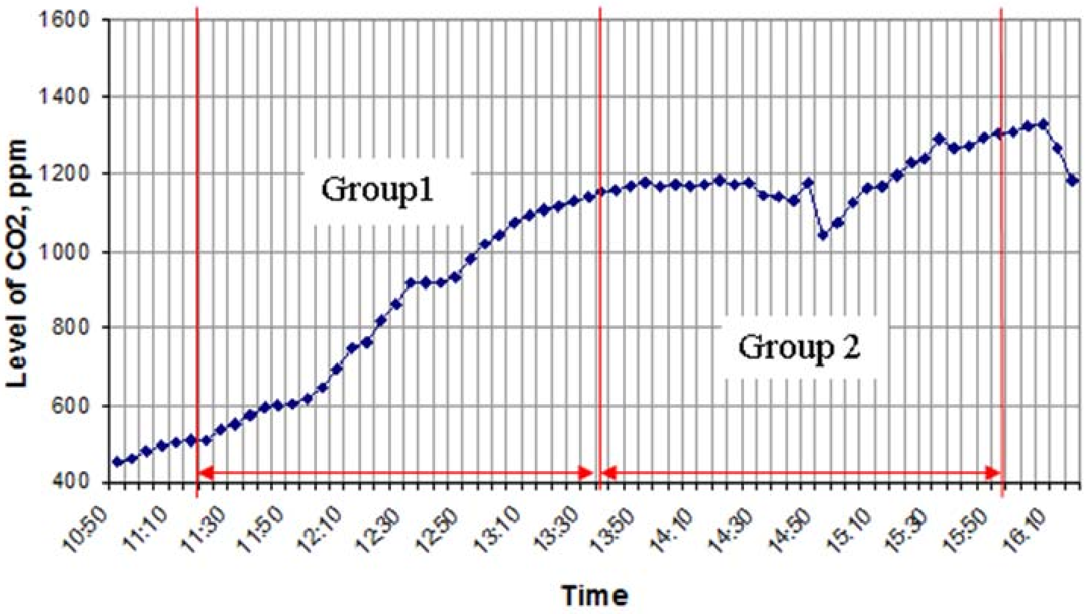

FIGURE 16. Level of CO_2 during measuring period.

As mentioned earlier, ventilation inside the classroom is provided by help of 5 exhaust air distribution devices and 3 supply air distribution devices and 1 supply air terminal unit. Measuring of air flow rate was made twice: before 1st exam and after 2nd exam. Significant difference between results of these 2 measurements was not found. Results of air flow rate measurements through these devices are shown in Table 8.

TABLE 8. Results of air flow rate measurements

Number of air distribution device	Size, form	Measuring equipment	Kv	Δp_{m1}, Pa	q_{v1}, dm^3/s	Δp_{m2}, Pa	q_{v1}, dm^3/s
Extract air							
1	KSO 160, round	Swema Air 125 Hood	-	-	26	-	25,8
2	KSO 160, round	Swema Air 125 Hood	-	-	22,4	-	22,8
3	KSO 160, round	Swema Air 300	4,8	34,3	28,1	33,1	27,6
4	KSO 100, round	Swema Air 300	2,1	58,1	16	56,6	15,8
5	KSO 100, round	Swema Air 125 Hood	-	-	21,3	-	22,0
Total					113,8		114
Supply air							
1	DYVB 100, rectangular	Swema Air 300	20	15,6	79		81
2	DYVB 100, rectangular	Swema Air 300	20	2,2	29,7		27,4
3	KSO 160, round	Swema Air 125 Hood	-	-	11,2	-	11,0
4	Stifab 200 rectangular	Swema Air 125 Hood	-	-	8,7	-	9,0
Total					128,6		128,4

According to Classification of indoor climate 2008 outdoor air flow determine by formula for achieving S2 category of indoor environment: outdoor air flow = 4 dm^3/s*86 m^2 + 6 dm^3/s* 50 person = 644 dm^3/s.

During measuring period there were 18 persons in the 1st group and 23 persons in the 2nd group. According to this fact supply air flow rate per person for the 1st group was 7,1 dm^3/s

per person and for the 2nd group was 5,6 dm^3/s per person. Exhaust air flow rate for the 1st group was 6,3 dm^3/s per person and for the 2nd group was 5,0 dm^3/s per person. According to D2 outdoor air flow is 6 dm^3/s per person.

5.2.3. Questionnaire

The year of birth of students who took part in the exam varies from 1963 till 1990 (most of them were born in 1989-1990). There are only 2 persons who smoke. Almost all participants are male (there are only 3 girls in 2 studying group). Most students found this lecture course interesting enough, but too difficult. Average value of hours which students spent for studying before exam is 5 hours 12 minutes. (For the 1 group this value is equal approximately 6 hours: for the second group is 5 hours). Most participants did not have problem with their health in the past and right now too. Before exam almost half of participants felt stress. Table 9 shows results.

TABLE 9. General information from questionnaire and measurements

		Group 1	Group 2
Number of students		18	23
Average grade		2,08	2,25
Did you sleep well?		9 persons gave positive answer	14 persons gave positive answer
Stress before exam		8 persons gave positive answer	9 persons gave positive answer
Do you find the course interesting?	Yes	1 person	6 persons
	Sometimes	12 persons	6 persons
	No	5 persons	11 persons
Was this course difficult?		16 persons gave positive answer	20 persons gave positive answer
How many hours did you study before exam?		average 6 h	average 5 h
Measurement (average values)	air temperature, ^0C	22,4	25,2
	CO_2 level, ppm	769	1197
	air flow rate, dm^3/s per person	7,1	5,6

The first group of participants (18 students) was satisfied with the classroom environment. There are only two disturbance factors which some of participants identified. They are light (1 participant was not satisfied) and stuffy "bad" air (answer of 6 participants). Another situation was with classroom environment for the 2nd group of participants (There are 23 persons). Participants from this group sensed that it was very high temperature of indoor air (8 persons such type of answer), stuffy "bad" air (4 answers) and dry air (3 answers Other factors of class environment disturbed participants of 2 groups sometimes or not at all. Full information about class room environment is presented in Figure 17. Scale in this Figure is in percentage form from 0% to 60 %. Per cent means how many persons in per cents who are dissatisfied of one or more indoor climate parameters in the classroom during the experiment.

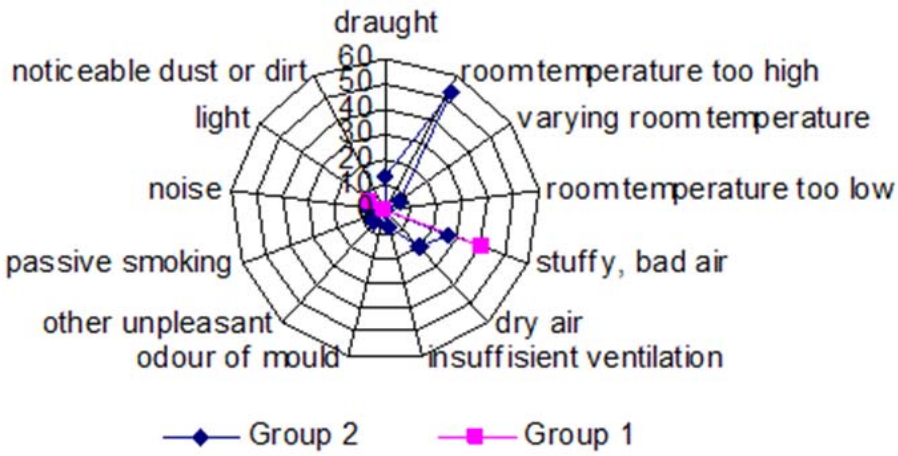

FIGURE 17. Classroom environment.

During the exam symptoms like fatigue, feel heavy – headed were sensed by participants of 2 groups. Students mentioned that the reason of these symptoms may be indoor climate. But the 2nd group sensed except these two other symptoms difficult concentrations, shortness of breath, hands dry, itching, red skin. Persons who sensed such type of symptoms in general did not know what the reason of them was. More detailed information about presented symptoms during the exam is presented in Figure 18.

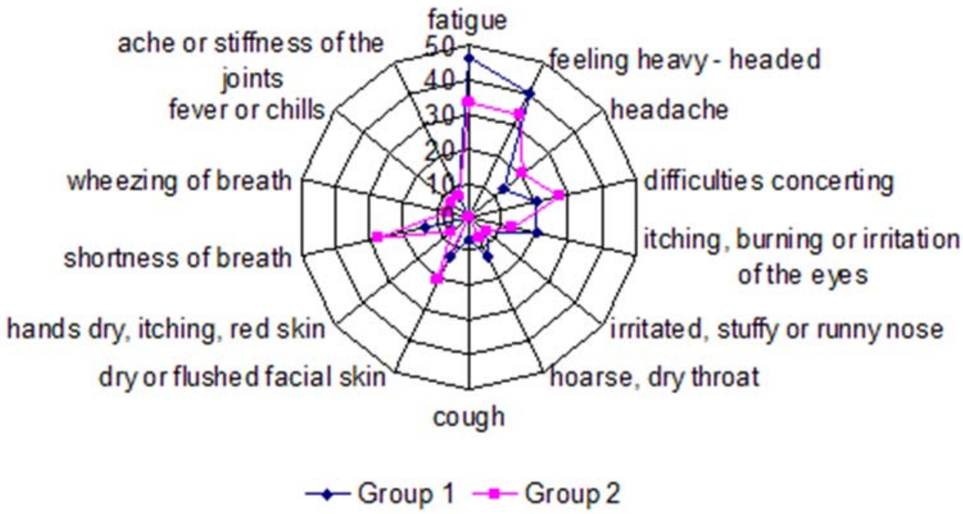

FIGURE 18. Symptoms, which participants sensed during exam.

In questionnaire there were so called "open questions", where students can write some comments about classroom environment and course. Some students wrote here that course was too difficult and time for studying before exam did not affect exam results. Other students (from the 2nd group) mentioned that temperature of air was too high and level of CO_2 was too high and it could be a reason of getting "bad" results at the exam.

5.2.4. Productivity

Exam was divided in 2 parts. During the first part of exam using materials like notes, books and so on was not allowed. In this part of exam teacher checks how students know theoretical information and understand all things which are related with his lecture. During the 2nd part students can use all material. In this case teacher checks how students can apply their knowledge in practice. Productivity of students was estimated by how many people will pass and what will be the average mark of the group.

The exam was successfully passed by 68 % students from these 2 groups. As you can see from Table 12 the average value of marks which students from the 1st group get is 2,08, for the 2nd group this value is equal 2,25. The average result from the 2nd group is more than the 1st group has. More detailed information about exam results are presented in Table 10.

TABLE 10. Exam results

Group number	Total amount of students	Number of persons who passed	Number of people who did not pass	Marks*	Number of students who got this marks
1	18	12	6	1	4
				2	4
				3	3
				4	1
				5	0
Average result of marks.					2,083
2	23	16	7	1	4
				2	5
				3	6
				4	1
				5	0
Average result of marks.					2,25

* Transcription of the scale of records, which was used like evaluation criteria for students' knowledge: 1 - satisfactory, 2 - highly satisfactory, 3 - good, 4 - very good, 5 - excellent.

VI. DISCUSSION

According to results which were received in this thesis work by measuring and interviewing participant with help of questionnaires it can be possible to indicate the influence of some factors of indoor climate and indoor air quality (CO_2 level) to productivity. But firstly general information from literature review and obtained results from FIOH study about productivity will be elaborate.

Literature review, which was done in the first part of thesis, shows that temperature, air flow rate, level of CO_2 affect productivity. Fluctuation of air temperature above or under 22 ^{0}C decreases productivity /15, p.24/. Comfortable temperature is 22 ^{0}C. For every 2 times increasing air flow rate increase productivity /17, p.636/. Productivity can be reduced from 5%

to 15% if there is poor air quality /16, p.13/. Concentration of CO2 above 600 ppm is associated with decreasing indoor air quality /6, p.1608/.

Scientists from FIOH from their study determined that high temperature (29 ^{0}C) affected on task performance if tasks related with reaction and attention. Temperature did not affect memory task. Participants did more errors if air temperature was equal 29 ^{0}C than when air temperature was 21 ^{0}C or 25 ^{0}C. Significant difference between task performance in 21^{0}C and 25^{0}C was not identified. Females sense thermal conditions between 21^{0}C and 25 ^{0}C significantly colder than males, even if they have the similar clothes. /21./

Measurements of air temperature and relative humidity were started in 25 minutes before 1st exam at 10.50. At this time the value of temperature, relative humidity, CO_2 level were minimum, because before the exam there was not any activity inside the class room. Supply air flow rate was constant all the time, so influence of it was not taken into account. Therefore combination action of relative humidity, temperature and CO_2 level might have some effect to productivity.

Examination of the 1st group of students was started at 11.15. Temperature was 20,9 ^{0}C and relative humidity 42,5 %RH at this moment. Then temperature of air started to increase and at the end of exam it achieved 24,4 ^{0}C. Relative humidity of air slowly decrease all the time and at the end it was 37,7 %RH. That is why students from the first group indicated that air is stuffy at the end of exam. Another reason of stuffy air it was a level of CO_2. At the beginning of the exam it was 450 ppm and then it increased all the time till the end of exam. At the moment when exam finished level of CO_2 achieved 1200 ppm. During exam all windows and doors were closed, so there was not possibility to add some “fresh” air from hall to class room. It is not surprising that closer to the end of exam student started to sense such type of symptoms like fatigue and feeling heavy headed. Of course the reason of such type of sense may be another. For example stress before exam, bad sleeping during the previous night or some other factors which are not related with indoor environment of classroom.

Exam for the 2nd group of students started at 13.30 immediately after 1st group finished their exam. It is important point out that classroom air did not have possibility to be refreshed. Therefore students from this group started the exam in “bad” indoor climate. During the exam such parameters as temperature and CO_2 level increased all the time. At the end of the exam they achieved 26,5 ^{0}C and 1294 ppm. It has been shown that the productivity decreases by 2

% for every degree of Celcius that is above 25 °C. The temperature in the classroom was at the end of the exam so high that this is worth mentioning. Relative humidity was constant 37,7 %RH during 1 hour 30 minutes from beginning of the exam, then it started to increase and at 15.30 it achieved maximum value 42,7 %RH. After the end of the exam temperature and relative humidity decreased, but CO_2 level continued to increase during 20 minutes and then started to decrease. Decreasing parameters of indoor environment is related with decreasing amount of students who stayed in the classroom after the end of the exam. According to results of questionnaires students from the 2nd group were not satisfied with the classroom environment. They indicated more factors which disturbed them during the whole exam. The factors were too high air temperature, stuffy and dry air. The same situation was with symptoms which presented during the exam. The most pronounced symptoms were fatigue, feeling heavy-headed, headache, dry or flushed skin and shortness of the breath. More than half of the students from the second group sensed them. Based on study of Seppänen, Fisk, Lei, "Effect of temperature on task performance in office environment" /15/ we can conclude that thermal conditions for 2nd group reduced productivity of the group on 3 % (value of average air temperature was 25,4 ^{0}C) and for the 1st group thermal conditions (value of average air temperature was 22,2 ^{0}C) did not reduce productivity.

If we compare results from measurements and requirements for indoor climate parameters which are in the guidelines thermal conditions were not unacceptable. After 40 minutes from the beginning of the exam for the 1st group air temperature started to exceed requirement values and until the end of the 2nd group exam it rose. During whole period of measuring relative humidity did not exceed recommended values of two countries for buildings where learning process is. CO_2 level achieved 1141 ppm closer to the end of the first group's exam, it met requirement, which give D2 /12/(recommended value 1200 ppm). CO_2 level for the 2nd group achieved maximum value in the middle of the exam and then continue to rise. Closer to the end of the 2nd group's exam CO_2 level exceeded recommended value on 100 ppm. Air flow rate per person for both group met requirements of D2 /12/. Therefore it can be said that indoor air quality and indoor climate for the second group was unacceptable from the beginning of the exam. (Temperature of air was 24 ^{0}C and CO_2 level was close to maximum value.) For the fist group indoor climate and indoor air quality did not meet requirement close to the end of exam.

From results which were received in this thesis we can see how combination of indoor environment factors affects productivity. Of course indoor environment was a reason which affects productivity of students as a result the grades which students got and amount of students who did not successfully pass exam.

According to obtained measurement results the exam result of the first group should be better (higher) than the second group, because they had exam in better indoor air quality and thermal conditions. But in fact exam result of the 2nd group a little higher than the first group. We can conclude that indoor environment was probably not decreasing productivity of the second group, which got better grades than the first group despite of the fact that the indoor air quality was worse during their exam. Therefore it can be said that students (adults) less sense fluctuation of indoor climate /19, p.23/. And in turn in short time period there was not significant influence of indoor climate to students' performance, and as result, to exam grades, because the reason of it that tasks which students did during the exam related with memory-type of tasks. As mentioned earlier, thermal conditions do not affect such type of tasks /21/.

One of a reason of better performance of the 2nd group was time for studying before exam, but questionnaire showed that students from this group spent less time for studying before exam than first group. It could be caused of better understanding educational material, which teacher had given during the classes. Probably another reason of high performance of the second group was good relationships or connections between students (social factor). Good students explained lectures material for students, who are not good in understanding this class. Moreover reasons were common progress in study of the second group or motivation of students to get good grades (personal factors). Almost half students (from each group) had stress before exam and did not sleep well, also it could be a reason of decreasing performance in two groups.

For increasing productivity it is not enough to design and maintain good indoor environment it gets clear after small investigation, which was done in this thesis. For better understanding how productivity can be increased we should do repeated studies and take into account other 3 factors like social (relationship with other people), organization (management role, organizational structure, workplace), personal (career achievement, home/work interesting and so on).

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APPENDIX 1 (1)

Example of questionnaire about indoor environment, which participants of this study filled after exam.

QUESTIONNAIRE ABOUT INDOOR ENVIRONMENT

Background factors

Year of birth		sex
Do you smoke?	☐ no ☐ yes, daily	☐ male ☐ female

This questionnaire concerns your indoor climate and possible symptoms you may be experiencing. This questionnaire aims at surveying the situation during this exam.

Classroom environment

Have any of the following factors disturbed you at your working place during the exam?

3 = very much	1 = not at all		
	1	2	3
draught	☐	☐	☐
room temperature too high	☐	☐	☐
varying room temperature	☐	☐	☐
room temperature too low	☐	☐	☐
stuffy “bad” air	☐	☐	☐
dry air	☐	☐	☐
insufficient ventilation at your workplace	☐	☐	☐
odour of mould	☐	☐	☐
other unpleasant odours	☐	☐	☐
passive smoking	☐	☐	☐
noise	☐	☐	☐
light that is dim or causes glare and /or reflections	☐	☐	☐
noticeable dust or dirt	☐	☐	☐

Are there other factors which disturb you?	☐ yes	☐ no
What are they?		

About the course

	yes	no	may be
Do you find this class interesting?	☐	☐	☐
Is the course difficult?	☐	☐	☐
Have you usually attended the lectures?	☐	☐	☐

APPENDIX 1 (2)

Was the exam difficult?	☐	☐	☐
How many hours did you study before exam?			

Present symptoms

During the exam have you had any of the following symptoms?

			If YES: Do you believe that it is due to your work environment?		
	yes	no	yes	no	do not know
fatigue	☐	☐	☐	☐	☐
feeling heavy - headed	☐	☐	☐	☐	☐
headache	☐	☐	☐	☐	☐
difficulties concerting	☐	☐	☐	☐	☐
itching, burning or irritation of the eyes	☐	☐	☐	☐	☐
irritated, stuffy or runny nose	☐	☐	☐	☐	☐
hoarse, dry throat	☐	☐	☐	☐	☐
cough	☐	☐	☐	☐	☐
dry or flushed facial skin	☐	☐	☐	☐	☐
hands dry, itching, red skin	☐	☐	☐	☐	☐
shortness of breath	☐	☐	☐	☐	☐
wheezing of breath	☐	☐	☐	☐	☐
fever or chills	☐	☐	☐	☐	☐
ache or stiffness of the joints	☐	☐	☐	☐	☐

Stress is a situation in which person feels anxious, restless, nervous or distressed or has difficulties sleeping because he or she cannot stop thinking of things.

Did you sleep well before exam?	☐ no	☐ yes
Have you experienced such symptoms of stress before exam?	☐ no	☐ yes
If YES: Do you think that it will influence to your exam result?	☐ no	☐ yes

Past / present diseases/ symptoms

Have you got problems with health last time?	☐ no	☐ yes
Have you ever had asthmatic symptoms?	☐ no	☐ yes
Have you ever had allergic reaction?	☐ no	☐ yes

Further comments

APPENDIX 2(1)

Results of measurements temperature, relative humidity of air and CO_2 level inside room 231 A.

№	Time, hh:mm	Data logger 1 (in the center of the room)		Data logger 2 (in front of the blackboard in the room)		TSI IAQ Calc (in the center of the room)
		Temperature, ^0C	Relative humidity, RH%	Temperature, ^0C	Relative humidity, RH%	CO_2 level, ppm
Group 1						
1	10:50	20,1	40,2	20,2	40	450
2	10:55	20,2	40,2	20,3	39,9	461
3	11:00	20,2	41,7	20,3	41	480
4	11:05	20,5	44	20,5	42,7	494
5	11:10	20,7	43,7	20,8	41,2	503
6	11:15	20,9	42,5	21	40	510
7	11:20	21	41,8	21	39,5	507
8	11:25	21,1	41,4	21,1	39,4	535
9	11:30	21,2	43,4	21,2	40,5	551
10	11:35	21,4	41,7	21,5	39,2	572
11	11:40	21,5	41,1	21,6	38,8	592
12	11:45	21,5	40,7	21,6	38,6	597
13	11:50	21,5	40,3	21,6	38,5	603
14	11:55	21,6	42,8	21,7	40,7	617
15	12:00	22,2	37,5	22,3	36,1	647
16	12:05	22,5	37	22,5	36	692
17	12:10	22,7	37,6	22,6	36,8	746
18	12:15	23	37,2	22,6	36,9	764
19	12:20	23,1	38,1	22,7	37,4	818
20	12:25	23,2	37,9	22,8	37,7	861
21	12:30	23,4	37,9	22,9	37,7	919
22	12:35	23,5	37,8	23,1	37,5	916
23	12:40	23,7	37,8	23,2	37,6	916
24	12:45	23,8	37,8	23,3	37,6	932
25	12:50	23,9	37,9	23,4	37,6	977
26	12:55	24	38	23,4	37,8	1018
27	13:00	24,1	37,8	23,5	37,6	1040
28	13:05	24,1	37,8	23,5	37,6	1074
29	13:10	24,2	37,6	23,7	37,7	1093
30	13:15	24,2	37,7	23,7	37,5	1105
31	13:20	24,3	37,7	23,7	37,7	1113
32	13:25	24,3	37,7	23,8	37,6	1130
33	13:30	24,4	37,8	23,8	37,7	1141

APPENDIX 2 (2)

Group 2						
34	13:35	24,5	37,8	24	37,9	1154
35	13:40	24,5	37,7	24	37,6	1160
36	13:45	24,6	37,7	24,1	37,6	1166
37	13:50	24,6	37,7	24,1	37,6	1178
38	13:55	24,6	37,7	24,1	37,5	1169
39	14:00	24,8	37,6	24,3	37,5	1172
40	14:05	24,8	37,5	24,3	37,7	1169
41	14:10	25	37,8	24,3	37,8	1173
42	14:15	25	37,6	24,6	37,2	1179
43	14:20	25,2	37,4	24,7	37	1174
44	14:25	25,3	37,4	24,7	37,4	1175
45	14:30	25,5	37,3	24,8	36,9	1143
46	14:35	25,5	37,4	24,6	37,2	1138
47	14:40	25,3	37,6	25	37,5	1131
48	14:45	25,6	37,9	25,3	37,7	1176
49	14:50	25,7	38,1	25,5	37,7	1040
50	14:55	25,5	38,9	25,4	37,9	1071
51	15:00	25,5	38,7	25,3	37,7	1124
52	15:05	25,6	38,5	25	39	1162
53	15:10	25,8	39,9	25,3	39,3	1169
54	15:15	25,9	39,9	25,6	39,6	1195
55	15:20	26	40	25,8	39,8	1226
56	15:25	26,1	41	25,5	40,2	1239
57	15:30	26,1	42,7	25,9	42,6	1290
58	15:35	26,3	39,8	26	39,6	1265
59	15:40	26,5	37,6	25,8	37,4	1272
60	15:45	26,5	35,9	26,3	34,9	1294
61	15:50	26,3	36,9	25,2	37,2	1303
62	15:55	26,1	36,5	25,8	36,3	1309
63	16:00	25,8	37,3	25,6	36,9	1321
64	16:05	25,6	36,9	25,4	36,7	1325
65	16:10	25,2	37	24,9	36,5	1264
66	16:15	24,9	37,2	24,7	36,9	1182