Indoor Air Quality
in junior high schools in Reykjavik

January 2009

By

Vanda Úlfrún Liv Hellsing

UNIVERSITY OF ICELAND
M.Sc. THESIS IN ENVIORNMENTAL AND NATURAL RESOURCES
SCHOOL OF ENGINEERING AND SCIENCES
FACULTY OF LIFE AND ENVIRONMENTAL SCIENCES

“ In the construction of buildings, whether for public purposes or as dwellings, care should be taken to provide good ventilation and plenty of sunlight…schoolrooms are often faulty in this respect. Neglect of proper ventilation is responsible for much of the drowsiness and dullness that…make the teacher’s work toilsome and ineffective.”

-Health Reformer, 1871

I here by declare that I am the author of this thesis and it has not been submitted, partially or as a whole, for examination before.

Vanda Úlfrún Liv Hellsing, kt. 210680-5199

Abstract

Apart from the home, the school environment is probably the most important indoor environment for children and adolescents. Children spend as much as 80-90% of their indoor time either at school or at home. In Iceland, school, and thereby its environment, is compulsory for children between 6-16 years of age. Several recent studies have concluded that the environment at school may affect the pupils' respiratory health and learning ability. The this study was to study the indoor air quality in junior high schools in Reykjavik with particular emphasis on levels of PM_{10} and ultra-fine particles(UFP). Measurements were performed in 74 classrooms in 15 public junior high schools in the Reykjavik city area. All the classrooms were occupied during measurements by children in 8th and 9th grade (13-15 years old) and their teachers. Levels of CO_2, PM_{10}, UFP, temperature and RH% were measured in each classroom. An environmental inspection was also performed in each classroom,where the fleece factor (m^2/m^3), shelf factor (m/m^3), number of persons per room volume (pers/m^3), personal outdoor air supply rate (L/s/person) and the air exchange rate (ac/hour) were measured and calculated. Levels of PM_{10} and UFP were measured immediately outside the 15 studied schools. A Kendall's tau-b correlation analysis was used to study potential correlations within and/or between indoor climatic and environmental factors. The same method was used to study correlations within and/or between levels of indoor PM_{10} and UFP, and outdoor levels of PM_{10} and UFP. Results were compared with those from comparable school studies in Taiyuan, China and Uppsala, Sweden. The results indicate a need for improvement in the indoor climate in junior high schools in Reykjavik. Mean levels of CO_2 in the classrooms were 1510 ppm, and significantly above the recommended max limit value of 1000 ppm. In approximately 87% of the schools mean CO_2 levels lay above the recommended max limit. The mean level of PM_{10} in the classrooms was 40.4 µg/m^3, ranging between 6.3-162 µg/m^3. The mean level of UFP in the classrooms was 8961 particles/cm^3 and ranged between 890-92692 particles/cm^3. The mean relative air humidity (RH%) in classrooms was 33%, with a range between 16.9-54.7%. The mean room temperature in the classrooms was 21.7 °C, ranging between 18.3-25.5°C. The mean temperature in each school ranged between 20.4-22.8°C. The mean number of persons per cubic meter in the classrooms was 0.104 pers/m^3, and ranged between 0.02-0.17 pers/m^3. The mean personal outdoor air supply rate in the classrooms was 4.7 L/s/person, and ranged between 1.5-39.7 L/s/person. Approximately 87% of the schools had a mean personal outdoor air supply rate below the recommended minimum rate (8 l/sperson). The mean air exchange rate in the classrooms was 1.6 ac/hour, and ranged between 0.5-17.2 ac/hour. All of the schools had an air exchange rate that exceeded the recommended minimum (0.8 ac/hour). The results showed no significant correlation between measured outdoor levels of PM_{10} and UFP and indoor levels of PM_{10} and UFP in the classrooms.

Ágrip

Utan heimilisins er skólaumhverfið mikilvægasta inniumhverfi barna og unglinga. Börn eyða allt að 80-90% af innitíma sínum á heimilum sínum og í skólanum. Nokkrar nýlegar rannsóknir hafa staðfest að skólaumhverfið er mikilvægur þáttur fyrir heilbrigði öndunarfæra og námsgetu nemenda. Markmiðið með þessari rannsókn er að skoða loftgæði innandyra í skólastofum í grunnskólum Reykjavíkur, með áherslu á styrk svifryks (PM_{10} og UFP). Mælingar fóru fram í 74 skólastofum í 15 grunnskólum í Reykjavík. Allar skólastofurnar voru í notkun við kennslu í 8., 9., og 10. bekkja þegar mælingar fóru fram. Í hverri stofu var mældur styrkur CO_2, PM_{10}, UFP ásamt hitastigi og raka (RH%) . Gerð var úttekt á umhverfi skólastofanna þar sem efnishlutfall (m^2/m^3), hilluhlutfall (m/m^3), nemendahlutfall ($pers/m^3$), einstaklingsbundin endurnýjun fersklofts (L/s/person) og loftskipti (lofskipti/klst) voru mæld og reiknuð út. Styrkur svifryks (PM_{10} og UFP) var mældur utandyra við alla 15 skólanna. Notuð var Kendall's tau-β sambandsgreining til að kanna sambandið innan og/eða á milli loftþátta innandyra og umhverfisþátta innandyra. Sama aðferð var notuð til að mæla hvort samband væri innan og/eða á milli styrks PM_{10} og UFP innandyra og utandyra. Niðurstöður mælinganna voru svo bornar saman við niðurstöður sambærilegra rannsókna sem framkvæmdar voru í Taiyuan í Kína Taiyuan, Kína og Uppsölum í Svíþjóð. Niðurstöðurnar bentu til að bæta megi inniloftslag í grunnskólum Reykjavíkur. Meðal styrkur CO_2 í skólastofunum var 1510 ppm, sem er fyrir ofan hámarks viðmiðunar gildi CO_2 (1000 ppm). Um það bil 87% skólanna voru með meðalgildi CO_2 fyrir ofan hámarksgildið sem mælt er með. Meðalstyrkur PM_{10} í skólastofunum var 40.4 $\mu g/m^3$, á bilinu 6.3-162$\mu g/m^3$. Meðal styrkur UFP í skólastofunum var á bilinu 890 - 92692 agnir/cm^3, með meðalgildið 8961 agnir/cm^3. Meðal rakastig í skólastofunum var á bilinu 16.9 - 54.7%, með meðalgidið 33%. Meðalhitastigið í skólastofunum var á bilinu 18.3-25.5 °C, með meðalgildið 21.7°C. Meðal hitastig í hverjum skóla var á bilinu 20.4-22.8°C sem er innan marka þess hitastigs sem mælt er með fyrir almenna vellíðan folks, sem er 20-24°C. Meðal fjöldi nemenda á hvern rúmmetra í hverri skólastofu var á bilinu 0.02-0.17 $pers/m^3$, með meðalgildið 0.104 $pers/m^3$. Meðal ferskloftsmagn í hverri skólastofu var á bilinu 1.5-39.7 L/s/person, með meðalgidið 4.7 L/s/person. Um það bil 87% af skólum voru með meðal ferskloftsmagn undir settu viðmiðunargildi (8 L/s/person). Meðal loftskipti í skólastofunum var 1.6 skipti/klukkutíma, og mældist á bilinu 0.5-17.2 loftkipti/klst. Meðal loftskipti í hverjum skóla var á bilinu 1-4.3 loftskipti/klst. Allir skólarnir voru með meðal loftskipiti fyrir ofan sett lágmarksgildi loftskipta (0.8 loftskipti/klst). Niðustöðurnar sýndu enga markttæka fylgni milli mælds styrks PM_{10} og UFP utandyra og styrks PM_{10} og UFP innandyra í grunnskólum í Reykjavík.

Acknowledgements

This thesis was partly sponsored by a grant from Reykjavik Energy's Environmental and Resource Fund.

If there wouldn't have been for the help and support of so many people, this thesis would never have been written. I would like to express my sincere gratitude to:

My main supervisors, **Dan Norbäck,** for the comprehensive guidance, for believing and supporting my ideas and helping me put them into action. Thank you for bringing all the equipment back and forth between Iceland and Sweden. I also want to thank you and **Gunilla Wieslander** for making me feel like home in Uppsala.

My co-supervisor, **Brynhildur Davíðsdóttir**, for the endless support, encouragement and for making me believe in what I do.

Guðrún Pétursdóttir, for supporting my study and for all the nice and encouraging talks.

Guihong Cai, for helping out with the measurements and making good Chinese food.

Þórarinn Gíslason, Katrín Bára Jörundsdóttir, for the loan of the equipment, good advice and for getting me in contact with Dan Norbäck.

Michael Clausen, for good advice and help during my first steps towards this study.

My best friend and husband, **Sveinn Birkir Björnsson**, for the endless love, all the good advice, patience and support during my studies. My three children for all the patience and support, you are the best! My family for being there, always, and believing in me, no matter what I decide to do.

Principals, teachers, other school employees and students that participated in this study. Thank you for allowing me to run around your schools and interrupting the teaching with the noise equipment.

My co-students, in the Masters Program in Environment and Natural Resources, for the help with SPSS, being there and cheering me up when ever I needed. I am quite certain that I wouldn't have gone through with this if it weren't for you and being able to study in Loftskeytastöðin.

All others, not mentioned, that contributed to this study and thesis in some way. Thank you.

And last, but not least my girlfriends, girls it is priceless to have friends like you.

List of Content

List of Tables

List of Figures

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CO	Carbon monoxide
CO_2	Carbon dioxide
ECRHS	The European Community Respiratory Health Survey
EPA	Environmental protection Agency
IEQ	Indoor Environment Quality
IAQ	Indoor Air Quality
I/O ratio	Indoor/Outdoor ratio
NO_2	Nitrogen dioxide
PM	Particulate matter
Pers/m^3	Persons per cubic meter
ppm	Parts per million
RH%	Relative air humidity
SBS	Sick building syndrome
Temp	Temperature
UFP	Ultra-fine Particles
VOC	Volatile organic compounds
WHO	World health organization

1 Introduction

The U.S. Environmental Protection Agency (U.S. EPA) has ranked indoor air pollution among the top five environmental risks. This is because indoor concentrations of some pollutants may be many times higher than their levels outdoors and people spend up to 90% of their time indoors, at home, at work and in recreational environments; therefore, indoor air pollution may pose a greater health threat than outdoor pollution (Heach & Lee, 2003).

The prevalence of asthma and allergies has increased in Iceland, during recent decades, as in many other industrialized countries (Gíslason, Björnsdóttir, Blöndal, & Gíslason, 2002). The main underlying reasons for this increase are still not known, but it has been suggested that poor indoor air quality and indoor allergens may cause symptoms in sensitized subjects, and a new onset of sensitization (Van Moerbeke & Braine, 1997; Smedje & Norbäck, 2001). Given the rising prevalence of asthma, and allergy worldwide, there is a need for evaluating the possible causes and identify measures to reduce the incidence of asthma and allergy (Sennhauser, Braun-Fahrlander, & Wildhaber, 2005).

It is particularly important to identify risk factors for children since young people are more susceptible to air pollution (Woolcock & Peat, 1997). For children, homes and schools are the most important places where as much as 80-90% of their indoor time is spent (U.S.EPA, 2002). Apart from the home environment, school is the most important indoor environment for children. There is also increasing concern about the school buildings themselves, because air exchange rate is often low, concentration of carbon dioxide (CO_2) high and the ventilation standards not fulfilled (Ruotsalainen, 1995; Smedje, Nordbäck, Edling, 1997; Willers, 1996). The concentration of dust is also often elevated in school buildings (Patchett, 1997; Perzanowski, 1999). There is a lack of studies on indoor climate in schools in Iceland.

This thesis, which is divided into seven main sections, addresses the issue of **indoor climate and levels of PM_{10} and ultra-fine particles in junior high schools in Reykjavik**. This main objective is divided into 6 sub-objectives, which all aim at evaluating the indoor climate in junior high schools in Reykjavik. The 6 sub objectives are: *To study levels of indoor climatic factors in the classrooms in junior high schools in Reykjavik; to study if there is any difference between indoor climatic* *factors in classrooms in junior high schools in Reykjavik; to study if there is any difference between indoor climatic factors in schools in Iceland, China and Sweden; to study if there is any difference between indoor environmental factors in schools in Iceland, China and Sweden; to study if there is a significant correlation within and/or between indoor climatic factors and indoor environmental factors in junior high schools in Reykjavik; and to study if there is a significant correlation within and/or between outdoor levels of* PM_{10} *and UFP, and indoor levels of* PM_{10} *and UFP.*

This study will be an important contribution, both academically and practically. This is the first Icelandic research on indoor climate in schools that is based on standardized methods. This means that the results should provide information that can be used as a base for further research on indoor climate in schools in Iceland and for comparison with studies abroad. The results should also provide practical information if indoor climate in Icelandic schools needs to be improved and if so, how it can be achieved.

This thesis is broken into seven sections. In the introduction section a brief overview is provided of the link between indoor air quality, children's health and the school environment. The aim and structure of the thesis is also presented. The second section gives background information on the indoor environment, outdoor air pollutants, school environment, particle pollution, health effects and climatic and environmental factors that can affect the indoor school climate. These are factors such as ventilation, number of students per room volume (pers/m^3), level of carbon dioxide (CO_2), relative air humidity (RH%) and temperature. This background information is based on earlier studies and other written sources, both printed and web-based. In the third section the main objectives of this study are presented, as well as the motivations for each of the objectives. The fourth section introduces materials and method that were used in this study. That is, the study population and design, methods used to assess the indoor climate and environment, and outdoor environment and finally statistical methods and the hypotheses tested. In section five the results from the study are presented, that is the results from the measurements of climatic factors and levels of particulate matter (PM_{10}), ultra-fine particles (UFP) that were performed inside and outside 15 junior high schools in Reykjavik. In the sixth section the results are discussed and in the seventh and the final section conclusions are drawn and suggestions on further studies related to indoor school environment in Iceland, presented.

2 Background

This background chapter is divided into eight sections, that are based on reviewed literature and other written sources and are meant to give background information about; indoor environment, outdoor air pollutants, particulate matter and other climatic and environmental factors that can effect indoor air quality in schools, health effects of air pollution, Icelandic laws and regulations on air quality and school environment, worldwide and in Iceland. This information is meant to provide a link between indoor air quality, particle pollution, school environment, and children's health and school performance.

2.1 Indoor environment

Indoor environmental quality (IEQ) is a generic term used to describe the attributes of enclosed spaces, including the thermal, acoustic and visual environment, as well as indoor air quality (IAQ). Both physical (measurable) and perceptual (human comfort) factors play a key role in defining IEQ. The IEQ in a building may have an influence the health, well being and comfort of building occupants, which in turn may impact on their productivity at work (Paevere, Brown, Leaman, Heerwagen, & Luther, 2008). The key components of IEQ can be divided into (Paevere, Brown, Leaman, Heerwagen, & Luther, 2008):

- Indoor air quality
- Thermal comfort
- Acoustic environment quality
- Luminous and visual environmental quality

Each indoor microenvironment is uniquely characterized, and is determined by local outdoor air, specific building characteristics and indoor activities (Stranger, Potgieter-vermaak, & Vand Grieken, 2007). IEQ has also been defined as anything of the built environment that impacts the health and/or comfort of the building occupants (California Integrated Waste Management Board, 2007).

Indoor air quality (IAQ) refers to the totality of attributes of indoor air that affect a person's health, well-being and comfort. According to the American Association of

School Adminastrators IAQ in schools involves all aspects of the environment from temperature, humidity and ventilation to the chemical and biological elements that exist inside schools (American Association of School Administrators, 2008). The U.S Environmental Protection Agency has ranked IAQ among the top five environmental risks to public health (U.S. Environmental Protection Agency, 1999). The IAQ is characterized by (Paevere, Brown, Leaman, Heerwagen, & Luther, 2008):

- Physical factors, such as ambient temperature, humidity and ventilation rate
- Air pollutant factors, such as pollutant levels and exposure times
- Human factors, such as occupant health status, individual sensitivity and personal control

The indoor air can be affected by the inflow of polluted outdoor air through windows or other openings, evaporation of substances from water, and in some locations, infiltration of radon and other gases into building from underlying soil and bedrock (Harrison, 2002). Other factors that may contribute to poor IAQ include poor cleaning practices, poor moisture control (e.g. water leaks or persistent damp surfaces), human occupancy (e.g. odours) and poor building maintenance (Paevere, Brown, Leaman, Heerwagen, & Luther, 2008). From previous studies it is apparent that indoor- outdoor ratios can alter considerably from one day to the next, even when building conditions (ventilation, window and door use etc.) remain the same (Li & Harrison, 1990; Colome, Kado, Jaques, & Kleinman, 1992: Thatcher & Layton, 1995). Major contributors to poor IAQ include can be summarized into (Paevere, Brown, Leaman, Heerwagen, & Luther, 2008):

- New building materials
- New furniture
- Office equipment
- HVAC system performance and maintenance
- Poor outside air quality

It has been suggested that modern buildings with better insulation may result in warmer, more humid houses with a poorer availability of fresh air (Jones, 1998). Poor ventilation has been associated with several health outcomes including sick building syndrome (SBS) symptoms, perceived air quality (PAQ) and respiratory allergies and asthma (Seppanen, W.J., & M.J., 1999). Building dampness, due to high indoor humidity causing condensation, poor building design or structure deficiencies, has been defined as a potential problem for respiratory health, by being a breeding ground for moulds, fungi, bacteria and dust mites (Ooi, K.T., M.H., & al., 1998). Luoma and Batterman showed in 2001 that in indoor environments, where there is no specific source of pollution (such as smoking and the combustion of fuel for heating and/or cooking), occupant related activities may represent a principal source of dust (composed of cloth fibers, hair fragments, soil particles, skin cells, re-suspended of various origin by walking, and emissions from materials handled, such as paper, fungi spores, and fibers, etc.) (Luoma & Batterman, 2001).

2.2 Outdoor air pollutants

Outdoor air pollution includes both gaseous and particulate pollution. The exact causes behind outdoor air pollution may be different for each city. Depending on the geographical location, temperature, wind and weather conditions, pollution is dispersed differently. However, sometimes this does not happen and the pollution can build up to dangerous levels (Berkeley National Laboratory, 2008). Sources of outdoor or ambient air pollution are varied and include both natural and man-made ones. Natural pollution is all around us, all of the time. However, sometimes concentrations can increase dramatically because of, for example, after volcanic eruptions, or at the beginning of the growing season. Man-made air pollutants are perhaps of more concern, given our ability to have greater control over its release to the atmosphere. The most common source of man-made air pollution outdoors, is the burning of fossil fuels, such as oil, coal and gas in power stations, industries, homes, jet planes and road vehicles. Depending on the nature of the fuel and type of the combustion process, pollutants released into the atmosphere from the burning of fossil fuels include nitrogen oxides (NOx), sulphur dioxide (SO_2), carbon monoxide (CO), lead, volatile organic compounds (VOC's) and particulate matter. (ARIC, 2000). Large particles are also derived from other sources, including agricultural practices or wind-blown soil and dust (American Lung Association, 2008). Air pollution can come both from primary and secondary sources. Primary pollution is emitted directly from sources like vehicles, factories, and secondary air pollution is pollution caused by reactions in air already polluted by primary emissions (from factories, vehicles, and so forth). An example of secondary air pollution is photochemical smog and ozone (OECD, 2001).

2.3 Particulate matter

Particulate matter (PM) is a name for a wide range of particles that are small enough to be carried by the air and therefore can be breathed in by people (Health Canada, 2008). Particles can come in almost any shape or size, and can be solid particles or liquid droplets. The particles can travel hundreds to thousands of kilometers, depending on their size (WHO, 2005).

Ambient particulate matter (PM) has been classified in three size distributions (Hind, 1999). PM_{10}, which consists of particles <10 µm in aerodynamic diameter, are able to reach the respiratory tract below the larynx. In comparison, the average size of a human hair is 70 µm.

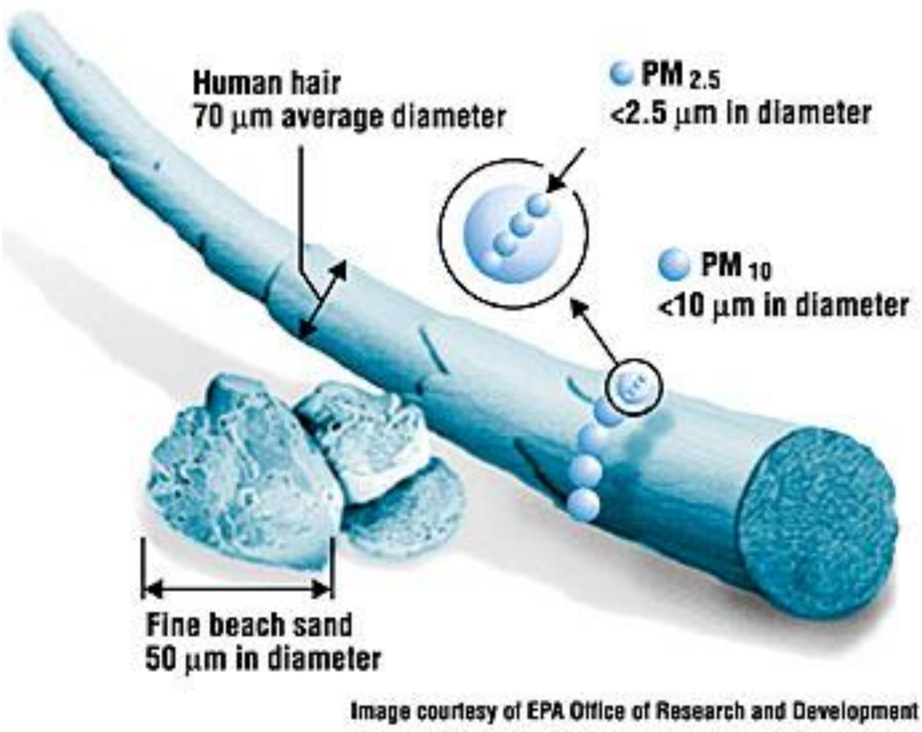

Figure 1: Comparison of particulate matter (PM) to average human hair. (Source: www.epa.org)

Particles smaller than 2,5 µm ($PM_{2,5}$) can penetrate into the gas-exchange region (alveoli) of the lung. In urban or industrialized areas $PM_{2,5}$ comprises 60-70% of the PM_{10} fraction and consist to a high degree of elemental carbon derived from stationary or mobile combustion sources. Ultra-fine particles (UFP) are approximately less than 100 nm in diameter ($PM_{0,1}$) and are component of air pollution, derived mainly from primary combustion sources (Hind, 1999).

2.3.1 Indoor particulate matter

It is generally accepted that indoor concentrations of particles derive from two sources: indoor and outdoor. However, the significance of both sources depends on a number of variables, e.g., air-exchange rate, outdoor air pollution, type of indoor activities, aerodynamic diameter of particles emitted, etc. (Yocom, 1982; Owen, Ensor, & Sparks, 1992; Wallace, 2000; Long, Suh, & Koutrakis, 2000; Monn, 2001). The dominating source for particle fraction with diameters < 1 μm is outdoor air, but indoor activities for particle fraction > 1 μm (Jansson, 2000).

Indoor particulate matter is a mixture of substances such as:

- Carbon (soot) emitted by combustion sources
- Tiny liquid or solid particles in aerosols
- Fungal spores
- Pollen
- A toxin present in bacteria (endotoxin) (Health Canada, 2008).

The main source of the airborne particulate matter in the majority of homes is the outdoor air (Health Canada, 2008). Some homes, however, do have other significant sources of indoor particulate matter, such as:

- Cigarette smoking
- Cooking
- Indoor pet allergens
- Non-vented combustion appliances such as gas stoves
- Wood-burning appliances
- Mould growth (Health Canada, 2008).

2.3.2 Particulate matter in Iceland

In the last few years, interest in particle pollution in Reykjavik has mounted; it's sources, possible effects and what can be done to avoid and/or reduce particle pollution. There has been a lot of media coverage of the health risks due to particle pollution and demands for action. Politicians have announced that if the levels of particle pollution are not reduced, it will be necessary to take some radical actions, such as banning studded tires, lowering speed limits or even closing roads to reduce particle pollution (Tillögur Gatnamálastjóra/Heilbrigðiseftirlits Reykjavíkur.) 2000; Fréttablaðið, 2008). The discussion and coverage though has mainly been limited to outdoor particle pollution. Indoor particle pollution has hardly been mentioned. Considering the attention and resources currently directed to improving the quality of outdoor air, it is perhaps surprising that so little attention seems to have been given to the (non-industrial) indoor environment in Iceland.

Particle pollution in Iceland, like other countries, has various sources, such as; fine soil dust, dust generated from rupture of the surface of roads, volcanic activity, pollen grain, and vehicle's exhaustion, vehicle's brake system and from rupture of tires. There is very little particle pollution from industries in Iceland and particle pollution from power plants is almost unknown (Tillögur Gatnamálastjóra/Heilbrigðiseftirlits Reykjavíkur, 2000; The Environment Agency of Iceland, 2008).

Studies have been conducted that aimed at assessing the sources of particle pollution in Reykjavik. In year 2000 the first numbers on the sources of particle pollution in Reykjavik, were published. These numbers were based on a comparison of measurements from different measuring stations in Reykjavik and all over Iceland. According to the results 20% of the particle pollution in Reykjavik come from sea salt blown from the sea, 20-30% from land dust, 10-15% from vehicle exhaustion and 35-50% from the tearing of the road (Línuhönnun, 2000 as cited in; Jóhannsson, 2007).

An Icelandic study on the combination of particulate matter outdoors in Reykjavik on days when the particle pollution is above the set limits (50 $\mu g/m^3$ per 24-hour) showed that 60% of the particles come from asphalt. This draws the attention to studded tires as a source of particle pollution. It is known that they tear the asphalt more then other winter tires (Ingason & Jóhannesson, 2002). Reduced use of studded tires would, without a doubt, have an effect on particle pollution in wintertime and especially the days when the pollution peaks, as similar studies in Oslo, Norway have shown (Bartonova, Larssen, & Hagen, 2002). Even though studded tires are one important factor for the levels of particle pollution, it is far from being the only one. Engine type (diesel or petrol), and car age are also important factors; new cars cause less particle pollution than older cars. (Umhverfisstofnun, 2003).

In 2003 another report was published based on a study of the combination of particle pollution in Reykjavik. This study was based on a chemical analysis of particle pollution in Reykjavik. According to this study was the mean combination of sources to particle pollution in Reykjavik was 2% break lining, 7% soot, 11% salt, 25% land dust and 55% from asphalt (Skúladóttir, Thorlacius, Larsen, Bjarnason, & Þórðarson, 2003).

In 2007 Jóhannsson, published his masters thesis, on particle pollution in Reykjavik. The thesis was divided into five sections, information on particle pollution, study on the source of salt in particle pollution, definition of plausible sources of earth dust, taking samples and analyzing the dirt that lies on the streets in Reykjavik and finally studying and speculating about the connection between studded tires and weather washing, dust binding the streets. According to Jóhannessons results there is no lack of laws or regulations to control the outdoor particle pollution from industry and vehicles exhaustion, rather a lack of actions that are taken in order to follow the laws and regulations. According to Jóhannesson there is a need for informing people of how the pollution could be prevented, reduced and how it can be avoided when it is over health limits (Jóhannsson, 2007). The salt in the particle pollution in Reykjavik, is mainly derived from the sea, and should not be seen as a big health threat. Most of the dust in Reykjavik can be traced back to land eruption due to different constructions within the city of Reykjavik. The dirt on the roads was only partly from asphalt, between 17-70%. Jóhannesson concludes that the use of studded tires is the largest contributing factor for tearing the roads, and by reducing the use, the particle pollution could decline. But Jóhannesson also points out that it is important to keep in mind, that even though the tearing is reduced by minimizing the use of studded tires, is it not certain that the particle pollution will reduce in proportion to that, because there are so many other factors that affect the levels of particle pollution in Reykjavik (Jóhannsson, 2007).

Natural sources, which are mainly soil, sand and sea, can greatly affect the levels of particle pollution. Levels of particle pollution in the air largely depends on wind, temperature, precipitation, more rain or wind means lower levels of outdoors particle pollution (Socialstyrelsen, 2006, as cited in: Hellsing, 2007).

2.4 Climatic Factors

2.4.1 Carbon dioxide – CO_2

It is a standard method to use levels of carbon dioxide (CO_2) as an indicator of human emissions. The Icelandic ventilation standard has a recommendation for indoor CO_2 levels at a maximum 1000 ppm (parts per million) and a mean level lower than 800 ppm (Building regulation nr.441/1998). The *American Society of Heating, Refrigerating and Air-Conditioning Engineers* (ASHRAE) ventilation standard has similar requirements of maximum 1000 ppm CO_2 (ASHRAE, 1999). A recent article concludes that sick building syndrome (SBS) decreased when CO_2 is reduced down to 800 ppm (as cited in: Norbäck, 2009). CO_2 is generally not found at hazardous levels in an indoor environment, yet it is often measured when trying to determine the indoor air quality of a building. The reason is that it is a good surrogate measure of how well the ventilation system is working in relation to the number of occupants. CO_2 transfers into a certain room through the breathing of those who are in the room. The level of CO_2 depends on the original level of CO_2, room volume, number of persons in the room, individual's age (weight), their activities, air-exchange rate and the time spent in the room. CO_2 can also results from burning, for example candles or from fireplaces (Heilbrigðiseftirlit Kjósarsvæðis, 2002). The air we exhale has the level of carbon dioxide is around 40.000 ppm and the levels in outdoor air is 350-450 ppm. When levels of carbon dioxide is between 500-1000 ppm, people starts to feel discomfort (Minnesota Department of Health, 2008). A study done on the concentration and number of particles in 64 classrooms in Germany, identified that increased concentrations of PM correlated significantly with increased level of CO_2 (as cited in: Stranger, Potgieter-Vermaak, & Grieken, 2008). It is very easy and inexpensive to measure CO_2 and thus it is commonly used as a preliminary test weather a ventilation system is adequate.

2.4.2 Room temperature and relative air humidity – temp and RH%

Information on the importance of room temperature and relative air humidity in school buildings is sparse (Smedje & Norbäck, 2000). Existing studies have showed that thermal conditions in schools (temperature and humidity) can affect pupils' school performance or attendance (Mendell, Heath, & Heath, 2005). Classrooms are a densely populated indoor environment, which can lead to both thermal discomfort and to perception of poor indoor air quality (Norbäck & Nordström, 2008). There is no temperature that is suitable for all building occupants, but temperature between 20-24°C has been seen as suitable for every-day wellness and creativity, but it has to be taken into account that factors like personal activity and clothing may affect personal comfort. Even so studies have indicated that the temperature should rather be lower than higher and that if the temperature goes above 24°C it can reduce peoples ability to perform subjective tasks (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990). As the indoor air temperature rises, so does the vaporization of chemicals from furniture, fittings and building materials (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990). Numerous factors that can affect room temperature, for example large glass windows that can also increase thermal problems during warmer parts of the year (Norbäck & Nordström, 2008).

Relative air humidity is defined as the ratio of the amount of water vapor in the air at a specific temperature to the maximum amount that the air could hold at that temperature and is expressed as a percentage (The American Heritage Medical Dictionary, 2007). The dominating factor affecting indoor air humidity is air temperature, because when cold air with high air humidity warms up indoors, the air humidity drops considerably, unless there are some sources for indoor humidity. Sources for indoor humidity can for example be from the respiratory tract, plants or other sources like bathrooms or kitchens (Heilbrigðiseftirlit Kjósarsvæðis, 2002).

There is no “ideal” humidity level, but according to the *American Society of Heating, Refrigerating and Air-Conditioning Engineers* (ASHRAE) acceptable relative humidity levels should range from 30-60% to achieve maximum occupant comfort (ASHRAE, 1999). Levels less than 20% in the winter and greater than 60 percent in the summer should be considered unacceptable. If relative air humidity goes under 20% it is more likely that dust will stay in the air. Low relative air humidity can also result in higher static electricity and more vaporization of chemicals from furniture, fittings and building materials. Elevated relative air humidity can also promote the growth of mould, bacteria, and dust mites, which can aggravate allergies and asthma (IDPH, 2008). The subject of air humidification is always discussed when constructing or reconstructing a building due to the fact that the most commonly reported discomfort indoor is the perception that the air is to dry (Skoog, 2006).

2.5 Environmental Factors

2.5.1 Ventilation

The purpose of ventilation is to remove pollutants generated by people, indoor activities, and building materials. The effect of building ventilation on humans has been reviewed in recent years (Norbäck & Nordström, 2008). It has been reported that there is limited evidence to suggest that ventilation-rate increases up to 10 l/s and persons may be effective in reducing symptom prevalence, while higher ventilation rates may not be effective (Godish & Spengler, 1996). Another review concluded that beneficial effects could be achieved by reducing CO_2 down to 800 ppm (Seppänen & Fisk, 2004). There are very few epidemiologic studies on the significance of ventilation in schools or university buildings, but there are some studies available from elementary schools and junior high schools (Norbäck & Nordström, 2008). One study found that an increase in the personal outdoor airflow rate from 1.3 to 11.5 l/s brought about by the installation of new ventilation systems with displacement ventilation[1] lowered the risk of asthmatic symptoms in schoolchildren (Smedje & Norbäck., 2000). A review on school environment concluded that there is a clear indication that classroom ventilation typically inadequate (Daisey, Angell, & Apte, 2003).

Total ventilation, a combination of unintentional air infiltration through the building envelope, natural ventilation through open doors and windows, and mechanical ventilation, provides a means for reducing indoor concentration of indoor-generated air pollutants (Shendell, Prill, Fisk, Apte, Blake, & Faulkner, 2004). Ceiling- or wall-mounted heating, ventilation and air conditioning (HVAC) systems are often used to mechanically ventilate classrooms, although these HVAC systems may provide less ventilation than intended as a result of design and installation problems, poor

[1] Displacement ventilation is an innovative concept for the supply of conditioned air and ventilatio of buildings It uses naural buoyancy of warm air to provide improved ventilation and comfort. In a displacement ventilation system, supply air is introduced to the space at or near the floor level, at a low velocity, at a temperature only slightly below the desired room temperature. The cooler supply air "displaces" the warmer room air, creating a zone of fresh cool air at the occupied level. Heat and contaminants produced by activities in the space rise to the ceiling level where they are exhausted from the space. Displacement ventilation systems are typically more energy efficient and quieter then conventional overhead systems. They also provide better ventilation efficiency, and thus improve indoor air quality Schaffner, C. R. (1999). *Displacement Ventilation.* Accesed 30. December 2008 from www.greenengineer.com: http://www.greenengineer.com/ideas/dv.htm.

maintenance, and because HVAC systems are often not operated continuously during occupancy (Shendell, Prill, Fisk, Apte, Blake, & Faulkner, 2004).

A steady-state indoor CO_2 concentration of 1000 ppm has been used as an informal dividing line between “adequate” and “inadequate” ventilation (ASHRAE, 2001). CO_2 concentration is only a rough surrogate for ventilation rate, primarily because the measured concentration is often considerably less than a steady-state concentration. Despite the limitations of CO_2 concentrations as a measure of ventilation rate, higher concentration has been associated with increased frequency of health symptoms and increased absence in studies of office workers (Erdmann, Steiner, & Apte, 2002; Milton, Glencross, & Walters). Studies have indicated that many classrooms have ventilation rates below the code minimum or with CO_2 concentrations above 1000 ppm (Carrer, Bruinen de Bruin, Franchi, & Valovirta, 2002; Daisey, Angell, & Apte, 2003; Lagus Applied Technologies, 1995; Research Triangle Institute, 2003).

2.5.2 Shelf and fleece factor

The fleece factor is defined as the area of all textile floor coverings, curtains and seats divided by the volume of the dwellings (m^2/m^3) (Skov, Valbjorn, & Pedersen, 1990). It has been shown that indoor dust contains different allergens and irritants (Gyntelberg, Suadicani, P., Wohlfahrt, J., et.al., 1994), and that fabrics, in carpets curtains and upholstered seats, constitute reservoirs and sink for such particles and compounds (Custovic, et.al., 1996; van der Wal, Hoogeveen, & van Leeuwen, 1998). The fleece factor is not by itself directly responsible for indoor air quality problems; rather, it is likely that it is simply an indicator. The shelf factor is the length of open shelves in each classroom, divided with the volume of the dwellings (m/m^3) (Godish, 1989). Smedje and Norbäck found that in classrooms with more fabrics and open shelves the concentration of formaldehyde was higher and there were more pet allergens (Smedje & Norbäck., 2001).

2.5.3 Number of persons – pers/m³

The “number of persons” stands for the number of persons/occupants that were present in the classrooms during the measurements. That includes the students and teachers. Previous research has demonstrated that occupant-related emissions of 1-25 μm particles significantly elevate the exposure levels in a person's microenvironment (Luoma & Batterman, 2001). It has also shown that occupants significantly affect the concentration of airborne particles > 5 μm (Thatcher & Layton, 1995). The mean number of students per classroom can vary significantly between countries. A study from primary school classrooms in Oslo, Norway, showed that the mean number of occupants were 22, while the mean number of occupants during measurements were 48 in a Chinese study and 20 in a Swedish study (Mysen, Berntsen, Nafstad, & Schild, 2005; Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

2.5.4 Personal outdoor air supply and air exchange rate

A longitudinal study found that an increase in the personal outdoor air supply rate from 1.3 to 11.5 l/s brought about by the installation of new ventilation systems with displacement ventilation, lowered the risk of asthmatic symptoms in schoolchildren (Smedje & Norbäck, 2000). Productivity among employees have been shown to increase when the air exchange rate is increased (as cited in: Gunnarsson, 2005).The ASHRAE ventilation standard has requirements of a minimum personal outdoor air supply of 8 l/s (ASHRAE, 1999). According to Icelandic regulations should the minimum air exchange rate be 0,8 ac/hour (Buliding regulation nr.441/1998).

2.6 Summary

Indoor air quality can be affected by many different factors. This study focused on the effect a selected number of factors of indoor environment, outdoor air pollution and particle pollution, on indoor quality. The indoor factors were divided into indoor climatic factors and indoor environmental factors.

The concept "indoor climatic factors" includes:

- Levels of indoor particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10}), indoor ultra-fine particles (UFP), indoor carbon dioxide (CO_2), temperature (temp) and relative air humidity (RH%) in the classrooms.

The concept "indoor environmental factors" includes:

- Shelf factor (m/m^3), fleece factor (m^2/m^3), number of persons per cubic meter ($pers/m^3$) personal outdoor air supply rate (L/s/person) and air exchange rate (ac/hour).

2.7 Health Effects

Clean air is essential for good health, and this is especially true when it comes to indoor air. The U.S. Environmental Protection Agency (U.S. EPA) has ranked indoor air pollution among the top five environmental risks. This is because indoor concentrations of some pollutants may be many times higher than their levels outdoors and people spend up to 90% of their time indoors, at home, at work and in recreational environments, therefore, indoor air pollution may pose a greater health threat than outside pollution (Heach & Lee, 2003). Most people, however, are unaware of the effects that poor indoor air quality can have on their health. The following chapter is divided into four sub chapters. In these chapters the main health effects of poor indoor air are discussed, the main health effects that poor indoor air can have, the health effects different levels of indoor CO_2, RH% and temperature can have, the Sick Building Syndrome (SBS), the main health effects of particle pollution and the main health effects that particle pollution can have on children.

2.7.1 Health effects of indoor air

Discomfort or diseases that are related to buildings have been divided into three categories (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990). First, illness or discomfort that is related to houses and the cause is known, such as allergies, contagious diseases and discomfort due to known pollution for example from chemicals. Second discomfort that is related to houses and the causes are unclear or unknown, often called sick building syndrome (SBS). SBS was once seen as a mass psychogenic illness, but today is it accepted as a certain phenomenon, due to unknown reasons (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990; Colligian, 1981). In cases of SBS it is common that people complain about irritation in eyes, nose, throat, airway, skin problems, undiagnosed allergies, tiredness, nausea and/or dizziness while staying in the building. The discomfort often increases, as the time spent in the building gets longer, but disappears or decreases when people leave the building. The reason for SBS is unknown, but it is a widely held opinion that the cause is more than one environmental factor and therefore the cause can even be different between buildings. Psychological reasons like stress are not seen as causing the discomfort, but can be a stimulating factor. In cases of such discomfort the employees can get unhappy, less productive and cause increased sick leaves among employees (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990). Third illnesses can be caused by pollution that people get exposed to indoors, without realizing it. In this case it is an illness that develops over a long time, such as cancer due to secondary smoking or pollution from chemicals that can cause mutation in genes (as cited in: Heilbrigðiseftirlit Kjósarsvæðis, 2002).

In 1990 the Administration of Occupational Saftey and Health in Iceland published a report on *Indoor Air and Peoples Wellness* (Translated by author; Inniloft og líðan fólks) (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990). In the report, factors that are often related to people's wellness in buildings are divided into four categories. Three categories with environmental factors, and one with a social or psychological factor. The following table illustrates these factors and two factors that were added by Árni Davíðsson, the author of a study on indoor air in schools and day-care centers in Iceland (Heilbrigðiseftirlit Kjósarsvæðis, 2002).

Table 1: Factors that can affect people's wellness indoors.

Physical	**Chemical**	**Biological**	**Psychological**
Temperature	Smoking	Acaris (dust mites)	Stress
Humidity	Formaldehyde	Mould	Social status
Ventilation	VOC	Pets	Imagination
Air ions	Microbiology poison	Other arthropods (insects)	
Static electricity	Other gases		
Particles and threads	Odour		

1) Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990. 2) Heilbrigðiseftirlit Kjósarsvæðis, 2002.

2.7.2 Sick building syndrome

The term "Sick building syndrome" (SBS) is used to describe a situation in which building occupants experience acute health and comfort effects that appear to be linked to time spent in the building, but no specific illness or cause can be identified. The complaints may be localized in particular room or zone, or may be widespread throughout the building (U.S.EPA, 2008).

According to the US Environmental Protection Agency (U.S.EPA), sick building syndrome is strongly suspected when the following circumstances are present:

- Symptoms are temporally related to time spent in a particular building or part of building
- Symptoms resolve when the individual is not in the building
- Symptoms recur seasonally (heating, cooling)
- Co-workers, peers have noted similar complaints

A recent study (in press) concluded that SBS is related to personal and environmental risk factors. In the office environmnet, SBS may have important economic implications affecting productivity. Also that more focus is needed on the indoor environment in schools, day care centres, hospitals and nursing homes for the elderly, because children, hospital patients and the elderly are sensitive subgroups (Norbäck, 2009).

2.7.3 Health effect of CO_2, RH%, temperature and ventilation

Carbon dioxide (CO_2) is generally not found at hazardous levels in indoor environments, they are extremely rare in non-industrial workplaces. Even so occupants may experience health effects in buildings where levels of CO_2 are elevated, like headaches, dizziness, restlessness, tiredness and so forth. Most of these symptoms are usually due to the other contaminants in the air that also build up as a result of insufficient ventilation. The CO_2 itself can cause headache, dizziness, nausea and other symptoms when exposed to levels above 5000 ppm for many hours (Minnesota Department of Health, 2008). High or low relative air humidity (RH%) can cause disscomfort among occupants. According to Berglund low air humidity affect comfort and health and in wintertime, when the relative air humidity indoor drops, respiratory problems increase (Berglund, 2002). High relative air humidity may contribute to water condensation and microbial growth, indirectily causing SBS (Norbäck, 2009). Low relative air humidity or dry air, has also been shown to cause dry and itchy skin, fatigue, feeling of illness and sickness The risk of bacteria and virus attacks is normally higher in environments with a high relative humidity (Gertis, 1999), but with particles (dust) in the air, even dry environments may represent a health hazard. The dry particle mass may cause an imbalance in the mucous membrane humidity, with resulting irritation (Holmberg & Chen, 2003). The indoor temperature affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and work performance (Seppanen, Fisk, & Faulkner, 2004). The indoor temperature has also been shown to effect people's productivity (Seppanen, Fisk, & Faulkner, 2004). A review on ventilation, health and productivity, EUROVEN, concluded that low ventilation rate is associated with effects on health and decreased performance in offices (Wargocki, P., Sundell, J., Biscchof, W., Brundrett, G., Famger, P., Gyntelberg, F., et al., 2002).

2.7.4 Health effect of particle pollution

People with heart or lung diseases, older adults, and children are considered at greater risk from particle matter than other people (EPA, 2003). It has been shown that long-term PM exposure is associated with elevated, cardiovascular and infant mortality and morbidity of respiratory symptoms, lung growth and function of the immune system. Particles may be carriers of carcinogenic, allergic and irritant substances (Indoor Environment and Health, 1999). A large quantity of specific allergens and many organic particles can increase of allergic and other hypersensitivity reactions (Holmberg & Chen, 2003). Long-term PM exposure has been associated with elevated total, cardiovascular and infant mortality and elevated morbidity of respiratory symptoms, lung growth and function of immune system. Short-term exposure has been consistently associated with mortality or morbidity especially in patients with asthma or respiratory diseases (Kappos, 2004). Ultra-fine particles (UFP) are considered important for adverse health aspects since they can be transported and deposited in the lungs. Because of high deposition efficiency, they can migrate from the lungs into the systemic circulation and to the heart (Penn, 2005). Airborne particles in classrooms may emanate from settled dust, containing allergens (Janssen, Hoek, Brunekreef, & Harssema, 1999; Ormstad, Johansen, & Gaarder, 1998). Respiratory effects, recorded as decreased nasal patency and higher concentrations of eosinophilic cationic protein (ECP) in nasal lavage fluid, have been found among the staff of schools with more settled dust and less cleaning (Walinder, Norbäck, Wieslander, Smedje, Erwall, & Venge, 1999).

The health effect of particle pollution largely depends on the size of the particles. Healthy people can get rid of particles that are larger than 5 μm by sneezing and coughing, but some particles that are 2,5-5 μm can transmit down into the lungs and cause irritation. Elderly, asthmatics and people with lung diseases like bronchitis can have difficulties getting rid of the bigger particles. Bigger particles can, by irritation and bristle of the mucous membrane, clear the way for infections. The particles don't only irritate and clear the way for infections, but they can also transmit unwanted chemicals that dissolve in the mucous membrane and have a clear way into the body's circulatory system. The smallest particles 0-2,5 μm are considered to be the most health threatening, because they transmit down the lungs and settle in the alveoli.

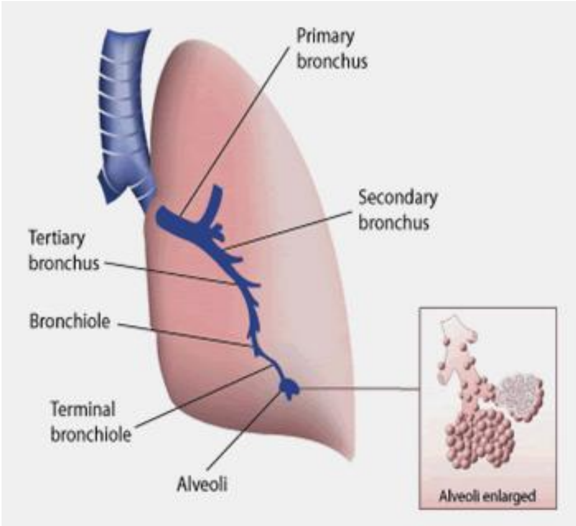

Figure 2: Particle Pollution in Lung.
From www.epa.gov

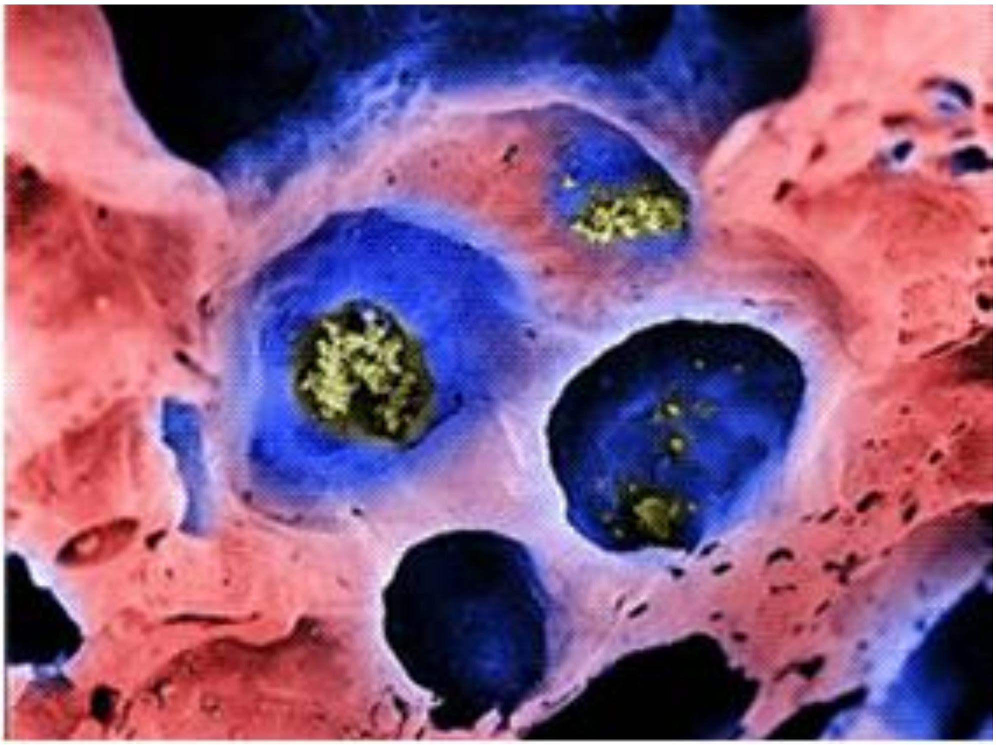

Figure 3: Particulate matter from diesel engines, in the alveoli. (Source: Lennart Nilsson).

Outdoor air in Scandinavia contains around 10 µg /m^3 particles (PM_{10}). Higher concentrations, up to 50 µg/m^3, cause increased risk for sensitive individuals, 100 µg/m^3 can result in hospital care for resperatory problems and over 100 µg/m^3 represents an increased mortality risk (Åhmansson, Björklund, Friberg, Ajne, & Lundberg, 1996).

2.7.5 Health effect of indoor air on children

Children are obliged to attend school at the age 6-16 and spend a certain amount of time in school each day. They do not really have knowledge of the effect that air pollution can have on them or ways to reduce or prevent air pollution in their school (The Preschool Act nr.66/1995). The school environment is the most important indoor environment for children aged 6-16, apart from the home (Smedje, 1997).

Children, even those without pre-existing illness or chronic conditions, are susceptible to air pollution because their lungs are still developing, and they are often engaged in vigorous activities, making them more sensitive to pollution than healthy adults. Studies have shown that in children, particulate pollution is associated with increased episodes of coughing and difficulty breathing, and decreased lung function (EPA, 2003). Children are at higher risk due to a number of reasons, for example, children take in more air per unit body weight at a given level of exertion than do adults. When a child is exercising at maximum levels as during a soccer game, they may take in 20 to 50 percent more air, and more air pollution, than an adult would in comparable activity (AQMD, 2005). They also have a higher uptake of air and therefore a higher uptake of air pollutants as well (Zhao, 2006). Studies on associations between indoor air quality and health in schools are rare (Daisey, Angell, & Apte, 2003). The studies that have been done have shown that indoor environment in schools and dwellings may influence children's health, increase asthma and allergies, infections and learning ability, and teacher and staff's productivity (USEPA, 1996). It has also been shown that school absenteeism can serve as an indicator of student or teacher's overall health condition, although attendance patterns result from a complex interaction of many factors (Alberg, Diette, & Ford, 2003; Weitzman, 1986).

2.8 Laws and regulations

The following laws and regulations are seen as relevant for indoor climate and levels of particulate matter (PM_{10}) and ultra-fine particles (UFP) in junior high schools in Reykjavik.

The Primary School Act nr. 91/2008[2]

This law applies to public primary schools (including junior high schools), private primary schools and certified teaching at the primary school level.

The Health Regulation nr.941/2002[3]

This regulation applies to all schools, teaching facilities and day care centers.

The Building Regulation nr.441/1998[4]

This regulation secures health- environmental- and security issues when building and maintaining buildings. The regulation applies to all school buildings.

Regulation nr. 251/2002[5]

This regulation applies to control, measurements, information flow and alerts to the public about several outdoor air pollutants, including particle pollution.

According to Icelandic laws, municipalities are responsible for the school environment, school equipment, dwellings, evaluation and maintenance. The school buildings and surrounding playgrounds must for fill the requirements of other Icelandic laws on work, environment and teaching. The dwellings and all school equipment should ensure the students and teacher's safety and wellness, that is, appropriate noise levels, lighting and ventilation (The Primary School Act nr. 91/2008).

Icelandic health regulations include a specific chapter on school environment, where 1.4 m^2 is defined as the minimum space for each student in a classroom (The Health Regulation nr.941/2002). The regulation also stipulates that ventilation in schools, classrooms and day care centers should be adequate, although the regulation does not

[2] Lög um grunnskóla nr. 91/2008
[3] Heilbrigðisreglugerð nr. 941/2002
[4] Byggingareglugerð nr. 441/1998
[5] Reglugerð um brennisteinsdíoxíð, köfnunarefisdíoxíð og köfnunarefnisoxíð, bensen, kolsýring, svifryk og blý í andrúmsloftinu og upplýsingar til almennings nr.251/2002

further define adequate levels of ventilation (The Health Regulation nr. 941/2002). The Icelandic Building Regulation stipulates guideline limits for adequate ventilation, according to which, the mean level of CO_2, should not exceed 800 ppm and the maximum level should not be more than 1000 ppm in any work- or dwelling space. (The Building Regulation nr.441/1998).

However, most laws and regulations on indoor air pollution in Iceland apply to industrial environments. It is not defined in the regulation, whether the mean level of CO_2 or the equilibrium CO_2 should be used for comparison.

According to instructions for schools and day care centers released by The Environmental Agency of Iceland, all schools and day care centers should follow the limits for CO_2 established in the The Building Regulation (The Environmental Agency of Iceland, 2003). There are no specific limits for indoor temperature or humidity in the Icelandic The Health Regulation s. There are no regulations for levels of particles indoors, but according to Icelandic regulations, the outdoor level of PM_{10} should not exceed 50 $\mu g/m^3$ (per 24-hours) (Regulation nr.251/2002).

New limits will be established for outdoor particle pollution in 2010, when changes that are already defined in regulation nr.251/2002 take affect. Since the regulation was implemented in 2002, the allowed yearly mean level of particle pollution has been 40 mg/m^3, and the number of days when the mean level of particle pollution exceeds 50 mg/m^3 (per 24-hours) is set at 35 times/days per year. From 2010, the limit for yearly mean level of particle pollution will be set at 20 $\mu g/m^3$; and the number of times/days when the mean level of particle pollution exceeds 50 $\mu g/m^3$ (per 24-hours) will be reduced to seven. (Jóhannsson, 2007).

No regulations, laws or guidelines apply for outdoor or indoor levels of ultra-fine particles (UFP). The ASHRAE ventilation standard has requirements of a minimum personal outdoor air supply of 8 l/s, which is widely used as a guideline (ASHRAE, 1999). According to Icelandic regulations the minimum air exchange rate should be 0.8 ac/hour (The Building Regulation nr.441/1998).

2.9 School environment

2.9.1 Worldwide

The school environment is very important for children worldwide. Schools can be contaminated by different chemical and biological substances, and impaired indoor climate, poor ventilation, as well as noise, light, and odor (Zhao, 2006). A number of studies have revealed that school air may be a source of a wide spectrum of air pollutants such as noise, NO_2, CO, volatile organic compounds, aerosols etc. The highest importance is currently attributed to aerosols because they represent a complex mixture of organic and inorganic substances with potential toxic, carcinogenic, inflammatory, allergenic and other adverse properties (Maroni, Seifert, & Lindvall, 1995; Jones, Thornton, Mark, & Harrison, 2000). Poor indoor environment can affect the children's respiratory health; reduce their mental health and their school performance (Mendell, Heath, & Heath, 2005). Epidemiological studies in Swedish schools have shown that current asthma was more common among pupils in schools that have more open shelves, lower room temperature (°C), higher relative air humidity (RH%), higher concentration of formaldehyde or other VOC and viable moulds or bacteria or more cat allergen (Smedje, Nordbäck, & Edling, 1997). Studies have shown lower report of asthmatic symptoms associated with improved school ventilation system. In areas with heavy outdoor air pollution, increased ventilation could introduce more outdoor air pollutants in the classrooms. (Smedje & Norbäck, 2000).

2.9.2 Iceland

Standardized studies on indoor school environment in Iceland are lacking, but some studies exist. In February 1995, Valsdóttir studied indoor air in three schools in Akureyri and Dalvík, located in the Eyjafjörður region in northern Iceland. Akureyri is the second largest urban area after the Greater Reykjavík area (StatsDirect, 2008). Dalvík is a region with a population of nearly 2000 in northern Eyjafjörður (Dalvíkurbyggð, 2008). Valsdóttir also presented results from measurements on indoor air in six schools in the Eyjafjörður region in 1997, in a conference publication from Lagnafélagið in 1997 (as cited in: Heilbrigðiseftirlit Kjósarsvæðis, 2002). The mean CO_2 concentration in 18 measurements from 6 schools in the Eyjafjörður region was 1370 ppm. The average max-concentration in 17 measurements in 6 schools was 1570 ppm. Valsdóttir also measured other environmental factors, such as air temperature, airspeed, relative air humidity (RH%) (as cited in: Heilbrigðiseftirlit Kjósarsvæðis, 2002).

In October 2002 the Health department for Kjósarsvæði published a report based on a study of indoor air quality in schools and day-care centers in Mosfellsbær and Seltjarnarnes. Mosfellsbær is a municipality in the Greater Reykjavik area, with a population around 8500. Mosfellsbær is situated some 17 km north of Reykjavik (Mosfellsbær, 2008). Seltjarnarnes is also a municipality in the Greater Reykjavik area, with a population around 4600 people (Seltjarnarnesbær, 2008). Seltjarnarnes is located on the northernmost tip of the capital peninsula Seltjarnarnes, west of Reykjavik center. The study included measurements of levels of carbon dioxide (CO_2), temperature and relative air humidity (RH%). According to the report the air quality in many of the classrooms was not according to the The Health Regulation s at the time (The Health Regulation nr. 149/1990) for mean levels of CO_2 (800 ppm). Out of the 16 classrooms 14 had mean levels of CO_2 above 800 ppm. Mean levels of CO_2 in the day-care centers were above 800 ppm in 7 out of 8 rooms. 16 out of 18 classrooms in the schools, had max-levels of CO_2 above 1000 ppm, and all the measurements from the day-care centers showed max-levels above 1000 ppm (Heilbrigðiseftirlit Kjósarsvæðis, 2002). The temperature in almost all the classrooms in the study from Mosfellsbær and Seltjarnarnes, was between 19-22°C. In some cases the temperature reached 24 °C. The RH% levels were between 20-46% (Heilbrigðiseftirlit Kjósarsvæðis, 2002).

Reykjavik's Health department performs a yearly health inspection in schools that include 1st to 10th grade. The health inspection includes an evaluation of the *school nurses facilities, schools gym, showers and dressing rooms, cooking facilities, treatment of chemicals* and the overall *school facilities*. The evaluation of the school facilities health and safety issues is based on Icelandic health regulations (The Health Regulation nr.149/1990). The *air exchange rate* is evaluated by measuring the level of CO_2 in the classrooms, while classes are in session in between classes and when the room is empty. These are short measurements that are supposed to give an idea on how the air exchange rate is in the classrooms. The report from the Health department in year 2000 showed that 19 out of the 40 schools that were evaluated had adequate low levels of CO_2 (Heilbrigðiseftirlit Reykjavíkur, Heilbrigðissvið, 2000).

It is evident that even though there have been studies on the indoor school environment in Iceland, such studies are lacking. Especially in the light of the importance of good indoor school environment for children’s health and school performance, and the heightened incidence of in particle pollution in Reykjavik.

3 Objectives

The main objective of this thesis was to **study indoor climate and levels of PM_{10} and ultra-fine particles in junior high schools in Reykjavik.** This main objective is then divided into 6 sub-objectives.

- ***To study levels of indoor climatic factors in the classrooms in junior high schools in Reykjavik.***
- ***To study indoor environmental factors in classrooms in junior high schools in Reykjavík.***
- ***To study if there is any difference between the data collected on indoor climatic factors in schools in Iceland, and existing data from previous comparable studies in China and Sweden.***
- ***To study if there is any difference between the data collected on indoor environmental factors in schools in Iceland, and existing data from previous comparable studies in China and Sweden.***
- ***To study if there is a significant correlation within and/or between indoor climatic factors and indoor environmental factors in junior high schools in Reykjavik.***
- ***To study if there is a significant correlation within and/or between outdoor levels of PM_{10} and UFP, and indoor levels of PM_{10} and UFP.***

In order to manage the indoor climate and levels of PM_{10} and UFP in junior high schools in Reykjavik, it is important to first gain knowledge of current situation. If the results of this study indicate that indoor climate and levels of PM_{10} and UFP, in junior high schools in Reykjavik, need to be improved, it is important to establish the problematic factors, and recognize the milestones needed to improve the situation.

The results from this study can be a useful contribution, both academically and practically. The study can be used as a baseline for future studies on indoor school environment in Iceland and can serve as a baseline for the both researchers and policy makers. The results should be useful to identify common problematic factors in indoor school environment in Iceland, and should strongly indicate what further research needs to be undertaken to improve understanding of indoor school environment in Iceland. The results might also serve as guidelines for policies, laws and regulations relevant to the subject.

4 Material and Methods

This fourth section describes the materials and methods used in the study. That is, the study population and design, methods used to assess indoor climate and environment, and outdoor environment and finally the statistical methods and the hypotheses that was tested.

4.1 Study population

School attendance is compulsory in Iceland for all children between the age of 6 and 16. The vast majority of Icelandic children attend public (non-private) schools. In the school year 2007-2008, approximately 36 such schools were in the Reykjavík municipality. The age range in the public schools in Reykjavik is not the same in all the 36 schools; 23 included classes from 1^{st} to 10^{th} grade (6-16 years old), 8 included 1^{st} to 7^{th} grade (6-12 years old), 1 included 1^{st} to 6^{th} grade (6-11 years old), 1 included 1^{st} to 9^{th} grade (6-15 years old), 1 included 7^{th} to 10^{th} grade (12-16 years old) and 2 included 8^{th} to 10^{th} grade (13-16 years old). Out of these 36 schools 27 included classes at 8^{th} and 9^{th} grade (13-15 years old), and therefore count as junior high schools. In 2007 there were 9259 students in 8^{th} and 9^{th} grade in schools in Iceland and 3096 students in schools in Reykjavik (Statistics Iceland, 2007). That means that 33.4% of students in 8^{th} and 9^{th} grade attend schools in Reykjavik municipality.

4.2 Study design

Fifteen public schools, which included classes at 8^{th} or 9^{th} grade (13-15 years old) were selected for the study. Schools that only had one 8^{th} or 9^{th} grade were not included in the study. This was done in order to be able to perform the measurements in 4-6 classrooms in each school (2-3 classes in each grade). Six schools had only one 8^{th} or 9^{th} grade. Out of a total twenty-one junior high schools that had more than one 8^{th} or/and 9^{th} grade, 15 were randomly selected. This was done without having any other knowledge about the schools except the number of students, grades and classes.

After selecting the 15 schools the principals at all the schools were contacted and all agreed to participate in the study. The schools had 2-7 classes in 8^{th} and 9^{th} grade. 4-6 classrooms were randomly selected in each school, depending on the size of the school. In total, measurements were performed in 74, 8^{th} and 9^{th}, grade classrooms that were occupied during the measurements, by 1419 students aged between 13 and 15 years.

For comparison with schools in Sweden and China data from previous studies was used (Kim, Elfman, Mi, Johansson, Smedje, & Norbäck, 2005; (Zhao, Elfman, Wang, Zhang, & Norbäck, 2006). The study from Sweden included eight primary schools (1st – 6th grade) in Knivsta, Uppsala county, situated in mid-Sweden. In each school were three classes were selected, except in one school, which only had two classes. Measurements were performed in 23 classrooms with the same method as used in China and Iceland (Zhao, Elfman, Wang, Zhang, & Norbäck, 2006). The study in China was based on measurements from ten junior high schools within Taiyuan city. The study contained, in total, measurements from 46 first year high school classes that included students aged between 11 and 15 years old.

4.3 Assessment of indoor climate and environment

The school buildings were inspected and all measurements were performed during February-Mars, 2008. All the schools were mostly constructed with concrete. And all the schools served meals that were cooked in the schools. Most of the schools were built without adequate cooking facilities for preparing meals for students. Since cooked meals for the students were introduced recently (2004-2005) most of the older schools have had to adapt to the new situation by putting up new cooking facilities without local exhaust ventilation. The floor material was mainly linoleum and walls were painted. The classrooms were cleaned daily by dry mopping and wet mopping once a week; some of the schools were cleaned with wet mopping every second or third week. None of the schools had been painted or redecorated in the last year.

An inspection was performed in the 74 classrooms, including measurement of room volume, total floor area, amount of open shelves and textiles and number of students. The room volume (m^3), shelf factor (m/m^3), fleece factor (m_2/m^3) and occupancy (number of persons/m^3) were calculated in each classroom. Fleece factor (m^2/m^3) was calculated as the ratio between the surface area of fabrics (m^2) and the room volume (m^3) (Skov, Valbjorn, & Pedersen, 1990). Room temperature, relative air humidity

(RH%) and CO_2 were measured with a Q-Trackt^{TM} IAQ Monitor (TSI Incorporated, USA), sampling one-minute average intervals. Particles were measured with both P-Trak™ (Model 8525 Ultrafine Particle Counter), measuring particles in the size range 0.02 to 1 micrometer, and Dust-Track^{TM} (Model 8520; TSI Incorporated, USA), measuring particles from approximately 1-10 micrometer (PM_{10}). The instruments were calibrated by the Swedish service laboratory for TSI equipment. All sampling was with one-minute average interval and measurements were performed during approximately 1 hour and 20 minutes, during normal activities. All instruments were placed at desk at 0.9 m above the floor, in the back of the classroom. It was obvious in some measurements that the students had been breathing directly into the instruments, this resulted in short peaks of exposure, especially to CO_2, that were omitted from the data. These levels were not included in the results. The number of persons in the classroom was noted, as well as open windows and open doors. The fresh air supply in the classrooms was calculated from the estimated equilibrium CO_2 concentration (ppm), by the formula below: The equilibrium CO_2 concentration was estimated manually from the CO_2-graphs.

$$A=P/(C_{mean}-C_0)*10^6/3600$$

Where A is the personal outdoor air supply rate, P denotes the personal emission rate of CO_2 in L/s, and C_{mean} and C_0 denote the mean CO_2 levels in the classroom, and in the outdoor air respectively (Norbäck et al., 1992). In the calculations, the author assumed a personal CO_2 emission equal to sedentary office work at sea level (18 L/h), and used the mean outdoor CO_2-level of 424 ppm in all schools. The air exchange rate was calculated by dividing the estimated total outdoor air flow (m^3/h), with the total volume of the classroom.

4.4 Assessment of outdoor environment

In parallel with the indoor measurements, temp, RH%, CO_2, PM_{10} and UFP were measured outside each school using the same methods. All sampling was with one-minute average interval and measurements were performed during approximately 3-4 hours.

4.5 Statistical methods and hypotheses tested

Correlation between different environmental and exposure factors was measured by a rank correlation test not requiring normal distribution (Kendall's tau-β). Two tailed tests and a 5% level of significance was applied in all statistical analyses. This method is based on standard methods that have been used in school studies in for example China and Sweden.

4.5.1 Kendall tau-β rank correlation test

The Kendall rank correlation coefficient or the Kendall's Tau test was developed by Maurice Kendall in 1938. It is used to measure the degree of correspondence between two rankings and assessing the significance of this correspondence. (StatsDirect, 2008). In other words, it measures the strength of association of the cross tabulations. The Kendall's Tau test are divided into Tau a, b and c. The results of this paper was based on the Kendall's Tau-β test, that tests the strength of association of the cross tabulations when both variables are measured at the ordinal level. It makes adjustments for ties (Abdi, 2007). The Kendall tau coefficient has the following properties:

- If the agreement between the two rankings is perfect (i.e., the two rankings are the same) the coefficient has value 1.
- If the disagreement between the two rankings is perfect (i.e., one ranking is the reverse of the other) the coefficient has value -1.
- For all other arrangements the value lies between -1 and 1, and increasing values imply increasing agreement between the rankings. If the rankings are completely independent, the coefficient has value 0.

In order to be able to compare the correlation between indoor climate factors and environmental factors from this study with the correlation between indoor climate factors and environmental factors in studies from Sweden and China, the same method was used. Comparison studies from China and Sweden used the Kendall Tau-β correlation test to calculate the strength of correlation between indoor climate and environmental factors.

4.5.2 Hypotheses tested

Different hypotheses were tested in the study, and the null hypotheses, H_0, can be formulated as follows:

- There is no difference between indoor climatic factors in classrooms in junior high schools in Reykjavik.
- There is no difference between indoor environmental factors in classrooms in junior high schools in Reykjavik.
- There is no difference between indoor climatic factors in schools in Reykjavik, China and Sweden.
- There is no difference between indoor environmental factors in schools in Reykjavik, China and Sweden.
- There is no significant correlation within and/or between indoor climatic factors and indoor environmental factors.
- There is no significant correlation within and/or between levels of outdoor PM_{10} and UFP and indoor levels of PM_{10} and UFP.

The concept "indoor climatic factors" includes:

- Levels of indoor particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10}), indoor ultra-fine particles (UFP), indoor carbon dioxide (CO_2), temperature and relative air humidity (RH%) in the classrooms.

The concept "indoor environmental factors" includes:

- Shelf factor (m/m^3), fleece factor (m^2/m^3), number of persons per cubic meter ($pers/m^3$), personal outdoor air supply rate (L/s/person) and air exchange rate (ac/hour).

5 Results

This section is divided into three chapters, based on the studies objectives. The chapters present the results for each sub objective. The chapters are meant to present the results for the main objectives, which are results on indoor climate and levels of PM_{10} and ultra-fine particles in junior high schools in Reykjavik. The first chapter presents the results on indoor and outdoor climate from the 15 junior high schools in the Reykjavik city area, Iceland. In the second chapter the results from Reykjavik, Iceland are compared to results from school studies in Taiyuan, China and Uppsala, Sweden. Kendal's tau-β correlation coefficients analysis is presented in the third chapter to assess the correlation within and between indoor climatic factors and indoor environmental factors, as well as correlation within and between measured levels of indoor PM_{10} and UFP and outdoor PM_{10} and UFP. The results are presented both graphically, in form of tables and text.

5.1 Indoor and Outdoor Climate in schools in Reykjavik, Iceland

Table 2: Average indoor and outdoor climate and environment in 15 junior high schools in Reykjavik, Iceland, during the measuring period.

Measurements from Junior High Schools in Reykjavik			
	n[a]	Mean (s.d.)	Min to max
Indoor climate and room inspection			
Number of persons	74	19 (4)	8-32
Classroom volume (m^3)	74	218 (141)	127-859
Pers/m^3	74	0.104(0.03)	0.02-0.17
CO_2 (ppm)	74	1510 (639)	534-3355
PM_{10} (µg /m^3)	74	40.35(25.85)	6.3-162
UFP (particles/cm^3)	74	9069 (12314)	890-92692
Outdoor air supply rate (L/s/person)[b]	74	4.7(5.2)	1.5-39.7
Air exchange rate (ac/hour)	74	1.6(2.8)	0.5-17.2
Temperature (°C)	65	21.7(1.2)	18.3-25.5
Relative humidity (%)	67	33(9)	16.9-54.7
Fleece factor (m^2/m^3)	74	0.02 (0.04)	0-0.24
Shelf factor (m/m^3)	74	0.05 (0.05)	0-0.36
	n[d]	Mean (s.d.)	Min to max
Outdoor climate			
CO_2 (ppm)[C]	14	424 (52)	310-471
PM_{10} (µg /m^3)	15	13(13)	1.3-49,5
UFP[C]	13	8157 (7450)	1066-28995
Temperature (°C)	15	2.4 (2.9)	(-2) -8
Relative humidity (%)	15	71 (21)	31.3-100

[a]Number of classrooms

[b]Calculated from the estimated equilibrium concentration of CO^2

[c]Measurements missing due to practical reasons.

[d]Number of schools.

Indoor climatic factors and indoor environmental factors were measured in 74 classrooms and outdoor climatic factors were measured outside all 15 participating junior high schools in Reykjavik, Iceland. The mean number of persons per room volume was 0.104 (SD 0.03, range 0.02-0.17). In the classrooms the mean CO_2 concentration was 1510 ppm (SD 639 ppm.; range 534-3355 ppm.). Out of the studied classrooms, 23% fulfilled the recommended level of CO_2, which is maximum 1000 ppm. Mean room temperature was 21.7 °C (SD 1.2°C ; range 18,3-25,5°C) and mean RH% was 33% (SD 9%; range 16.9-54.7%) (Table 2). The mean personal outdoor air supply was 4.7 L/s/person (SD 5.2; range 1.5-39.7 L/s/person), and only 12% of the classrooms fulfilled the recommend ventilation standard of 8 l/s per person (ASHRAE, 1999). Most of the classrooms had a restroom directly connected to the classroom, with mechanical exhaust ventilation. However, inspection revealed that airflow was in many cases very low in these ventilation ducts. Only one of the schools had displacement ventilation. The mean shelf factor was 0,05 m/m^3 (SD 0.05; 0-0.36 m/m^3) and the mean fleece factor was 0.02 m^2/m^3 (SD 0.04; 0-0.24 m^2/m^3). Most of the classrooms had padded, textile-covered chairs, none of classrooms had wall-to-wall carpets. There were on average 19 persons per classroom (SD 4; range 8-32). The mean room volume was 218 m^3 (SD 141; range 127-859 m^3).

Mean indoor concentration of PM_{10} was 40 $\mu g/m^3$ (SD 16 $\mu g/m^3$; range 6 -162 $\mu g/m^3$) and the mean concentration of ultra-fine particles was 9069 particles/cm^3 (SD 12314; range 890-92692 particles/cm^3). Higher levels of UFP were observed in relation to cooking activities at lunch break or afternoon meals. The mean outdoor CO_2 concentration was 424 ppm (SD 52 ppm; range 310-471 ppm), mean temperature was 2.4°C (SD 2.9; range-2-8°C) and mean RH% was 71% (SD 21%; range 31.3-100%) (Table 2). The mean outdoor PM_{10} was 13 $\mu g/m^3$ (SD 13 $\mu g/m^3$; range 1-49 $\mu g/m^3$) and the mean outdoor UFP was 8157 particles/cm^3 (SD 7450 particles/cm^3; range 1066-28995 particles/cm^3).

The comparison of indoor climatic factors and indoor environmental factors in the junior high schools in Reykjavik, Iceland, during the measuring period, are presented in Table 3 and 4. The comparison is shown graphically in figure 4- 14.

5.1.1 Comparison of indoor climatic factors

Table 3: Comparison of indoor climatic factors in 15 junior high schools in Reykjavik, Iceland, during the measuring period.

Nr.	n[a]	PM_{10}		UFP		CO_2		$EqCO^2$		Temp		RH%	
		Mean (s.d)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max
1	5	72.4 (17.1)	58.5-97.2	7922 (3257)	3878-11469	2020 (562)	1538-2758	2675 (623)	2100-3500	20.7 (0.75)	20.1-21.7	47 (3.1)	42.6-49.9
2	6	55.6 (19.9)	39.4-88.4	4415 (4217)	890-11133	1743 (510)	1047-2498	2433 (372)	2100-3100	22.8 (0.90)	21.6-23.7	43.6 (3.32)	39.4-47.5
3	7	49.7 (56)	9.9-162	13099 (10663)	3956-31049	1347 (1031)	534-3355	1742 (1156)	550-3850	21.1 (2.2)	18.3-23.7	35.9 (10.7)	23.5
4	6	54.2 (43.7)	22.1-123.3	2733 (646)	1950-3700	1816 (651)	1072-2639	2733 (646)	1950-3700	21.23 (0.73)	20.3-22.1	34.8 (3.07)	31.3-38.9
5	5	33.8 (15.3)	19.5-58.5	6054 (3705)	1366-9972	1436 (512)	859-2225	2070 (719)	1250-2800	21.6 (0.33)	21.2-22.1	32.8 (5.23)	26-38.6
6	4	47.7 (15.1)	33.3-68.9	6125 (2096)	4441-9160	2353 (839)	1759-2946	2727 (1093)	1954-3500	20.4 (0.07)	20.3-20.4	35 (7.78)	29.5-40.5
7	4	30.2 (13.5)	15.3-48.1	7559 (6894)	2202-16857	1037 (6894)	1016-1057	1625 (318)	1400-1850	22.8 (0.21)	22.6-22.9	25.75 (3.89)	23-28.5
8	4	8.7 (2.3)	6.3-10.8	6709 (494)	6359-7058	621 (42)	573-649	850 (50)	800-900	22 8 (0.85)	21.2-22.9	19.3 (1.3)	18-20.6
9	4	33.5 (10.4)	20.8-44.1	12826 (4812)	8725-18418	1839 (812)	885-2738	2213 (1009)	1150-3500	22.2 (0.66)	21.4-23	31.25 (6.69)	23.5-38.9
10	4	35.4 (10.2)	27.3-50.4	6425 (1928)	4846-8948	1596 (307)	1291-2023	2013 (484)	1650-2700	21.8 (1.0)	21.3-23.3	32.9 (2.11)	30-34.6
11	4	30 (12.6)	17.1-46.8	6773 (3669)	3291-10567	1351 (679)	745-2294	1575 (897)	800-2850	22.4 (2.1)	21-25.5	22.23 (6.17)	17-31.1
12	4	32.2 (17.1)	13-54.6	8399 (4411)	2758-13059	1589 (603)	910-2352	1950 (722)	1050-2800	21.7 (0.85)	21-22.9	32.7 (3.41)	28-35.6
13	6	30.6 (4.7)	23.4-37.7	9902 (6580)	2031-19719	995 (156)	829-1231	1625 (479)	1000-2300	20.9 (1.24)	18.7-21.7	33 (3.11)	28.8-37.9
14	6	38.7 (9.4)	26-49.5	30148 (38080	4120 -	1779 (216)	1577 -	2210 (191)	2050 -	21.7 (0.43	21-22.1	36.42	35.1 -

				)	9269 2		2087		2500	)		(1.51)	38.6
15	6	34 (12.1)	18- 49.5	5328 (5066)	1521 - 1264 7	1097 (199)	756- 1252	1590 (413)	900- 2000	21.9 (0.8)	21.1 - 23.1	36.2 (2.8)	32.8 - 39.6
Mea n	**5**	**39.1**		**8961**		**1508**		**2002**		**21.7**		**33.3**	
SD	**1. 1**	**14.9**		**6495**		**449**		**523**		**0.72**		**7.1**	
Min	**4**	**8.7**		**2733**		**621**		**850**		**20.4**		**19.3**	
Max	**7**	**72.4**		**30148**		**2353**		**2733**		**22.8**		**47**	

[a] Number of classrooms in each school.
(s.d): standard deviation.

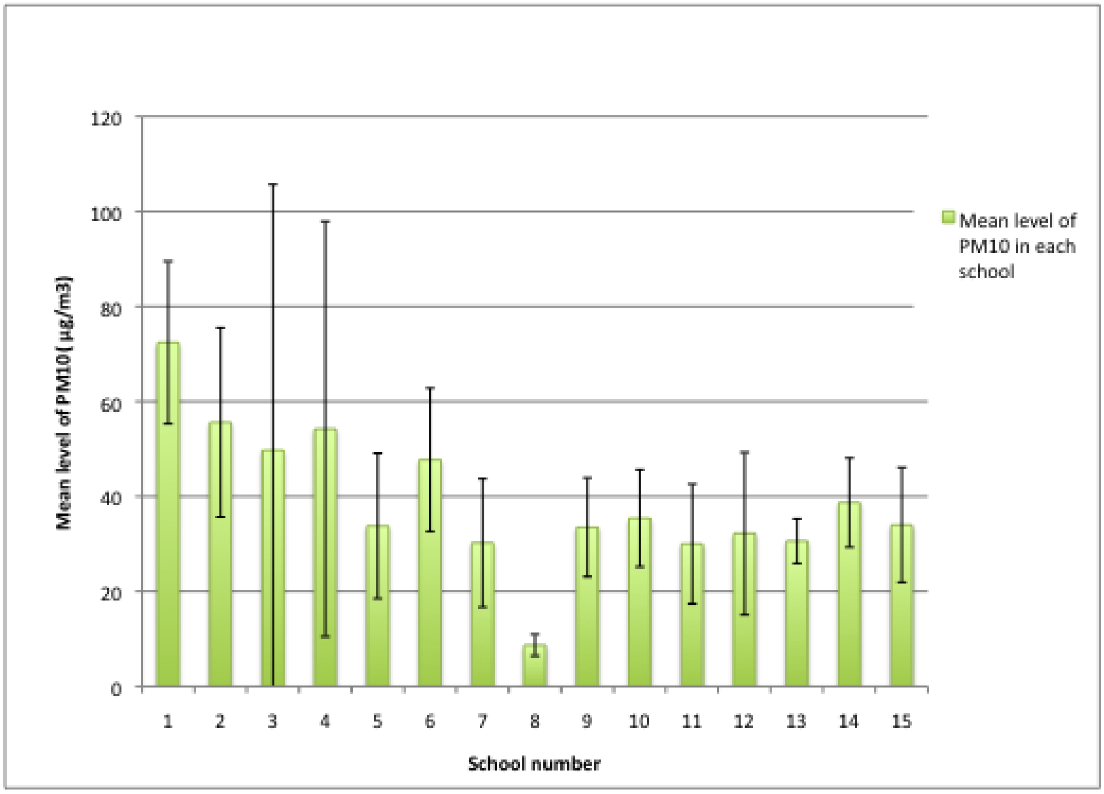

Figure 4: Comparison of mean level of PM_{10} (µg/m^3) in 15 junior high schools in Reykjavik, Iceland, during the measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 4 compares the mean level of PM_{10} in each studied school, which ranges from 8.7 to 72.4 µg/m^3. The school with the lowest mean levels of PM_{10} in the classrooms, was school number 8, were the levels ranged between 6.3-10.8 µg/m^3 (see table 3).

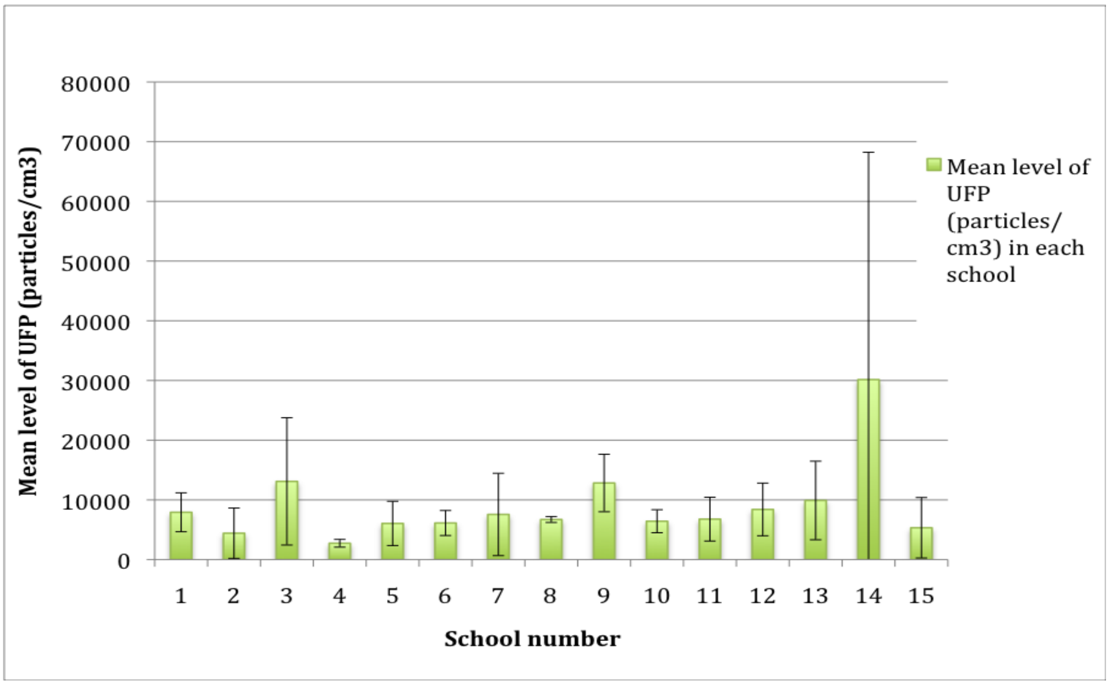

Figure 5: Comparison of mean level of UFP (particles/cm^3) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 5 shows the mean level of ultra-fine particles (UFP), in the schools that were studied. The mean level of UFP ranges from 2733 particles/cm^3 in school number 4, to 30148 particles/cm^3 in school 14. The mean level from school number 14 is significantly higher than the mean levels from the other schools. Five measurements of UFP, were performed in five classrooms. Two of the measurements showed significantly higher values of UFP. That is 40407 particles/cm^3 and 90692 particles/cm^3.

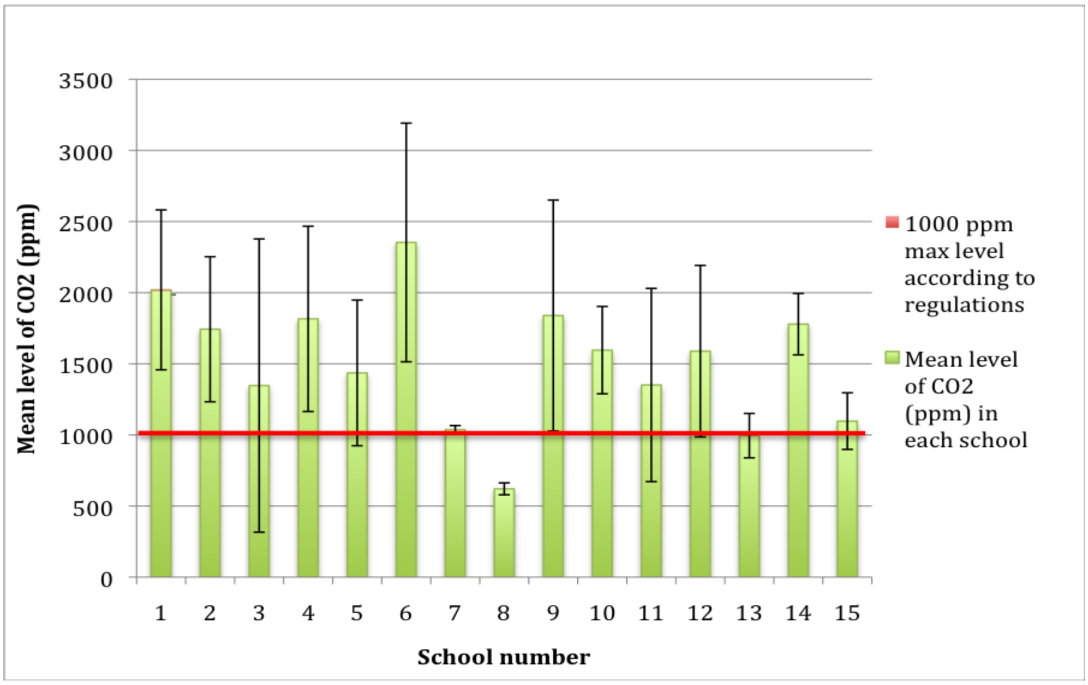

Figure 6: Comparison of indoor mean level of CO_2 (ppm) in 15 junior high schools in Reykjavik, iceland, during measuring period. The red line demonstrates the recommended max level according to Icelandic building regulations, which is 1000 ppm. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 6 depicts a comparison of mean level of CO_2 in 15 junior high schools in the municipality of Reykjavik, during the measuring period. The lowest mean level was in school 8, 621 ppm, and the highest in school 6, 2353 ppm. According to the Icelandic building regulation, the mean level of CO_2 should not be above 800 ppm and the max level should not pass 1000 ppm (The Building Regulation nr.441/1998). Fourteen out of fifteen schools had mean levels above 800 ppm. and thirteen out of fifteen had mean levels above 1000 ppm. The measured CO_2-levels in the classrooms ranged greatly in several of the schools, which explains the big standard deviation in several of the schools.

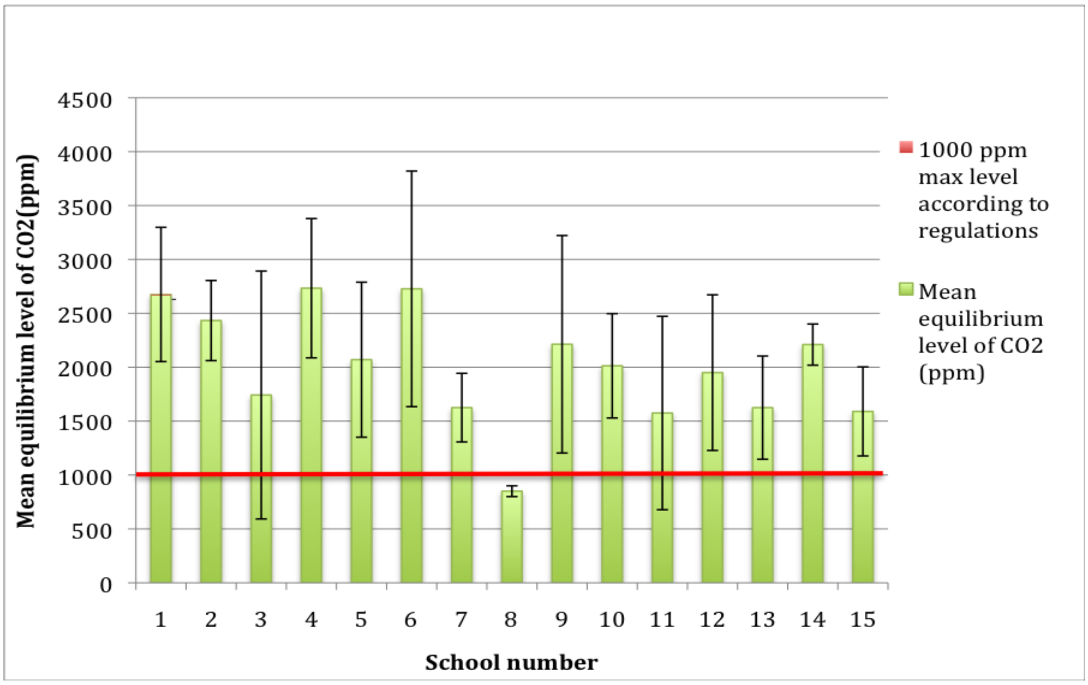

Figure 7: Comparison of mean equilibrium level of CO_2 (ppm) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The red line demonstrates the recommended max level according to Icelandic building regulations, which is 1000 ppm. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 7 shows a comparison of mean level of equilibrium CO_2 (ppm) during the measuring period, in the Reykjavik city area in Iceland. The levels ranged from 850 ppm in school number 8, to 2733 ppm. in school number 4. School number 8 was the only school, of the measured schools, that had a mean level of equilibrium CO_2 below the 1000 ppm, limit. Thus approximately 93% of the measured schools had levels above the recommended max limit (1000 ppm). All of the schools had a mean limit above the recommended mean limit (800 ppm).

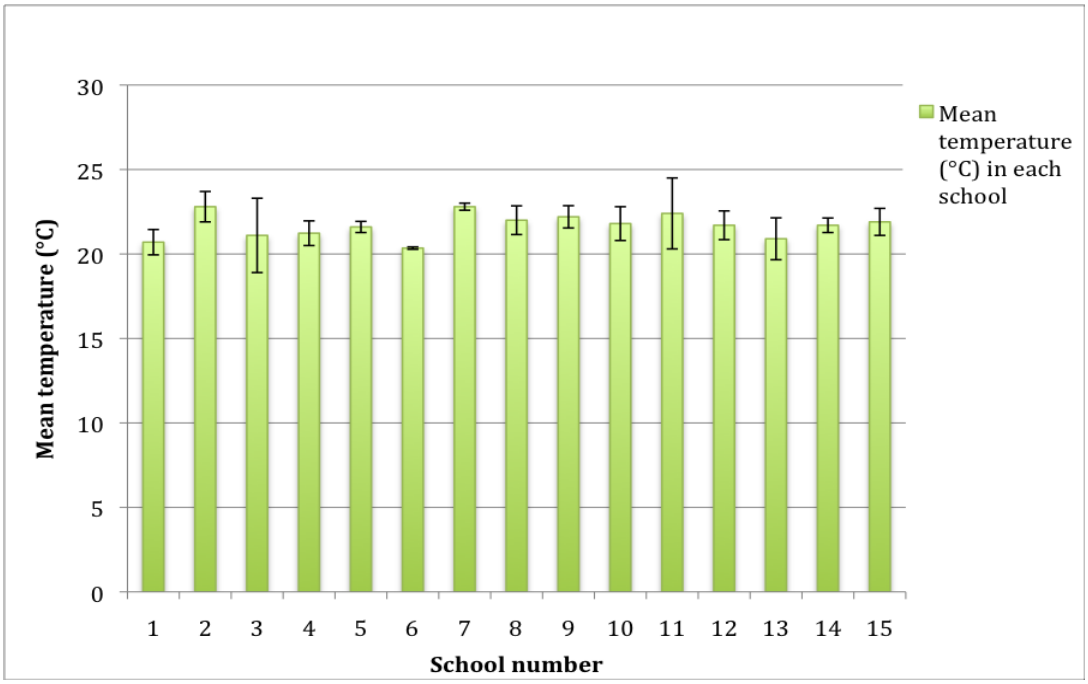

Figure 9: Comparison of mean temperature (°C) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d.) in each participating school.

During the measurement period the mean temperature in the classrooms in the 15 schools, range from 20.4°C in school number 6 to 22.8°C in school number 2 and school number 7.

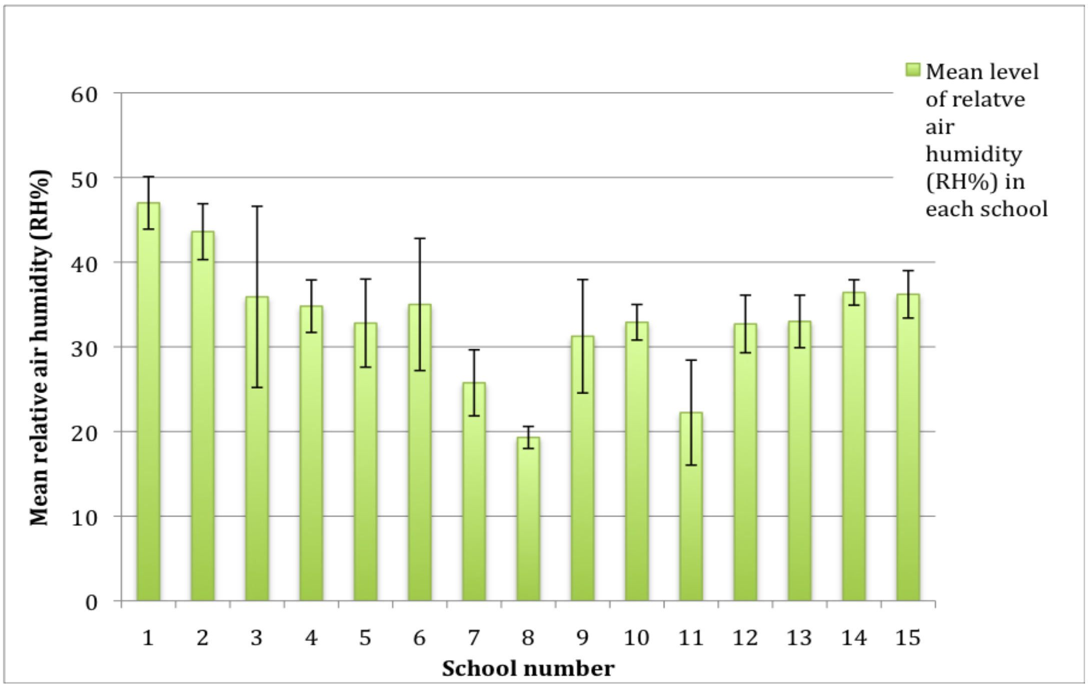

Figure 9: Comparison of mean level of relative air humidity (RH%) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 9 illustrates the results for the measurements of mean level of relative air humidity (RH%). The relative air humidity ranged from 19.3% in school number 8, to a mean level of 47% in school number 1.

5.1.2 Comparison of indoor environmental factors

Table 4: Comparison of indoor environmental factors in 15 junior high schools in Reykjavik, Iceland, during measuring period.

Nr.	n[a]	**Shelf factor (m/m^3)**		**Fleece factor (m^2/m^3)**		**Pers/m^3**		**Outdoor air supply (L/s/person)**		**Air exchange rate (ac/h)**	
		Mean (s.d.)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max	Mean (s.d.)	Min to max
1	**5**	0.050 (0.02)	0.049-0.053	0.0116 (0.016)	0-0.029	0.13 (0.022)	0.1-0.15	2.3 (0.6)	1.6-3	1.1 (0.3)	0.7-1.5
2	**6**	0.017 (0.028)	0-0.071	0.07 (0.013)	0.056-0.088	0.11 (0.018)	0.08-0.13	2.6 (0.4)	1.9-3	1 (0.2)	0.7-1.3
3	**7**	0.055 (0.018)	0.036-0.087	0.035 (0.018)	0.015-0.064	0.11 (0.017)	0.09-0.13	10 (14.6)	1.5-39.7	4.3 (6.4)	0.6-17
4	**6**	0.046 (0.014)	0.027-0.07	0	0-0	0.13 (0.028)	0.09-0.17	2.3 (0.6)	1.5-3.3	1 (0.2)	0.7-1.3
5	**5**	0.025 (0.025)	0.025-0.12	0	0-0	0.10 (0.24)	0.08-0.13	3.6 (1.7)	2.1-6.1	1.4 (0.9)	0.6-2.8
6	**4**	0.063 (0.14)	0-0.14	0.014 (0.028)	0-0.056	0.13 (0.02)	0.11-0.15	2.4 (1.2)	1.6-3.3	1.2 (0.8)	0.7-1.8
7	**4**	0.044 (0.038)	0-0.085	0.0235 (0.22)	0-0.05	0.10 (0.035)	007-0.15	4.3 (1.1)	3.5-5.1	1.9 (0.04)	1.9-1.9
8	**4**	0.007 (0.0007)	0.006-0.007	0	0-0	0.02 (0.016)	0-0.04	11.8 (1.4)	10.5-13.3	1.2 (0.4)	1-1.6
9	**4**	0.049 (0.017)	0.036-0.07	0	0-0	0.11 (0.042)	0.05-0.14	3.7 (2.3)	1.6-6.9	1.2 (0.5)	0.6-1.9
10	**4**	0.064 (0.041)	0-0.115	0.0851 (0.11)	0-0.237	0.11 (0.011)	0.10-0.13	3.3 (0.9)	2.2-4.1	1.3 (0.3)	1-1.6
11	**4**	0.062 (0.05)	0-0.126	0.0413 (0.02)	0.014-0.061	0.09 (0.02)	0.07-0.12	6.7 (4.8)	2.1-13.3	2.4 (2.2)	0.5-5.5
12	**4**	0.034 (0.02)	0-0.067	0	0-0	0.10 (0.026)	0.07-0.12	4.1 (2.6)	2.1-8	1.3 (0.6)	0.9-2.1
13	**6**	0.051 (0.045)	0.013-0.133	0	0-0	0.07 (0.015)	0.06-0.10	4.8 (2.2)	2.7-8.7	1.3(0.6)	0.7-2.3
14	**6**	0.084 (0.15)	0-0.36	0.009 (0.02)	0-0.052	0.12 (0.015)	0.10-0.14	2.8 (0.29)	2.4-3.1	1.2(0.1)	1.1-1.3
15	**6**	0.068 (0.037)	0-0.10	0.05 (0.028)	0.02-0.099	0.09 (0.053)	0-0.14	5.12 (3.03)	3.2-10.5	1.5(0.3)	1.2-1.9
Mean	5	**0.048**		**0.023**		**0.101**		**4.65**		**1.6**	
SD	**1.1**	**0.020**		**0.028**		**0.028**		**2.83**		**0.8**	
Min	4	**0.007**		**0**		**0.02**		**2.3**		**1**	
Max	7	**0.084**		**0.085**		**0.13**		**11.8**		**4.3**	

[a] Number of classrooms in each school.
(s.d.): Standard deviation

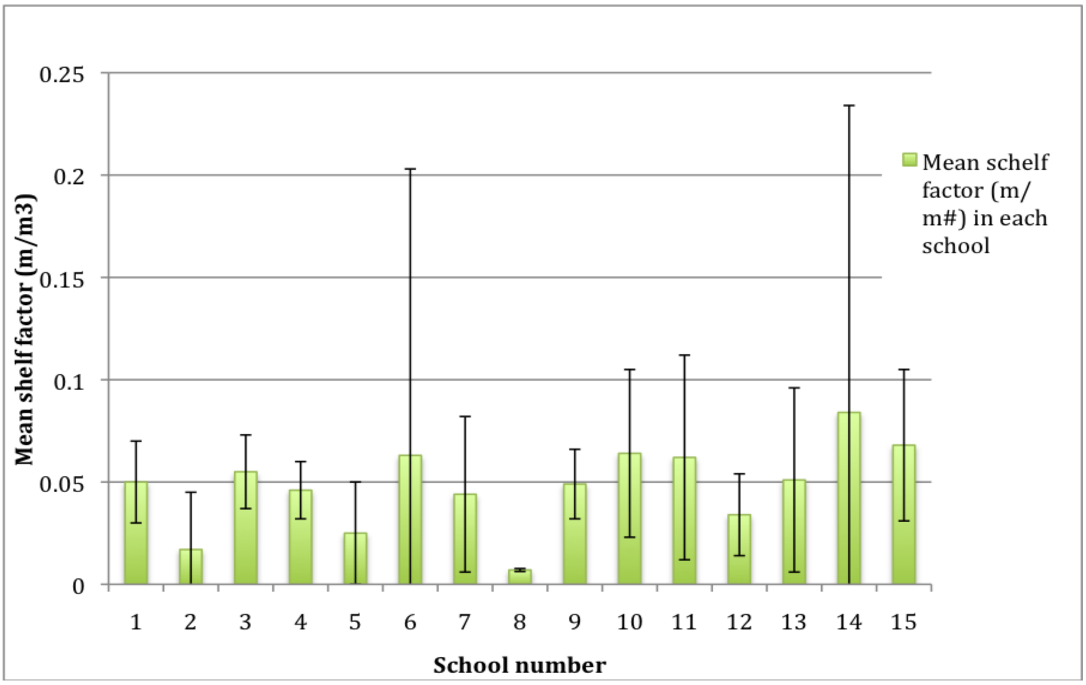

Figure 10: Comparison of mean shelf factor (m/m^3) in junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 10 depicts that the mean shelf factor in each school ranged from 0.007 to 0.0084 m/m^3. Most shelves were in school number 14, which had the mean shelf factor 0.084 m/m^3, with a range between 0-0.36 m/m^3. The big standard deviation is caused by the fact that the some of the schools had many meters of open shelves, while others had no open schelves.

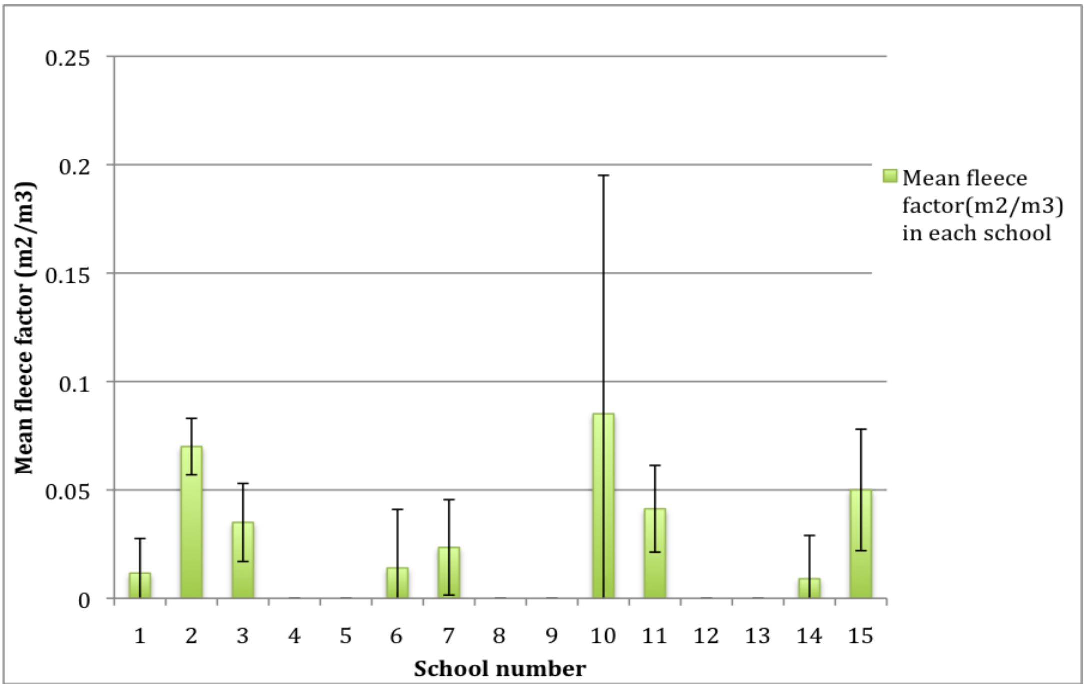

Figure 11: Comparison of mean fleece factor (m^2/m^3) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Figure 11 demonstrates that the fleece factor in the 15 measured junior high schools in the Reykjavik city area vary relatively much between the schools. Six of the schools had the mean fleece factor 0. The mean fleece factor in the other 9 schools ranged from 0.009 m^2/m^3 in school number 14 to 0.085 in school number 10. The standard deviation in school 10, is caused by the big range of fleece factor in school number 10.

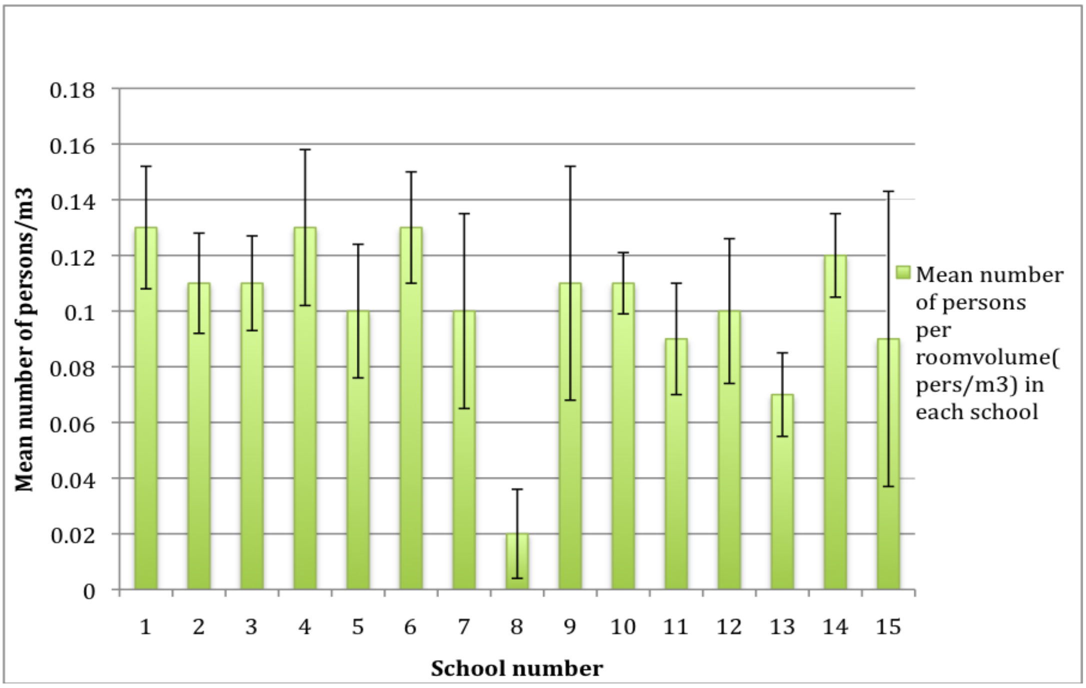

Figure 12: Comparison of mean number of persons per room volume (pers/m^3) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

The mean value of persons per cubic centimeter (pers/m^3) ranged from 0.02 pers/m^3 in school number 8 to 0.13 pers/m^3 in schools number 1.4 and 6. The mean value for persons/m^3 in school number 8 was significantly lower then the mean values from the other 14 schools.

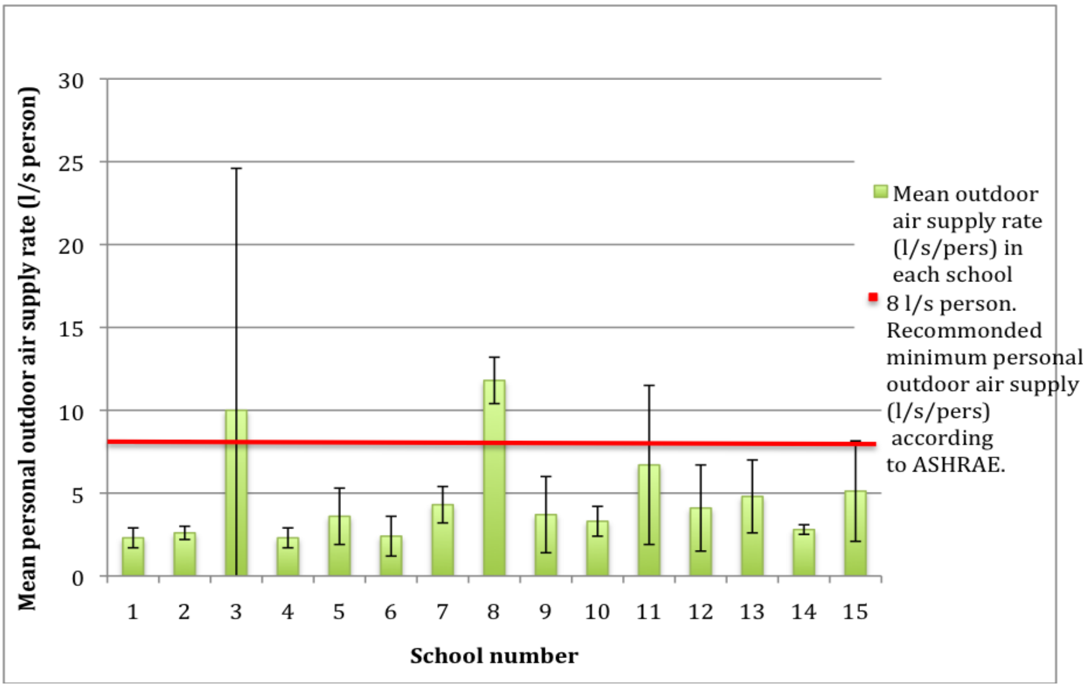

Figure 13: Comparison of mean personal outdoor air supply rate (L/s/person) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The red line represents the recommended minimum personal outdoor air supply rate (ASHRAE, 1999). The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Based on the measurements performed in the 15 participating junior high schools in Reykjavik City area, the mean outdoor air supply rates (L/s/person) for each school was calculated. The figure above presents the results from those calculations, which range from 2.3 to 11.8 L/s/person. Two of the schools had a mean personal outdoor air supply rate above the recommended minimum personal outdoor air supply rate, which is 8 L/s/person. According to this approximately 86% of the schools had a mean personal outdoor air supply rate below the widely used recommended minimum, according to the *American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)*, which is 8 L/s/person (ASHRAE, 1999). The big standard deviation in school number three is caused by the big range of personal outdoor air supply rate in the measured classrooms in school number 10. Measurements were performed in six classrooms in school 10, one of those measurements showed a significantly higher personal outdoor air supply rate, or 39,7 (ac/hour).

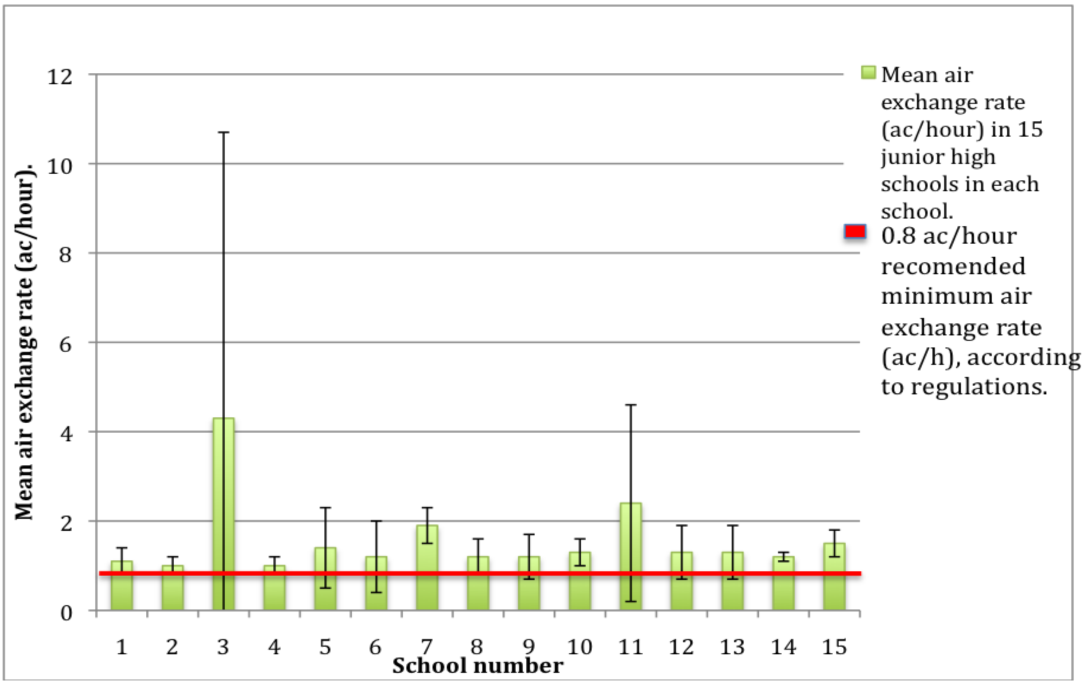

Figure 14: Comparison of mean air exchange rate (ac/h.) in 15 junior high schools in Reykjavik, Iceland, during measuring period. The black vertical lines demonstrate the standard deviation (s.d) in each participating school.

Based on the outdoor air supply rate, the mean air exchange rate (ac/hour) for each school was calculated. The mean air exchange rate in the 15 schools, ranged from 1 exchange per hour in schools number 2 and 4, to 4.3 exchanges per hour in school number 3. Seven measurements were performed in seven classrooms in school number 3. Six of those classrooms showed an air exchange rate between 0.6 ac/hour and 3.2 ac/hour. In one classroom was the air exchange rate was 17 ac/hour. All of the schools had a mean air exchange rate above the recommended minimum air exchange rate for work and dwelling areas, which is 0.8 ac/hour (The Building Regulation nr.441/1998).

5.2 Indoor climatic, indoor environmental and outdoor climatic factors in schools in Reykjavik, Iceland, Taiyuan, China and Uppsala, Sweden.

The minimum, maximum and mean levels of indoor climatic factors, indoor environmental factors and outdoor climatic factors in Reykjavik, Iceland, Taiyuan, China and Uppsala, Sweden are compared in table five.

Table 5: Comparison of minimum, maximum and mean levels of indoor climatic factors, indoor environmental factors and outdoor climatic factors in Iceland, China and Sweden.

	Iceland			China			Sweden			
	n[a]	Mean (s.d.)	Min to max	n[a]	Mean (s.d.)	Min to max	n[a]	Mean (s.d.)	Min to max	P-value
Indoor climate and room inspection										
Number of persons	73	19 (4)	8-32	46	48 (8)	33-60	23	20 (7)	8- 43	<0,001
Classroom volume (m^3)	74	218 (141)	127-859	46	193 (18)	161-225	23	202 (87)	82 -470	0,16
CO_2 (ppm)	65	1510 (639)	534-3355	24	2211 (1005)	789-4170	23	761 (196)	400 -1170	<0,001
Outdoor air supply rate (L/s/person)[b]	74	4,7(5,2)	1,5-39,7	24	3,6 (2,8)	1,3-10,4	22[c]	14,8 (7,0)	6,2-31,7	<0,001
Temperature (°C)	65	21,7(1,2)	18,3-25,5	24	14,7 (2,2)	11,2-18,4	23	21,4 (0,6)	20,2-22,5	<0,001
Relative humidity (%)	67	33(9)	16,9-54,7	24	42(10)	31-62	23	31 (8)	20-46	<0,001
Fleece factor (m^2/m^3)	74	0,02 (0,04)	0-0,24	23[c]	0,03 (0,03)	0-0,14	23	0,08 (0,08)	0,01-0,36	0,001
Shelf factor (m/m^3)	74	0,05 (0,05)	0-0,36	23[c]	0(0)	0-0	23	0,10 (0,06)	0-0,22	<0,001
	n[d]	Mean(s.d.)	Min to max	n[d]	Mean(s.d.)	Min to max	n[d]	Mean(s.d.)	Min to max	P-value
Outdoor climate										
CO_2 (ppm)[C]	14	424 (52)	310-471	10	522 (26)	480-559	8	368 (21)	345-395	<0,001
Temperature (°C)	15	2,4 (2,9)	-2-8	10	-1,8 (-2,1)	-5,5-2,6	8	5,0 (4,8)	0-13,7	0,002
Relative humidity (%)	15	71 (21)	31,3-100	10	52 (11)	31,3-100	8	82 (20)	34-97	0,006

[a]Number of classrooms

[b]Calculated from the estimated equilibrium concentration of CO^2

[c]Measurements missing due to practical reasons.

[d]Number of schools.

The average number of persons per classroom in Taiyuan, China, is more then twice as high as the number of persons in each classroom in Reykjavik, Iceland and Uppsala, Sweden. The classrooms in Taiyuan, China had on average 48 persons in each classroom, compared to 19 persons in Reykjavik, Iceland and 20 persons in Uppsala, Sweden. The mean CO_2 level in Reykjavik, Iceland, was 1510 ppm, 2211 ppm in Taiyuan, China and in Uppsala, Sweden the mean CO_2 level was below the recommended limit of 1000 ppm. or 761 ppm. The mean classroom temperature in Reykjavik, Iceland and Uppsala, Sweden was 21.7°C and 21.4°C. The mean temperature in Taiyuan, China was 14.7°C. The relative air humidity in classrooms was 42% in China, 33% in Iceland and 31% Sweden. The outdoor level of CO_2 in Iceland (424 ppm.) was in between outdoor CO_2 levels in China (522 ppm.) and Sweden (368 ppm.). The shelf factor in classrooms in Reykjavik, Iceland was 0.05 m/m^3 and 0.10 m/m^3 in Uppsala, Sweden. No shelves were used in Chinese classrooms (shelf factor 0 m/m^3). The comparison of all indoor and outdoor factors in Reykjavik, Iceland, Taiyuan, China and Uppsala, Sweden, is shown in Table 5 and comparison of the indoor climatic and indoor environmental factors are shown graphically in figure 16-22, below.

5.2.1 Comparison of min, max and mean indoor climatic factors

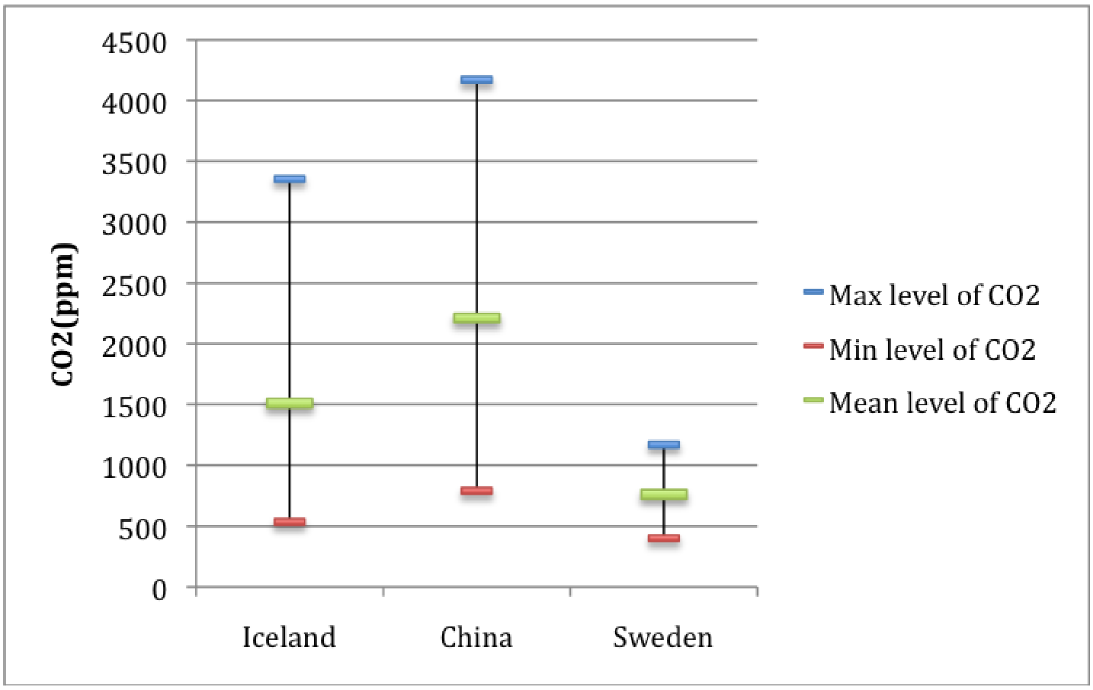

Figure 15: Comparison of min, max and mean level of CO_2 (ppm) in schools in Iceland, China and Sweden (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

The measured level of CO_2 ranged between 534-3355 ppm. in Reykjavik, Iceland, 789-4170 ppm. in China and 400-1170 ppm. in Uppsala, Sweden. The mean level of CO_2 was 1510 ppm. in Iceland, 2211 ppm in China and 761 ppm. in Sweden. The mean levels in Iceland and China were both above the recommended maximum level for CO_2, which is 1000 ppm (The Building Regulation nr.441/1998).

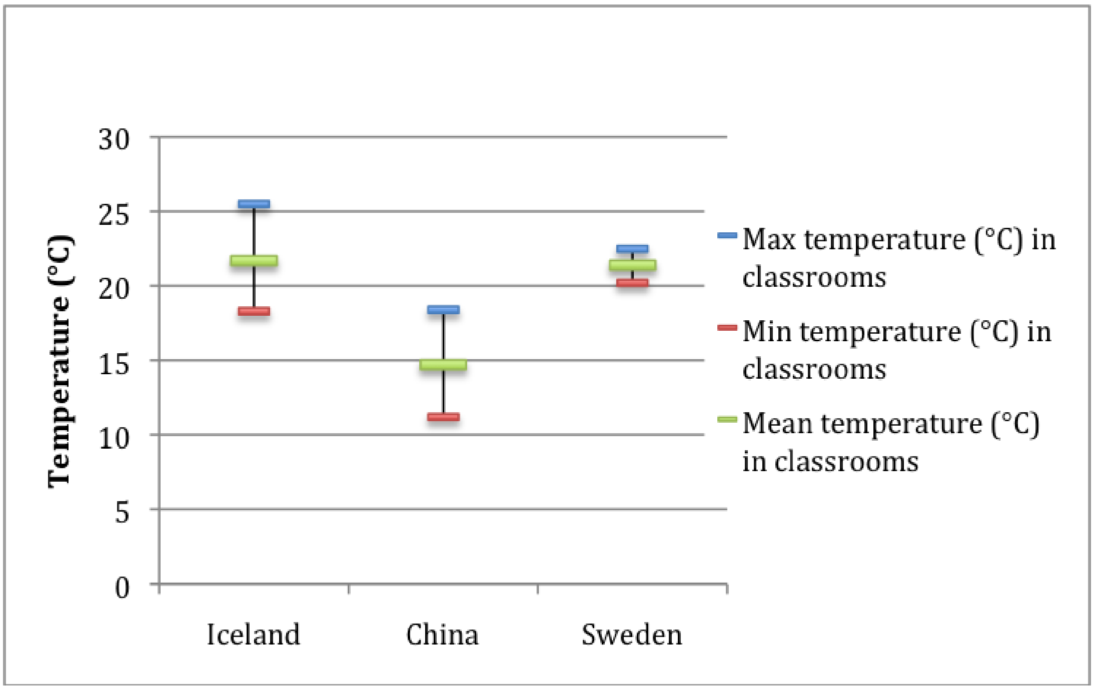

Figure 16: Comparison of min, max and mean temperature (°C) in schools in Iceland, China and Sweden (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

The temperature ranged between 18.3-25.5 °C in Iceland, 11.2-18.4°C in China and 20.2-22.5°C in Sweden. The mean temperature was 21.4 °C in Sweden and 21.7°C in Iceland. In China was the mean temperature in the classrooms 14.7°C.

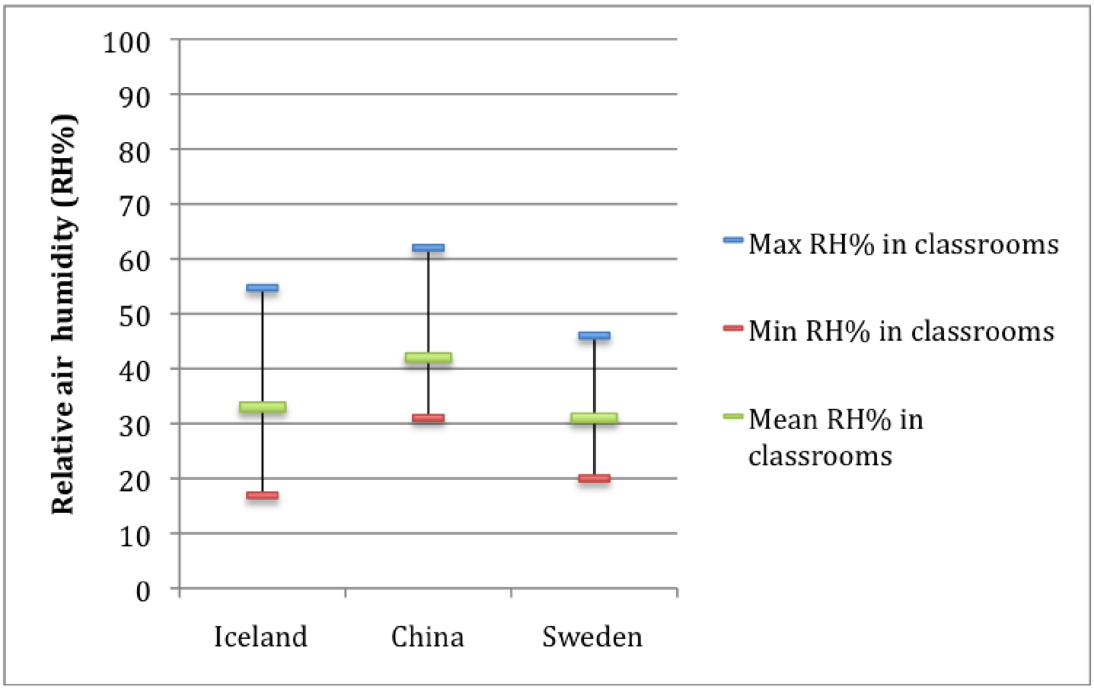

Figure 17: Comparison of min, max an mean level of relative air humidity (RH%) in schools in Iceland, China and Sweden (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

Figure 17 shows the results for the measurements of minimum, maximum and mean levels of RH% in classrooms in schools in Iceland, China and Sweden. The RH% ranged between 16.9-54.7 % in Iceland, 31-62% in China and 20-46% in Sweden. The mean RH% was 33% in Iceland, 42% in China and 31% in Sweden.

5.2.2 Comparison of miin, max and mean indoor environmental factors .

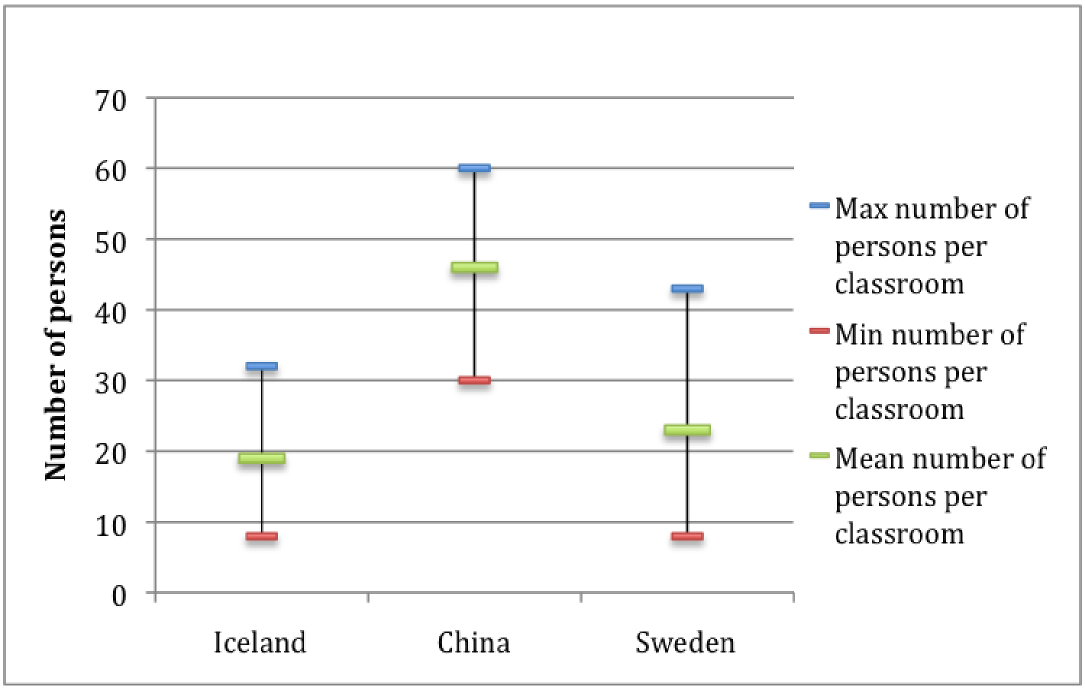

Figure 18: Comparison of min, max and mean number of persons i each classroom in schools in Iceland, China and Sweden (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

The number of persons in each measured classroom ranged from 8-32 persons in Iceland, 33-60 persons in China and 8-43 in Sweden. The mean number of persons in each measured classroom was 19 persons in Iceland, 48 persons in China and 20 persons in Sweden.

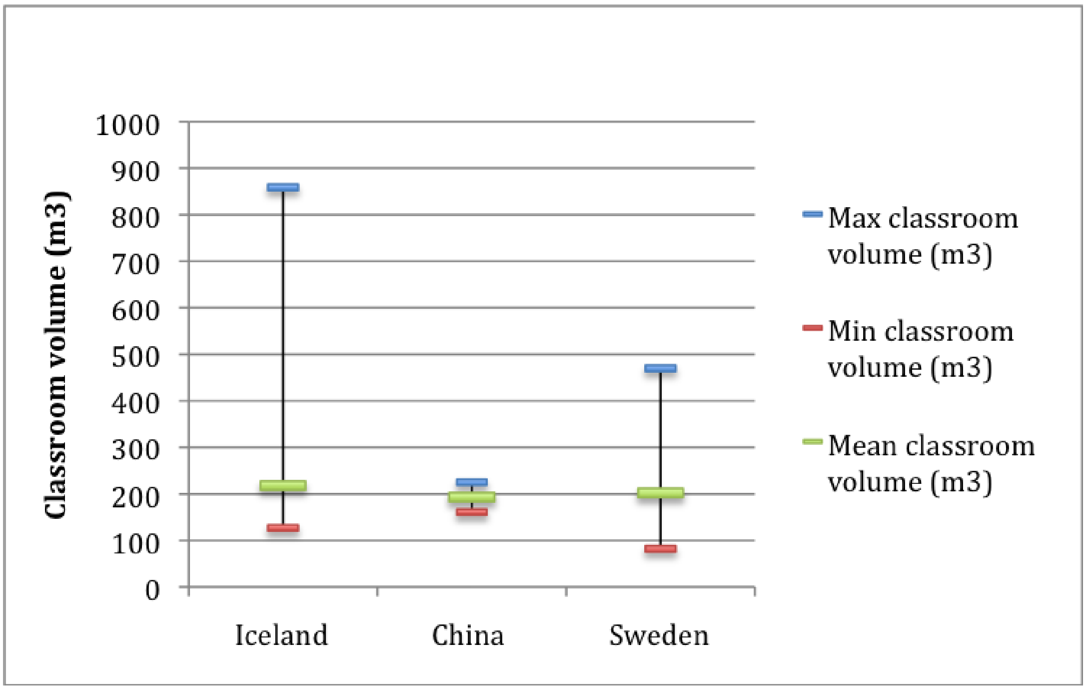

Figure 19: Comparison of min, max and mean classroom volume (m^3) in schools in Iceland, China and Sweden, during measuring periods (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006)

The classroom volume ranged from 127-859 m^3 in Iceland, 161-225 m^3 in China and 82-470 m^3 in Sweden. The classrooms in Iceland, China and Sweden all had a mean volume all around 200 m^3, or 218 m^3 in Iceland, 193m^3 in China and 202 m^3 in Sweden.

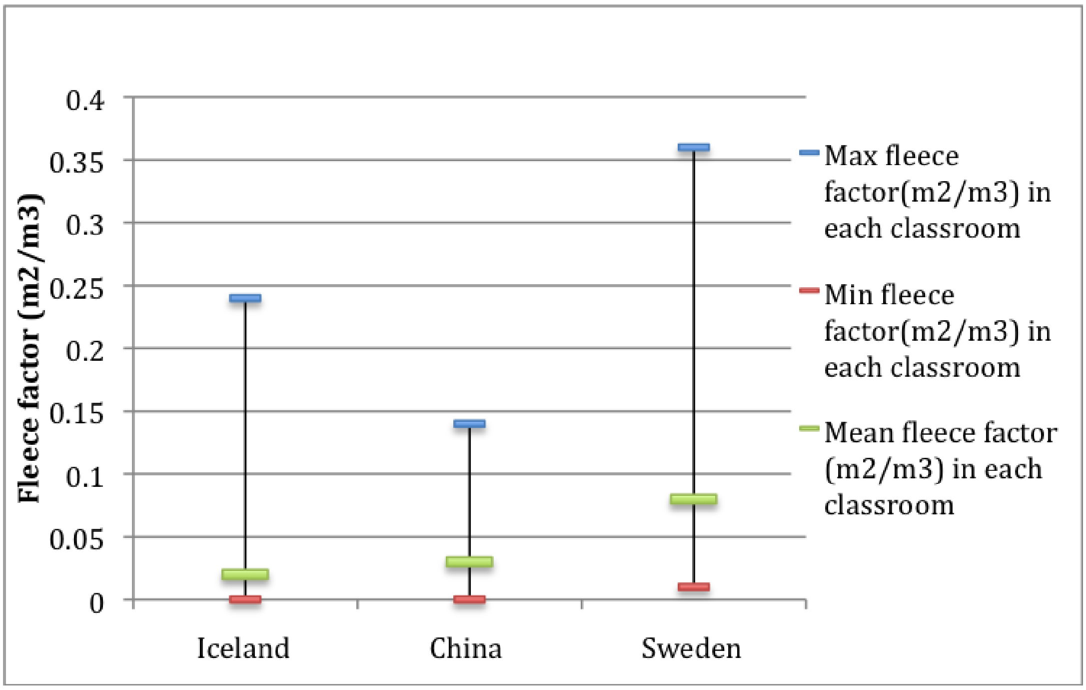

Figure 20: Comparison of min, max and mean fleece factor (m2/m3) in classrooms in Iceland, China and Sweden, during measuring period (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

The fleece factor (m^2/m^3) in the classrooms ranged from 0-0.24 m^2/m^3 in Iceland, 0.014 m^2/m^3 in China and 0.01-0.36 m^2/m^3 in Sweden. The mean fleece factor in Iceland was 0.02m^2/m^3, 0.03 m^2/m^3 in China and 0.08 m^2/m^3 in Sweden. All of the classrooms had padded chairs, which were not included when measuring the fleece factor in the classrooms. If chairs had been included when calculating the fleece factor in junior high schools in Reykjavik, the fleece factor would have been much higher.

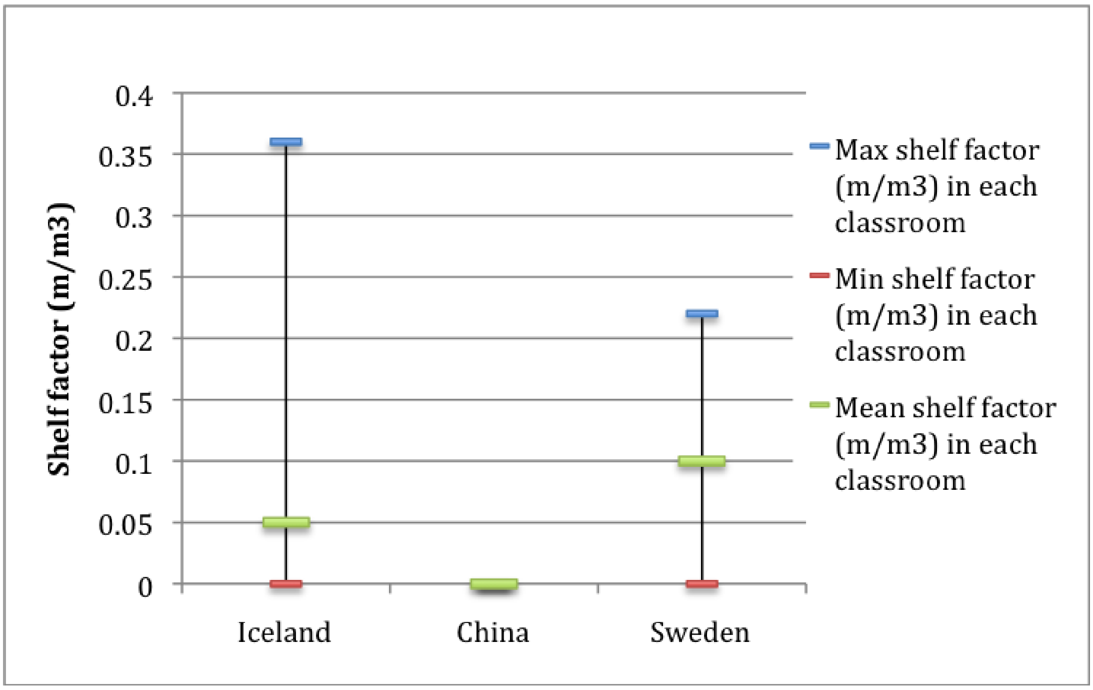

Figure 21: Comparison of min, max and mean shelf factor (m/m3) in classrooms in Iceland, China and Sweden (Source: Zhao, Elfman, Wang, Zhang, & Norbäck, 2006).

None of the classrooms that were studied in China had any open shelves, therefore was the shelf factor for China 0 m/m^3. The shelf factor ranged between 0-0.36 m/m^3 in Iceland and between 0-0.22 m/m^3 in Sweden. The mean shelf factor in Iceland was 0.05 m/m^3 and 0.1 m/m^3 in Sweden.

5.3 Correlation within and between different environmental and climatic factors

5.3.1 Correlation within and/or between indoor climatic factors and indoor environmental factors.

Table 6: Kendall's tau-β correlation analysis within and/or between indoor climatic factors, indoor environmental factors, in schools in the Reykjavik city area, Iceland. (Data were available in 74 classrooms, see full appendix 1, table for further information).

	Indoor Climatic Factors					Indoor Environmental Factors				
Kendall's tau-β	PM_{10}	UFP	CO_2 (ppm)	Temp (°C)	RH%	pers/m^3	Shelf factor (m/m^3)	Fleece factor (m^2/m^3)	Ac/h.	Air Supply
Indoor Climatic Factors										
PM_{10}	1.000									
UFP	.063	1.000								
CO_2	.433**	.014	1.000							
Temp	-.048	.141	-.016	1.000						
RH%	.414**	-.121	.486**	-.154	1.000					
Indoor Environmental Factors										
Pers/m^3	.316**	.073	.328**	0.67	.196*	1.000				
Shelf factor	-.025	-.003	-.019	-.059	-.084	.005	1.000			
Fleece factor	.124	-.103	.025	.202*	.138	.035	-.108	1.000		
Ac/h.	-.163	.116	-.459**	.065	-.387**	.150	.038	.070	1.000	
air supply	-.417**	.086	-.756**	.044	-.551**	-.276**	.024	-.014	.585**	1.000

**. Correlation is significant at the 0.01 level (2-tailed), ($P<0.01$).
*. Correlation is significant at the 0.05 level (2-tailed), ($P<0.05$).

Levels of PM_{10} were positively correlated to levels of CO_2, RH% and number of persons per room volume (pers/m^3) (tau-β 0.316, 0.433; $P<0.01$). A significant negative relationship was found between the levels of PM_{10} and the personal outdoor air supply rate (L/s/person) (tau-β -0.417, $P< 0.01$). UFP were not correlated with any of the measured indoor climatic factors or indoor environmental factors. There was a significant positive correlation with relative air humidity (RH%) and number of persons per room volume (pers/m^3) (tau-β 0.329, 0.486, $P<0.01$). Significant negative relationship was found between the CO_2 levels and the personal outdoor air supply (L/s/person) and air exchange rate (ac/hour) (tau-β -0.459, -0.756; $P<0.01$).

The temperature (°C) was positively associated with the classrooms fleece factor (m^2/m^3) (tau-β 0.202, $P<0.05$). RH% was positively correlated to the number of persons per room volume (pers/m^3) (tau-β 0.196; $P<0.05$). A significant negative correlation was found between the RH% and personal outdoor air supply and the air exchange rate (ac/hour) in the classrooms (tau-β -0.387 and -0.551; $P<0.01$). Personal outdoor air supply (L/s/person) was significantly correlated with the number of persons per room volume (pers/m^3) and the air exchange rate (ac/hour) (tau-β -0.276 and 0.585, $P< 0.01$).

5.3.2 *Correlation between indoor levels of PM_{10} and UFP and outdoor levels of PM_{10} and UFP.*

Table 7: Kendall's tau-β correlation analysis within and/or between indoor levels of PM_{10} and UFP, and outdoor levels of PM_{10} and UFP in schools in the Reykjavik city area, Iceland. (Data were available from 15 measurements outside the schools and in 74 classrooms, see full appendix 1, Table 8 for further information)

	Indoor PM_{10} and UFP		Outdoor PM_{10} and UFP	
Kendall's tau-β	PM_{10}	UFP	PM_{10}	UFP
PM_{10}	1.000			
UFP	.063	1.000		
PM10[a]	.029	-.024	1.000	
UFP[a]	-.161	.004	.141	1.000

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
a Outdoor levels of PM_{10} and UFP

The table above, number 7, illustrates the Kendall's tau-β correlation analysis within and or between indoor levels of PM_{10} and UFP, and outdoor levels of PM_{10} and UFP in school Reykjavik. No significant correlation was found between or within levels of indoor PM_{10} and UFP and outdoor PM_{10} and UFP.

6 Discussion

In the following chapter the objectives of this thesis are discussed, based on the presented results. That is, both the main objective, which was **to study indoor climate and levels of PM_{10} and ultra-fine particles in junior high schools in Reykjavik,** and the 6 sub objectives. The sub-objectives were: *to study levels of indoor climatic factors in the classrooms in junior high schools in Reykjavik, to study indoor environmental factors in classrooms in junior high schools in Reykjavik, to study if there is any difference between indoor climatic factors in schools in Iceland, China and Sweden, to study if there is any difference between indoor environmental factors in Iceland, China and Sweden, to study if there is a significant correlation within and/or between indoor climatic factors and indoor environmental factors in junior high schools in Reykjavik and to study if there is a significant correlation within and/or between outdoor levels of PM_{10} and UFP, and indoor levels of PM_{10} and UFP.*

6.1 Methodological consideration

The schools as well as the classrooms were randomly chosen, there should be no selection bias regarding the characteristics of the investigated classrooms. There is a lack of standardized methods for exposure measurements, but we chose methods that were suitable for performing during school lessons and/or that have relatively commonly been used. All of the classrooms had padded chairs, which were not included when measuring the fleece factor in the classrooms. If chairs had been included when calculating the fleece factor in junior high schools in Reykjavik, the fleece factor would have been much higher. In several of the calculations of mean level in each school was the standard deviation very large, which shows that the data from the measurements are very widely spread and reduces the reliability of the mean level in some cases.

6.2 Levels of indoor climatic factors in the classrooms

6.2.1 Particulate matter – PM_{10}

The mean level of PM_{10} in the classrooms was 40.4 µg/m^3 and ranged between 6.3-162 µg/m^3. The mean level of PM_{10}, in the 15 participating schools ranged between 8.7-72.4 µg/m^3. As there are no guideline limits for indoor levels of PM_{10} in Iceland, the author used the outdoor health limit as a proxy, which was 50 µg/m^3 in year 2002 and will be lowered in steps, down to 20 µg/m^3 (per-24-hour) in 2010 (Regulation nr.251/2002). Compared to the health limit from 2002, 4 of the schools (schools number 1, 2, 3 and 4) had mean levels of PM_{10} above health limits. Compared to the expected health limit for 2010, all the schools, except school number 8, had mean levels above the health limits. Based on earlier studies, this can be seen as an important result, as studies have shown that particle pollution is significantly associated with children's health (EPA, 2003). Possible reasons for the low levels of PM_{10} in school number 8 could be the displacement ventilation system and the low number of persons per cubic meter (pers/m^3) compared to the other participating schools.

6.2.2 Ultra-fine particles - UFP

The mean UFP level in the 15 participating junior high schools in Reykjavik, was 9069 (particles/cm^3) ranged between 2733-30148 particles/cm^3. The mean level of UFP in the classrooms was 8961 particles/cm3 and ranged between 890-92692 particles/m^3. School number 14 had a significantly higher mean level, than the other schools, or 30148 particles/ cm^3. Five measurements were performed in school number 14 and two of them showed significantly higher values of UFP, that is 40407 particles/cm^3 and 90692 paricles/cm^3. Both of those measurements were performed at a similar time, which indicates that the source for those high levels may be the same. The measurements were performed the hour before lunchtime, that raises the question if the source to this high levels of UFP was in-school cooking (all meals were prepared in the schools). These high levels explain the big standard deviation in school number 14. These high levels of UFP are quite significant, as eq. one study showed an association between ever having asthma and indoor/outdoor UFP exposure (Kim J.L., 2006).

6.2.3 Carbon dioxide – CO_2

The mean levels of CO_2 in the classrooms measured in the junior high schools in Reykjavik, was well above the recommended max limit value of 1000 ppm (The Building Regulation nr.441/1998; ASHRAE, 1999), or 1510 ppm. This is in agreement with the Icelandic studies from Eyjafjörður and Kjalarnes, which both showed that the mean levels of CO_2 were above the recommended max limit of 1000 ppm (Heilbrigðiseftirlit Kjósarsvæðis, 2002) The mean levels of CO_2 in each measured classroom in junior high schools in Reykjavik, ranged between 534-3355 ppm. The mean level of CO_2 in each school ranged between 621-2353 ppm. School number 13 was barely below the recommended max limit, with the mean level of 995 ppm. School number 8 had the lowest mean level, or 621 ppm. which is also below the recommended mean level of CO_2 (800 ppm.). None of the classrooms in school number 8, had a level of CO_2 above the recommended max limit value of 1000 ppm. The levels ranged between 573-649 ppm. The reason for this difference between school number 8 and the other schools, may be because school number 8 was the only school that had a displacement ventilation and/or because the number of persons per room volume (pers/m^3) was much lower in school number 8 than in the other 14 participating schools.

Only one school had mean level below the recommended mean level, which is 800 ppm. That means that approximately 87% of the schools had mean levels of CO_2 above the recommended max limit (1000 ppm) and approximately 93% of the participating schools had mean levels of CO_2 above the recommended mean level (800 pp.). This is a much higher proportion above the recommended max limit, than the result in the report that was published in 2000, by Reykjavik's health department, where 52.5% (21 measurements out of 40) of the measurements showed to be inadequate (Heilbrigðiseftirlit Reykjavíkur, Heilbrigðissvið, 2000). This difference can possibly be explained by the difference in measurement methods. The measurements performed by the Health department, are short measurements that are supposed to give an idea on how adequate the air exchange rate is in the classrooms.

The high values of CO_2 in junior high schools in Reykjavik indicates that the ventilation in the schools is inadequate. This result is in agreement with results from a review on school environments, which indicated that classroom ventilation is typically inadequate (Daisey, Angell, & Apte, 2003). Some schools had a mechanical ventilation system, in most cases they didn't functioning properly. This matches the earlier stated fact, that even though carbon dioxide (CO_2) is not found at hazardous levels in an indoor environment, the level of CO_2 can be used as a proxy measure of how well the ventilation system is working (Heilbrigðiseftirlit Kjósarsvæðis, 2002).

6.2.4 Temperature - °C

The mean room temperature in the classrooms in the 15 junior high schools in Reykjavik, was 21.7 °C, and the mean temperature in the classrooms ranged between 18.3- 25.5°C. the mean temperature for each school ranged between 20.4-22.8°C. This is within what is seen as suitable for every-day wellness, that is, a temperature between 20-24°C (Gunnarsdóttir, Rafnsson, & Kristjánsson, 1990). The temperature in all of the investigated classrooms ranged from 18.3°C to 25.5°C. All of the measurements were done during wintertime, when factors such as large glass windows for example, can increase thermal problems during warmer parts of the year (Norbäck & Nordström, 2008).

6.2.5 Relative air humidity – RH%

The mean relative air humidity (RH%) in classrooms was 33%, with a range between 16.9-54.7%. The mean RH% in the 15 participating schools was 33.3% and ranged between 19.3-47%, this is almost the same range that was measured in a previously conducted Icelandic school study, that had a range between 20-46% (Heilbrigðiseftirlit Kjósarsvæðis, 2002). Even though there is no "ideal" humidity level, the mean relative air humidity levels in the 15 measure schools can be seen as quite low. Three of the schools (number 7, 8 and 11) had a mean level below 30%. School number 8 had the lowest mean level, 19.3%. School number 8 had a significantly lower number of persons per room volume (pers/m^3), which is in agreement with what has been shown before, that is that the respiratory tract is one of the sources to indoor air humidity (Heilbrigðiseftirlit Kjósarsvæðis, 2002). The low RH% and low level of PM_{10} in school number 8, is in contradiction to studies that have shown that if relative air humidity goes under 20% it is more likely that dust will stay in the air. Low relative air humidity can also result in higher static electricity and more vaporization of chemicals from furniture, fittings and building materials (IDPH, 2008).

6.3 Environmental factors in the classrooms

6.3.1 Shelf factor – m/m^3

The mean shelf factor in the classrooms was 0.05 m/m^3, and ranged between 0- 0.36 m/m^3. The mean shelf factor in the 15 participating schools was 0.048 m/m^3 ranged between 0.007 m/m^3 and 0.084 m/m^3. The range in the shelf factor was quite large, like in school 14 were it ranged between 0-0.36 m/m3. While other schools like school number 8, had almost the same shelf factors in all classrooms. School number 8 had almost no open shelves in any classroom, all the storage were in closed shelves.

6.3.2 Fleece factor – m^2/m^3

The mean fleece factor in the classrooms was 0.02 m^2/m^3 and ranged between 0-0.24 m^2/m^3. The mean fleece factor in the 15 schools was 0.023 m^2/m^3 and ranged between 0-0.085 m^2/m^3. Six of the schools had the fleece factor 0 (schools number 4, 5, 8, 9, 12 and 13). Almost all of the schools had padded chairs. This fleece factor was not taken into account when calculating the overall fleece factor. This could effect the results on the relationship between the effect of the fleece factor on other climatic factors and should be measured in future studies.

6.3.3 Number of persons – $pers/m^3$

The mean number of persons in each classroom in the 15 participating schools was 19, and ranged between 8-32. The mean number of persons per cubic meter in the classrooms was 0.104 $pers/m^3$, and ranged between 0.02-0.17 $pers/m^3$. The mean number of persons per cubic meter in each school was 0.101 $pers/m^3$ and ranged between 0.02 -0.13 $pers/m^3$. The mean value for persons per cubic meter in school number 8, was significantly lower then the mean values from the other 14 schools. School number 8 is designed differently than the other participating schools. The classrooms are much bigger than the classrooms in the other schools, and are shared by more than one class (2-3 classes in each room/one open space) at the same time. The classrooms could be divided down to smaller spaces, if needed. This explains the significantly lower number of persons per cubic meter. This is one of the possible reasons for the low levels of CO_2 and PM_{10} in the classrooms in school number 8.

6.3.4 Personal outdoor air supply rate – L/s/person.

The mean personal outdoor air supply rate in the classrooms was 4.7 L/s/person, and ranged between 1.5-39.7 L/s/person. The mean personal outdoor air supply rate in the 15 schools was 4.65 L/s/person, and ranged between 2.3-11.8 L/s/person. Most of the schools, 13 out of 15, or approximately 87% of the schools, had a mean personal outdoor air supply rate below the recommended minimum rate, which is 8 L/s/person (ASHRAE, 1999). One measurement in school number 3 showed a personal outdoor air supply rate that was significantly higher than all the others (39.7 L/s/person). The reason for this high supply rate was that all the windows and the classroom door stood open during the measurement in that classroom. This affected the results significantly and the mean personal outdoor air supply in school number 3 would probably have been below the recommended limit if the windows and door had been mostly closed like in other classrooms in that school. If this measurement from school number 3 is seen as an outlier, and not taken into account, school number 8 was the only school to have a mean personal outdoor air supply rate above the minimum recommended rate.

6.3.5 Air exchange rate – ac/hour

Although the mean personal outdoor air supply rate in most of the participating schools failed to reach the recommended minimum rate (8 L/s/person), all of the schools had an air exchange rate (ac/hour) that exceeded the recommended minimum (0.8 ac/hour) (The Building Regulation nr.441/1998). This is important in light of earlier studies that have indicated that productivity increases when the air exchange rate is increased (Gunnarsson, 2005). This indicates that the occupancy of the space should be used to establish an appropriate outdoor air supply, and should follow any changes in occupant density. The mean level in the classrooms was 1.6 ac/hour, and ranged between 0.5-17.2 ac/hour. One measurement proved significantly higher, or 17.2 ac/hour. That measurement was obtained from school three, the same school that had a personal outdoor air supply rate 39.7 L/s/person. The recommended minimum air exchange rate is 0.8 ac/hour. In the 15 participating junior high schools in Reykjavik was 1.6 ac/hour, and ranged between 1-4.3 ac/hour, which means that all of them were above recommended minimum air exchange rate.

6.4 Indoor climatic factors in schools in Iceland, China and Sweden

6.4.1 Carbon dioxide – CO_2

The mean CO_2 levels in Reykjavik, Iceland and Taiyuan, China were both above the recommended limit, which is 1000 ppm (The Building Regulation nr.441/1998). The mean level in the classrooms in Iceland was 1510 ppm and 2211 ppm in China. In Sweden the mean level of CO_2 was well below the recommended limit, or 761 ppm. The CO_2 levels were not only lower in Sweden, they were also more stable. The CO_2 level in classrooms in Sweden ranged between 400-1170 ppm, while the levels ranged between 534-3355 ppm in classrooms in Iceland and between 789-4170 ppm in China. This indicates that the use of displacement ventilation, which are used in Swedish schools and reduces the CO_2 levels in the classrooms, enables Swedish schools to keep the mean CO_2 level below the recommended limit, 1000 ppm (Kim, 2006; Smedje and Norbäck, 2000). The only school, out of the 15 participating junior high schools in Reykjavik, that had a displacement ventilation, had similar levels of CO_2, as schools in Sweden. The Icelandic school that had an displacement ventilation (school number 8) had the mean level 621 ppm, and ranged between 573-649 ppm.

6.4.2 Temperature - °C

The mean classroom temperature in Reykjavik, Iceland and Uppsala, Sweden was quite similar or 21.7°C and 21.4°C, compared to this, the mean classroom temperature was low in Taiyuan, China, or 14.7°C. Even though the mean classroom temperature was almost the same in Sweden and Iceland, the temperature in the Swedish classrooms was much more stable, ranging between 20.2-22.5°C in Sweden, compared to 18.3-25.5°C in Iceland. In the classrooms in China the temperature was much lower than in classrooms in Iceland and Sweden. It ranged between 11.2-

18.4°C. Much like the comparison of CO_2 levels, this measurement also indicates that indoor school climate is much more stable in Sweden compared to Iceland and China.

6.4.3 Relative air humidity – RH%

The results showed that the relative air humidity was higher in classrooms in China then in classrooms in Iceland and Sweden, or 42% vs. 33% in Iceland and 31% in Sweden. These three mean levels are all within the levels that are recommended by ASHRAE, which is between 30-60% (ASHRAE, 1999). The RH% in the classrooms in Sweden and Iceland are just at the lower end of the recommended RH% level.

6.5 Indoor environmental factors in schools in Iceland, China and Sweden

6.5.1 Number of persons and classroom volume in Iceland, China and Sweden

The high levels of CO_2 in classrooms in Taiyuan, China can partially be attributed to the fact that the number of persons per room volume in Taiyuan, China proved to be more than twice as high as the number of persons in each classroom in Reykjavik, Iceland and Uppsala, Sweden; 48 persons in each classroom in Taiyuan, China, compared to 19 persons in Reykjavik, Iceland and 20 persons in Uppsala, Sweden. The classroom volume in China only ranged between 161-225 m^3, while classrooms in Iceland ranged between 127 m^3-859 m^3 and in Sweden they ranged between 82-470 m^3. So even though more were persons in each classroom in China the classrooms were not bigger. Studies have shown that the number of persons per room volume affects the level of CO_2 in the room (Heilbrigðiseftirlit Kjósarsvæðis, 2002). Crowdedness has been shown to have both a beneficial effect on lowering respiratory diseases and to be associated with increased prevalence of respiratory infections (Cardoso, Cousens, & Siqueira, 2004; (Zhao, Elfman, Wang, Zhang, & Norbäck, 2006). The association between increased prevalence of respiratory infections and crowdedness is understandable since closer contact between people allows infections to spread more easily, particularly in a very crowded indoor environment like in Chinese schools (Zhao Z., 2006). All of the classrooms had a mean volume all around 200 m^3, or 218 m^3 in Iceland, 193 m^3 in China and 202 m^3 in Sweden. The fact that number of persons per classroom in Iceland was quite similar to the number of person per classroom in the study from Uppsala, Sweden, draws the attention to the biggest difference between the classrooms in Sweden and Iceland, which is that most of the inspected schools in Sweden had a new type of displacement ventilation system, while only one of the Icelandic schools had a similar displacement ventilation system.

6.5.2 Fleece factor in classrooms in Iceland, China and Sweden

According to the results there is no significant difference between the fleece factors in classroom in Iceland, China and Sweden. The fleece factor measurements had quite wide ranges in all the studied schools. What has to be taken into account is that almost all the chairs in Iceland were padded, which would elevate the fleece factor in Iceland dramatically. The chairs for the students were neither padded in China nor Sweden. If the fleece factor from the chairs in Iceland is not taken into account, the results showed that the fleece factor (m^2/m^3) in the classrooms ranged from 0-0.24 m^2/m^3 in Iceland, 0-0.014 m^2/m^3 in China and 0.01-0.36 m^2/m^3 in Sweden. The mean fleece factor in Iceland was 0.02m^2/m^3, 0.03 m^2/m^3 in China and 0.08 m^2/m^3 in Sweden.

6.5.3 Shelf factor in classrooms in Iceland, China and Sweden

There was a significant difference between the shelf factor in classrooms in Taiyuan, China compared to the shelf factors in classrooms in Reykjavik, Iceland and Uppsala, Sweden. In China the shelf factor was 0 m/m^3 in all the inspected schools. There were no open shelves in classrooms in the participating schools in Taiyuan, China. The shelf factor ranged between 0-0.36 m/m^3 in Iceland and between 0-0.22 m/m^3 in Sweden. The mean shelf factor in Iceland was 0.05 m/m^3 and 0.1 m/m^3 in Sweden.

6.6 Correlation within and/or between indoor climatic factors and indoor environmental factors in classrooms in Reykjavik, Iceland.

The indoor climatic factors studied were PM_{10}, ultra-fine particles (UFP), CO_2, temperature and relative air humidity. The indoor environmental factors studied were number of persons per room volume ($pers/m^3$), shelf factor (m/m^3), fleece factor

(m^2/m^3), personal outdoor air supply rate (L/s/person) and air exchange rate (ac/hour).

The data showed that levels of PM_{10} in the classrooms positively correlated to levels of CO_2 in the classrooms (tau-b -0.433; P< 0.01). This indicates that if the levels of CO_2 in the classrooms were lowered, by using for example displacement ventilation, the levels of PM_{10} in the classrooms would also be lower. This results are consistent with results from a study done on the concentration and particle number in 64 classrooms in Germany, which identified that increased PM concentrations correlated significantly with increased CO_2 (as cited in: Stranger, Potgieter-Vermaak, & Grieken, Characterization of indoor air quality in primary schools in Antwerp, Belgium, 2008). Positive correlation between levels of PM_{10} and CO_2 is in agreement with previous studies (Thatcher & Layton, 1995; IDPH, 2008).

The levels of PM_{10} were found to positively correlate to number of persons per room volume and levels of RH% in the classrooms (tau-b 0.316, 0.414; P<0.01). This indicates that the persons in the classrooms are the source to both RH% and PM_{10}, which is in agreement with earlier studies (Luoma & Batterman, 2001; Thatcher & Layton, 1995; Skoog, 2006). This also indicates that the combination of number of persons per classroom, levels of RH% and levels of PM_{10}, has more effect than the low RH%, on the levels of PM_{10}. A multivariate analysis is needed to explain this combination better. There was also a significant negative relationship between the levels of PM_{10} and personal outdoor air supply rate (L/s/person) (tau-b -0.417; P< 0.01). This shows the importance of adequate personal outdoor air supply rate when trying to minimize the levels of PM_{10} in the classrooms. Most of the participating schools in Reykjavik, Iceland - 13 out of 15 - had a mean personal outdoor air supply rate below the recommended minimum rate, which is 8 L/s/person (ASHRAE, 1999). Thus, the increase of personal outdoor air supply rate should be considered if the aim is to reduce PM_{10} in classrooms in Reykjavik, Iceland. There was no correlation found between indoor levels of UFP and any of the measured indoor climatic factors or indoor environmental factors. This indicates that the source for UFP in the classroom is a source that was not included in this study. This could be sources like cooking or burning of candles in the schools.

The results for levels of CO_2 in the classrooms in Reykjavik, Iceland, showed that there was a positive correlation between the indoor levels of CO_2 and indoor levels of RH% and the number of persons in each classroom (pers/m^3) (tau-b 0.329 and 0.486, P<0.01). This is consistent with earlier studies that have shown that the level of CO_2 depends on the number of persons per the room volume. A significant negative relationship was found between the CO_2 levels and the personal outdoor air supply (L/s/person) and air exchange rate (ac/h) (tau-b -0.459 and -0.756, P<0.01). This is consistent with the statement that the levels of CO_2 can be used as a measurement of how well the ventilation system is working (Heilbrigðiseftirlit Kjósarsvæðis, 2002). The mean personal outdoor air supply rate was 4.7 L/s/person, which underlines the importance of following the requirements of a minimum personal outdoor air supply of 8 L/s/person (ASHRAE, 1999), when aiming to keep the levels of CO_2 below the recommended level of 1000 ppm (The Building Regulation nr. 441/1998).

The temperature (°C) in the classrooms in Reykjavik, Iceland was positively associated with the fleece factor (m^2/m^3) in the classroom (tau-b 0.202; P<0.05). This could partially be explained by the fact that the fleece factor in the classrooms in Reykjavík, Iceland was almost exclusively derived from curtains in the classrooms. Curtains have an isolating effect and reduce the effects of radiant heat exchange near big windows.

The level of RH% in the classrooms was positively correlated to the number of persons per room volume (pers/m^3) (tau-β 0.196; P<0.05). If we look at the comparison of relative air humidity in Taiyuan, China, Reykjavik, Iceland and Uppsala, Sweden, the results agree with the stated fact that the respiratory tract is a source for indoor humidity. (Heilbrigðiseftirlit Kjósarsvæðis, 2002). The mean RH% in the classrooms was 33% in Iceland and 31% in Sweden, but in China the mean RH% was quite higher, or 42%. The number of persons in each classroom was significantly higher in China than in Iceland and Sweden. The mean number of persons was 48 in China but 19 persons in Iceland and 20 persons in each classroom in Sweden. This indicates that the persons, or rather their respiratory tract, are one of the sources of indoor air humidity (Heilbrigðiseftirlit Kjósarsvæðis, 2002). The result indicated a significant negative correlation between the RH% and personal outdoor air supply and the air exchange rate (ac/hour) in the classrooms (tau-β -0.387 and-0.551; P<0.01). Even this result indicates that the relative indoor air humidity is correlated to the number of persons in the classroom. Personal outdoor air supply (L/s/person) was correlated with the number of persons per room volume (pers/m^3) and the air exchange rate (ac/hour) (tau-β -0.276 and 0.585; $P < 0.01$).

6.7 Correlation within and/or between indoor and outdoor levels of PM_{10} and UFP.

The results from the Kendall's tau-β correlation analysis, within and between indoor levels of PM_{10} and UFP, and outdoor levels of PM_{10} and UFP in the schools in the Reykjavik city area, Iceland, showed no significant correlation. This result contradicts other studies that have shown that the outdoor air can have significant affect on the indoor air, and is even the main source for indoor air pollution (Srivastava, 2003; Gusten & Stridenhag, 1995; as cited in; Hellsing, 2007). This indicates that the sources for PM_{10} and UFP in classrooms in Reykjavik, Iceland, are inside the schools or classrooms. Earlier studies have established that otherwise, the levels of indoor particles should correlate to the outdoor particle levels (Socialstyrelsen, 2006). One reason for the difference in PM_{10} measurements could be inadequate ventilation in classrooms in Iceland. Another possible explanation could be that the outdoor levels of PM_{10} in Iceland are too low to have any significant affect on the indoor levels of PM_{10}. A possible reason for the difference in UFP measurements is that sources for UFP outdoors might not be the same as sources for indoor UFP, and the indoor sources are possibly stronger.

7 Conclusion and Future Implications

The background information and results of this thesis indicate that the indoor climate in junior high schools in Reykjavik could be improved. This should be the aim of the City of Reykjavik, which is responsible for providing children with a healthy school environment. Indoor climate in schools is an especially important issue since it can affect student's health and learning ability, as well as the teachers and other school staff's health and productivity.

Mean levels of CO_2 in the classrooms, were above recommended maximum levels of CO_2 (1000 ppm), or 1510 ppm. One of the participating junior high schools in Reykjavik, Iceland had a displacement ventilation system. This was the only school that had a mean level of CO_2 below the recommended indoor maximum level of CO_2. This indicates that Reykjavik's junior high schools have inadequate ventilation systems and installation of displacement ventilation systems should be considered, where possible. Compared to the guidelines for outdoor levels of PM_{10}, the levels of indoor PM_{10} in the classrooms can be considered relatively high. This raises the question whether there is a need for guidelines on indoor levels of PM_{10} in schools. Especially considering the fact that school attendance is compulsory for children 6-16 years old, and the school indoor environment is where they spend most of their time outside the home.

The indoor levels of PM_{10} did not correlate with the outdoor levels of PM_{10} Some of the indoor measurements showed very high levels of UFP, which did not correlate with the outdoor levels of UFP. The fact that neither the levels of PM_{10} or UFP in the classrooms did correlate with the outdoor levels of PM_{10} and UFP shows that the main source for indoor PM_{10} and UFP is located inside the schools.

Even though all of the studied schools had a mean air exchange rate above the recommended minimum level, 0.8 ac/hour, only 2 out of 15participating schools had a mean personal outdoor air supply rate above the recommended minimum rate, which is 8 L/s/person. This indicates that a mean air exchange rate of 0.8 ac/hour, is not enough for highly occupied indoor environments, such as schools. There was a significant positive correlation between the levels of PM_{10} and personal outdoor air supply rate, but not between PM_{10} and air exchange rate. The temperature in the classrooms in the junior high schools in Reykjavik, Iceland was within what has been defined as the “comfort zone”, and should therefore not have any negative effect on the student’s health or learning abilities. The same applies to the temperature in Uppsala, Sweden, but the temperatures in classrooms in Taiyuan, China were much lower (mean temp was 14.7 °C). The RH% in the classrooms (33%), was within defined recommendations for suitable indoor environments (30-60%).

The mean RH% (33%) in junior high schools in Reykjavik, Iceland was just slightly above the RH% in schools in Uppsala, Sweden, which was 31%, while the RH% was considerably higher in Taiyuan, China, or 42%. The main difference between indoor school environment in Reykjavik, Iceland, Taiyuan, China and Uppsala, Sweden was the level of CO_2. The mean level of CO_2 in the classrooms in Sweden (761 ppm), was well below the recommended maximum level of CO_2, while the mean level of CO_2 in Iceland (1510 ppm) was above the recommended limit and the mean level in classrooms in China (2211 ppm) was even higher. This suggests inadequate ventilation systems in classrooms in both, Reykjavik, Iceland and Taiyuan, China.

The Kendall’s tau-b correlation analysis showed a correlation within and/or between some of the indoor climatic factors and indoor environmental factors in junior high schools in Reykjavik, Iceland. Indoor levels of PM_{10} were positively correlated to levels of CO_2, RH%, and number of persons per room volume. Indoor levels of PM_{10} were negatively correlated to personal outdoor air supply rate. There was a significant negative correlation was found between the levels of CO_2 in the classroom and the personal outdoor air supply rate (-0.756; $P < 0.01$). This shows the importance of good ventilation systems in schools, and that the levels of CO_2 can be used as an indicator for indoor air quality.

The conclusions can be summarized into the following statements:

- The recommended minimum air exchange rate (0.8 ac/hour) is not enough for highly occupied indoor environments, such as classrooms.
- The main sources for PM_{10} and UFP in the classrooms, are located inside the schools.
- Ventilation systems in schools need to be improved, in order to:
    - Increase outdoor air supply

  - Increase air exchange rate
  - Reduce levels of PM_{10} and CO_2

- There is a need for clear legal framework on IAQ in schools
  - Clear guideline limits on indoor air pollution
  - Clear instructions and/or rules about how to prevent and/or reduce air pollution in schools.
  - Clear laws or regulations on who is responsible for preventing and/or reducing air pollution in schools.

Fleece factor measurements in each classroom should include all textiles. In this study, padded chairs were excluded from the fleece factor measurements. Almost all chairs in the studied classrooms had padded chairs. Had the padded chairs been included, the fleece factor in classrooms in Reykjavik would have been much higher. If this research were to be repeated the textile on the padded chairs should be included.

Due to the lack of studies of the indoor school environment in Iceland, there are many interesting and necessary aspects of the indoor school environment in Iceland that are unexplored. Below are some suggestions on future research topics.

- Studies have shown that there is an association between the indoor air quality in schools and the children's health, and learning ability, and teacher's and staff's productivity (USEPA, 1996). It would be interesting to study if the indoor school environment in Iceland has similar effects on it's students, teachers and other staff.

- The results of this study showed that the levels of ultra-fine particles (UFP), have a wide range and some measurements showed exceptionally high values of UFP. The reason for these high levels could not be explained by the measurements that were performed in this study. Further studies on indoor levels of UFP are needed, in order to gain knowledge about the sources to the indoor UFP. It would be interesting to study if food preparation and cooking utensils in the schools are the source for the high levels of indoor UFP.

- The effect that particulate matter has on people’s health is not only dependent on the size, but also on the combination of the particulate matter (Health Canada, 2008). By studying the combination of the particulate matter in the schools in Iceland, a lot of knowledge could be gained about how harmful the particulate matter in schools in Iceland actually is.
- The quality of indoor school environment is not only dependent on the climatic and environmental factors that were measured in this study. Factors such as the level of volatile organic compound (VOC), formaldehyde, nitrogen dioxide (NO_2), mould, bacteria and factors like noise and lighting are very important for the quality of the indoor school environment. In order to gain better knowledge about the quality of the indoor school environment in Iceland, it is important to measure and study these factors as well

8 Bibliography

Abdi, H. (2007). The Kendall Rank Correlation Coefficient. In N. Salkind (Ed.), *Encyclopedia of Measurement and Statistics.* Thousand Oaks (CA): Sage.

Åhmansson, N.-E., Björklund, S., Friberg, L., Ajne, B., & Lundberg, H. (1996). *Particles and Health - A Contemporary Problem for Study (In Swedish).* Skandia's environmental commission., Stockholm.

Alberg, M., Diette, G., & Ford, J. (2003). Invited comentary: attendance and absence as markers of health status- the example of active and passive cigarette smokin. *Am. J. Epidemiol , 157*, 870-3.

American Association of School Administrators. (2008). Indoor Air Quality and the School Environment- Ensuring our children's health and academic sucess. *www.aasa.org* .

American Lung Association. (2008). *Outdoor Air Pollutants*. Retrieved December 29, 2008, from Particle Pollution Fact Sheet: http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=50324

ARIC. (2000). *Encyclopedia of the Atmospheric Environment*. (C. a. Atmosphere, Producer) Retrieved November 27, 2008, from Outdoor Air Pollution: http://www.ace.mmu.ac.uk/eae/Air_Quality/Older/Outdoor_Air_Pollution.html

ASHRAE. (2001). *Standard 62, Ventilation for Acceptable Indoor Air Quality.* Atlanta, GA.: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

ASHRAE. (1999). *Ventilation for Acceptable Indoor Air Quality, Standard.* Atlanta, GA.: American Society for Heating, Refrigerating and Air Conditioning engineers.

Baldauf, R., Thoma, E., Hays, M., Shores, R., Kinsey, J., Gullett, B., et al. (2008). Traffic and meterological impacts on near-road air quality: summary of methods and trends from the Raleigh Near-Road Study. *J Air Waste Manag Assoc. , 58* (7), 865-78.

Bartonova, A., Larssen, S., & Hagen, L. (2002). *Utvikling i luftforurensningen 1991-2001. Utslippsreduserende tiltak og PM10 partikkelkonsentrasjoner i Oslo og Drammen.* Norsk institutt for luftforskning. Oslo: NILU.

Berglund, L. (2002, July). Comfort and humidity. *ASHRAE Journal* , 35-41.

Berkeley National Laboratory. (2008). *Welcome to Lawrence Berkeley National Laboratory's ELSI Project.* Retrieved November 26, 2008, from Outdoor Air Pollution: http://www.lbl.gov/Education/ELSI/pollution-main.html

The Building Regulation nr.441/1998. *Byggingareglugerð nr.441/1998.*

California Integrated Waste Management Board. (2007, October 22). *Indoor Environmental Quality.* Retrieved December 29, 2008, from California Sustainable Design Training:
http://www.ciwmb.ca.gov/greenbuilding/Training/StateManual/IEQ.doc

Cardoso, M., Cousens, L., & Siqueira, d. G. (2004). Crowding: risk factor or protective factor for lower respiratory disease in young children? *BMC Public Health* (4), 19.

Carrer, P., Bruinen de Bruin, Y., & Valovirta, E. (2002). The EFA project: Indoor air quality in European schools. *Indoor Air , 2*, 296-3000.

Colligian, M. (1981). The Psychological Effects of Indoor Air Pollution. *Bull NY Acad Med.* (57), 1014-25.

Colome, S., Kado, N., Jaques, P., & Kleinman, M. (1992). Indoor-outdoor air pollution relations: Particulate matter less than 10 um in aerodynamic diameter (PM_{10}) in homes of asthmatics. *Atmos Environ , 26*, 2173-78.

Custovic, A., Green, R., Taggart, S., Smith, A., Pickering, C., Chapman, M., et al. (1996). Domestic allergens in public places. II Dog (Can fl) and cockroach (Bla g2) allergens in dust and mite, cat , dog and cockroach allergens in the air in public buildings. *Clinical and Experimental Allergy. , 26*, 1246-52.

Daisey, J., Angell, W., & Apte, M. (2003). Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air , 13*, 53-64.

Dalvíkurbyggð. (2008). *Dalvíkurbyggð*. Retrieved november 21, 2008, from www.dalvik.is

Erdmann, C., Steiner, K., & Apte, M. (2002). Indoor carbon dioxide concentration and SBS syndroms in office buildings revisited analyses of the 100 building BASE study dataset. *Indoor air , 2*, 443-8.

Gertis, K. (1999). More co-operation between building physics and building services. *Sci. Rev. , 42*, 87.

Gíslason, D., Björnsdóttir, U., Blöndal, Þ., & Gíslason, Þ. (2002). Evrópurannsóknin Lungu og heilsa (ECRHS): Hverjar eru helstu niðurstöður fram að þessu í ljósi sérstöðu Íslands? *Læknablaðið , 88*, 891-907.

Gíslason, D., Gíslason, Þ., Blöndal, Þ., & Helgason, H. (1995). Bráðaofnæmi hjá 20-44 ára Íslendingum. *Læknablaðið , 81*, 606-12.

Godish, T. (1989). *Indoor Air Pollution Control.* CRC Press.

Gunnarsdóttir, H., Rafnsson, V., & Kristjánsson, V. (1990). *Inniloft og líðan fóks.* Reykjavík: Vinnueftirlit ríkisins.

Gunnarsson, J. M. (2005). Áhrif innilofts á afkastagetu og heilsu fólks. Heilnæmara vinnuumhverfi sparar miljónir króna árlega. *Lagnafréttir 33 , 19* (2), 32-40.

Gusten, J., & Stridenhag, O. (1995). Experience of Measures Taken to Improve the Air Quality in Schools. *Air filtration Review* (16), 5-8.

Gyntelberg, F., Suadicani, P., Wohlfahrt, J. N., Skov, P., Valbjorn, O., Nielsen, P., et al. (1994). Dust and the sick building syndrome. *Indoor Air , 4*, 223-238.

Heath, G., & Mendell, M. (2002). Do indoor environments in schools influence student performance? A review of the literature. *Indoor Air , 1*, 802-7.

Health Canada. (2008, Agust 8). *Health Canada*. Retrieved november 17, 2008, from Environmental and Workplace Health, particulate matter.: http://www.hc-sc.gc.ca/ewh-semt/air/in/poll/particul/index-eng.php

The Health Regulation nr.941/2002. *Heilbrigðisreglugerð nr.941/2002.*

The Health Regulation nr. 149/1990. *Heilbrigðisreglugerð nr.149/1990.* Replaced by The Health Regulation 941/2002.

Heilbrigðiseftirlit Kjósarsvæðis. (2002). *Loftgæði í skólum og leikskólum. Mælingar á koltvísýringi, loftraka og lofthita í grunnskólum og leikskólum á Kjósarsvæði.* Heilbrigðiseftirlit Kjósarsvæðis.

Heilbrigðiseftirlit Reykjavíkur, Heilbrigðissvið. (2000). *Skýrsla um niðurstöður heilbrigðiseftirlits í grunnskólum Reykjavíkur árið 2000.* Reykjavik.

Hellsing, V. (2007). *Áhrif svifryks á loftgæði innandyra. Niðurstööur rannsókna. Tillögur að mótvægisaðgerðum.* Reykjavik: Nýsköpunarsjóður Námsmanna.

Hind, W. (1999). *Aerosol Technology (2nd.ed).* New York: John Wiley & sons.

Holmberg, S., & Chen, Q. (2003). Air flow and particle control with different ventilation systems in a classroom. *Indoor Air , 13,* 200-4.

IDPH. (2008). *Environmental Health Fact Sheet.* (I. D. Health., Producer) Retrieved September 14, 2008, from http://www.idph.state.il.us/envhealth/factsheets/indoorairqualityguide_fs.htm

Indoor Environment and Health (1999). Sweden: National Institute of Public Health.

Ingason, Þ., & Jóhannesson, Á. (2002). *úttekt á stöðu nagladekkjamála, nýjar naglagerðir, önnur þróun.* . Reykjavik: Vegagerðin.

Janson, C., Chinn, S., Jarvis, D., & Burney, P. (1997). Physician-diagnosed asthma and drug utilization in the European community Respiratory Health Survey. *Eur Respir J. , 10,* 1795-802.

Janssen, N., Hoek, G., Brunekreef, B., & Harssema, H. (1999). Mass concentration and elemental coposition of PM10 in classrooms. *Occup Environ Med. , 56,* 482-7.

Jansson, A. (2000). *Particles in Indoor Air (In Swedish).* Stockholm: National Institure for Working life.

Jones, N. (1998). Ventilation revisited. *Emerg Med Serv , 27* (1), 68.

Jones, N., Thornton, C., Mark, D., & Harrison, R. (2000). Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural location. *Atmos. Environ. , 34*, 2603-12.

Jóhannsson, Þ. (2007). *Svifryksmengun í Reykjavik.* M.Sc. ritgerð í umhverfisfræði, Verkfræðideild Háksóla Íslands. Reykjavik: Háskólaprent.

Kappos, A. (2004). Health effects of particles in ambient air. *Int. J. Hyg. Environ. Health , 207*, 399-407.

Kim, J., Elfman, L., Mi, Y., Johansson, M., Smedje, G., & Norbäck, D. (2005). Current asthma and respiratory symptoms among pupils in relation to dietary factors and allergens in the xhool enviornment. *Indoor Air* , 170-182.

Kim, L. (2006). *Environmental Factors in Relation to Asthma and REspiratory Symptoms among Schoolchildren in Sweden and Korea.* Department of Medical Sciences, Akademiska sjukhuset, Uppsala University. Uppsala: Uppsala Universitet.

Krieger, J., D.L., H., & Higgins, D. (2002). Housing and health: time agian forpublic health action. *AM J Public Health , 92* (5), 758-68.

Lagus Applied Technologies. (1995). *Air Change Rates in Non-residental Buildings in California.* San Diego, CA.: California Energy Commission.

Law about primary schools nr. 91/2008. Lög um grunnskóla nr. 91/2008.

Li, Y., & Harrison, R. (1990). Coparison of indoor and outdoor concentrations of acid gases. ammonia and their associated salts. *Environ Technol , 11*, 315-326.

Long, C., Suh, H., & Koutrakis, P. (2000). Characterixation of indoor particle sources using continuous mass and size monitors. *J. Air Waste Manage. Assoc. , 50*, 1236-50.

Luoma, M., & Batterman, A. (2001). Characterisation of particulate emissions from occupant activities in offices. *Indoor Air. , 11*, 35-48.

Maroni, M., Seifert, B., & Lindvall, T. (1995). *Indoor Air Quality, A Coprehensice Reference Book. Air Quality Monographs.* (Vol. 3). Amsterdam: Elsevier.

Mendell, Heath, M., & Heath, G. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? Acritical review of the literature. *Indoor Air , 15* (1), 27-52.

Milton, D., Glencross, P., & Walters, M. Risk of sick leave associated with outddor ventilation level, humidification, and building-related complaints. *Indoor Air , 2*, 212-21.

Minnesota Department of Health. (2008, May 14). Retrieved December 30, 2008, from Carbon Dioxide: http://www.health.state.mn.us/divs/eh/indoorair/co2/index.html

Monn, C. (2001). Exposure assessment of air pollutants: a review on spatial heterogeneity and indoor/outoor/personal exposure to suspended particulate matter, nitrogen dioxide and ozone. *Atmos. Environ. , 35*, 1-32.

Mosfellsbær. (2008). Retrieved november 22, 2008, from Mosfellsbær. Welcome to Mosfellsbær: www.mos.is

Mysen, M., Berntsen, S., Nafstad, P., & Schild, P. G. (2005). Occupancy density and benefits of demand-controlled ventilation in Norwegian primary schools. *Energy and Buildings , 37* (12), 1234-1240.

Norbäck, D. (2009). An update on sick building syndrome. *Current Opinion in Allergy and Clinical Immunology , 9*, 0-0.

Norbäck, D., & Nordström, K. (2008). An experimental study on effects of increased ventilation flow on students' perception of indoor environmet in computer classrooms. *Indoor Air , 18*, 293-300.

OECD. (2001, November 22). *Glossary of Statisticla Terms*. Retrieved November 28, 2008, from Secondary ari pollution: http://stats.oecd.org/glossary/detail.asp?ID=2405

Ooi, P., K.T., G., M.H., P., & al., e. (1998). Epidemiology of sick building syndrome and its associated risk factors in Singapore. *occup Environ Med , 55* (3), 188-93.

Ormstad, H., Johansen, B., & Gaarder, P. (1998). Airborne house dust particles and diesel exhaust particles as allergen carriers. *Clin Exp Allergy.* , 702-8.

Owen, M., Ensor, D., & Sparks, L. (1992). Airborne particle sizes and sources found in indoor air. *Atmos. Environ. , 26*, 2149-62.

Patchett. (1997). Cat allergen (Fel d 1) levels on school children's clothing and in pramary school classrooms in Wellington, New Zealand. *J Allergy Clin Immunol , 100*, 755-59.

Peat, J., Dickerson, J., & J.Li. (1998). Effects of damp and mould in the home on respiratory health: a review of the literature. *Allergy , 53* (2), 120-8.

Paevere, P., Brown, S., Leaman, A., Heerwagen, J., & Luther, M. (2008, May 8). Indoor environment, productivity and sustainable commercial buildings. *Your Building, profiting from sustainability .*

Penn. (2005). Combustion-derived ultrafine particles transport organic toxicants to target respiratory cells. *Environ Health Perspect , 113*, 956-63.

Perzanowski. (1999). Relevance of allergens from cats and dogs to asthma in the northernmost province of Sweden: School as a major site of exposure. *J Allergy Clin Immunol , 103*, 1018-24.

Platts-Mills, T., R.B., S., L.M., W., & et.al. (1995). Is there a dose-response relationship etween wxposure to indoor allergens and symptoms of asthma? *J Allergy Clin Immunol , 96* (4), 435-40.

Platts-Mills, T., W.R., T., & R.C., A. (1992). Dust mite allergens and asthma: report of a second international workshop. *J Allergy Clin Immunol , 89* (5), 1046-60.

Regulation nr.251/2002. Reglugerð um brennisteinsdíoxíð, köfnunarefisdíoxíð og köfnunarefnisoxíð, bensen, kolsýring, svifryk og blý í andrúmsloftinu og upplýsingar til almennings.

Research Triangle Institute. (2003). *California Rortable Classrroms Study.* RTI International, Research Triangle Park.

Rostron, J. (1997). *Sick Building Syndrome: Concepts, Issues, and Practice.* Taylor & Francis.

Ruotsalainen. (1995). Ventilation and indoor air quality in Finnish schools. *Norweigan Society of Chartered Engineers and International Society of Indoor Air Quality and Climate.* , 489-93.

Schaffner, C. R. (1999). *Displacement Ventilation.* Retrieved December 30, 2008, from www.greenengineer.com

Seltjarnarnesbær. (2008). *Seltjarnarnesbær*. Retrieved november 22, 2008, from Seltjarnarnes-Information: www.seltjarnarnes.is

Sennhauser, F., Braun-Fahrlander, C., & Wildhaber, J. (2005). The burden of asthma in children: a European perspective. *Peadiatr. Respir. Rev. , 6*, 2-7.

Seppanen, O., Fisk, W. J., & Faulkner, D. (2004). *Control of themperature for health and productivity in offices.*

Seppanen, O., & W.J., F. (1999). Association of ventilation system type with SBS symptoms in office workers. *Indoor Air , 12* (2), 98-112.

Seppanen, O., W.J., F., & M.J., M. (1999). Association of ventilation rates and CO2 concentrations with health and other resposes in commercial and institutional buildings. *indoor Air , 9* (4), 226-52.

Shendell, D., Prill, R., Fisk, W., Apte, M., Blake, D., & Faulkner, D. (2004). Association between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor Air , 14*, 333-41.

Shendell, D., Winer, A., Weker, R., & Colome, S. (2003). Evidence of inadequate ventilation in portable classrooms: results of a pilot study in Los Angeles County. *Indoor Air* .

Skoog, J. (2006). Relative Air Humidity in Hospital Wards- User Perception and Techinical Consequences. *Indoor and Built Environment , 15* (1), 93-97.

Skov, P., Valbjorn, O., & Pedersen, B. (1990). Influence of indoor climate on the sick building syndrome in an office environment. *Scandinavian Journal of Work, Environmental an Helath , 16*, 363-71.

Skúladóttir, B., Thorlacius, A., Larsen, S., Bjarnason, G. G., & Þórðarson, H. (2003). *Method for determing the compisition of airborn particle pollution. Composition of particle air pollution in Reykjavik.* Iðntæknistofnun Íslands.

Smedje, G. (1997). Asthma among secondary schoolchildren in relation to the school environment. *Clin Exp Allergy. , 27* (11), 1270-78.

Smedje, G., & Norbäck, D. (2001). Incidence of asthma diagnosis and sel-reported allergy in relation to the school environment- a four-year follow-up study in schoolchildren. *Int J Tuberc Lung Dis , 5* (11), 1059-66.

Smedje, G., & Norbäck, D. (2001). Irritants and Allerges at School in Relation to Furnishings and Cleaning. *Indoor Air , 11*, 127-133.

Smedje, G., & Norback, D. (2000). New ventilation systems at select school in Sweden- effects on asthma and exposure. *Arch Environment Health , 55* (1), 18-25.

Smedje, G., Nordbäck, D., Edling, C., & . (1997). Asthma among secondary schoolchildren in relation to the school environment. *Clin Exp Allergy , 27* (11), 1270-8.

Socialstyrelsen. (2006). *Partiklar i inomhusmiljön - en litteraturegenomgång.* Uppsala: Socialstyrelsen, Akademiska sjukhuset.

Srivastava, J. (2003). Relationship between indoor and Outdoor Air Qualitu in Delhi. *Indoor Build Envion , 12*, 159-165.

Statistics Iceland. (2007). *Statistics Iceland*. Retrieved november 16, 2008, from http://www.statice.is/Statistics/Education/Compulsory-schools: www.statice.is

StatsDirect. (2008). *StatisticalHelp*. Retrieved november 17, 2008, from Kendall's rank correlation: www.statsdirect.com

Stranger, M., Potgieter-Vermaak, S., & Grieken, V. (2008). Caracterization of indoor air quality in primary schools in Antwerp, Belgium. *Indoor Air* (18), 454-463.

Stranger, M., Potgieter-vermaak, S., & Vand Grieken, R. (2007). Coparative overview of indoor air quality in Antwerp, Belgium. *Environ. Int.* (33), 6.

Sunyer, J., Anto, J., Tobias, A., & Burney, P. (1999). Generational invrease of self-reported first attack of asthma in fifteen industrialized countries. *Eur Respir J. , 14*, 885-91.

Thatcher, T., & Layton, D. (1995). Deposition, resuspension and penetration of particles within a residance. *Atmos Environ , 29*, 1487-95.

The American Heritage Medical Dictionary. (2007). *The Free Dictionary*. Retrieved November 26, 2008, from Medical dictionary: http://medical-dictionary.thefreedictionary.com/Relative+air+humidity

The Environmental Agency of Iceland. (2003, February 27). *Umhverfis- og heilbrigðisstofa Reykjavíkur.* Retrieved November 25, 2008, from Leiðbeiningar fyrir skóla og leikskóla: http://umhverfisvefurinn.is/2/default.asp?sid_Id=1514&tid=999

The Environment Agency of Iceland. (n.d.). *Loftgæði.* Retrieved January 3, 2009, from Svifryk: http://www.ust.is/Mengunarvarnir/Loftgaedi/Svifryk/

U.S. EPA. (1999). Indoor Air Quality Tools for Schools: Actions to Improve IAQ. U.S. Environmental Protection Agency. *EPA Indoor Environments Divison* .

U.S.EPA. (2003, September). *Particle Pollution and Your Health*. U.S. Environmental Protection Agency (Office of Air and Radiation) Retrieved September 17, 2008, from www.epa.gov/air

U.S.EPA. (2002). *Child-specific exposure factors handbook (Interim Report).* Washington DC: U.S. Environmental Protection Agency, Office of Research and Development, National Center of Environmental Assessment.

Umhverfisstofnun. (2003, December 2). *www.ust.is.* Retrieved December 2, 2008, from Samsetning svifryksmengunar í Reykjavík Niðurstöður rannsókna á uppruna svifryks: http://www.ust.is/NyttEfni/nr/1166

Van der Wal, J., Hoogeveen, A., & van Leeuwen, L. (1998). A quick screeening method for sorption effects of volatile organic compoinds on indoor materials. *Indoor Air , 8*, 103-12.

Van Moerbeke, D., & Braine-l', A. (1997). *European Allergy White Paper.* Belgium: UCB Institute of Allergy.

Vand Roosbroeck, S., Jacobs, J., Janssen, N., Oldenwening, M., Hoek, G., & Brunekreef, B. (2007). Long-term personal exposure to PM2,5, soot and NOx in children attending schools located near busy roads, a validation study. *Atmos. Environ* (41), 3381-3394.

Vinod, M. (2003). Effect of indoor air pollution from biomass combustion on prevalence of asthma in the elderly-Reserch. *Environmental Health Perspectives , 111* (1), 71-78.

Vaughan, S., Paul, G., David, M., & Craig, W. (2002). The Relationships between Indoor and Outdoor Respirable Particulate Matter: Meteorology, Chemistry and Personal Exposure. *Indoor Built Environ , 11*, 266-274.

Walinder, R., Norbäck, D., Wieslander, G., Smedje, G., Erwall, C., & Venge, P. (1999). Nasal patency and lavage biomarkers in relation to settled dust and cleaning rountines in schools. *Scand J Work Environ Health* (25), 137-43.

Wallace, L. (2000). Correlation of personal exposure to particles with outdoor air measurements, a review of recent studies. *Aerosol Sci. Technol. , 32*, 15-25.

Wargocki, P., Sundell, J., Biscchof, W., Brundrett, G., Famger, P., Gyntelberg, F., et al. (2002). Ventilation and health in non-industrial indoor environments: report from European multidisiplinary scientific consensus meating (EUROVENT). *Indoor Air , 12*, 113-128.

Weitzman, M. (1986). School absence rates as outcome measures in studies of children with chronic illness. *J. Chronic Dis. , 39*, 799-808.

Willers. (1996). Sick building syndrome symptoms among the staff in schools and kindergartens: Are the levels of volatile organic compounds and carbon diocide responsiible? *Indoor Build Environ , 5*, 232-235.

WHO. (2005). *Health effects of transport-related.* (B. K.-D. Michal krzyzanowski, Ed.) Retrieved December 1, 2008, from World Health Organization: http://www.bvsde.paho.org/bvsacd/cd63/e86650/conten.pdf

Woolcock, A., & Peat, J. (1997). *Evidence for the increase in asthma worldwide.* Ciba Found Smp

Yocom, J. (1982). Indoor-outdoor air quality relationships: a critical review. *J. Air Pollut. Control Assoc. , 32*, 500-20.

Zhao, Z. (2006). *indoor and Outdoor Air Pollution in Relation to Allergy and Asthma in Taiyuan, China.* Department of Medical Sciences, Occupational and Environmental Medicine, Akademiska sjukhuset. Uppsala, Sweden: Uppsala University.

Zhao, Z., Elfman, L., Wang, Z., Zhang, Z., & Norbäck, D. (2006). A coparative study of asthma, pollen, cat and dog allergy among pupils and allergen levels in schools in Taiyuan city, China, and Uppsala Sweden. *Indoor Air* .

Appendix 1. Correlation table between indoor climatic factors, indoor environmental factors and outdoor PM10 and UFP

Table 8: Kendal's tau correlation within and between indoor climatic factors, indoor environmental factors and outdoor climatic factors, during measuring period in Reykjavik, Iceland.

		Indoor Climatic Factors					Indoor Environmental Factors					Outdoor Climatic Factors	
Kendall's tau-b		PM_{10}	UFP	CO_2	Temp (°C)	RH%	ShelfFactor	Fleecefactor	pers.perm3	air supply	exrate	PM10	UFP
PM10	Correlation Coefficient	1,000	,063	,433**	-,048	,414**	-,025	,124	,316**	-,417**	-,163	,029	-,161
	Sig. (2-tailed)	.	,452	,000	,575	,000	,764	,166	,000	,000	,056	,732	,078
	N	74	67	65	65	66	70	70	70	65	65	70	60
UFP	Correlation Coefficient	,063	1,000	,014	,141	-,121	-,003	-,103	,073	,086	,116	-,024	,004
	Sig. (2-tailed)	,452	.	,870	,110	,157	,970	,256	,380	,331	,183	,782	,968
	N	74	68	62	62	64	68	68	68	62	62	68	58
CO2	Correlation Coefficient	,433**	,014	1,000	-,016	,486**	-,019	,025	,328**	-,756**	-,459**	,075	-,145
	Sig. (2-tailed)	,000	,870	.	,856	,000	,829	,792	,000	,000	,000	,396	,122
	N	74	62	65	65	65	65	65	65	64	64	65	57
Temp	Correlation Coefficient	-,048	,141	-,016	1,000	-,154	-,059	,202*	,067	,044	,065	-,011	-,066
	Sig. (2-tailed)	,575	,110	,856	.	,074	,495	,032	,434	,617	,454	,900	,485
	N	65	62	65	65	65	65	65	65	64	64	65	57
RH	Correlation Coefficient	,414**	-,121	,486**	-,154	1,000	-,084	,138	,196*	-,551**	-,387**	-,039	-,224*
	Sig. (2-tailed)	,000	,157	,000	,074	.	,318	,131	,019	,000	,000	,651	,015
	N	74	64	65	65	67	67	67	67	65	65	67	59
ShelfFactor	Correlation Coefficient	-,025	-,003	-,019	-,059	-,084	1,000	-,108	,005	,024	,038	-,006	,215*
	Sig. (2-tailed)	,764	,970	,829	,495	,318	.	,217	,953	,785	,662	,940	,016
	N	70	68	65	65	67	74	74	72	65	65	74	64
Fleecefactor	Correlation Coefficient	,124	-,103	,025	,202*	,138	-,108	1,000	,035	-,014	,070	-,201*	-,018
	Sig. (2-tailed)	,166	,256	,792	,032	,131	,217	.	,688	,884	,454	,025	,852
	N	70	68	65	65	67	74	74	72	65	65	74	64
pers.perm3	Correlation Coefficient	,316**	,073	,328**	,067	,196*	,005	,035	1,000	-,276**	,150	-,054	-,062
	Sig. (2-tailed)	,000	,380	,000	,434	,019	,953	,688	.	,001	,077	,515	,491
	N	70	68	65	65	67	72	72	72	65	65	72	62
Oairsupply	Correlation Coefficient	-,417**	,086	-,756**	,044	-,551**	,024	-,014	-,276**	1,000	,585**	-,108	,181
	Sig. (2-tailed)	,000	,331	,000	,617	,000	,785	,884	,001	.	,000	,224	,055
	N	65	62	64	64	65	65	65	65	66	65	66	58
exrate	Correlation Coefficient	-,163	,116	-,459**	,065	-,387**	,038	,070	,150	,585**	1,000	-,098	,167
	Sig. (2-tailed)	,056	,183	,000	,454	,000	,662	,454	,077	,000	.	,266	,076
	N	65	62	64	64	65	65	65	65	65	65	65	57
OPM10	Correlation Coefficient	,029	-,024	,075	-,011	-,039	-,006	-,201*	-,054	-,108	-,098	1,000	,141
	Sig. (2-tailed)	,732	,782	,396	,900	,651	,940	,025	,515	,224	,266	.	,091
	N	70	68	65	65	67	74	74	72	66	65	90	77
OUFP	Correlation Coefficient	-,161	,004	-,145	-,066	-,224*	,215*	-,018	-,062	,181	,167	,141	1,000
	Sig. (2-tailed)	,078	,968	,122	,485	,015	,016	,852	,491	,055	,076	,091	.
	N	60	58	57	57	59	64	64	62	58	57	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 2. Reykjavik City Area- Distribution of Participating Schools