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Indoor Air Quality (IAQ)

Using Temporal Data and GIS to Visualize IAQ in Campus Buildings

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Abstract

There is no doubt that indoor air quality (IAQ) is essential for human health because of the long exposure time human has inside. But the legislation and relevant policy about indoor air are far behind outdoors. Recently indoor air quality has been paid attention, some relevant epidemiological studies were carried and WHO published indoor air quality guidelines accordingly as the reference of policy-making. The demand and requirement of good indoor air quality is booming from legislation enforcement and market need. So the monitoring and controlling for indoor air quality in buildings, which are diversified, are needed to be done economically and efficiently. The integration of building information modelling (BIM), geographic information system (GIS), online sensor and cloud computing technologies offers promising solution for good indoor air quality by managing the building intelligently, controlling cost and real-time monitoring. This report studies the possibility to have the 3D visualization indoor air temporal data with ArcGIS software with preliminary similar test data for some campus buildings as part of OPEN tietojärjestelmät project from Mikkeli University of Applied Sciences.

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Indoor air quality (IAQ), GIS (Geographic Information System), Online monitoring, BIM (Building Information Modeling, Cloud computing, Temporal data, 3D visualization.

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ABBREVIATIONS

AEC	Architecture Engineering and Construction
ALRI	Acute Lower Respiratory Infections
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BC	Black Carbon
BIM	Building Information Modeling
BoD	Burden of Disease
CAD	Computer Aided Design
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COPD	Chronic Obstructive Pulmonary Disease
CPD	Construction Products Council
CPR	Construction Product Regulation
CSA	Chemical Safety Assessment
EPRD	Energy Performance of Building Directive
ESRI	Environmental System Research Institute
ETS	Environment Tabaco Smoke
EU	Europe Union
FCFC	Framework Convention on Tobacco Control
GDBT	GeoDataBase Table
GIS	Geographic Information System
GML	Geographic Markup Language
GPRS	General Packet Radio Service
GPSD	General Product Safety Directive
GPT	General Purpose Technology
GSM	Global System for Mobile
HESE	Health Effect of School Environment
IaaS	Infrastructure as a Service
IAQ	Indoor Air Quality
IFC	Industry Foundation Classes
IFC	Industry Foundation Classes

MUAS	Mikkeli University of Applied Sciences
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
PaaS	Platform as a Service
PM	Particulate Matter
PBT	Persist, bio-accumulative and Toxic
QMS	Quality Monitoring System
SaaS	Software as a Service
SVHC	Substances of Very High Concern
TCCP	Trusted Cloud Computing Platform
TVOC	Total Volatile Organic Compounds
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial BUS
vPvB	very Persist and very Bio-accumulative
WDCDMA	Wideband Code Division Multiple Access
WHO	World Health Organization
WLAN	Wireless Local Area Networks
XML	eXtensible Markup Language

1 INTRODUCTION

90% of the human life is spent indoor. Indoor air as one of the essential elements for living plays very important role for human health due to the long exposure time. Unfortunately, the relevant indoor air legislation is behind the outdoor air. So far, there is even no specific indoor air regulation / directive in the EU (European Union) level. But WHO (World Health Organization) has several guidelines about indoor air, which can be used as the recommendation.

The current building is becoming more diversified and complex, which needs more economical and effective management. Intelligent building and real-time monitoring are rapidly developing because of the demand and technological advantages. The Integration of BIM and GIS makes it possible to manage building lifecycle as a whole. Online sensors combined with cloud computing and modern technology make it possible to manage indoor air quality in real-time, and visualize the data along with the architectural model of the building.

What kinds of legislations are related with indoor air quality in EU? How does ArcGIS software manage the indoor air quality temporal data? What are the key pollutants and factors for indoor air quality? What are the related technologies supporting monitoring and managing indoor air quality? They are the main research questions for this report.

This report studies the possibility to have the 3D visualization of indoor air temporal data with ArcGIS software for some campus buildings as part of OPEN tietojärjestelmät project from Mikkeli University of Applied Sciences (MUAS). The report gives brief overview of building information modeling (BIM), geographic information system (GIS), online sensor technology and cloud computing as related technologies knowledge. Its main theory part discusses indoor air legislation in EU, selects several main indoor air pollutants according to the WHO indoor air quality guidelines and other documents, and explains their risks and their thresholds. Indoor air in campus building is taken as case study for indoor air analyzing and visualization. The campus

building geographic information is downloaded from ERSI download center. ArcGIS is selected tool for the indoor air temporal data visualization.

2 METHODS AND MATERIALS

The reference materials are from the ongoing OPEN tietojärjestelmät Project in Mikkeli University Applied Sciences, authority offices (e.g. EU or WHO) publications, public research paper from Google scholar and products website. The data acquisition is from the supervisors of the thesis, e.g. campus map data

The report structure has two main parts: theory and case study. This report is the first feasibility study of the indoor air quality monitoring in OPEN tietojärjestelmät project. Therefore although not all theories are utilized in the case study part, it is still written in the report as the knowledge background which will be used for continuous indoor air quality study of the OPEN tietojärjestelmät project.

This study summarizes the relevant publications and research papers for the general understanding of indoor air problems. Some data about the indoor air pollutants may have bias from different information source. The values from WHO indoor air guidelines are taken into this report when there are biases about threshold or epidemiological study result. The case study is assumed that the data is taken from online sensors instead of the laboratory. The sample taking methodology for the indoor air pollutants is not used in the case study part. The raw data for the case study is assumptive data meaning that it is not real data from any campus or online sensor; instead it is the trial data which is only used for analysis purpose as the preliminary study for indoor air quality visualization.

3 INDOOR AIR QUALITY

In average the human spends 90% of their time indoor. Due to the huge amount of exposure time, the indoor air quality is essential for health, comfort and productivity. The poor indoor air may cause variable diseases e.g. respiratory system disease (throat irritation, lung infection etc.), asthma, allergy, and hypersensitivity pneumonitis and humidifier fever.

According to the European study on air quality in school -- HESE (Health Effect of School Environment) project, the particles and poor ventilation are the main issues for the indoor air in school in Europe. The indoor air quality monitoring and controlling are very important to make sure that health stay in school. (Health Effect of School Environment 2006.)

The key methods to keep good indoor air quality are contaminant control, humidity management, ventilation and filtration (A guide to understand ASHRAE Standard 62-2001 2002). It is important to monitor indoor air quality and maintain it in the non-harmful level for human beings. But the indoor air quality monitoring and maintenance is quite complicated since the sources of the poor indoor air are variable from different origins. The contaminants may come from the human themselves since they exhale too much carbon dioxide gas when there are too many people inside. The contaminants may be caused by the building materials. The domestic cleaning (disinfectant, polishing etc.) and products inside (carpet, furniture etc.) may contaminate the indoor air too. Besides the factors which are mentioned above, the ventilation system and the outdoor air play important roles for the indoor air quality as well. (Indoor Air Quality Management Quality Group 2003.)

Although there are too many reasons why the indoor air quality is poor, the contaminations can be classified to four different groups: chemical contaminants (e.g. carbon monoxide, formaldehyde), physical factors (e.g. temperature, air velocity), biological agents (e.g. bacteria, virus, and mold) and radiation (e.g. radon.) (Indoor Air Quality Management Quality Group 2003.)

3.1 Indoor Air Quality Legislation

The understanding about the pollutants and its impact on human is the first step to reduce them. WHO published the new volume of the first global indoor air guideline on December 2010. It provided the information and reference for the relevant policy making. The guideline listed the most common indoor air pollutants and their adverse effect on human health which were approved by the scientific researches. (First WHO indoor air quality guidelines on indoor chemical now released 2010.) In 2003, the Eu-

ropean Union had the new strategy on environment and health to reduce the diseases which are caused by environment, in which the action 12 was about indoor air quality (Opinion on Risk Assessment on Indoor Air Quality 2007). After extending the scope to carcinogens and mutagens, the Directive on workplace safety and health 89/391/EEC cover ETS (Environment Tabaco Smoke) in line with WHO FCFC (Framework Convention on Tobacco Control) which was entered into force on February 2005. ETS (Environment Tabaco Smoke) is classified as carcinogen in Directive 89/654/EEC and Dangerous Substances Directive 67/548/EEC. (Jantunen et al 2011.)

However, due to the variable sources of indoor air contaminants, there is no specific legislation dedicatedly for indoor air quality yet. But there are the regulations and/or legislations about pollutants, product and building which have the parts related with indoor air quality in the European Union level. (Bluyssen 2010.)

The National Institute of Health and Welfare (THL) and Institute of Occupational Health (TTL) in Finland involve in the indoor air quality management. The relevant indoor air quality legislation in Finland is not written in this report since Finland as member of EU has to correspond to the legislations from EU and meet all the requirements.

3.1.1 Directive EC1907/2007

Based on the information from the European Commission website, REACH is the abbreviation of Registration, Evaluation, Authorization and Restriction of Chemical substances. One of the main reasons why REACH was established was there were a huge amount of chemical products produced and sold in the European market for long time with big manufacturing volume, but there was no any information about their safety and the adverse impact on human being and environment. Therefore there was an urgent need to make up the information gap where the manufactures should publish the substances risk assessment and estimate the potential hazards with precautious principle. Its regulation about chemical safety and usage in the European commission (EC1907/2007) is enforced on 01.July 2007. (REACH 2013.)

When the product volume is more than 10 tons in the European market, the CSA (Chemical Safety Assessment) should be done to clarify the risk during manufacturing and usage. The exposure assessment and risk characterization information required for the chemical substances are SVHC (Substances of Very High Concern), PBT (Persist, bio-accumulative and Toxic), vPvB (very Persist and very Bio-accumulative) and others which are proved by the scientific researches to cause serious adverse impact on human being and environment. They include the substances which produce carcinogenic, mutagenic and toxic materials during manufacturing. The products can be banned in the market if needed according to REACH. (REACH 2013.)

3.1.2 Directive 92/75/EEC

Council Directive 92/75/EEC on 22 September 1992 on labeling and standard product information of the consumption of energy and other resources by household appliances is to harmonize the environment and the consumption by defining the energy standards on the domestic product (Council Directive 92/75/EEC). In its recast version, the industry, commercial sectors and even the non-energy products which are related with energy usage are included in the directive, e.g. windows, its installation and usage are significantly connected with energy-saving. The purpose of Council Directive 92/75/EEC is to optimize the efficiency performance, strengthen innovation and competitiveness inside the European market, besides the economic reasons, it also can balance the environment and consumption and combat the deteriorated climate change. The reason why it is related with indoor air quality is it relates with ventilation system in the building. The thermal comfort and indoor air quality should be considered together with the energy consuming to have the optimum green living environment. (Jantunen et al 2011.)

3.1.3 Directive 2001/95/EC

Directive 2001/95/EC of the European Parliament and of the Council of 3 December 2001on general product safety is the other one which is related with indoor air quality. Its purpose is to ensure that the product in the European market is safe. (Council Directive 2001/95/EC.) It is called GPSD (General Product Safety Directive) in short. It

covers all the products, especially the products for children and the elderly. The installation, composition and accessories are all included in the directive as the safety concern. But it only requires the safety for human being not for the environment. The users have the right to know the risk evaluation about every phase of the whole life cycle of the product. (Jantunen et al 2011.)

3.1.4 Directive 89/106/EEC

The modification of the European Standards on construction CPD/CPR (Construction Product Directive 89/106/EEC /Construction Product Regulation No. 305/2011) is related with Directive 93/86/EEC [CE Marking] (Council Directive 89/106/EEC). The full names about the two are quoted from EU laws website: council directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products. Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC (Regulation (EU) N. 305/2011).

They not only covered the materials in the construction fixed on the ground (including the finished and under construction) but also have the regulations about indoor temperature and indoor insulation. (Jantunen et al 2011.)

3.1.5 Directive 2002/91/EC

Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings defines the energy performance inside and outside and their efficiency. It is EPRD (Energy Performance of Building Directive) in short. It lays down the framework for the energy performance calculation methodology, the minimum requirement of the energy performance (for new building and the big renovation of finished building), energy certification and the building boiler and air-conditions inspection. (Directive 2002/92/EC.)

Although the directive clearly claims that the indoor climate is covered, the method how to measure it and its target are not listed clearly. According to the researches, it is found out lots of products which effect the building energy performance have the im-

pact on indoor air quality. However, the assumption is the indoor climate is not all about indoor air quality, but it is still the big step for indoor air quality from legislation area. It is expected the recast version will cover more details about indoor air. (Jantunen et al 2011.)

3.2 Indoor Air Risk

Indoor air as one of the most important living element is very important for human health. According to the WHO health report in 2002, the health effect by indoor air quality was significant. 2.7% of the global BoD (Burden of Disease) was directly caused by indoor air pollutants. The lower income the country had, the higher death rate it had by indoor air quality due to the reason the solid fuel was used more in developing countries.(Indoor Air Quality National Burden of Disease Estimates 2007.)

There are strong evidences that indoor air pollutants can cause diseases, e.g. ALRI (Acute Lower Respiratory Infections) for children who are younger than 5 years old and COPD (Chronic obstructive Pulmonary Disease) and lung cancer for adults (Indoor Air Quality National Burden of Disease Estimates 2007). Other than that the WHO health report provided more evidences about the relationship between indoor air pollutants and diseases (Indoor Air Pollution Health Effect 2013).

3.2.1 Indoor Air Risk Assessment

Indoor air risk assessment and management are very complicated because the pollution sources are variable, the affected disease symptoms are individual by age and body condition, the exposure level may affect differently, the way of living and culture are changing because of globalization and immigration, the building convention and climate are different. Therefore SCHER (Scientific Committee on Health and Environment Risk) initiated a report in 2007 about the indoor air risk assessment by specialists to give the opinion how to precede the complicated task.

SCHER recommended that the indoor air risk assessment should be done with the basic paradigm in toxicological risk assessment regulation. In Europe there are several directives which are related with the risk assessment: Commission Regulation (EC)

1488/94 of 28 June 1994 laying down the principles for the assessment of risks to man and the environment of existing substances in accordance with Council Regulation (EEC) No 793/93; Commission Directive 93/67/EEC of 20 July 1993 laying down the principles for assessment of risks to man and the environment of substances notified in accordance with Council Directive 67/548/EEC; TGD (Technical Guidance Document on Risk Assessment). When it is very obvious that the disease is caused by extreme indoor air pollutant (e.g. very dirty dampness), the risk assessment can be skipped and the risk management will be done directly. (Opinion on Risk Assessment on Indoor Air Quality 2007.)

The risk assessment steps which SCHER recommended are illustrated in the figure 1. The process is similar with other risk assessment, but SCHER wrote recommendations or tips for each step for indoor air risk assessment. (Opinion on Risk Assessment on Indoor Air Quality 2007.)

Hazard Identification. The indoor air hazards are chemicals, particles matters, radon, microbes, pets and pests, humidity, temperature and ventilation. Based on the health risk, the chemicals are grouped, group 1 with high priority (formaldehyde, CO, NO_2, benzene and naphthalene); group 2 with low priority (styrene, toluene, xylenes, acetaldehyde), group 3 needs further research (ammonia, limonene). (Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU 2005.)

Dose Exposure. Biomarkers are recommended to be used for dose exposure relationships when it is available. When the dose exposure is about occupational exposure, the exposure duration should be adjusted to 8 hours (the normal dose exposure is 20 hours). (Opinion on Risk Assessment on Indoor Air Quality 2007.)

Exposure. There are more than 900 organic compounds found in the indoor air. The pollutants may affect human health mainly by inhalation, but all routes (ingestion, dermal and inhalation) should be considered because of their importance. Biomonitoring is recommended to use for exposure assessment when it is available. (Opinion on Risk Assessment on Indoor Air Quality 2007.)

Risk Characterization. In risk characterization the average, median exposure and other ranges should all be considered, due to the reason that the sensitive sample group may react greatly in the low exposure. (Opinion on Risk Assessment on Indoor Air Quality 2007.)

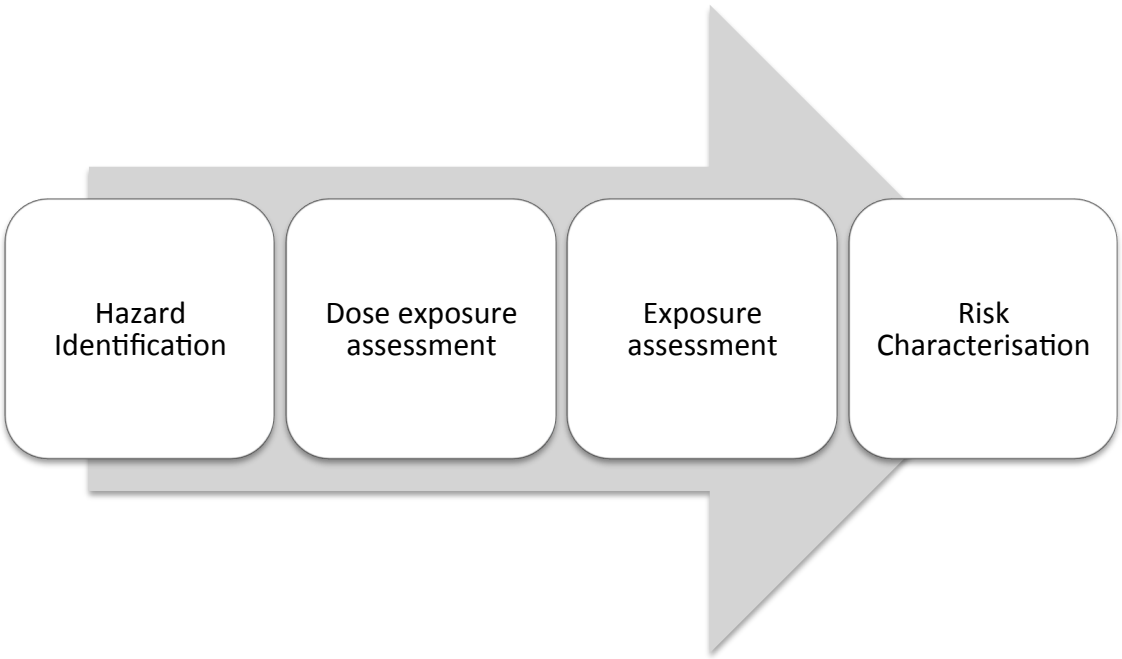

FIGURE 1. Indoor Air Risk Assessment Steps.

3.2.2 Method to Reduce Indoor Air Risk

Although the reasons of poor indoor air are variable, the indoor air can be significantly improved by reducing the indoor air pollutants. In the developing countries, especially in the rural area, to improve the stove which has better combustion efficiency, better ventilation and working power can lower the poor indoor air level. Another efficient way to improve the indoor air quality in the developing countries is to change solid fuel to other more efficient and green energy alternatives, e.g. LPG (Liquid Petroleum Gas), electricity, solar power.

The ventilation in the building plays very important role for indoor air. The methods could be having a better chimney or having bigger cooking windows or design the ventilation system according to the local climate and the relevant building legislation. If none of the methods can be done, there are still some way to contribute on improving the indoor air quality or avoid the indoor air pollutants for the vulnerable group.

For example only burn the dry wood which can reduce the smoke. (Indoor Air Pollution Health Effect 2013.)

3.3 Temperature, Humidity and Ventilation Rate

Temperature, humidity and ventilation rate play key roles on the human's thermal comfort indoors and they are related with the pollutants distribution and concentration especially for the VOCs (Volatile Organic Compounds) and biological contaminants e.g. mould (Sung et al. 2012). The microbial growth prerequisites related with temperature and relative humidity are in figure 2 (40 ^{o}F is about 4.4 ^{o}C, 100 ^{o}F is about 37.8 ^{o}C). (A guide to understand ASHRAE Standard 62-2001 2002.)

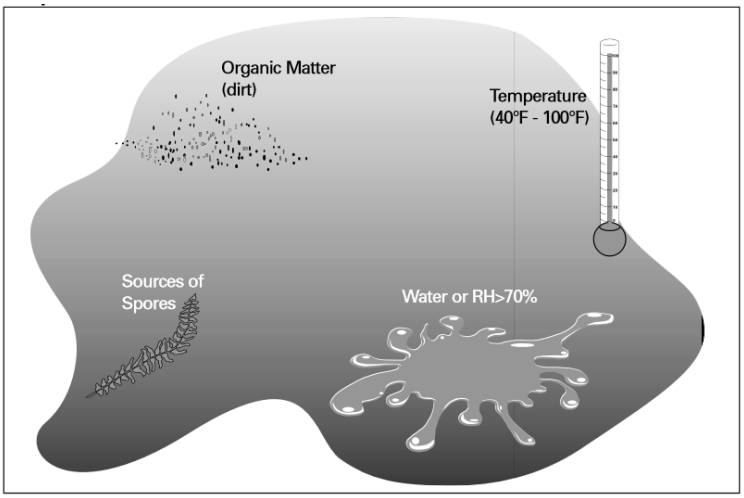

FIGURE 2. Prerequisites of Microbial Growth (A guide to understand ASHRAE Standard 62-2001 2002).

When the temperature inside is about 25°C, the human's productivity is in the best shape. When it is colder than 18 ^{o}C or hotter than 28 ^{o}C, the productivity drops dramatically. The oxygen content indoor is affected by the room temperature and relative humidity. (Sun & Zhu 2012.) When the relative humidity is lower than 15% at 22 ^{o}C, human's eyes have adverse effect and it will be worse when the temperature is raised slightly (Snjezana 2009a).The recommended relative humidity according to ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) stand-

ard 62-2001 is from 30% to 60% (A guide to understand ASHRAE Standard 62-2001 2002).

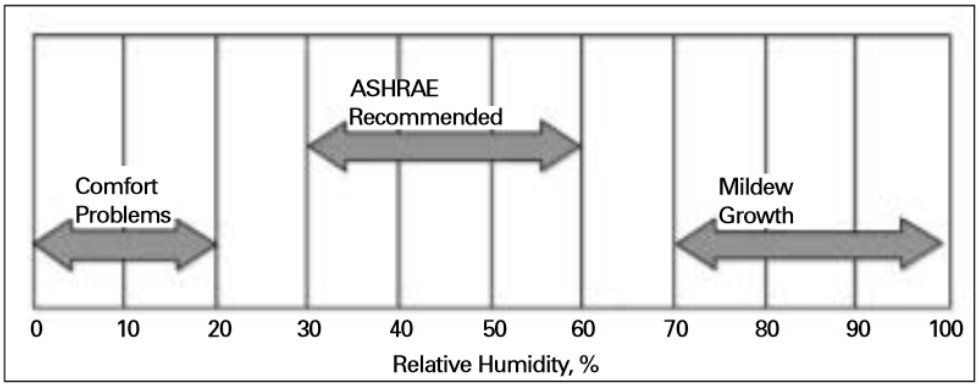

FIGURE 3. Recommended Relative Humidity Rate Indoor (A guide to understand ASHRAE Standard 62-2001 2002)

ASHRAE standard 62-2001 is Ventilation for Acceptable Indoor Air Quality. According to it, the ventilation rates for different areas are listed in table 1 (1000ft^2 is 92.9m^2).

TABLE 1. Ventilation Rate Indoor According to ASHRAE Standard 62-2001 (A guide to understand ASHRAE Standard 62-2001 2002.)

Application	Estimated Maximum Occupancy (people/1000 ft^2)	Outdoor Air Requirements	
		cfm/person	cfm/ft^2
Offices			
Office space	7	20	
Reception areas	60	15	
Telecommunication centers and data entry areas	60	20	
Conference rooms	20	20	
Public Spaces			
Corridors and utilities			0.05
Public restrooms		50	
Locker and dressing rooms			0.5
Smoking lounge	70	60	
Elevators			1.0

3.4 Selected Indoor Air Chemical Pollutants

The epidemiology researches and relevant legislations about indoor air quality are quite behind the outdoor air (First WHO indoor air quality guidelines on indoor chemical now released. 2010). In the WHO Air Quality Guidelines for Euro (second edition) published in 2000, the ETS (Environment Tabaco Smoke), MMVF (Man-Made Vitreous Fibers) and Radon were classified in the indoor air pollutants category (Danzon et al. 2000), however the pollutants from outdoor can be the reason of the poor indoor air too. All 35 pollutants about outdoors and indoors listed from the air quality guidelines for Europe are written in table 2.

TABLE 2. Air Pollutants in WHO Air Quality Guidelines for Euro (second edition) (Danzon et al. 2000).

Organic Air Pollutants	**Inorganic Air Pollutants**	**Classical Air Pollutants**	**Indoor Air Pollutants**
Acrylonitrile Benzene Butadiene Carbon disulfide Carbon monoxide 1,2-Dichloroethane Dichloromethane Formaldehyde Polycyclic aromatic Hydrocarbons (PAHs) Polychlorinated biphenyls (PCBs) Polychlorinated dibenzodioxins and dibenzofurans (PCDDs/PCDFs) Styrene Tetrachloroethylene	Arsenic Asbestos Cadmium Chromium Fluoride Hydrogen sulfide Lead Manganese Mercury Nickel Platinum Vanadium	Nitrogen dioxide Ozone and other photochemical oxidants Particulate matter Sulfur dioxide	Environmental tobacco smoke (ETS) Man-made vitreous Fibers (MMVF) Radon

(Continues)

(Continues)

Toluene Trichloroethylene Vinylchloride		

According to the relevant indoor air quality reports from WHO, the following pollutants as common sources of poor indoor air are explained briefly in this report: benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, polycyclic aromatic hydrocarbons, radon, trichloroethylene and tetrachloroethylene, dampness and mold. Another reason why they are written is the data about their toxicity and epidemiology and exposure level for health concerns is available. For other pollutants (acetaldehyde, asbestos, biocides, pesticides, flame retardants, glycol ethers, hexane, nitric oxide, ozone, phthalates, styrene, toluene,xylenes), there is no enough evidence for guidelines. Due to the limited data available for combination of air pollutants, the recommendation for pollutants combination is not given in the indoor air quality guideline from WHO. (First WHO indoor air quality guidelines on indoor chemical now released 2010.)

3.4.1 Benzene

Benzene is clear, colorless, volatile, flammable liquid aromatic compound with its characteristic odor. Benzene as genotoxic carcinogen exists both outdoors and indoors. But its concentration level indoors is higher than outdoors because it comes from outside to inside and there are more benzene emission sources indoors e.g. solvents, building materials. The sources of benzene as indoor air pollutants are variable. They may come from outdoors or the building materials, garage, furniture, solvent and heating & cooling system. The ventilation and the distance from the oil, coal, gas, chemicals and steel factories are the key factors for the benzene concentration indoors. Because of its low melting point, it exists mainly in vapor phase. The reaction with hydroxyl radicals, ozone and nitrate radicals can reduce its concentration. Inhalation is the main routine for human body. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

There is no safe level of benzene recommended because of its adverse health effects (carcinogenicity, genotoxicity and haematotoxicity), it should be kept as low concentration as possible since it may cause leukemia via inhalation. When its concentration is 1 μg/m^3, the geometric mean of estimated leukemia risk is 6 x 10^{-6}. The concentration of benzene related with excess lifetime risk of 1/10 000 is 17 μg/ m^3. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.2 Carbon Monoxide

Carbon monoxide is odorless, tasteless and colorless, so it is quite hard to be detected by human being. Carbon monoxide is toxic gas for human being since Carbon monoxide binds with haemoglobin forming COHb (carboxyhaemoglobin) which reduces blood to carry oxygen and impairs the release of oxygen from haemoglobin to extravascular tissues. The incomplete burning of wood, petrol or coal (carbonaceous fuels) may create carbon monoxide. Exposure to carbon monoxide may cause angina, reduce the moving capability or even cause mortality. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

WHO suggests that the exposure in high carbon monoxide concentration (100 mg/m^3) should be less than 15 minutes in short term peak exposure, 1 hour in excess exposure. For chronic exposure should be less than 8 hours of 10 mg/m^3, the epidemiological studies show that long term exposure adverse effects are different from short term exposure in several factors. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.3 Formaldehyde

Formaldehyde is colorless gas with flammable character and can react very active in room temperate. Formaldehyde both exists outdoors and indoors, but indoor has higher concentration because of the more emitting sources existed. The reaction between ozone and terpenes creates formaldehyde indoors, which is so called secondary formation of formaldehyde. The main routines to human body are inhalation, ingestion and from skin. Formaldehyde causes adverse health effects (sensory irritation, concen-

tration distraction, lachrymation, coughing, death etc.) via inhalation. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

There are plenty of studies showing that huge amount of exposure in formaldehyde may cause cancer or other diseases in experimental animals (mice or rat). The symptoms on human under certain exposure are listed in table 3.

TABLE 3. Adverse Effect Symptoms after Short Term Formaldehyde Exposure (Danzon et al. 2000).

Concentration (mg/m^3)	**Exposure Time**	**Health Effect in General Population**
0.03	Repeated Exposure	Detect odor (10%)
0.18	Repeated Exposure	Detect odor (50%)
0.6	Repeated Exposure	Detect odor (90%)
0.1-3.1	Single and repeated exposure	Nose and throat irritation
0.6-1.2	Single and repeated exposure	Eyes irritation
0.5-2.0	3 to 5 hours	Nasal mucus flow rate decreases
2.4	40 minutes on 2 days	Headache
2.5-3.7	not defined	Biting sensation in eyes and nose
3.7	Single and repeated exposure	Pulmonary function in decreases
5-6.2	half hour	Lachrymation
12-25	not defined	Strong lachrymation lasting for one hour
37-60	not defined	Pulmonary oedema, pneumonia, danger to life
60-125	not defined	Death

3.4.4 Naphthalene

Naphthalene is white crystalline power with odor. It normally is in the gas phases and it is volatile. The main source of naphthalene is mothball, without mothball, the naphthalene indoors is about 0.001mg/m^3 even when another source of naphthalene (e.g. combustion of biomass) exists; with mothball its concentration indoors increases up to 100-fold. The best way to control naphthalene exposure is to ban mothball. It is also used as the ingredient of painting and insecticide. Wood smoke and gasoline may also contain naphthalene. (WHO Guidelines for Indoor Air Quality :Selected Pollutants 2011.)

The main route for human under its exposure is inhalation. Naphthalene exposure mainly causes the adverse effect on respiratory track, tumor in animal and haemolytic anaemic in humans. According to the studies, naphthalene exposure 0.01mg/m^3 is recommended as LOAEL (Lowest Observed Adverse Effect Level). (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.5 Nitrogen Dioxide

Nitrogen dioxide is formed when nitric oxide is oxidized. In the gas phase, it has reddish brown color and its pungent odor. It is volatile in gas phase. When nitrogen dioxide reacts with water, it forms nitrous acid which is one common pollutant indoors. Since it exists mostly in gas phase, the main route of nitrogen dioxide is inhalation. (Danzon et al. 2000.)

For the short term exposure studies, the health of a healthy person in rest or light exercise situation is not affected by nitrogen dioxide when its concentration is less than 1880 μg/$m^{3.}$ The asthmatics and adverse effect on pulmonary function are likely to be the relevant diseased caused by nitrogen dioxide although there is still uncertainty in the healthy database and studies. For long term exposure, it is clearly showed that the animals have plethora effect after several weeks to months of nitrogen dioxide exposure (less than 1880μg/m^3). But due to the unknown risk of long term exposure for human, the relevant epidemiological studies cannot be carried on. The exposure-response relations of nitrogen dioxide in both short term exposure and long term are

not very clear because of quantities of uncertainties. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

Gas stove is the main source of nitrogen dioxide indoors. There is no direct exposure-response relationship between the peak nitrogen dioxide in short term and long term exposure and the relevant disease for adult and children under 2 years old. But there is a study showing that the children aged between 5 to 12 years have 20% higher risk in lower respiratory disease when they are exposed in 30μg/m^3 (2 week average). (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.6 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are one of the subclasses of polycyclic organic matter (POM), which defines the compounds of all organic structures having three or more fused aromatic rings. Polycyclic aromatic hydrocarbons (PAHs) are one big organic compound group which has two or more fused aromatic rings. It has three different types depending on the molecular weight. Low molecular weight polycyclic aromatic hydrocarbons (PAHs) has two or three rings, they are in vapor phases normally. Middle molecular weight aromatic hydrocarbons (PAHs) have four rings; it may be in vapor phase or in particulate phase depends on temperature. High molecular weight polycyclic aromatic hydrocarbons (PAHs) have five or more rings; most of them are bound to particles. The polycyclic aromatic hydrocarbons (PAHs) which are bound to particles are very hazardous to human.

Some fungi and microorganisms in soil can degrade polycyclic aromatic hydrocarbons (PAHs); it can also be metabolized by many organisms in terrestrial and aquatic. In the atmosphere polycyclic aromatic hydrocarbons (PAHs) may be subject to direct photolysis and it can react with lots of pollutants e.g. ozone, nitrogen dioxide, sulfur dioxide and hydroxyl radicals. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

Polycyclic aromatic hydrocarbons (PAHs) have very complicated composition because of inhibitory, additive and synergistic. It may be different from site to site. B[a]P is the best known and one of the most potent carcinogens in PAHs, therefore it

is used as the indicator PAHs compound and used it as the PAHs concentration guideline. (Danzon et al. 2000.)

Lung cancer is the most serious adverse effect of exposure to PAHs indoors. When exposed in B[a]P (concentration of 1.2 ng/m3) for lifetime, the lifetime cancer risk is 1/10 000. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.7 Radon

Radon is colorless and odorless radioactive gas. It is formed by the decay of radium in soil and rocks. Radon is one of the ionizing radiations and potent carcinogens causing lung cancer. Therefore in WHO air quality guideline for Europe, it is written that no safe level is recommended. But in WHO international radon project it is recommended 100Bq/m^3 to minimize health hazard. There is direct evidence of exposure-response relation between radon exposure and lung cancer after the epidemiological studies in the residential building for 30 years. The cancer risk is different for smokers, non-smokers and ex-smokers. The risk rate is highest for smokers and lowest for non-smokers, ex-smokers are in the middle. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

Due to the difference of radon emission in different countries and the variable building standards and materials, the recommendation radon exposure level should be considered together with building regulation, monitoring methods and national radon program if there is. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.8 Trichloroethylene (TCE)

Trichloroethylene is a clear, colorless, sweet ethereal smell and volatile chlorinated hydrocarbon which is used to remove the grease from metal, glue solvent. It is also one of the ingredients of painting and varnishes. Human can be exposed to trichloroethylene from air, water, food and the materials which have trichloroethylene. Most of the trichloroethylene is inhaled to lungs which pass it to blood taking it to other parts of the body e.g. liver and kidney. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

When the concentration is more than 540 000 μg/m^3 most of the person can smell it. There is direct evidence that trichloroethylene causes cancer for animals and positive epidemiological studies show that it may lead cancer for human especially liver cancer. When its concentration is more than 40 000 μg/m^3 for long term, it may affect the central nervous system. Eyes and respiratory tract are irritated at the 300 000 μg/m^3 exposure for short time. Because of its carcinogenicity and genotoxicity, there is no safe level is d recommended. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.9 Tetrachloroethylene (PCE)

Tetrachlorethylene (PCE) is colorless, volatile, ether like smell liquid. Tetrochlorethylene (PCE) is used as dry cleaning agent, degreaser for metal and industrial solvent. It also applies in textiles, paint removers, printing inks and cleaning fluids. Lot of domestic products have tetrachlorethylene (PCE) e.g. fragrances, sport and stain removers, wood cleaners, motor vehicle cleaner, dry cleaned fabrics and water repellents. Tetrochlorethylene (PCE) may contaminate water, human get it from shower or drinking. The contaminated soil by tetrochlorethylene (PCE) is one of the indoor pollutant sources. The workers from dry cleaning industry even could exhale tetrochlorethylene (PCE) from their breath. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

Tetrachloroethylene concentration indoor is less than 5 μg/m^3 normally. Inhalation is the main route for human body in tetrachloroethylene exposure. The risk of cancer and effect on central nervous system are the main adverse health effect. In the short term exposure, the adverse effect only happens when tetrachloroethylene concentration is very high (340 mg/m^3), therefore in the WHO indoor air quality guideline, only the long term value is given. (WHO Guidelines for Indoor Air Quality: Selected Pollutants 2011.)

3.4.10 Dampness and Mold

The biological contaminants are one of the main indoor air pollutants together with chemical contaminants. Microbial indoor air pollutants are variable, it may be the allergic agents e.g. pollen or the bacteria, fungi, algae and protozoa coming from outdoors. Many of the microbial pollutants are from dampness, poor ventilation and caused by high moisture. Dampness is recommended as the risk indicator for asthma and respiratory symptoms, since there are lots of epidemiological studies available showing that dampness and moldy building increase the respiratory symptoms risk, therefore the biological contaminant indoors can use dampness as the risk indicator. (WHO Guidelines for Indoor Air Quality - Dampness and Mold 2009.)

Exposure to microbial which is related with dampness and mold may lead to hypersensitivity pneumonitis, allergy etc. especially for the vulnerable groups which are atopic and allergic people. But the relationship between health adverse effect and the dampness and mold cannot be quantified precisely, so the relevant guideline value or thresholds cannot be recommended. Instead it is recommended to use the precautious principle to prevent such pollutants.(WHO Guidelines for Indoor Air Quality - Dampness and Mold 2009.)

The dampness and mold are not emphasized enough in the building regulations and standards. When the surfaces or structure of the building have many visible molds or there is strong mold smell, it means that the indoor air has already had many biological pollutants. Design, construction and maintains are very important to prevent biological contaminants for indoor air. (WHO Guidelines for Indoor Air Quality - Dampness and Mold 2009.)

3.4.11 Particles in Indoor Air

Particles indoors may be from outdoors or the indoor activities like cooking. Particles also may come from the reaction indoors e.g. ozone reacts with terpenes. The particle matters and their adverse effect on human health outdoors have had quite many relevant researches and studies, however the particles indoors have quite little infor-

mation. The adverse effect caused by particles indoors has scarcer information compared with outdoors. (Snjezana 2009b.)

Part of the particles from outdoors may be filtered out before they have the possibility going inside, but it depends on the particles' size (figure 4). The ventilation system is very important to decrease the particles' concentration indoors (Snjezana 2009b).

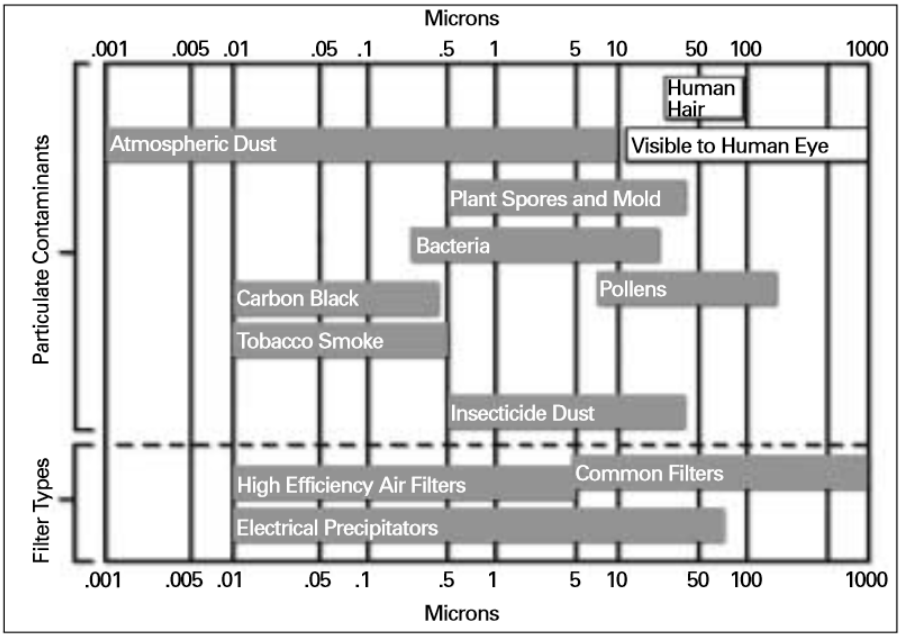

FIGURE 4. Common Particle Contaminants and Their Characteristics (A guide to understand ASHRAE Standard 62-2001. 2002).

3.4.12 Summary Table for the Selected Pollutants

The adverse effect and the recommended value of the chemical pollutants which are illustrated in this report are listed as summary in table 4.

TABLE 4. Summary List of the Indoor Air Selected Pollutants

Pollutants	Adverse Effect	Recommended Value	Comments
Benzene	Acute myeloid leukaemia	No safe level exposure is recommended	Genotoxicity

(Continues)

(Continues)

Carbon monoxide	Ischaemic heart disease	10 mg/m^3 for 8 hours 30 mg/m^3 for 1 hour 60 mg/m^3 for 0.5 hour 100 mg/m^3 for 0.25 hour	
Formaldehyde	Sensory irritation	0.25 mg/m^3 for 0.5 hour	
Naphthalene	Respiratory tract lesion in animal studies	0.25 mg/m^3 (annual average)	
Nitrogen dioxide	Respiratory infection	200 μg/m^3 for one hour 40 μg/m^3 (annual average)	
Polycyclic aromatic hydrocarbons (PAHs)	Lung cancer	8.7×10^{-5} per ng/m^3 of B[a]P	B[a]P is taken as the marker of PAHs.
Radon	Lung cancer and possible leukeamia cancer and extrathoracic airways cancers	100 Bq/m^3	
Trichloroethylene	Liver, kidney, blue duct and non-Hodgkin's lymphoma cancers	No safe level exposure is recommended	Genotoxicity
Tetrachloroethylene	Renal disease	0.25 mg/m^3 for year-long exposure.	
Dampness and mold	hypersensitivity pneumonitis, allergy etc.	No safe level is recommended	

3.5 Indoor Air Quality Assessment

Because of the importance of indoor air, it is mandatory to assess the indoor air quality in certain period to ensure it not jeopardize human health. The quality control plan should be ready before the measurement and analysis. The quality criteria value helps to classify indoor air quality to different levels, which can be used as reference to make decisions and have the mitigation plan accordingly.

3.5.1 Indoor Air Quality Criteria

There are many sources of indoor air contaminants, but the indoor air quality should be defined with measurable values. Some of the common factors for good indoor air are defined. Their parameters have two classes to identify indoor air quality. The table 5 and table 6 list the value for each parameter.

TABLE 5. Indoor Air Quality Values for Offices and Public Places based on 8 hours average test period (Indoor Air Quality Management Quality Group 2003)**.**

Parameter	**Unit**	**Value of Good Class**	**Value of Excellent Class**
Temperature	^{o}C	<25.5	20-25.5
Humidity	%	<70	40-70
Ventilation Rate	m/s	<0.2	<0.3
Carbon Dioxide (CO2)	ppmv	<1000	<800
Carbon Monoxide (CO)	$\mu g/m^3$	<10,000	<2000
	ppmv	<8.7	<1.7
Particulates Matter (PM10)	$\mu g/m^3$	<180	<20
Nitrogen Dioxide (NO2)	$\mu g/m^3$	<150	<40
	ppbv	<80	<21
Ozone (O3)	$\mu g/m^3$	<120	<50
	ppbv	<61	<25

(Continues)

(Continues)

Formaldehyde (HCHO)	μg/m^3	<100	<30
	ppbv	<81	<24
Radon (Rn)	Bq/m^3	<200	<150
Airborne Bacteria	cfu/m^3	<1000	<500

TABLE 6. Indoor Air Quality for Individual VOCs (Indoor Air Quality Management Quality Group 2003).

Compound	Unit	Value of Good Class
Benzene	μg/m^3	16.1
	ppbv	5
Carbon tetrachloride	μg/m^3	103
	ppbv	16
Chloroform	μg/m^3	163
	ppbv	33
1,2-Dichlorobenzene	μg/m^3	500
	ppbv	83
1,4-Dichlorobenzene	μg/m^3	200
	ppbv	33
Ethylbenzene	μg/m^3	1447
	ppbv	333
Tetrachloroethylene	μg/m^3	250
	ppbv	37
Toluene	μg/m^3	1092
	ppbv	290
Trichloroethylene	μg/m^3	770
	ppbv	143
Xylene (o-,m- p-isomers)	μg/m^3	1447
	ppbv	333

3.5.2 Indoor Air Sample Taking

The sample taking standards should be followed to get the reliable and comparable data for indoor air quality. The sample criteria, taking period and the sample point number and location are recommended. (Indoor Air Quality Management Quality Group 2003.)

The sample criteria do not suggest testing the enclosed area which does not have MVAC system (Mechanical Ventilation and Air Conditioning) e.g. room for electricity and storage. The sample measurement should be taken for 8 hours as one period which should include the peak time e.g. rush hour. The number of sample points depends on the room size. The detailed requirement is listed in table 7. At least one sample from outdoor should be taken (except ventilation rate) as well since outdoor air affects indoor air. The samples should be taken among the MVAC zones, the places where are under complains and the areas with high and low density of occupants. (Indoor Air Quality Management Quality Group 2003.)

TABLE 7. Minimum Number of Sample Points (Indoor Air Quality Management Quality Group 2003).

Room Size (m^2)	Sample Point Number
< 3 000	1 per 500 m^2
3 000-5 000	8
5 000 - < 10 000	12
10 000 - < 15 000	15
15 000 -< 20 000	18
20 000 -< 30 000	21
⩾ 30,000	1 per 1 200 m^2

If the samples are measured by online monitor, the data logging of every five minutes should be used for analysis. The sample should be stored according to the instruction of the measurement agent, if there is no information about it, the sample can only be stored for maximum five days. The bacterial sample should be incubated in one day.

3.5.3 Indoor Air Quality Compliance Requirement

For physical parameters, there should be more than 90% of the sample points' value lower than the good class value. For chemical and biological parameters, there should be more than 50% of the sample points' value lower than the good class value. (Indoor Air Quality Management Quality Group 2003.)

If the TVOC measurement value is higher than the good class value, the individual compounds of VOCs should be measured separately. The test method of individual VOCs compounds can follow the organic compendium procedures from US EPA. If all ten individual compounds test results are lower than good class value, it is considered that the TVOC test is passed. (Indoor Air Quality Management Quality Group 2003.)

3.5.4 Indoor Air Quality Control

The assurance of the measurement equipment and agents should be checked beforehand. The calibration should be done according to the instruction. It is recommended to record the information of the manufacturer including the serial number and other unique identification.

The quality control plan should have the information how to prepare the sample, how to handle them, calibration of the instrument and data management etc. The details from storage to treatment should be written to avoid the contamination and deterioration.

3.6 Economic Benefits of Improving Indoor Air Quality

With poor indoor air, it is possible to get diseases or SBS (Sick Building Syndrome). The health care cost, working performance and absence which are caused by poor indoor air affect economic benefit. From the research done in US about the indoor air benefits in office, the ventilation rate requirement in US is 32 cfm per person, but many of the offices do not achieve the requirement. They calculated that if the ventilation rate in offices increases 1.1%, 12.4 million workers' performance would be im-

proved and SBS decreases by 18.8%. The estimated economic value was about 13.5 billion dollars; energy cost was about 0.04 billion dollars (figure 5). (Fisk et al. 2011.)

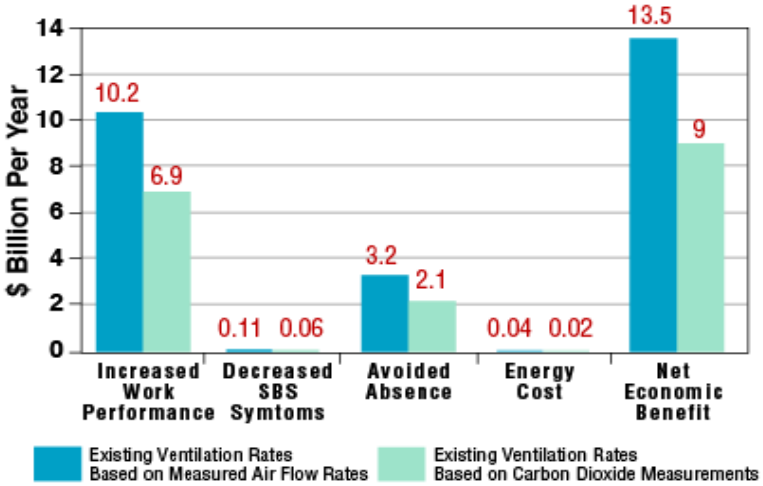

FIGURE 5. Economic Benefits and Cost by Increasing Ventilation Rate (Fisk et al. 2011).

Another study was about the economic benefits and cost related with thermal comfort. When the temperature in office was not more than 23°C, 40 million workers working performance can be increased by 0.2% and 12% less winter dissatisfaction; there would be 8 million SBS less every week. The estimated economic benefit was 3.4 billion dollars (figure 6). (Fisk et al. 2011.)

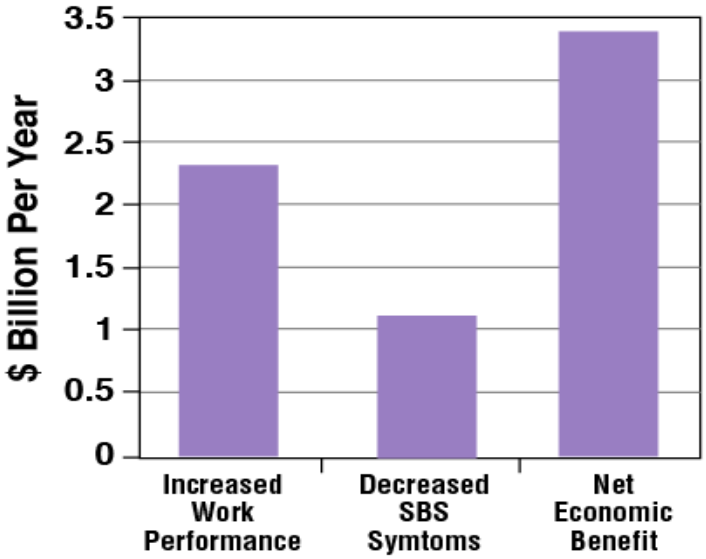

FIGURE 6. Economic Benefits and Cost by Control Temperature in winter (Fisk et al. 2011).

3.7 Indoor Air Quality in School

Technical University of Denmark had project researching the indoor environment and learning in School, they found out that the learning capability is considerably affected by classroom conditions (Snjezana 2009c). According to the WHO project SINPHONIE (Schools Indoor Pollution and Health: Observatory Network in Europe), the pollutants should be followed in schools are dampness and mold, CO_2 concentration (related with insufficient ventilation), nitrogen dioxide (NO_2), formaldehyde and benzene (optional). (Methods for Monitoring Indoor Air Quality in School 2011.)

According to the recommendation, the value of each factor for good indoor air quality are carbon dioxide (CO_2) < 800 ppmv, nitrogen dioxide (NO_2) < 21 ppbv, formaldehyde < 24 ppbv and benzene < 5 ppbv (EPD 2003). The possibility and severity of each parameters are different, high carbon dioxide (CO_2) may happen often due to the full classroom of pupils, but its adverse effect is not lethal in control level of school. nitrogen dioxide (NO_2) may happen when the classroom is next to the busy road, concentration of formaldehyde and benzene normally are under control, but if there are new renovation, furniture or other facilities which emit formaldehyde and benzene, they may cause serious problem. The risk assessment matrix is listed in table 8.

TABLE 8. Risk Assessment Matrix for carbon dioxide (CO_2), nitrogen dioxide (NO_2), formaldehyde and benzene.

	Likelihood Unlikely	**Likelihood Moderate**	**Likelihood Almost Certain**
Severity Minor		carbon dioxide (CO_2)	
Severity Major		nitrogen dioxide (NO_2)	
Severity Serious	formaldehyde and benzene		

4 RELATED TECHNOLOGIES

The study about indoor air quality in the project aims to have the indoor air quality online monitoring and controlling automatically in real time. The indoor air can be detected from online sensors, from which the data is saved to cloud. The data information about the facilities is managed by BIM. The data about the indoor air and building facilities can be integrated and analyzed together. For the future research of this topic, the technologies about indoor air online sensor, BIM, GIS and cloud computing are needed. The relevant knowledge about them is written briefly in this report as background knowledge for the future study of this topic in the project.

4.1 Indoor Air Quality Monitoring and Sensors

Sensors can send their data either wirelessly using various methods, including radio or audio waves, infrared beams or other methods. Choosing the right methods does depend on the environment where the sensors are located. Heavy metal structures create Faraday's cage, which radio transmission is impossible to penetrate. Infrared or laser beams require visibility between the sender and receiver, and weather can render it unusable.

Cost –effortless methods currently is to transmit information via wireless networks, where is data transfer capability, such as WDCDMA (Wideband Code Division Multiple Access), UMTS (Universal Mobile Telecommunications System) and alike. They do require the 3rd party to operate, which is the phone network carrier, maximum transmit range is around 30km radius around the base station, depending on land shapes, and transmit frequencies used. WLAN (Wireless Local Area Networks) is alternative, easy to set up and use, it has only the range of 20-50 meters, and range can quickly drop in environments where there are heavy concrete and such around, so possibly more relay stations has to be set up between the sender and receiver, or some of them transmit via using cable, either traditional copper wiring, or more common nowadays, optical fiber. Cables reach ranges from 200 meters (Ethernet) to thousands of miles with added repeaters, such as the optic cables running under the Atlantic Ocean.

The demand of indoor air quality real-time monitoring is growing rapidly because of the strict relevant legislation and requirement from intelligent building technology. There are variable indoor air quality monitoring sensors available based on different technologies and methods, from BC (Black Carbon) pigment analysis on cell phone (Kelsey et al. 2008) to nanotechnology.

It is impossible to list all the sensors and their technologies in the current market and relevant research projects. This chapter only illustrates some sensors as examples of current indoor air quality sensor technologies.

The electrochemical analyzer as normal method is used to detect the gases indoor, carbon monoxide (CO) and carbon dioxide (CO_2) are tested by DPIR (Non-Dispersive Infrared) because their molecule have specific wavelength. Different companies have their own special methods than the conventional ways. IAQ monitor™ (Picture 1) which is invented by PPM technology Inc. uses PID (Photoinonization) detector for TVOC (Total Volatile Organic Compounds) measurement and patented digital CMOSens® technology to measure temperature and humidity (Mini Wireless IAQ Monitor. 2011). CMOSens® technology enables the sensor component to be combined with the analog and digital signal processing circuitry on a tiny CMOS silicon chip.

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Picture 1. IAQ monitor™ from PPM Technology Inc. (Mini Wireless IAQ Monitor. 2011).

Chemiluminescence, which is the emission of light as the result of chemical reaction, of nitro-oxides materials is used to measure nitrogen monoxide (NO), nitrogen dioxide (NO_2). Beta-ray attenuation with corresponding size distribution filter can be used to test ozone, PM_{10} and $PM_{2.5}$ (Particulate Matter). (Liu et al 2012.)

3M as one of the leading companies in the environment monitoring field has EVM series environment monitoring product. EVM-7 is designed to monitor indoor air quality with innovative technologies (Picture 2). (3M 2012.)

Picture 2. EVM-7 Air Monitor from 3M. (3M 2012.)

The measuring methods for each parameter which can be done by EVM-7 are listed in table 9) (3M 2012).

TABLE 9. Measurement Methods in EVM-7

Parameter	Measurement Method	Unit
Particulates	90° Light Scatting	mg/ m^3 or ug/ m^3
VOC (Volatile Organic Compounds)	PID (Photoionization Detector)	ppm
CO_2 (Carbon Dioxide)	NDIR (Non-Dispersive Infrared)	ppm

(Continues)

(Continues)

CO (Carbon Monoxide)	Electrochemical	ppm
Cl_2 (Chlorine)	Electrochemical	ppm
EtO (Ethylene Oxide)	Electrochemical	ppm
HCN (Hydrogen Cyanide)	Electrochemical	ppm
H_2S (Hydrogen Sulfide)	Electrochemical	ppm
NO (Nitric Oxide)	Electrochemical	ppm
NO_2 (Nitrogen Dioxide)	Electrochemical	ppm
SO_2 (Sulfur Dioxide)	Electrochemical	ppm
O_2 (Oxygen)	Electrochemical	%

4.2 BIM, CAD and GIS

In this chapter, the skeletons of the knowledge about BIM, CAD and GIS are introduced. Their differences among them are discussed to clarify the terms and their functionalities.

4.2.1 BIM

BIM is the abbreviation of Building Information Model. It is developed because of the existed heterogeneous standards and file formats in the current industry. The requirements of seamless alternative which can integrate all the phases and manage the whole lifecycle hasten the idea of BIM and fasten its development.

BIM is the revolutionary technology in the current AEC (Architecture, Engineering, and Construction) industry. It not only has all the physical and functional parameters of the 3D virtual building which provides the direct view of the future facility, but also manages the whole comprehensive lifecycle of the building from planning to demolition. (Fuller 2009.)

The conventional methods before was static and passive model, but BIM is a dynamic and active model, with the function of online sensor, the self-updating build or so called intelligent building becomes feasible.(Fuller 2009.) Static and passive means monitoring via sensors, for example air quality, temperature, amount of people and so

forth, not so much adding possibilities to interact with their environment whenever and wherever. Dynamic and active means the building can adjust its interior or relevant facilities to fulfill the requirements e.g. indoor air quality or propose the solutions e.g. real time emergency response.

BIM integrates the vendors, suppliers, constructors, architects, engineering and managers, which enhances the work efficiency and reduces the communication obstacles and misunderstandings. (Fuller 2009.) BIM is the future trend in the AEC industry because of its numerous advantages, which is supported by the new technologies.

There is no doubt that BIM has prospering future. But there are still several limitations which should be solved. First of all, it is the lack of technical standard for interoperability, secondly legal design liability is obscure, and the last the ownership of BIM model in practice e.g. management capability, cost and training is not defined as the universal convention. (Fuller 2009.)

BIM will support dynamic sensors and have the real time function, not only the static sensor; it will have the function to predict the trend and support sustainable system, not only the function like drawings (floor plans etc.), spatial management tools. (Fuller 2009.)

4.2.2 CAD

CAD means Computer Aided Design. Most commonly it means design by engineers with programs like Autodesk's AutoCAD or Dassault's SolidWorks. It is used to model 2D/3D models of objects to large buildings and other systems, allowing engineers to also test structures and change things flawlessly and effortlessly. It interprets and manipulates the architecture elements e.g. the geometrical properties, the graphic symbols. It is the building graphic modeling or drawing based model.

BIM is based on CAD (Ibrahim et al. 2004). BIM is not anything new, it has been always the ideal method but due to the technology limitation, it was not possible to be developed. Thanks to the new technology, BIM finally comes to use, it not only the

geometry which CAD has too but also the building information (Fuller 2009). BIM models the true architecture objects.

Since 1950s, CAD replaced the pen and note hand-drawing method gradually after long time resistance. CAD finally cleaned all the obstacles when the governments announced that only digital format file was accepted in the bid. After research and interview, it is more challenging from CAD to BIM comparing from hand-drawing to CAD. Since from hand-drawing to CAD, only the tools were changed, but from CAD to BIM it is from two dimensions to three dimensions. Therefore the time for BIM to replace CAD might be quite long unless there is mandatory regulation or requirement to use BIM popup in the AEC industry. (Robson & Littlemore 2011.)

4.2.3 GIS

GIS is Geographic Information System. It has the topography information and is used to analyze the spatial data and select the optimum location for decision making.

ArcGIS is one of the modeling products from ESRI Company. With it, the user can do the planning and analysis, data and asset management to aware the operation and to finish the complicated geographic information system task in the field. It has the possibility to integrate with another the information system framework in different industries for information management, e.g. with BIM. It uses various kinds of spatial data and makes it possible to build time-spatial connection with arbitrary data with it.

Temporal data in ArcGIS stands for a status in time, for example the weather change in one city or indoor air quality change in 5 minutes interval in one building. Temporal data has time value which can be used to visualize temporal data. The time slider is for the visualization after the time property has been set in ArcGIS. Time value can be a point time (called time instant in ArcGIS) or the duration of time (called time extent in ArcGIS) with starting time and ending time. Visualization the temporal data helps to check the changing patterns (e.g. land-use), follow the tracks (e.g. hurricane-moving), map progress (e.g. real-time tsunami), examine changes (e.g. carbon monoxide (CO) level) and visualize change (e.g. online traffic jam map). (ESRI 2012.)

Comparing with BIM, it does not have the semantic information of the building element. In the nutshell, it is a drawing tool. BIM normally is to visualize the building and manage the building information. The main differences between GIS and BIM are summarized in the table 10 (Irizarry & Karan 2012).

TABLE 10. Main Differences between GIS and BIM (Irizarry & Karan 2012).

Difference	GIS	BIM
Modeling Environment	Used outdoors. Position the buildings.	Used indoors. Site utilities and terrain modeling.
Reference System	Geospatial data. Georeferenced with global coordinate system or map projections.	Has its own reference standard. e.g. the left corner of the building.
Drafting	Mainly used in the existing building, it has less details and used in the smaller scale.	It has more details and larger scale.
Application Area	Urban and city area.	Building and its elements.
3D Modeling	In the beginning phase, not so developed	Full 3D environment and rich set of spatial features and attributes.

Besides the differences listed in the table 10, the relation of the objects in GIS is based on coordinate since it is geolocation, the relation of the objects in BIM is of importance, and it decomposes and specializes the object (Laat & Rerlo 2011).

BIM and GIS are different tools for its own purpose. But their interoperability could solve complex problems that their interoperability can be done at the semantic level. The solutions are GML (Geographic Markup Language) and IFC (Industry Foundation Classes). OGC (Open Geospacial Consortium) announces the BIM-CAD-GIS architecture. Industry and academe have plenty of research and projects ongoing.

CityGML as the open data model and XML-based format for virtual 3D model is one of the softwares. (Irizary & Karan 2012.)

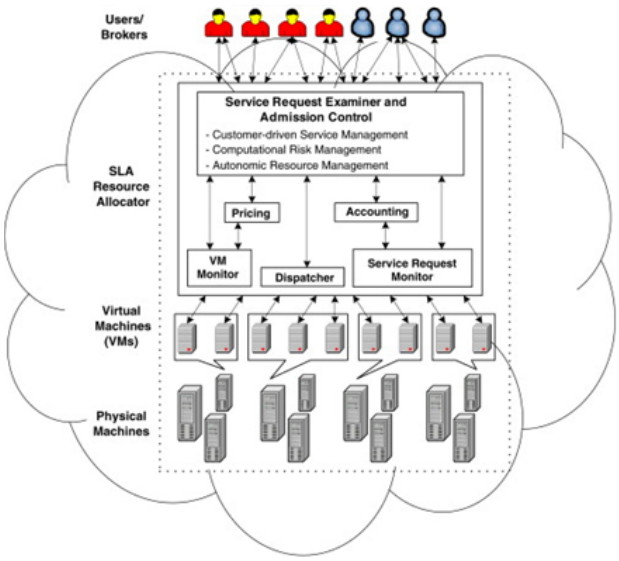
4.2.4 BIM & CAD & GIS Integration

The integration among BIM, CAD and GIS has promising future and there are quite many researches about how to integrate them. Although the difficulties from technologies and legal area are the obstacles for the future development, the booming market about the intelligent building management will for sure help the future study to find ways to succeed.

4.3 Cloud Computing

Cloud computing means storing information in to the cluster of computers where data is coupled within the cloud transparent to the user. It can have just few computers, or even tens of thousands of computers. In case some of them are not available, the remaining ones will continue servicing the data uninterrupted and transparent to the end user. Cloud can also react to growth needs, by adding dynamically capacity to the cloud. This can mean adding processing power, storage or other needs.

Computing is becoming the fifth utility after the telephony, gas, water and electricity (Buyya et al. 2009). Cloud computing is one of them as together with distributed computing, cluster computing and grid computing. Cloud computing as the new commercial implementation of the computer science idea has significant impact in many industries. Cloud is quite typical service provided delivery, where one can buy the service needed exactly, and having no administration woes or extra cost from the maintenance. A metaphor about cloud computing is that before everybody had their own well in the backyard, nowadays they have tap water instead. Therefore they can use the 'pay-as-you-go' consuming pattern. One of the cloud architectures is illustrated in picture 3 (Buyya et al. 2009). Michael agrees with its significant effects in various industries, she claims that cloud computing makes the software more attractive as a service and it changes the hardware provision method, which helps the entrepreneurs reduce the cost having their own server or other facilities and have more revenue to the real innovation (Armbrust et al. 2010).



PICTURE 3. High Level Market-Oriented Cloud Architecture (Buyya et al. 2009).

There are different classifications about cloud computing. One is public cloud and private cloud as it is understood easily literally. Public cloud means that the cloud is set for the general public. Private cloud is for the customers as its exclusive use. According to the service the cloud offers, it has SaaS (Software as a Service), IaaS (Infrastructure as a Service) and PaaS (Platform as a Service). Several service and computing companies has started to offer their Cloud solutions lately. Some have been around the block for a long time. Few to mention are Google and Amazon, with their respective Google Cloud and Amazons EC2 platform. (Armbrust et al. 2010.)

4.3.1 Cloud Computing and GIS

The current new trend 3D images, which have complicated and big amount of spatial information, are happening in the parallel with the cloud computing emergence. Cloud computing offers a flexible, scale, transparent and economic solution for massive 3D GSI data processing. (Park et al. 2010.) There is another change which the geospatial industry is facing: intensity, for example, concurrent access, spatiotemporal data and computing. The cloud computing provides the required infrastructure, it can deal the access peak, provide the real time response and have better support for data utilization and processing. (Yang et al. 2011.)

To integrate cloud computing with GIS, the data storage is more flexible and the custom service is more transparent. Cloud computing makes the interaction and real-time functions much easier and faster in GIS. It optimizes the network allocation in both service layer and application layer. (Zhao & Geng 2010.)

All the GIS suppliers announced the future plan to support cloud and its development plan about it, e.g. ESRI published the new interactive map application which has the cloud computing technology. There are plenty of research and project using the integration of cloud computing and GIS. In one global marine biogeographic research, the integration improves its performance significantly. The global research project solved the standard compliance, data storage and elasticity problems with cloud computing. (Brynjolfsson et al. 2010.) In the 3D noise map in Soul, the performance with cloud computing was slower comparing with conventional way but it was more stable and flexible (Park et al. 2010). The integration of cloud computing and GIS improves the social impact and user interaction and definitely have prospering future with the booming marketing requirement and more development support.

4.3.2 Challenges and Opportunity of Cloud Computing

Cloud computing has the benefits of virtualization, failover and automatic scalability. It changes the operating expense to capital expense, therefore the risk of over provision and under provision is reduced, and the inventory utility is optimized. (Armbrust et al.2010.) She describes the advantages of the cloud comparing with the conventional way in the table 11.

TABLE 11. Comparison between Cloud and the Conventional Data Center

(Armbrust et al.2010.)

Advantage	Cloud	Conventional Data Center
Infinite resource on need	Yes	No
Optimize the hardware utility on need.	Yes	No
Pay as you go manner	Yes	No

(Continues)

(Continues)

Optimize the finance investment.	Yes	Usually not
Utilize the workloads from different companies	Yes	Depends
Operations is simplified and utilization is increase because of virtualization	Yes	No

But cloud computing technology may have to solve the problems such as security, interoperability and complementarity (Brynjolfsson et al. 2010). Cloud computing is similar with electricity as utility; both are the platform and the 'power' for the innovations, they are so called GPT (General Purpose Technology). Unfortunately nowadays cloud computing is not as easy as electricity, which is easily used as plug-and-play. But the future of cloud computing is to work as a platform rather than discrete tool. There will surely emerge more services and applications and be the great driver of creativity, productivity in the modern economy. (Brynjolfsson et al. 2010.)

One coin has two sides; the obstacles can be taken as opportunities. The new standard APIs emerges when the cloud computing has the interoperability problem. The encryptions and the firewall which are used to secure data in cloud will solve the data confidentiality problem. The data transfer bottlenecks will be fixed with higher bandwidth switches. (Armbrust et al.2010.) The challenges always create opportunities. Many new technologies are deployed to solve the cloud computing problems. For example, based on the fact that more and more clients are worrying about the confidentiality and integrity of their data, Nuno and his team invented the TCCP (Trusted Cloud Computing Platform) for IaaS (Infrastructure as a Service) to prevent the confidentiality violations. With this platform the user can attest the Iaas provider and check if the service is secure before launching the virtual machines. (Santos et al. 2009.)

5 CASE STUDY: CAMPUS BUILDINGS IAQ VISUALIZATION

The case study is the preliminary test for indoor air quality visualization. The similar GIS data with building X located in MUAS and the similar indoor air quality data

from the sensors are used in the case study. The visualization of the real indoor air quality from the online sensors located in Building X and in MUAS main campus will be done in future in the project based on the study output of this report.

The assumption of the case study in this report is that online monitoring sensor does the indoor air measurement and saves the data. The target of the case study is to have visualization in the software not to analyze the indoor air quality in the campus building; the method to visualize changing is same for all parameters. Which parameters are selected does not affect the case study result. For this case study, temperature, relative humidity and formaldehyde are chosen to visualize their changes.

Microsoft Excel is used to save the indoor air data which is written like the data log from online monitor sensing, ArcGIS is selected to draw building plan map and visualize indoor air temporal data.

5.1 OPEN tietojärjestelmät project

The thesis work is part of the OPEN tietojärjestelmät -project funded by EU in Mikkeli University of Applied Sciences. OPEN tietojärjestelmät -project is part of environmental technology studies and innovation works. In this project alternative monitoring and control systems for example to authority use will be developed. Main developing task is to create open cloud computing system for all citizens to use.

OPEN tietojärjestelmät project started in February 2012. There are several online monitoring sensors installed and used, which measure the water quality in Lake Saimaa, algae in Pitkäjärvi, waste water measurement in Metsäsairila landfill and the weather situation in city center of Mikkeli. The cloud computing technology and website visualization are being in operation with the cooperation of observis OY. ArcGIS is selected as one of the visualization tools for all the online monitoring results and analysis.

The aim for the indoor air quality study in the project is to analyze the indoor air quality in building X located in Patteristonkatu 3, Mikkeli. The online monitoring sensor was installed in the X building by the construction company and the data is saved in

the server. The indoor air quality data is collected automatically and analyzed in real time with 3D visualization in the software.

5.2 Campus Buildings and Indoor Air Quality Data

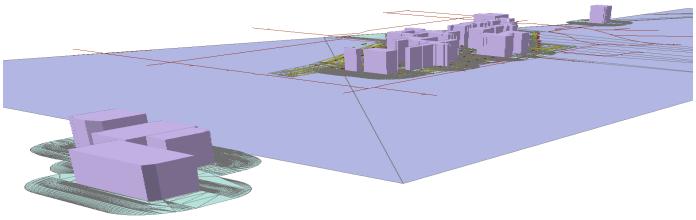
The case study is only the preliminary test for indoor air quality visualization; therefore the assumptive data of campus building and indoor air quality is acceptable here although it is not the geographic data and indoor air quality data.

The data of campus buildings and indoor air quality is used in the case study as the preliminary test data. The campus geographic data (BISDM 2.0 Campus Viewer) is downloaded from the ESRI website. It is not the real geographical campus building data but one demo data which is provided by ESRI Company (ESRI, 2013). The campus building polygon shape file is used to join the assumptive indoor air quality data.

The indoor air quality data in the case study has temperature, humidity and formaldehyde as the examples of 3D visualization. The data about indoor air quality is not recorded by online sensors or from the laboratory test. It is from assumptive data which doesn't exist. Its purpose is to show the indoor air quality change in the 3D visualization. The assumption is it is recorded from 01.02.2013 to 15.02.2013 for all the campus buildings. Three scenarios are set for each parameters and their relevant visualization are checked from the software.

5.3 GIS work

As mentioned, ArcGIS is selected as the software tool for this feasibility study. Since one of the purposes is to test the 3D visualization for the indoor air quality temporal data, ArcScene is selected from ArcGIS menu. ArcScene has the functionality to have the geographic data in 3D view by placing relevant features. In this case study, the campus buildings are extruded to 3D looking buildings (Picture 4) from shape file.



PICTURE 4. Campus Building in 3D view.

5.4 Temporal Data Visualization

The visualization is done by time slider which is designed for temporal data in ArcScene. The indoor air quality data saved in excel is not geographic data which cannot be used in ArcScene directly. The conversion tool functions from ArcToolbox conversed the excel data to geodatabase (Table to Table action in figure 7) first before all other actions in the software.

After the excel file is conversed to right data format, the next action is to join the indoor air quality data with the geographic campus building data. Since the geographic campus buildings data has the building name which can identify each building, but there is no connection with the indoor air quality data which is saved as separate file in ArcScene. The indoor air data and the geographic campus building data should be joined together to have the relevant analysis. Before the visualization, the one-to-main join is done by making query table (Make Query Table in figure 7), meaning that the building name information matches the indoor air quality data for each building.

After joining the indoor air data and the campus building geographic data, the query table file should be saved as layer file which can be visualized as temporal data in ArcScene. The working flow in the software is illustrated in figure 7.

The action ‘convert time field’ in figure 7 is optional step. If the field is not written in proper time format, AcrScene has the function to convert it automatically. This function makes it possible to integrate the data from online sensors with the geographic data in the software.

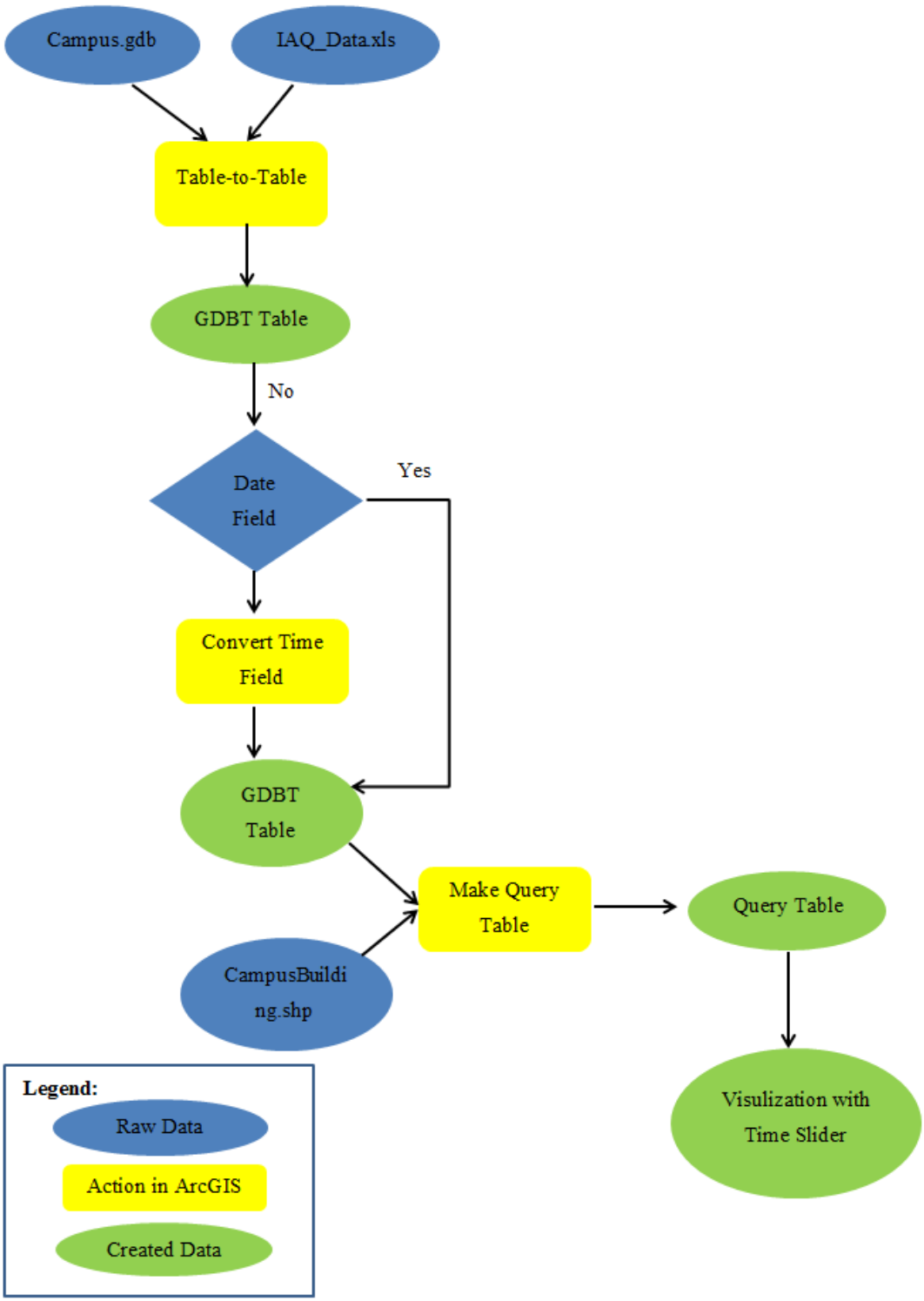


FIGURE 7. Work Flow in ArcGIS.

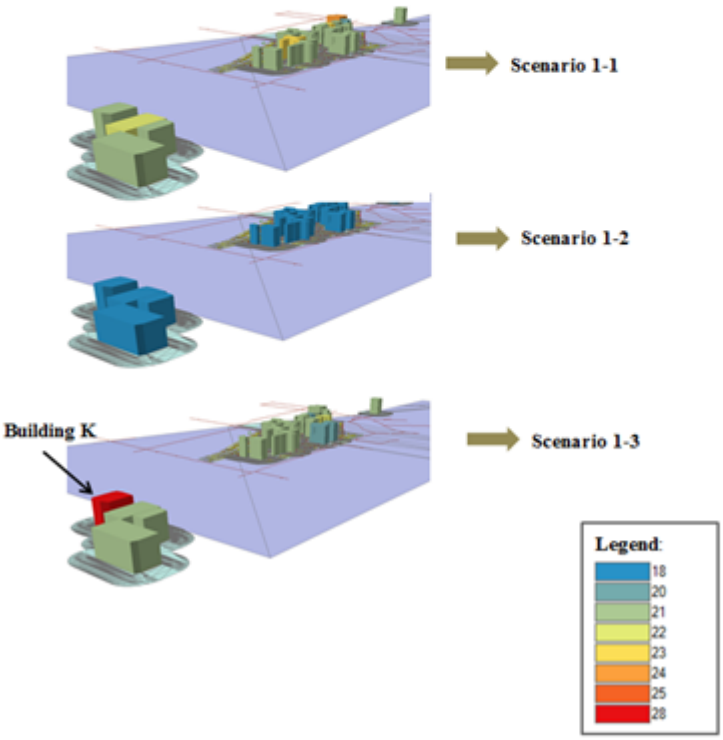
5.5 Cast Study Visualization Result

The result is about the indoor air quality 3D visualization with temporal data. It only focuses on the final visualization for selected parameters. The indoor air risk assessment is not in the case study scope. The time slide is used to show the data change for each data. Three scenarios and their visualization results are listed in the following.

The first scenario is about temperature. It shows the normal temperature in the building and lower temperature in the weekends. When the temperature is not in the thermal comfort zone, it shows the alarm in red (picture 5).

Scenario 1 about temperature:

- 1.Temperature in every building is kept from 20 ºC to 25ºC in working days.
- 2.Temperature in every building is 18 ºC in weekend to save energy.
- 3.Temperature in K building on 01.02.2013 was 28 ºC.

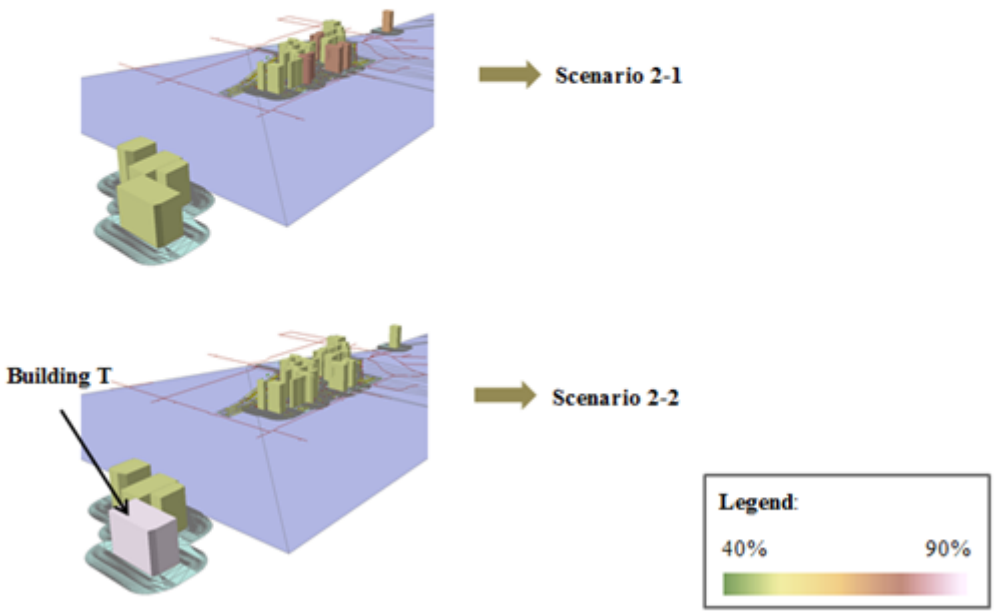


PICTURE 5. Scenario 1 about temperature and its visualization.

The second scenario is about relative humidity. The assumption is the relative humidity is kept in the comfortable range no matter of the weather condition. But the sudden water leaking makes it increased in some building. Form the visualization, the malfunctioned building can be found quickly (picture 6).

Scenario 2 about relative humidity:

- 1.Relative humidity in every building is kept from 40% to 70%.
- 2.Relative humidity in building T was 90% because of water leaking on 13.02.3013.

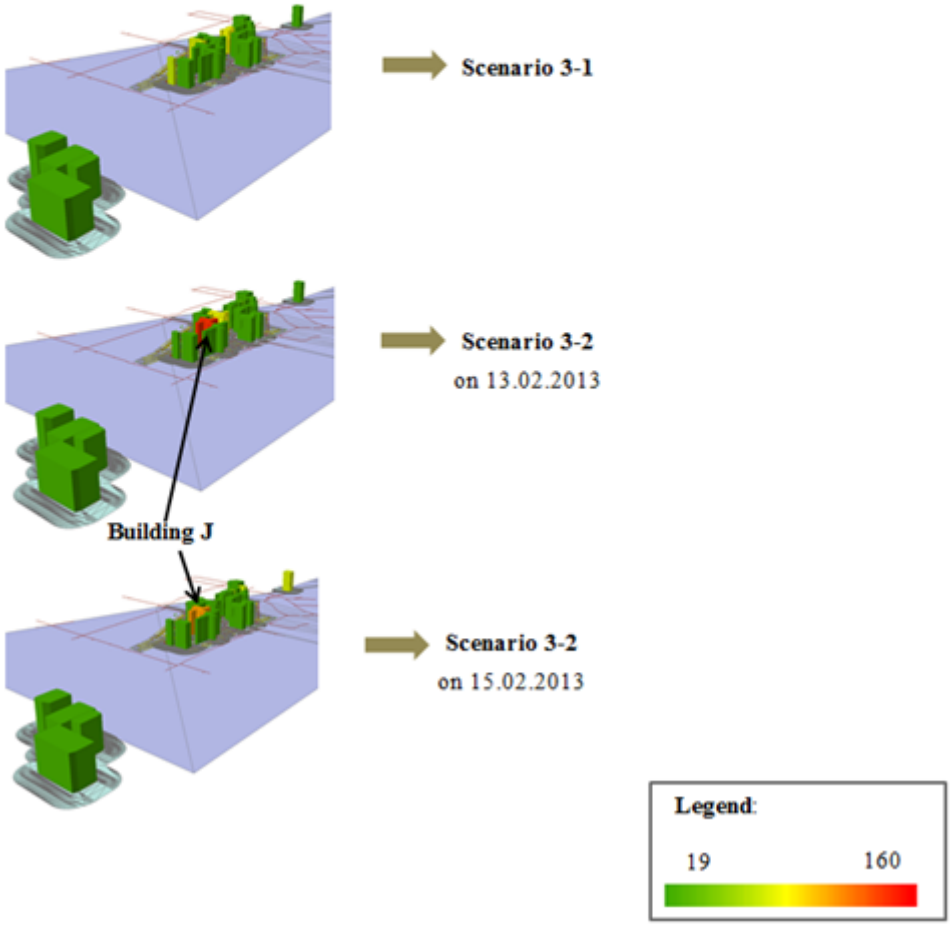


PICTURE 6. Scenario 2 about relative humidity and its visualization.

The third scenario is about formaldehyde. Its concentration level in every building is controlled in the acceptable level but in building J its concentration increased dramatically on 13.02.2013 because of renovation. Its concentration was decreasing every day from 13.02.2013 to 15.02.2015 which is shown in the visualization (picture 7).

Scenario 3 about formaldehyde:

- 1.Formaldehyde in every building is less than 30 μg/m³
- 2.Formaldehyde in building J was bigger than 100 μg/m³, because of the renovation from 13.02.2013 to 15.02.2013.



PICTURE 7. Scenario 3 about formaldehyde and its visualization.

The video was made to visualize the result, comparing with pictures, the video was the better way to demo the visualization for these three scenarios is video, which can show the change daily. In this report, the screen shots of their visualization in the software are inserted as pictures; only the typical changes of each parameter are recorded in the picture format in the report.

6 DISCUSSION AND CONCLUSION

Although there is still little information about indoor air contaminants and their adverse effect on human health, indoor air quality is getting attention from the authorities because of its essential importance for human health. The epidemiological studies and relevant research show that poor indoor air does jeopardize human health and cause huge amount of economic cost.

The current available technologies e.g. building information modeling (BIM), geographic information system (GIS), online sensors, clouding computing can monitor and manage the indoor air quality in the real time, economic, efficient and precaution way. Different online monitors for air quality offer the possibility to have the measurement done quickly and accurately. The integration between online sensors and BIM technology not only can monitor the indoor air but also manage it intelligently. With the powerful functions on the geographic data manipulation and 3D visualization, GIS offers the cooperation with BIM and online sensors to manage and control indoor air quality. Cloud computing contributes on the cost saving and data flexibility. But due to the technical, legal or other reasons, the indoor air quality data which is collected by the building information system is not always easy to access for GIS integration.

The trial visualization of indoor air quality in ArcGIS shows the changes in 3D view, it makes monitoring easier and faster. The real time management can be done more efficiently. It shows the current situation and gives alarm when the quality is over the recommended threshold. The visualization in 3D method offers easy and fast way to take actions and make decision.

The result from the case study is only the preliminary test as the reference for the future development on the same topic. In further study, there may be other practical, organizational or security issues when setting up GIS database. The case study in the report showed that indoor air quality visualization can be done with GIS although the assumption is there is one sensor in one whole building. It would be nicer to have the visualization for each floor of the campus buildings, but setting up floor plan for the whole campus which can be used for 3D visualization takes time if the data is used

professionally for multi-purposes. For the future study of the topic having more complicated visualization for each floor, it can be done easily with the same method and process.

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