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DETERMINING THE BEST LOCATION OF SMOKE SENSOR IN OFFICE ROOM

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DESCRIPTION

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Determining the best location of smoke sensor in office room

Abstract

Smoke detectors are considered to be the most effective type of fire detectors. But where should they be installed in an office room to give a signal in time? Instructions for installing of smoke detectors are usually given in general terms, thus further information of the best location of smoke detectors would be needed.

The aim of this Bachelor's thesis was to determine the best location of the smoke detector in an office room. Research was divided into two subtasks. The first was a comparison of smoke detector installation instructions in 3 different countries (USA, United Kingdom, and Russia). Normative documents in these countries are similar, but each country emphasizes its own parameters which affect decision of the fire engineer. The second subtask was to carry out laboratory experiments. They were conducted to study the air flow patterns in an office room and response times of smoke detectors in different locations.

The investigated office room was about 11 m^2, and there was a desk, chair and computer. The room had supply and exhaust valves. Four smoke detectors, connected to a panel, were placed in different locations (ceiling, walls, alongside of computer, and inside exhaust duct). Smoke generator was put under the table and smoke was introduced to the room as puffs. In reality this might resemble the situation in which the computer starts to burn and produce smoke. As soon as the smoke reached one of the detectors, a lamp was lit in the panel. The response time in seconds for each detector was recorded. Response times of 20 different locations of the smoke detectors were studied.

The best location according to the results is in points of the ceiling which are close to the expected ignition source and have sufficient air flow movement around them. Location inside exhaust duct gives the best response time, but it requires frequently cleaning of the smoke detector.

Subject headings, (keywords)
Smoke sensor, smoke alarm, smoke detector, air flow patterns, automatically actuated device, carbon monoxide sensor, flame sensor, fire detection system, heat sensor, ionization smoke detector, optical smoke detector, photoelectric smoke detector, sampling detector, smoke chamber, and smoke machine.

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CONTENTS

DEFINITIONS

Air sampling-type detector – a detector that consists of a piping or tubing distribution network that runs from the detector to the area(s) to be protected. An aspiration fan in the detector housing draws air from the protected area back to the detector through air sampling ports, piping, or tubing. At the detector, the air is analyzed for fire products.

Automatically actuated fire detector – a device designed to detect the presence of a fire signature and to initiate action.

Combination detector – a device that either responds to more than one of the fire phenomenon or employs more than one operating principle to sense one of these phenomenons.

Control panel of the fire alarm – a system component that receives inputs from automatic and manual fire alarm devices and might supply power to detection devices and to a transponder(s) or off-premises transmitter(s). The control panel might also provide transfer of power to the notification appliances and transfer of condition to relays or devices connected to the control unit.

Detector – part of an automatic fire detection system that contains at least one sensor which constantly, or at frequent intervals, monitors at least one suitable physical and/or chemical phenomenon associated with fire, and that provides at least one corresponding signal to the control and indicating equipment.

Fire alarm – the component of a fire alarm system, not incorporated in the control and indicating equipment, which is used to give a warning of a fire.

Fire detection system – system (other than a single self-contained smoke or fire alarm) in which an alarm of fire can be initiated automatically.

Fire alarm system – a system or portion of a combination system that consists of components and circuits arranged to monitor and annunciate the status of fire alarm or supervisory signal-initiating devices and to initiate the appropriate response to those signals.

Ionization smoke detection – the principle of using a small amount of radioactive material to ionize the air between two differentially charged electrodes to sense the presence of smoke particles.

Initiating device – a system component that originates transmission of a change-of-state condition, such as in a smoke detector, manual fire alarm box, or supervisory switch.

Line-type detector – a device in which detection is continuous along a path.

Manually actuated device – the component of a fire detection and alarm system which is used for the manual initiation of an alarm.

Photoelectric (optical) smoke detection – the principle of using a light source and a photosensitive sensor onto which the principal portion of the source emissions is focused.

Smoke alarm – a single or multiple station alarm responsive to smoke.

Smoke box test – a smoke test, which is realized with a constant high velocity in a wind tunnel.

Smoke machine – a device which emits a dense vapour that appears similar to fog or smoke.

Spot-type detector (point detector) – a device in which the detecting element is concentrated at a particular location.

1 INTRODUCTION

According to the current laws in many countries, we should install fire protection systems in all buildings. To protect against fire in time we need to have effectively working fire detecting devices. There are a lot of different types of such devices. Basically we have two main types of fire detection systems: manually actuated and automatically actuated devices. Nowadays automatically actuated devices are more popular (because we can live calm when we do not have to worry about the possibility of a fire). Smoke detectors are the most widely used type of fire protecting systems all over the world because they are also the cheapest one. But where they should be installed to give a signal in time?

To make the smoke come to the smoke sensor we need to locate it carefully. Otherwise there will be a risk of a fire or we will be disturbed by false alarms. The main goal of this bachelor's thesis is to determine the best location of the smoke sensor in a laboratory office room. Research is needed to ensure safe laboratory environment and also to investigate the best location of smoke detector in an ordinary case. The main research goal consists of following steps:

1. To show the differences between instructions of installing smoke detectors in standards of three countries (Russia, USA, United Kingdom).
2. To study smoke detector locations in the laboratory office room to ensure the minimum response time of the smoke alarm.
3. To see if the laboratory experiments suggest the same optimal location of smoke detectors as the recommendations given by normative documents in the 3 countries.

Different normative documents give us a lot of information how to install smoke detectors. In this thesis work comparison of instructions for installing smoke detectors in three different countries will be submitted. Distinctions between standards of USA, Russia, and United Kingdom will be shown and optimal locations will be found out.

A series of laboratory experiments will be done to confirm expectations about the proper location of the smoke detector after comparison of standards. Measurements of the response time of the smoke detector located in the office room while spreading a fire will be done and the description of them will be included into the thesis.

Measurements will be done in the laboratory office room in the building A of Mikkeli University of Applied Sciences. There is no smoke detector system in this office room and it is necessary to choose location for the smoke detector to provide good fire detection system inside. Smoke detectors will be installed in different points of the ceiling, walls, inside and near to the exhaust terminal unit. After counting the response time of each detector it will become possible to get results for confirmation expectations and to determine the best location of smoke detector.

2 THEORETICAL BACKGROUND

2.1 Danger of the fire

According to the Guide for standard messages, fire is in the top five causes of death in United States of America and it is also the third main cause of incidental injury and death through the children under the age of 15. Every year fires kill on average 3,635 people in more than 1.587,000 fires in United States – it is about nine people per day. Fire reduces the amount of oxygen and increases the concentration of deadly toxic gases like a carbon monoxide in the air. Asphyxiation kills three times more people than burns. The best way to prevent a fire is to prevent it from the beginning. That's why the immediate identification of the ignition of a fire is the most important problem. /1, p.23./

The fastest way to warn people about a fire ignition is by means of smoke detector or another automatic device. A smoke detector is a special device which detects tiny smoke particles given off while something burns. In the risk of fire it activates the fire alarm system or sounds an alarm. Fire alarm system may be also programmed to have a three-minute delay before turning on evacuation alarm to detect an area where the smoke sensor has been activated and to initiate other actions like closing fire dampers and activating smoke controls. Smoke detectors are preferred in offices, closets and classrooms because they provide an effective early warning. Installing smoke detectors may not always be required by norms, standards and codes, but installed smoke detector must be fully functioning. /2, p.1-3./

The statistics shows that smoke alarms sounded in, approximately, the half of the fires in United States in 2004. Occupants with smoke detectors can easily detect and control fires they have without help of the fire departments. It certainly reduces the statistics. More than 96% of houses have at least one smoke detector. Nowadays this number is undoubtedly greater. But only three-quarters of them are working. The main reasons of the smoke alarm failure are missing or dead batteries, the lack of cleaning and the wrong location of the sensor. /3, p.2, 13-14./

2.2 Fire detection devices

As a rule fire detection devices are divided into two basic types: manually actuated and automatically actuated devices (Figure 1).

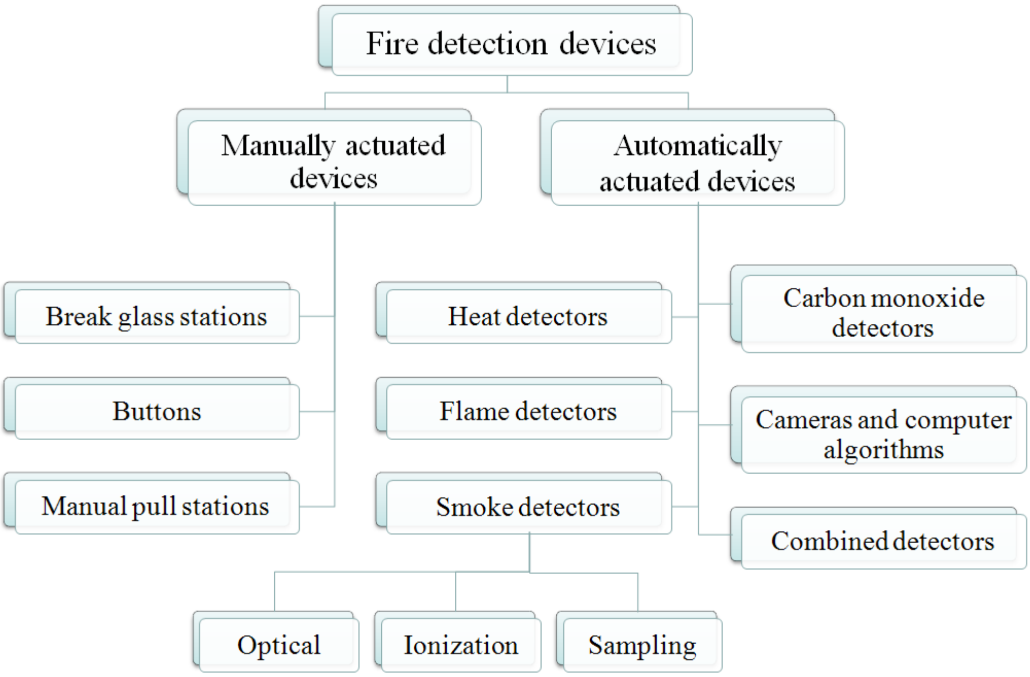

FIGURE 1. Fire detection devices

Manually actuated devices are located near the exits and in many cases look like the red button on the wall. Somebody should push the button in a risk of a fire. But it will be late when somebody will push the button after he will see the flame.

Modern automatically actuated fire alarms are used to detect fire at the earliest possible stage. They were produced for working 24 hours per day without any human intervention. Fire detection sensors are divided into smoke sensors, flame sensors, heat sensors, carbon monoxide sensors and also cameras operated by computer algorithms. As a rule fire detection sensors trigger at a critical value. There are point fire detectors, linear and sampling fire detectors. Point fire detectors take sample in that place where they are installed. The linear one consists of elements which look like cameras. They are installed in front of each other on the opposite walls of the room and based on laser technologies. This type of detectors can operate in large spaces up to the 100 meters long. Sampling fire detectors are the kind of smoke detectors which can be located in the ventilation system or another place and it takes the samples of the air at specified predetermined intervals. /4./

Heat detectors are sensitive to the temperature. They can be passive or active. Passive ones do not use energy and when the temperature rises to the critical point, the sensor produces a specific signal (due to the thermo electrical effect) or breaks the electrical circuit of alarm. Active detectors use energy sources. They can give information not only when the temperature will rise to a critical point but they also turn on the alarm when the temperature increases very fast. /4./

Flame detectors detect infrared or ultraviolet radiation from a flame by inserted photo detector. They can detect both smoldering and flaming fires. They are used in places where fire can starts rapidly without smoke. /4./

Carbon monoxide (CO) detectors are a very important part of fire safety systems in buildings. The main problem with CO is that it does not smell. Carbon monoxide is produced by portable generators, stoves, burning coal and wood. CO can cause death even if you are not sleeping because people can not detect the existence of this gas. That is why it is so important to use carbon monoxide detectors. There are three basic types of them: metal-oxide-semi-conductor (MOS), biometric and electrochemical. There is no need to check batteries with using the first technology (MOS), because it is always connected to the house power. Biometric detector has gel-coated disk, which becomes dark in the presence of CO. Changing the color of the disk turns alarm on. Electrochemical detectors work because the chemical reaction with CO creates electrical current. The most part of CO detectors alarm when CO concentration rapidly increases. There are also detectors which detect the long-term changes of CO concentration but they are rather expensive. Laws of many countries prescribe us to have at least one CO detector in each home. /5./

Cameras operated by computer algorithms are used mostly in lofty voluminous areas or other places which traditionally are the most challenging for fire safety. They are irreplaceable in tunnels, big stadiums, industrial facilities and others. Cameras are able to recognize smoke and flames at great distances in seconds. They send live video to the fire station and turn alarm on. Computer algorithms help to determine smoke and flame patterns and to cut out secure events. /6./

2.3 Smoke detectors

Smoke detectors are considered to be the most effective type of fire detectors. It is so because they detect risky situations when materials are just smoldering before burning. It helps to protect lives and important documents from a potential fire in many cases. /7, p.22./

All smoke detectors consist of a sensor, alarm sounding device and a power tool like a battery. There are basically two smoke detection technologies: optical (photoelectric) and ionization. Both smoke detectors sense the occurrence of a fire. The photoelectric detector is actuating faster in slowly smoldering fire without a visible flame. And ionization chambers are better for fire with flames. It is so because optical smoke detector easier senses large, visible smoke particles. The ionization one senses small, invisible particles. /8./

The ionization smoke sensor is based on the radioactive source (typically Americium-241, an alpha-emitting radionuclide). Radioactive particles ionize air. Very low electrical current starts to flow between negative and positive electrodes. When the smoke particles enter the sensor’s chamber, it causes reducing current flow. Then electronic devise senses the reduced flow and turns the alarm on. Figure 2 shows how the ionization type of smoke alarms works. /8./

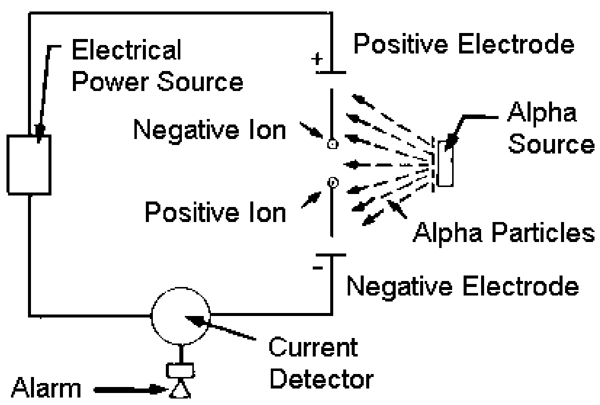

FIGURE 2. Working principle of the ionization smoke alarm /8/

Optical smoke sensors determine the presence of visual smoke by scattering the rays of light. They are working almost the same as presence detectors in automatic lightning. When there is no smoke, light can not get to the chamber. But in the instance of a fire light rays become to be scattered off the smoke particles like it is shown in Figure 3. The light shines across the chamber to the photo-cell. Photoelectric cell senses the scattered light and triggers the alarm horn. /8./

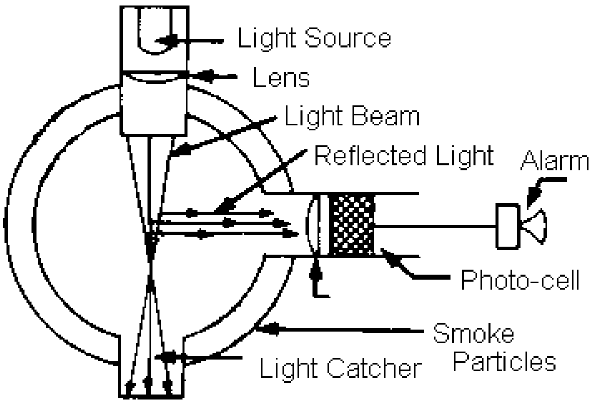

FIGURE 3. Working principle of the optical smoke sensor /8/

Combined detectors have a wider range of application in comparison with the optical or ionization type of smoke detectors. Combined means two sensors in one device. Pioneer combined smoke detectors had maximal operating temperature of 50-70°C. And the signal “Fire” was provided when one of the parameters increased to the critical value. It is the same situation if you will locate two smoke sensors close to each other. New versions of combined smoke alarms can realize more complicated mode. Fire alarm could be turned on in achieving the weighted average of several factors. It will ring before the one of parameters will increase to the critical point. For example combined smoke detector can monitor the density of the smoke and rising the temperature in the room at the same time. Given operation logic helps to reduce alarm’s response time in fires which are accompanied by several factors. So, combined smoke alarms have the advantages of the optical and ionization sensors into one unit which detects smoldering and flaming equally well. /7, p.8./

Fire engineers and occupants have to know about the following weaknesses of smoke alarms to provide saving lives and property from a fire. All battery operated smoke detectors need to be checked at least once per month by pressing a test button. Detector with dead battery will not save your life. It is also very important not to install smoke detectors close to the steam rooms and bathrooms. Smoke detectors installed in such way will trigger false alarms. Smoke detector could be also put out of action if it is dirty. Smoke detectors are very sensitive. Insects or cobwebs can set off the fire alarm. To prevent these problems every smoke detector need to be checked and cleaned with the help of the vacuum cleaner. /9./

2.4 Experience in researching smoke detectors

There are a lot of articles and journals about smoke detectors all over the world. Researchers have written about their experiences in studying smoke detectors and holding experiments all-time. Different research institutes are studying and testing new models of smoke detectors. The most interesting experiences in the field of smoke detecting are mentioned in this bachelor's thesis. Three research articles are described in the following chapter. The first one /10/ is about full-scale fire modeling in an office to investigate the influence of ignition source conditions on smoke detector actuation. The second article /11/ is about activation algorithms of smoke detectors in large eddy fire simulation modeling. And the last one /12/ is about locating the very early smoke detectors in vertical laminar clean rooms according to the trajectories of smoke particles.

2.4.1 Influence of fire ignition locations on the actuation of smoke detectors in a furnished office

Chi-Ming Lai et al. conducted full-scale experiments in this study about the influence of fire ignition locations on the actuation of smoke detectors and wet-type sprinklers in a furnished office. The area of the office was approximately 27 square meters and height was 3.3 meters. Office room was equipped with movable and fixed fire loads to investigate the influence of ignition source mode on the smoke detector and sprinkler actuation. The fixed fire load was made of wall furnishings (plywood walls and cabinets). The movable fire load was presented as wooden cribs. Wooden cribs were made up of 200 stacked strips like it is shown in Figure 4 and they were used to research seven fire scenarios. /10./

FIGURE 4. A wood crib /10, p.1452/

A facility for full-scale fire tests and a combustion gas continuous analysis system were used for the research work. The combustion gas continuous analysis system consists of the flue gas analyzer (O_2, CO, CO_2, NO_x, and HC analyzing), an optical density analyzer, and a flow rate/temperature monitor. /10./

The complete scheme of the office is shown in Figure 5. There are a total of 21 sets of thermocouple trees, 4 sprinklers (S1–S4), 1 gas analyzer (G) and 4 smoke detectors (square symbols D1–D4) in the investigated office. Seven fire scripts with different fire source characteristics were investigated. In the first and second scripts the fire source was located in the room center. The difference was in the size of the ignition source (200 stacked wood strips against 100 strips). In the third, the northeastern and southwestern wood cribs were ignited. In the fourth, the central wooden crib was ignited and the southeastern crib was not. In the fifth, the northwestern wood crib was ignited while the center was not. In the sixth and seventh, single and double sofas were ignited. /10./

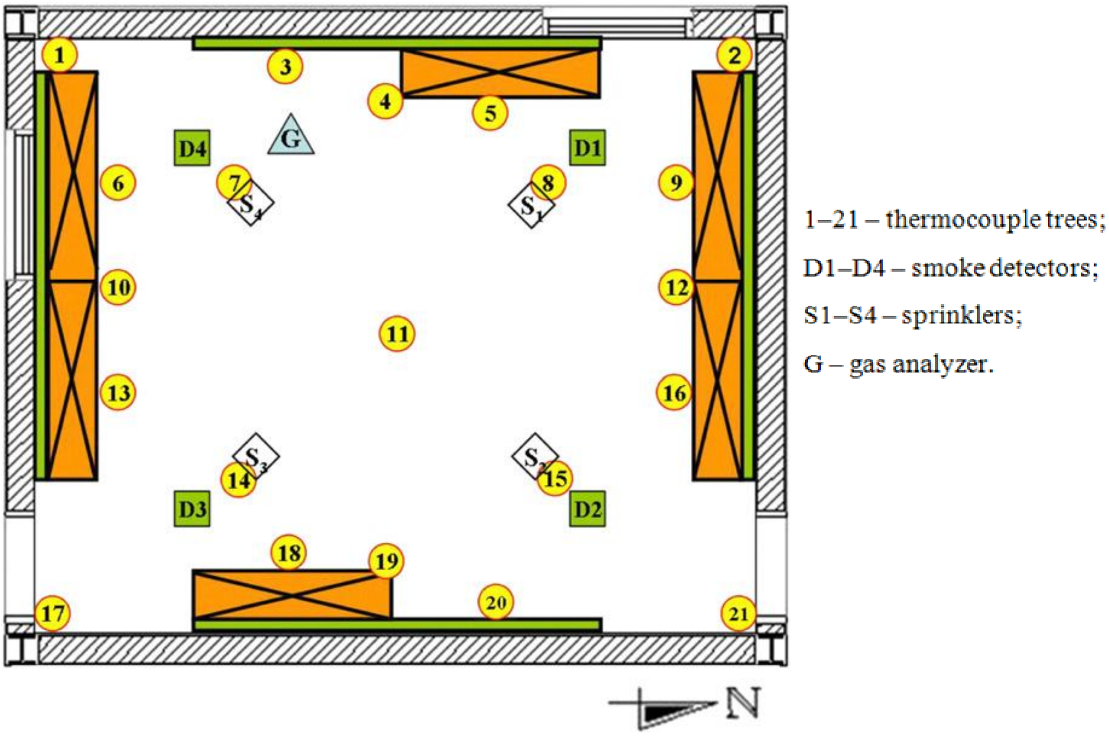

FIGURE 5. Overall layout of the investigated office and the measurement apparatus /10, p.1450/

The results of Chi-Ming Lai et al. investigation are following:

1. The air change rate significantly impacts the actuation times of smoke detectors and sprinklers. The actuation time of both smoke detectors and sprinklers become shorter when the air change rate increases.

2. The fire load does not significantly affect the smoke generation at the initial stage in a room fire and therefore does not change the response time of the smoke detector.

3. Different combustibles are characterizeв by different smoke emission rates, which affect the actuation times of smoke detectors.

4. When the ignition is somewhere near a corner, the plume corner effect greatly increases and smoke detectors at that position can activate faster. A fire source at the center of the room and distant from wall furnishings may reduce the possibility of the fire spreading. /10./

2.4.2 A smoke detector activation algorithm for large eddy simulation fire modeling

A study of Wei Zhang et al. simulates the smoke detector activation, which is a very important research topic today. Historically, fire safety engineers have been testing smoke sensors by a global independent safety certification organization “Underwriters Laboratories” and have been giving detector’s rating according to the smoke box test. The smoke box test is a smoke test, which is realized with a constant high velocity in a wind tunnel. But in reality air velocities are much lower than in smoke box tests. It means that the concentration of smoke should be higher in the situation of a real fire than in smoke box test. Therefore, smoke box testing results can not be used to determine the response speed of smoke detector at least in their original form because at lower air change rates the alarm will not sound at the same smoke concentration. Two methods were developed to solve this problem. The first method is to correlate results with temperature changing outside the smoke detector. The second method is to calculate difference between actual and rated smoke concentrations outside the smoke sensor by modeling the smoke transport into the smoke chamber. /11./

Temperature correlation method was developed earlier. It is based on relating the smoke concentration with the temperature in the sensors of 1970s, because at that time sensors were more sensible for the temperature than for smoke. Later, the alternative activation algorithms of smoke detectors were developed and those new algorithms rely mostly on the smoke density. The new problem was such that in real situation with low air velocities smoke gets to the chamber much slower than to the detector’s surface due to entry resistance. Time for getting air inside the smoke detector is the function of the free steam velocity in the room. We need to take it into account when we are doing smoke box test. The difficulty is that we have to take into account both smoke concentration and air (smoke) velocity near detector. This method is called Heskestad model. It is good in case of rather high air velocities. Less smoke velocity causes higher mistakes and the activation delay will be much longer than in theory. The most noticeable mistakes are in the case of smoldering fires because of the lack of a heat transfer for increasing velocities while smoldering. /11./

The number of smoke particles, their size and distribution has a big influence on the smoke detector activation. And it is very expensive to determine the transport time of smoke into the sensor's chamber because the scale of the smoke detector is too small in comparison with room volume. So we need to have a simple model of transporting the smoke inside the chamber. We also have to take into account smoke detector's work principle (photoelectric or ionization). The smoke concentration which refers to the alarm sounding is known as an activation threshold value of detector. Current models can foretell only the concentration of smoke particles outside the detector. /11./

The lag-time model was improved by Newman and Cleary. They took into estimation time for smoke mixing inside the smoke detector chamber besides the time which is needed for smoke to penetrate the house. And the smoke flow rate is a function of the pressure drop across the access way. They calculated mixing time as the mass of smoke inside the chamber divided by the mass flow rate of smoke in the flaming area. The mass of smoke inside the smoke detector can be determined if we know the size of detector, air velocity at the location of it and the mass fraction of smoke. /11./

Wei Zhang et al. in his study compared two models (Heskestad and Claery) of smoke entry calculation with the help of simple wind tunnel. Figure 6 shows the configuration of modeled tunnel. /11./

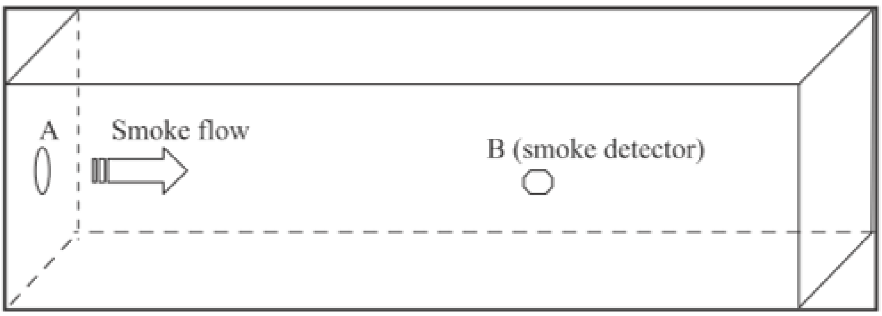

FIGURE 6. The configuration of wind tunnel /11/

During the experiment the velocity and the concentration of smoke near the detector's location were constant for a given run. The velocity was changed from 0.01 to 1.0 m/s. At high velocities the response speed of the sensor was the same in both models. But in the case of low air velocities (less than 0.2 m/s) the difference between the Cleary and Heskestad models became noticeable. If air velocity in the room is less 0.1 m/s the distinctions in response speed are tens to hundreds of seconds as it is shown in Figure 7 below. /11./

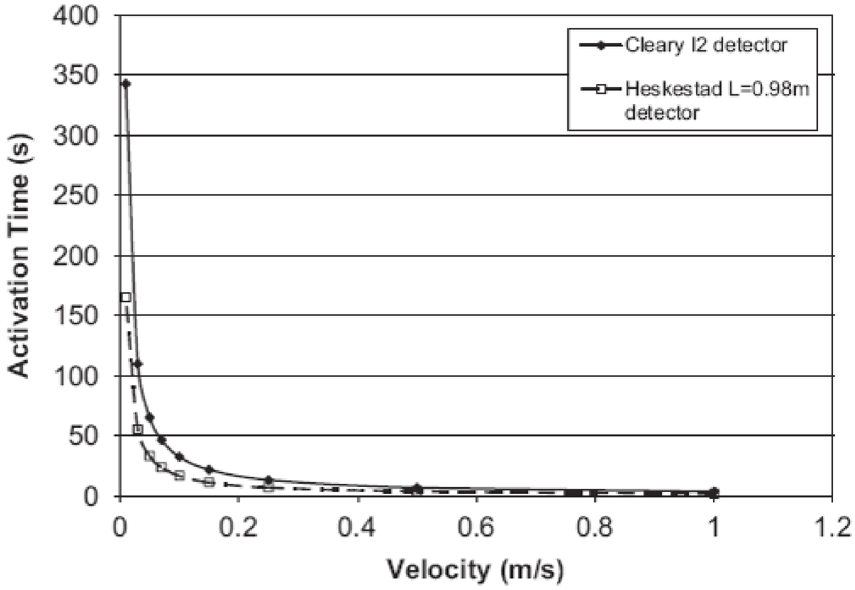

FIGURE 7. Predictions of smoke detector activation time as a function air velocity using the lag-time models of Heskestad and Cleary /11/

In this study the comparison of two characteristic lag time models was introduced. Generally, the time of filling the smoke detector by smoke depends on the air velocity at the detector location. Differences between these two models of activation time logarithms were detected at the velocities less than 0.2 m/s. This comparison gives a good possibility for determining the activation time of the smoke detectors in low velocities with minimum mistakes. /11./

2.4.3 Locating the very early smoke detector apparatus in vertical laminar clean rooms according to the trajectories of smoke particles

The third study described in this bachelor's thesis is Shih-Cheng Hu et al. investigation about the location of a very early smoke detector apparatus (VESDA) system in clean rooms. Research was needed to find the best location for the fire detection system and was based on studying the trajectories of smoke particles in the clean rooms. VESDA system compares the air structure every 4 seconds with ambient air samples taken up to 30 hours before the current sampling. A signal is sent out to warn the personnel in the occurrence of any significant difference. /12./

The work of Shih-Cheng Hu is divided into two sections: the first is the development of a numerical model and comparing the results with experiments and the second part is applying the model to the existing clean room to investigate the movement of smoke particles in the clean room environment. For sub-task the reduced-scale clean room experiments of Heskestad were simulated to validate the numerical model. /12./

The investigated clean room system was considered as an enclosure. The influence of the exhaust and the make-up air on airflow pattern was disregarded. The fan was a driving force on the airflow in the clean room, which is shown in Figure 8. /12./

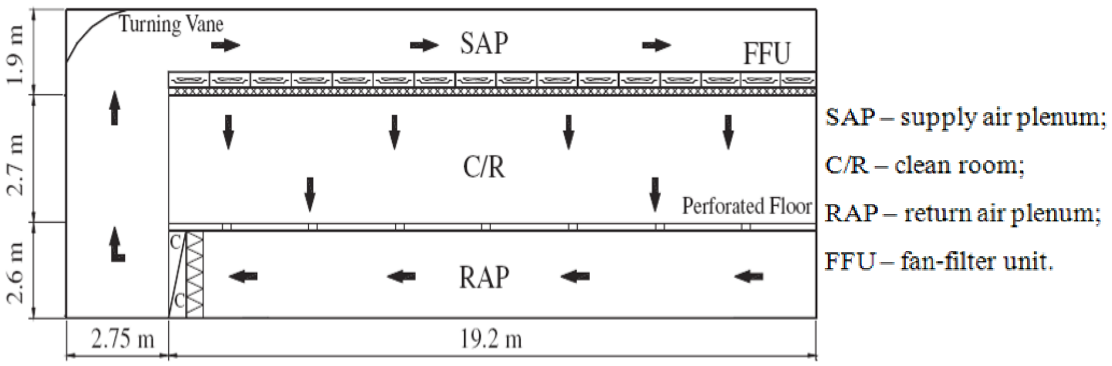

FIGURE 8. The fan-filter unit (FFU)–type unidirectional clean room /12/

A fire in the simulations was made as a supply of high temperature airflow coming out through the surface area occupied by the fire. The trajectories of smoke particles in the case of the different sizes of fire and different locations have been simulated. One of the pictorial diagrams of this simulations is shown in Figure 9. /12./

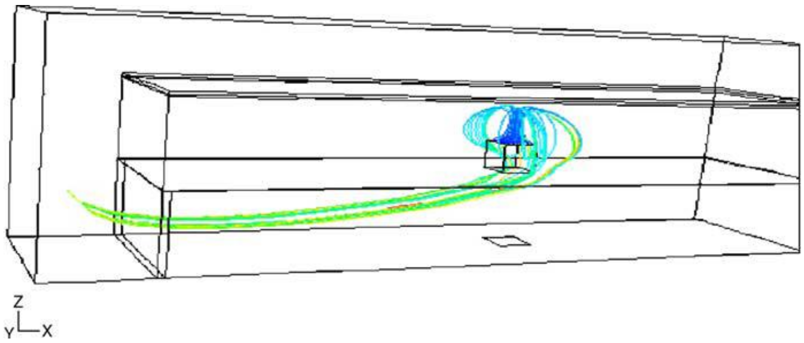

FIGURE 9. The trajectories of 5 mm smoke particles in the clean room /12/

Results of this research work are following:

1. The high-temperature particles in the clean rooms tend to move downwards due to the downward airflow.

2. The smoke particle motions under different ambient temperatures are similar and the particle size has a little effect on the motion path of the smoke particles. The speed of the particles differs slightly with different scenarios.

3. In the case of different fire source locations, the distributions of the particles is different.

4. When the smoke particle reaches the RAP, it is forced away from the raised floor by a substantial distance due to flow pressure. The high-temperature smoke particles initially tend to follow the airflow in a clean room to the RAP. In light of this, a VESDA system must be fitted near the RAP. /12./

2.5 Development of the research topic

Smoke detectors are considered to be obligatory part of building's equipment all over the world. They are used everywhere to warn people timely about danger of a fire since the fire is in smoldering phase. Smoke detectors are often used in combination with other types of fire detection systems. Technologies in smoke detectors field are improving and a lot of investigations are carried out. Research studies cover not only functionality of smoke detection devices; also influence of their proper location is studied.

Profound studies of international researchers indicate that the topic of researching smoke detectors is very popular nowadays. People aim to improve the quality of fire detecting systems and their elements. Great deal of knowledge is available to the fire protection engineers. But there are still a lot of specific topics of regarding smoke detectors which are not yet studied.

3 COMPARISON OF INTERNATIONAL RECOMMENDATIONS

The proper location of smoke sensor is the most difficult part in using automatically actuated fire detection devices. There are a lot of opinions where we should install smoke sensors. Manufacturers give us many alternatives for good location. Normative documents of different countries give us almost similar instructions for locating smoke detectors. However, each country has its own fire protection normative and its own recommendations about using smoke detectors. In the following chapter the difference between prescriptions of installing smoke detectors in normative documents of three different countries: USA, United Kingdom, and Russia will be investigated.

3.1 USA standard NFPA 72

NFPA 72 is a national fire alarm code of the USA and it covers all kinds of spaces, including offices. According to the NFPA standard, the location of smoke detectors should be designed in accordance to the functions and thermal environment of the protected area. Engineer have to evaluate potential smoke and dust sources, electrical and mechanical influences before installing the smoke detector to minimize the number of false alarms. Generally, location should be based on the assumed smoke flows produced by the anticipated fires and on others pre-existing ambient flows which could appear in the protected area. Design solution should take into account such parameters of the protected space as the configuration of the room, ceiling characteristics, combustion characteristics of materials and ambient environment. Smoke detector should be installed closer to the expect hazard in the most suitable place. /13, p.75-82./

The first specific prescription of NFPA 72 about any dimensions while locating is that spot-type smoke detectors have to be located on the ceiling more than 100 mm from the wall to the near edge of the detector. The second is to locate them on the sidewall from 100 to 300 mm from the ceiling to the top of the spot-type smoke detector. For the purpose of minimizing dust contaminants, smoke detectors should be located in an orientation given by manufacturer. The smoke detector should be installed so that the air flow patterns in a space do not prevent entering the smoke particles into the sensing chamber of detector. There are also a lot of prescriptions about spacing detectors in big spaces and about the installation of beam-type and sampling-type smoke detectors. Smoke detectors can not be located in the way of supply air. But they have to be located in areas with a high air circulation to provide minimum detecting time. /13, p.75-82./

3.2 United Kingdom standard BS 5839

The spacing and siting recommendations of the British Standard BS 5839 Part 1 for the smoke detectors are based on the requirements to restrict the time taken to get smoke inside the detector's chamber and to ensure that the combustion products reach the sensor in adequate concentration. /14, p. 49-62./

Any possible patterns of air movements should be taken into account while locating smoke detectors. High air change rates in air conditioning and ventilation systems may affect the response speed of smoke detectors by directing fresh air over them, or by drawing smoke particles away. It is observed that smoke detectors should not be mounted directly in the fresh air input from air conditioning systems. A distance must be longer than 1 m between the sensor and the supply air valve. /14, p. 49-62./

The distance between any point of the room and the smoke detector should be less or equal to 7.5 meters. Basically, according to BS 5839, smoke alarms should be installed on the ceiling more than 500 mm from any wall or beam like it is shown in Figure 10. But it is allowed to locate detectors on the wall between 150 mm and 300 mm from the ceiling if the bottom of the detector is above the level of the door opening. The distance between the surface and the sensitive element of the detector is not less than 25 mm or more than 600 mm in the case of installing on the ceiling or roof. /14, p. 49-62./

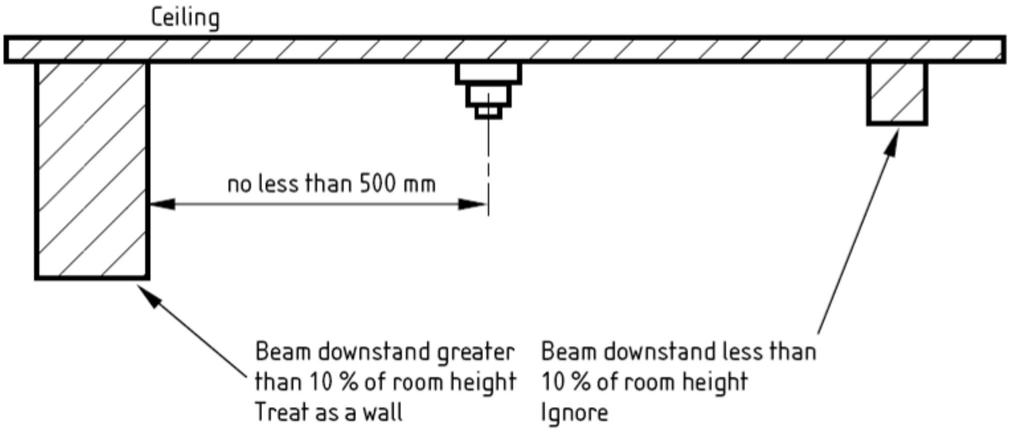

FIGURE 10. Ceiling obstructions treated as walls /14, p.55/

Smoke detectors could be installed within ventilation extract ducts. Such smoke detectors are needed to help in the prevention of the smoke spreading by the ventilation system by stopping any recirculation in the presence of a fire. Duct-mounted smoke detectors can not be used as a main fire detection system because the extraction of the smoke together with the clean air could reduce the efficiency and because duct-mounted detectors are not working properly while air-handling unit is switched off. To avoid the problems mentioned above and the fast accumulation of dust in the duct-mounted detectors it may be necessary to install a smoke detector near each of the extract points. /14./

3.3 Russian standard NPB 88-2001

According to the Russian designing and regulations norms called “Fire-extinguishing and alarm systems”, fire detection devices have to be installed in every protected premise. Generally, spot type smoke detectors should be installed under the ceiling. Detectors could be mounted on the walls, columns and other bearing structures or even fixed on cables when it is impossible to mount them under the ceiling. /15, p. 33-37./

Siting the smoke detectors should be performed according to the air flow patterns in the protected premises caused by supply and exhaust ventilation. The distance between air supply or exhaust valve and the nearest point of the detector should be less than 1 meter. The maximum distance to the wall is 4.5 meters when the height of the ceiling is 3.5 meters and 4.0 meters when ceiling is higher. Smoke detectors should be installed in two layers if room is higher than 12 meters. /15, p. 33-37./

Any obstructions should be taken in to account while mounting the smoke detectors. The distance between smoke detector and nearest wall or obstruction should be at least 100 mm. In the case of fixing on cables, detectors have to have steady position and orientation in space and they also should be installed less than 300 mm from the ceiling. The distance between the corner and the nearest point of the smoke detector should be more than 100 mm in the case of mounting on the wall. /15, p. 33-37./

3.4 Comparison of the normative documents

The normative documents about locating smoke detectors are quite the same in these three countries. But they focus on different things. The comparative table of the prescriptions of the normative documents of USA, United Kingdom and Russia (old and new norms) is given in the Appendix 1. This table shows if the country uses in its normative documents the main items of installing smoke detectors. Majority of countries all over the world has the same rules as presented countries. The table in Appendix 1 shows similarities and differences of the recommendations given by normative documents. It helps to determine location for the smoke detector which will give the shortest delay between starting the smoke spreading and turning on the alarm.

The standard of Great Britain gives the strictest recommendations about installing smoke detectors according to the Appendix 1. This normative document gives the engineer distinct areas of the room to mount the smoke detector. The Russian current standard is quite close to the British one, but the safety distances are smaller in it. These two documents both provide no information about analyzing the supposed ignition and about locating detectors in the middle of the room. Generally the standard of Great Britain BS 5839-1 and the standard of Russia NPB 88-2001 are the most complicated between compared documents.

The comparison of the current Russian standard NPB 88-2001 /15/ and expired SNIP 2.04.09-84 /16/ shows that the quality of standards in the fire detection field is improving. The expired standard consisted less information about the location of the smoke detectors, because the need of installing them was not so obvious earlier.

The standard of the USA is the most general between three valid standards. It does not provide any information about location the smoke detectors near or inside the ventilation terminal units, it does not have information about suspending detectors on cables under the ceiling or about distances between detector and specific parts of the building like a wall corners. But USA standard is only one between compared that gives instructions to take the assumed fire ignition into account before locating smoke detectors.

3.5 Practical considerations

According to the comparison of USA, Russia and Great Britain standards it is possible to find out the optimal locations of the smoke detector in any space. Recommendations are similar; however, each document gives its own handling. All viewed documents are considered to be comprehensive standards, which include recommendations about installation smoke detectors and other fire alarms in all kinds of buildings, including very complicated design cases.

The amount of recommendations given in standards is very large, but they are mostly not as profound as it would be necessary to locate the smoke detector straightly after studying the standard. For example, compared normative documents have no clear recommendations about location smoke detectors according to the air flow patterns. There is also no information about designing smoke detection system in cases of using chilled beams, displacement ventilation terminal units, cooling devices and other modern ventilation devices. There is also no exact information about designing smoke detection systems in cases when designer knows location of the supposed ignition.

The recommendations can never give answers to all questions that may rise in real buildings, because it is necessary to take into account big variety of factors. And these factors differ from each other every time. There is no library of the simple typical cases. That is why experiments are needed to study optimal location of the smoke detector in each real case.

The comparison of the normative documents provides several locations of the smoke detector which are needed to be investigated in this bachelor's thesis:

1. Over the supposed ignition.
2. Inside the exhaust duct.
3. Near to the exhaust terminal unit.
4. In the middle of the ceiling.
5. Other locations which were mentioned in norms.

4 STUDY CASE

The best location of the smoke detector was studied in an existing office room which belongs to the HVAC laboratory at the Mikkeli University of Applied Sciences. It is situated on the ground floor of the A-building of Mikkeli University of Applied Sciences. The area of this office is 10.9 square meters. It is intended for a laboratory assistant. There is a desk with personal computer and two chairs near it inside the room (Figure 11). The problem is that laboratory assistant is not always at his working place and in the case of fire he may take no notice of it. It was very important to locate smoke detectors in this room in such case which will give the shortest delay of their response. In the danger of ignition the smoke detector will turn the fire alarm on by connecting it to the main fire alarm system of the campus.

FIGURE 11. The office room used for laboratory experiments

4.1 Investigation methods

4.1.1 Background and procedure

Investigating process in this bachelor’s thesis consists of several parts, which are shown in Figure 12 below.

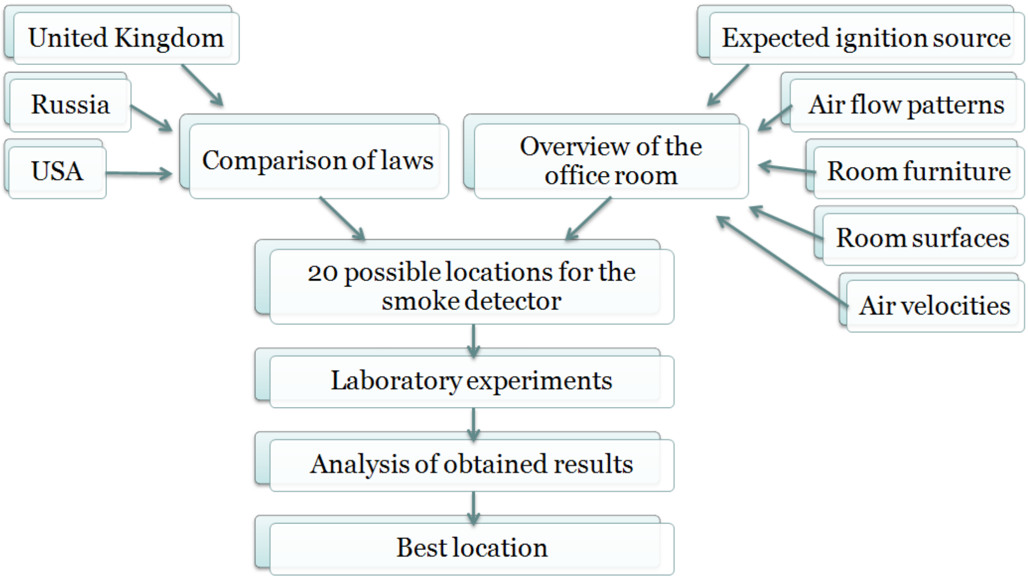

FIGURE 12. Determining the best location of the smoke detector

As it is shown in Figure 12, initially investigation is divided into two independent subtasks. The first one is the comparison and analysis of international normative documents. The second subtask is the overview of the office room. Next two subtasks needed to be put together and to be analyzed. 20 different locations of the smoke detector are the result of this analyze. Then these locations were checked by introducing smoke to the office room and by recording response time for each location.

Laboratory experiments were divided into two steps. The first one is preparative period and the second step is measurements of the response time of smoke detectors in different locations. Preparative step included following tasks:

1. To overview the room space and to compare existing air flow rates with given by normative documents.
2. To determine and to draw the picture of the air flow patterns in the office room.
3. To analyze the trajectory and the velocity of smoke flow.
4. To locate smoke detectors in the assumed best position.

4.1.2 Testing equipment

Determining the best location of the smoke detector was based on measuring the response time of smoke detectors and on analyzing obtained results. Several devices were needed for the investigation:

1. Swema Flow 3000 with SwemaFlow 125 hood for measuring both supply and exhaust air flow rates in range from 2 to 125 dm^3/s. It is based on the Swema principle of the net of hot wires, which give small inaccuracies of measured values. Measuring the supply air flow rate by this device is illustrated in Figure 13.

FIGURE 13. Measuring the volume flow in the supply air valve by Swema Flow 125

2. TSI VELOCICALC 8388-M-FI micro manometer is used for the measuring of pressure drops in the supply and exhaust valves for calculating the volume flow of air through them. Figure 14 shows how pressure drop in exhaust air terminal unit was measured.

FIGURE 14. Measuring the pressure drop in the exhaust terminal unit by TSI VELOCICALC 8388-M-FI

3. Dräger Air Current Test Kit (is shown in Figure 15) is used for determining the airflow patterns in the office room to make analyze of the smoke spreading patterns after ignition. And this device is a quick and inexpensive help in making pictures of air flow patterns.

FIGURE 15. Dräger Air Current Test Kit

4. Martin Magnum 1200 smoke machine is used for producing smoke for the experiments (it is shown in Figure 16). Maximum fog output for this machine is 290 m^3 per minute. It was used with capacity approximately 70 m^3/min = 19.5 liters per second. The smoke was spread for 14 seconds. In each experiment the amount of smoke inside the office room was approximately 275 liters.

FIGURE 16. The smoke machine Magnum 1200

5. A stopwatch timer is used for monitoring the response speed of smoke detectors.

6. An optical smoke detector Ei186 is used in this investigation. It senses visible smoke particles of smoldering fires by using the light scatter principle. Four equal alarms are connected to the control panel. The control panel has four signal lamps for determining which detector is giving a signal of alarm. There is also a possibility to connect the control panel to the computer and to connect up to 12 Ei186 alarms into one network. Horns were extracted before experiments not to disturb neighborhood. Figure 17 shows smoke alarm connected to the control panel and stopwatch lying on it.

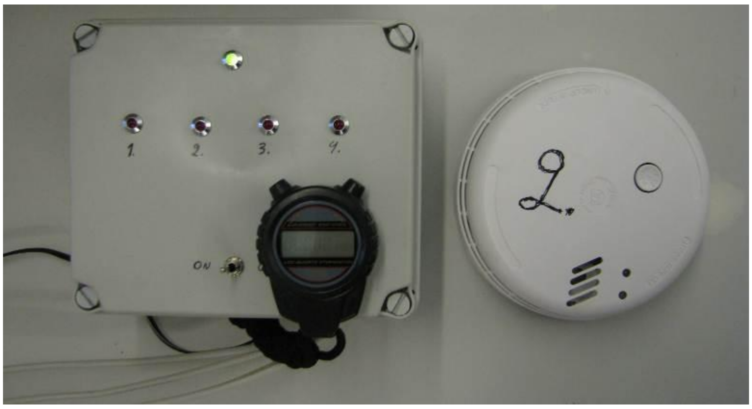

FIGURE 17. Smoke detector with the control panel and stopwatch

7. A halogen lamp is used to achieve heat output from the simulated ignition.

8. Swema 3000 with SWA 03 draught sensor. Omnidirectional air velocity sensor which is shown in Figure 18 was used to measure low velocities in different points near the inner surfaces of the investigated room. It measures velocity from 0.05 to 3 m/s and has response time less than 0.2 seconds.

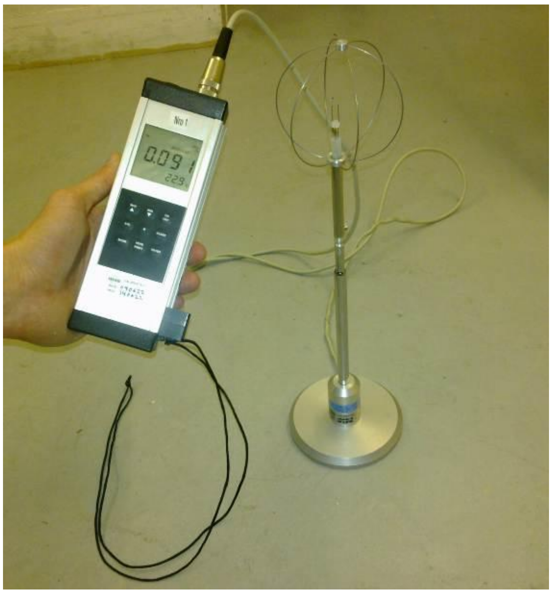

FIGURE 18. Swema 3000 with SWA 03 probe

4.1.3 Overview of the office room

Measured office room was designed for the one worker and has a seat for the visitor. The width of the office is 3.9 meters, the depth is 2.8 meters, and the height is 3.3 meters (Figure 19). There are two windows and the table with computer close to the one of them. There is a bookcase in front of the computer. All surfaces of the room are covered with a plastic envelope to be sure that nothing prevents reaching the exact results of the measurements. The ceiling is also covered with plastic film because in original form it had a lot of relieve wood sectors which will prevent easy spreading the smoke to the smoke detector.

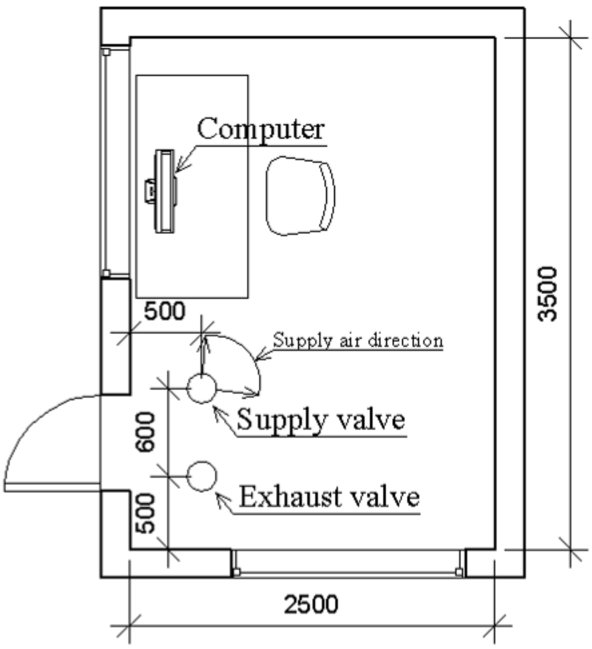

FIGURE 19. Plan of the office room

Ventilation of the office is provided by central air handling unit. It provides clean fresh air with temperature 23 °C. Air flow rates for the office were almost constant during the experiment. They were checked before each experiment by TSI micro manometer.

Existing air supply valve in office room is Fläkt Woods KTS 160. It is located on the ceiling near the entrance like it is shown in Figure 19. The opening of the valve is 10 mm and it is sealed up by scotch tape on two thirds. Supply air flow of remained part of valve is turned to the opposite corner of the room. K-factor of the valve was determined by the interpolation of given k-factors in the Product catalogue of Fläkt Woods /17, p.33/. Existing exhaust air valve is Fläkt Woods SET 160. It is located on the distance 600 mm to the supply terminal unit like it is shown in Figure 19. K-factor for this type of exhaust valves is 6.7 when they are fully open /17, p.40/.

Then the volume flow of the terminal unit was determined in liters per second by using Equation 1. K-factors and the differences of pressure inside the duct and outside were inserted into this equation to get air volume flow. The measurements of pressure drop (Δp_m) in supply and exhaust valves were done with TSI VELOCICALC 8388-M-FI micro manometer.

Equation 1: $$q_v = k \times \sqrt{\Delta p_m}$$ /17, p.8/

Calculated air volume flows were compared with values measured by the air flow measuring device Swema Flow 3000 with SwemaFlow 125 hood. The results of measurements are shown in Table 1 and they are also compared there between each other and with the requirements of the National building code of Finland D2 /18/.

TABLE 1. Measured air flow rates in the office room

Measured quantity	Measuring device	Supply air unit (KTS 160)	Exhaust air unit (SET 160)
Pressure drop, Pa	TSI 8388-M-FI	39	9
K-value	TSI 8388-M-FI	3,0	6,7
Volume flow, dm^3/s	TSI 8388-M-FI	18,7	20,1
	Swema Flow 125	19,0	19,5
Minimum volume flow according to D2, dm^3/s		16,4	16,4

The results show that the volume flow measured with help of the Fläkt Woods Product catalogue are quite the same with values measured by Swema device based on the net of hot wires. Required outdoor air flow is 1.5 dm^3/s per square meter for offices and similar rooms according to the D2 /18, p. 33, Table 2/. Obtained volume flow through the terminal units is a little higher than required.

4.1.4 The analysis of the air flow patterns

Analyzing air flow patterns in the room is a very important part of the investigation. Flow patterns were studied with the help of a smoke machine and Dräger Air Current Test Kit. The picture of air flow patterns was a result of this part of the investigation. Firstly, the office room was dimensioned and the 3D model of the office room with showing the exhaust and supply air ducts was made in a computer program Autodesk Revit 2012. The 3D picture of the room is shown in Figure 20.

FIGURE 20. 3D model of the office room used for laboratory experiments

The discovering of air flow patterns was made by spreading puffs of smoke with help of Dräger Air Current Test Kit. At the same time the picture of patterns was drawn and photos were taken. Figures 21 and 22 illustrate air flow patterns in the investigated office room.

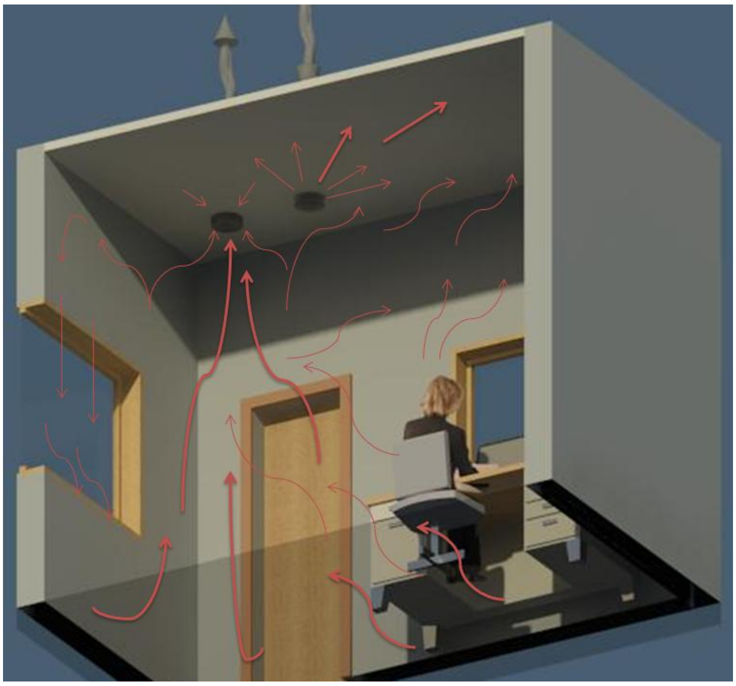

FIGURE 21. Air flow patterns in the office room

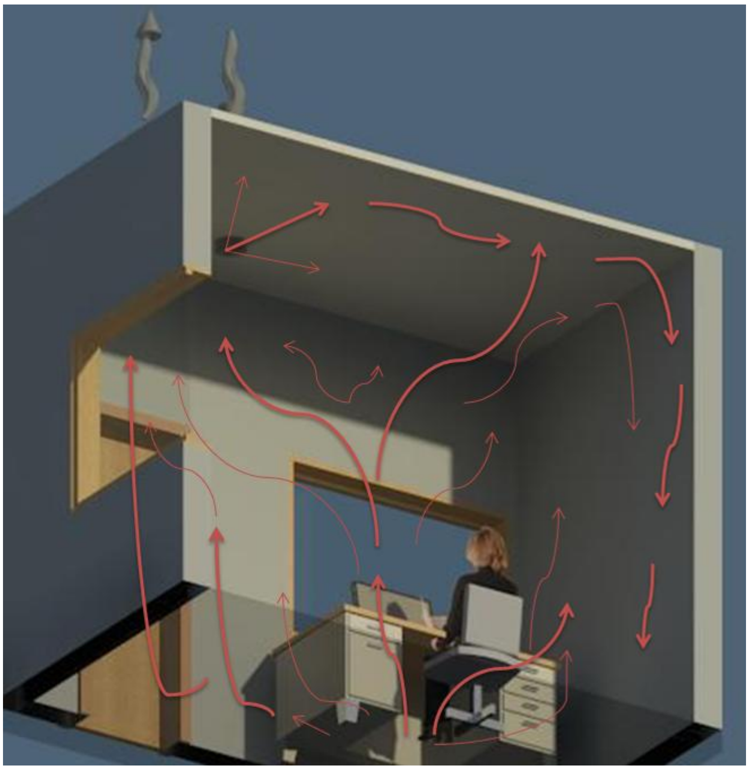

FIGURE 22. Air flow patterns in the office room

As it is shown in Figure 21 and Figure 22, supply air is well mixed with the indoor air. Bold lines show the main patterns of the air in the room.

Generally, supply air is blowing along the ceiling from one corner to another as it is shown in Figures 21 and 22 above. Then it goes downstairs and flows diagonally near the floor in direction of exhaust air valve. In the center of the room the part of a flow moves upwards because of the temperature rising. On the level approximately 1.5 meters the flow is divided into two: one part goes to the exhaust valve and another is mixing with the supply air patterns.

Warm air from the computer is moving upwards all around the table. One part of this air goes straightly to the exhaust ventilation duct and another part is mixing with the supply air. The movement of the smoke in case of starting a fire inside the computer is the same as the air movement. Therefore it can be possible to estimate good locations for the smoke detectors in the room according to these simple drawings of the air flow patterns.

According to the picture of air patterns the following locations of the smoke detectors could give good results of the response speed:

1. On the wall over the computer between the window and the ceiling.
2. On the ceiling above the computer.
3. Inside the exhaust duct.
4. In the top of the corner behind the worker.
5. On the wall between the door and the window on the height of about 2 meters.

4.1.5 Measurement setup and protocol

Laboratory measurements were carried out in constant thermal conditions with constant air change rate in the office room. Firstly, smoke detectors were compared with each other to exclude any inaccuracies between their responses due to the errors in manufacturing process. Then they were mounted in their own positions in the room for making the measurements of the response speed. They were placed according to the investigation of the air flow patterns in the room and to the comparison of active normative documents of Russia, USA and United Kingdom.

Determining the best location of smoke detector was based on recording the response time of smoke detectors and analyzing obtained results. There were four optical smoke detectors for each experiment. Each smoke detector was connected to the control panel with 6 meters wire. The lamps of control panel were lighted up every time when any smoke detector alarmed. Response time was taken from the stopwatch as a time interval between the beginning of spreading smoke and the lighting of the correspond lamp.

One minute before each experiment search-light located under the table near the computer had been turned on to simulate heat output from the fire. It was needed to make measurements more realistic, because heat output takes place in the case of each fire. The spreading of smoke was started by pushing the button on the smoke machine’s console. Figure 23 shows the measurement installation at once after switching on the fire ignition by the smoke machine.

FIGURE 23. Ignition of the fire by pressing the button on the console of the smoke machine

Each experiment gave a possibility to take response time only for four locations of smoke detectors. That is why office room needed to be well aired after each experiment to have much more experiments without any interference of permanent smoke. The number of different locations (20) was selected so, to confirm assumptions and that there should not be any place in the room with unknown smoke response time characteristics. Figure 24 and Figure 25 show smoke detector locations in the office room.

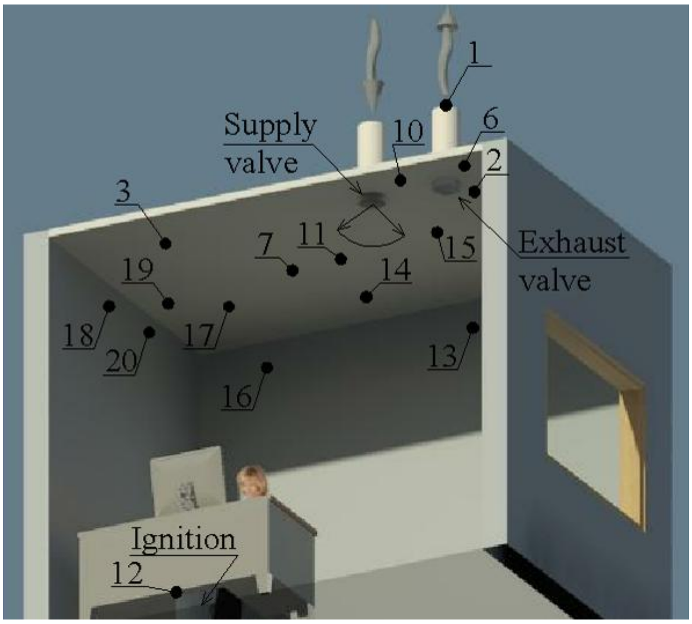

FIGURE 24. Locations of smoke detectors inside the investigated office room. (Detailed information of the locations 1-20 is given in Table 3)

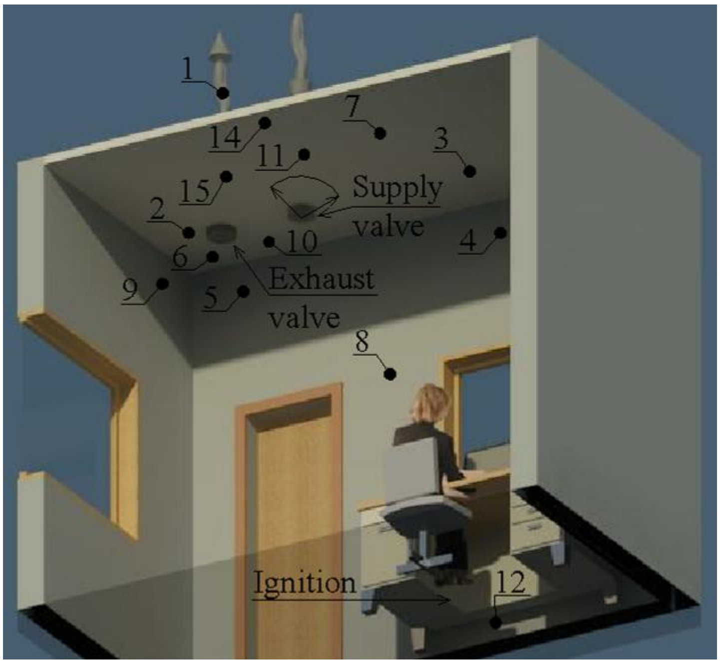

FIGURE 25. Locations of smoke detectors inside the investigated office room. (Detailed information of the locations 1-20 is given in Table 3)

The results of the response time measurements were recorded in Appendix 2. The measurement protocol consists of the brief description of the location, response time and the rating of the detector.

The first column of the Appendix 2 describes briefly the investigated location of the smoke detector in the room. Each location of smoke detector was tested three times. The results of the experiments have to be recorded during the experiment each time when a lamp on the control panel is lighted up into the columns 2-4. When the laboratory experiments are ended, the column of the average time has to be calculated. The column "Rating" is based on the average time numbers and shows which location gives better response time.

4.1.6 Air velocities alongside of the smoke detectors

Air velocities in the room were taken into account in studying the best location of the smoke detector. It was expected that the higher velocities near the detector's location let the smoke particles come inside the smoke chamber faster than in the case of low velocities. Air velocities near each smoke detector were measured by Swema 3000 with SWA 03 draught sensor. Results of air velocity measurements are shown in the Table 2.

TABLE 2. Air velocities near the smoke detectors' locations

Location according to the Figures 25 and 26	Velocity, m/s
1. Inside the exhaust duct	0,99
2. Close to the exhaust duct	0,09
3. On the ceiling above the computer	0,08
4. On the wall over the computer	0,10
5. On the wall near exhaust duct and over the door	0,07
6. On the ceiling between the exhaust duct and the wall with door	0,11
7. In the middle of the ceiling away from the supply flow patterns	0,92
8. Between door and window on the height 2000 mm	0,09
9. On the sidewall close to the exhaust duct, 150 mm from the ceiling	0,04
10. Between exhaust duct and supply duct	0,07
11. In the middle of the ceiling on the way of fresh air	1,04
12. Under the table near to the ignition	0,09
13. On the back side wall, 150 mm from the ceiling	0,14
14. In the middle across the ceiling, 300 mm to the back side wall	0,24
15. In the middle along the ceiling, opposite to the supply and exhaust duct	0,27
16. On the back side wall 500 mm from the corner and 200 mm from the ceiling	0,53
17. On the ceiling 500 mm from the back side wall and 500 mm from the side wall	0,40
18. On the side wall, 150 mm from the ceiling and 1600 mm from the back side wall	0,09
19. On the ceiling, 200 mm from the side wall and 1 m. from the back	0,14

side wall	
20. On the side wall, 150 mm from the ceiling and 1 m. from the back side wall	0,12

As it is shown in the Table 2 above, velocity near mounted smoke detectors ranged from 0.04 to 1.04 m/s, the mean velocity was 0.28 m/s. The highest air velocity was in the air stream from the supply valve and the lowest on the side wall close to the exhaust duct. It is clear to assume that in points with enough but not very high air velocity, response speed of detector will be the highest. Laboratory experiments have to be carried out to confirm this assumption.

4.2 Results of the laboratory studies

The average response time of smoke detectors was 49.6 seconds. It ranged from 34 to 71 seconds except for two measurements. The detailed results of the laboratory studies are introduced in the Appendix 2 in table form.

One of the exceptions was the location under the table near the computer. Measurements showed that the response time of the sensor located almost near the fire ignition is 11 seconds. It is the time which is necessary for smoke particles to get into the sensing chamber in enough high concentration without time losses for transportation. The second point was marked with number 18. The sensor did not give alarm at all in this location. The reason might be in the low smoke concentration near this point because of the good smoke mixing with the indoor air and very low velocity (0.09 m/s) near that location.

The response time of other 18 locations can be explained by the air flow patterns and velocities. The maximum time difference was approximately 37 seconds, but it is easy to notice that main part of locations gave response time from 45 to 55 seconds.

Locations 2, 6, and 10 are situated near each other and close to the exhaust duct, but their response time was 62, 71, and 54 seconds, respectively. This time difference shows that air flow patterns are not the same near the exhaust duct location. And also response time is not as low as in case of location inside the exhaust duct. This fact can be explained by very low velocity near these three points. The velocity was 0.09, 0.11 and 0.07 m/s, respectively. In point with the highest velocity the response time was the lowest. It can be so because point 10 was closer to the ignition on the way of smoke patterns. In the 6th location velocity is the highest between 3 locations, but response time is the longest. It can be so because this smoke detector is located near the corner, where smoke particles can not access along of exhaust valve influence (see Figure 21 and 22).

Locations 3 and 4 gave response time 47 and 42 seconds. 4th location was on the wall over the computer and 3rd – on the ceiling over the computer. Air patterns near 4th location moved upwards with velocity 0.10 m/s and near the location 3 only 0.08 m/s in average during the experiment. Smoke particles moved upwards from the ignition location, that is why the location number 4 gave better results than 3rd one.

Location 17 gave better response time than locations 19, 20, and 16 which were near the 17th. It can be explained by the velocity near the smoke detectors. Velocity near location 16 was 0.53 m/s – it is very high because of the fresh air stream from the supply air valve. Air movement near the 19th and 20th locations was very slow, that is why it was needed more time for smoke to get to those points of the office room. And the response time of the 17th location was only 38 seconds. It is so, because air velocity near this location was high enough to transfer smoke particles fast and low enough because of good mixing with indoor air patterns.

Comparing results of the measurements (Appendix 2) and results of investigation of air flow velocities near mounted smoke detectors (Table 2) gives a notion of dependence between air velocities and response times. Smoke particles can not access the smoke detector's chamber fast if the velocity of smoke patterns is low, and vice versa if velocity is high enough, smoke particles merge with air patters and come inside the chamber fast enough.

But it is not just air and smoke velocity that affect the response speed. The character of smoke patterns and also the distance between ignition and detector affect the time between fire starting and alarm switching. In the Table 3 five locations with the shortest response time are shown.

TABLE 3. Five locations of smoke detectors with the minimum response time

Rating	№	Description	Time, sec
1	1	Inside the exhaust duct	**34**
2	17	On the ceiling 500 mm from the back side wall & 1000 mm from the side wall	**38**
3	11	In the middle of the ceiling on the way of fresh air	**39**
4	7	In the middle of the ceiling behind the computer	**41**
5	4	On the wall over the computer	**42**

The first in the rating is location inside the exhaust duct. It is so because the part of the smoke is going straightly to the exhaust valve like it is shown in Figure 21 and 22. But this location can not be the best because of the necessity of the frequent cleaning from dust.

The second one is location 17. It is shown in the Figure 24. Smoke particles are merged with the fresh air somewhere in the center of the room and then with velocity 0.4 m/s come with supply air patterns to this detector's location with enough high concentration. Figure 22, where smoke patterns are shown, explains so good result in point 17.

11th location is the 3rd in rating. Smoke, which goes to the extract air valve, is captured by the supply patterns and that is why in this point response time is only 39 seconds in spite of the fact that clean air from the supply air valve is blowing with mean velocity almost 1.04 meters per second through this smoke detector.

Location 7 in the middle of the ceiling behind the computer gave response time 41 seconds. It is a little bit better than in location 4 (42 seconds). Air velocities in these locations are similar. Difference is that in 4th location smoke patterns enter the detector's chamber in upwards direction while in 7th location smoke is coming after mixing with supply patterns in horizontal rotation. Character of smoke patterns in these two points can be seen in Figure 22.

5 DISCUSSION

Current normative documents of fire protection in Russia, Great Britain and USA emphasize that it is important to study ventilation and ambient environment in areas in which smoke detectors are installed.

Current Russian standard provides detailed recommendations for designing the optimal location of the smoke detector in comparison with British and USA standards. However, the fire standard of Great Britain gives the strictest recommendations in case of installing smoke detectors. This normative document advises the engineer to choose distinct areas of the room to mount the smoke detector. But as it was shown in laboratory experiments in this thesis, location inside the exhaust duct could not be used without any other secure fire detection device inside the room.

Location of spot-type smoke detector inside the exhaust duct is not a good variant, not only because of necessity of frequent cleaning. There is also a possibility of switching off ventilation system in case of the fire from the short-circuit failure in electric system of the protected area. In this case smoke can not even reach smoke detector location inside the exhaust duct with enough high concentration in time.

Location of smoke detectors near the extract air valves is not a good decision either, because extract air patterns have usually mainly upwards flow direction and velocities in points near the extract terminal unit are usually low. Also detector’s location close to the supply terminal unit on the way of the fresh air is not considered to be good because concentration of smoke, involved in supply air patterns would be very low.

In high spaces normative documents recommend to locate smoke detectors under the ceiling on cables or to connect them to the wall for providing enough high concentration of smoke near the detector in danger of a fire.

It is important to notice that none of studied standards contains information about locating smoke detector in the middle of the ceiling. It is so because in real life shape of the ceiling and locations of air devices are more complicated than in the investigated office. Recommendations of standards also do not have any straight information about location. It is because of unlikeness of design situations. That is why in each specific case investigation is necessary to perform before mounting smoke detectors.

Results of the laboratory measurements in this bachelor's thesis show that the best location of the smoke detector inside the investigated office room is on the ceiling on the way of supply air flow patterns on the opposite to the supply valve location on the ceiling (location 17) in case of computer ignition. That is because supply air patterns have big influence on the smoke mixing in the room. Points of the ceiling far from the supply air device with velocities from 0.3 to 1.0 m/s are considered to give better results than others. It is because of involving smoke particles by the main supply air flow and because of well mixing of smoke with ambient environment.

Experiments showed that in cases when dangerous substances or dangerous items are kept inside the room, it is good to locate smoke detectors over those points as close to the assumed ignition as possible. In real case, when nobody can assume in which point of the room the fire will be ignited, location of smoke detectors should be designed according to the air flow patterns somewhere in the middle of the ceiling. Smoke from any point of the room will flow through the middle of the ceiling with higher probability than through any other point of protected space.

The topic of this thesis is a new study in addition to which were done before. Determining the best location of the smoke detector is a very important research problem. Optimal location of the smoke detector (location 17) was determined for the small office room. Results of this bachelor's thesis can become a basis for the following investigation. Gradually there would be a possibility to collect a database including different typical cases of smoke detector location in all kinds of buildings.

Measurements of response time in this work indicated that delay time between starting of smoke spreading and switching on the smoke alarm is 11 seconds. It is rather long time and the concentration of smoke particles also reduces fast while mixing with clean air inside the room. That is why the future investigation of the smoke detectors' operation and activation principles must be also carried out.

The laboratory studies have several limitations. For example it was assumed that the trajectory of the smoke particles is the same as trajectory of the air patterns. In real fire it is not so. The future investigation based on simulation with real fire is also good to carry out.

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APPENDIX 1. Comparison of international normative documents in case of installation smoke detectors

Country	USA	United Kingdom	Russia (new)	Russia (old)
Standard	NTFA 72 /13/	BS 5839-1 /14/	NPB 88-2001 /15/	SNIP 2.04.09-84 /16/
Year	2002	2002	2002	1997
Take in account:				
1. Ceiling shape and surface	YES	YES	YES	YES
2. Ceiling height	YES	YES	YES	YES
3. Configuration of protected area	YES	YES	YES	YES
4. Burning characteristics of materials	YES	YES	YES	YES
5. Ventilation	YES	YES	YES	NO
6. Ambient environment	YES	YES	YES	NO
7. The supposed ignition	YES	NO	NO	NO
Spot-type smoke detector may be located:				
1. On the ceiling from a sidewall to the near edge of detector, mm	≥100	≥500	≥100	-
2. On the sidewall down from the ceiling to the top of detector, mm	100÷300	150÷300	100÷300	≤300
3. On the wall from the corner, mm	-	≥500	≥100	-
4. Max. distance between the smoke detector and further wall (h=3.5m), m	6,37	7,5	4,5	4,5

5. Spacing in the typical case (h=3.5m), m	9,1	15	9	9
6. Inside the exhaust duct	-	YES	NO	-
7. Close to the exhaust duct	-	-	≥1000	-
8. Distance from the air inlet, mm	-	≥1000	≥1000	-
9. Clear space below each detector, mm	-	≥500	-	-
10. In the middle of the ceiling	-	-	-	-
11. Under the ceiling, mm	-	25÷600	≤300	≤300

APPENDIX 2. Results of measurements of smoke detector response time in the office room

Location according to the Figure 24 & 25 \ Response time, sec.	Experiment			Average time	Rating
	1	2	3		
1. Inside the exhaust duct	33	32	36	**34**	**2**
2. Close to the exhaust duct	56	68	62	**62**	**14**
3. On the ceiling above the computer	43	47	51	**47**	**9**
4. On the wall over the computer	40	45	42	**42**	**6**
5. On the wall near exhaust duct and over the door	61	77	76	**71**	**15**
6. On the ceiling between the exhaust duct and the wall with door	62	70	81	**71**	**15**
7. In the middle of the ceiling away from the supply flow patterns	43	40	41	**41**	**5**
8. Between door and window on the height 2000 mm	56	41	61	**53**	**11**
9. On the sidewall close to the exhaust duct, 150 mm from the ceiling	65	45	56	**55**	**13**
10. Between exhaust duct and supply duct	62	52	49	**54**	**12**
11. In the middle of the ceiling on the way of fresh air	40	43	34	**39**	**4**
12. Under the table near to the ignition	11	12	9	**11**	**1**
13. On the back side wall, 150 mm from the ceiling	48	55	41	**48**	**10**
14. In the middle across the ceiling, 300 mm to the back side wall	44	53	43	**47**	**9**
15. In the middle along the ceiling, opposite to the supply and exhaust duct	50	48	36	**45**	**8**

16. On the back side wall 500 mm from the corner and 200 mm from the ceiling	43	46	44	**44**	**7**
17. On the ceiling 500 mm from the back side wall and 500 mm from the side wall	48	34	33	**38**	**3**
18. On the side wall, 150 mm from the ceiling and 1600 mm from the back side wall	-	-	-	**-**	**16**
19. On the ceiling, 200 mm from the side wall and 1 m. from the back side wall	58	63	43	**55**	**13**
20. On the side wall, 150 mm from the ceiling and 1 m. from the back side wall	51	48	41	**47**	**9**