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Indoor climate relation to the maintenance of HVAC systems

Bachelor's thesis

Double degree programme in building services engineering

2021

XAMK

South-Eastern Finland
University of Applied Sciences

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Author (authors)	Degree title	Time
Reda Maksimavičiūtė	Bachelor of building services engineering	January 2022

Thesis title

Indoor climate relation to the maintenance of HVAC systems

31 pages
1 page of appendices

Commissioned by

Supervisor

Petteri Järvelä

Abstract

The maintenance of HVAC systems is closely related to microclimate conditions. It guarantees heating, cooling, filtered outdoor air, humidity and temperature control for the occupants. The main aim of this Bachelor's thesis is to research how a poorly maintained HVAC system can affect indoor climate.

The literature review will reveal what determines good indoor air quality and its relation to a system's maintenance. The main system maintenance steps and every six months schedules are introduced. How unattended systems can harm human health and how fast bacteria and fungi can grow in the systems are examined.

The results will show the main design mistakes that affect air distribution, movement, controls, equipment, and hydronic performance. Without avoiding design mistakes, systems require more maintenance, damage air quality, and lose effectiveness. Unfortunately, the mistakes are difficult to detect in the following construction steps, and they can lead to partial system failure and poor human well-being.

Keywords

HVAC maintenance, ventilation, equipment

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1 INTRODUCTION

The maintenance and operation of HVAC systems in buildings commonly have focused on complying with requirements for safety, health and providing comfortable, hygienic conditions to avoid complaints from the occupants of the building. Maintenance has a close relation to microclimate conditions. The HVAC system's equipment should provide heating, cooling, filtered outdoor air and humidity and temperature control to maintain comfortable conditions. Although all buildings have different types of HVAC systems, the best maintenance and operation helps to ensure good indoor air quality. It also helps to save energy, comply with government policies, attain sustainability goals and improve occupants' comfort.

This thesis in the literature review part will investigate how the maintenance of HVAC systems affects people worldwide and indoor air quality. According to the European Commission, people spend about 85 - 90 per cent of their time inside the buildings /1/. Therefore, it is essential that the indoor air quality (IAQ) be comfortable and not harmful to health. Chemical, biological contaminants, and inadequate ventilation are the reason for occupants' illnesses. One way to ensure that IAQ is good is to take care of the HVAC system. Each system and device have its specific maintenance. Failure to comply with them can cause air pollution and malfunctions. This will be investigated in the literature review.

Although all devices in the HVAC system have their maintenance principles that can be followed, equipment can still fail. One reason for their failure is design mistakes, which will be investigated in this Bachelor's thesis. In addition, they can lead to equipment over-working, pressure changes and system imbalance. All these problems can be solved by ensuring that the system is appropriately maintained and checked regularly or changing equipment or the whole HVAC system in the worst case. In addition, good maintenance is the only way to avoid excessive money spending on new system parts.

2 AIMS

This main aim of this Bachelor thesis is to research how a poorly maintained HVAC system can affect indoor climate. This work will also respond to a few additional research questions. First of all, it will describe what an inadequate microclimate is and what symptoms it can cause to occupants. Secondly, it will be examined how to take care of HVAC systems and what occupants can do to ensure that the system works properly. Thirdly, microbial growth and indoor air pollutants in air filters and legionella bacteria in ventilation systems with humidifiers will be discussed.

This Bachelor’s thesis also analyses the most common HVAC design defects related to air distribution, air movement, controls, equipment and hydronic, which affect the maintenance of systems.

3 SICK BUILDING SYNDROME

Poor maintenance and improper cleaning are the most critical factors influencing the sick building syndrome (SBS). According to the NIOSH (The USA National Institute for Occupational Safety and Health), 52 per cent of SBS cases is because of inadequate ventilation, which is closely related to the poor upkeep of the systems /2/.

3.1 Causes and symptoms of SBS

"Sick building syndrome "(SBS) is the name given to a set of no specific illnesses and symptoms that afflict multiple occupants. The discomfort that people experience can be localized in a particular zone or room and may be widespread through the building.

The causes of SBS are inadequate ventilation, chemical contaminants from indoor and outdoor sources, biological contaminants, lighting and noise. Indoor air quality is a significant determinant of healthy life and people’s well-being because humans spend up to 90 per cent of their lifetime in indoor areas /1/. The most common symptoms that can disappear in hours or in rare cases in days are sensory irritation in eyes, nose or throat, skin irritations, neurotoxic symptoms such as mental fatigue, reduced memory, and power of concentration, odour, and taste complaints. In addition, sufferers of SBS can see their productivity levels reduced by up to 20 per cent. /3, p.291-303./

People can also notice, not only feel the symptoms in the building. The most familiar signs that can be easily spotted are the growth of the mould in areas where water is present and moisture issues, such as wet walls or ceiling tiles. Other symptoms that can be noticed are musty odours, the smell of chemicals or exhaust fumes, stuffy air and excess humidity, and temperature variance. For example, some areas are too hot and others too cold /4/.

There are several reasons for the SBS, but usually, the several factors working together affect people noticeably. The leading cause of SBS is inadequate ventilation.

3.2 Inadequate ventilation

Many reasons may lead to the inadequate functioning of ventilation systems, such as malfunctioning ventilation systems, poorly maintained systems, badly designed or ill-controlled systems, or inadequate air distribution within the space. /3, p.291-303./ To achieve good air quality, the system must supply sufficient fresh air to all occupied spaces in the building and remove contaminated used air, reducing the concentration of any air contaminants. In buildings with mechanical or forced ventilation, the air supply speed must be determined, considering the level of occupancy and the amount of smoking in a given area to ensure a sufficient supply of fresh air. In addition, fans and dampers can fail in mechanical systems, resulting in ineffective air distribution via the supply system. In buildings with natural ventilation, air movement patterns outside the building are complex, and if there are some obstructions in the building, these factors can prevent cross-ventilation. Apart from mechanical and natural ventilation problems, air quality may be reduced if the supply air fails to mix effectively with the existing indoor air. This can occur due to incorrectly set dampers and diffusers, creating localized pockets of stagnant air. Also, physical obstructions can prevent the designed airflow. To sum up, many problems occur due to system equipment maintenance, insufficient fresh air, and incorrect system.

3.3 Chemical and biological contaminants

A significant cause of the sick building syndrome is chemical contaminants such as gases, vapours, particles, and fibres, which pollute indoor air and may derive from inside or outside the building. Several familiar gas sources can be found in buildings, such as carpets and furnishings, glues, solvents and cleaning fluids, environmental tobacco smoke, and office equipment. Naturally occurring gases are CO, CO2 and VOCs (Volatile organic compounds).

Internal sources of pollution mainly consist of the synthetic materials within furnishings and the fabric of the building that may release VOCs. The emission and heat level can increase the contamination by using computers and fax or copy machines. Poor maintenance and inappropriate cleaning methods can release chemicals from cleaning agents into the environment, further compounding the situation. External emissions such as car exhaust fumes and other industrial pollutants add to the poor indoor air quality and circulate the occupants as they gain entry via intended and non-intended openings within the building fabric. /5, p. 55-66./ Despite naturally occurring gases, there are some particulates and fibres, such as metals and asbestos. Metals are toxic, and outdoor air contaminated by the vehicular exhaust is the primary source of exposure to lead dust, entering through poorly maintained ventilation systems. Asbestos is a naturally occurring toxic fibrous material used in old buildings as duct insulation. Asbestos increases the risk of damage and cancer in various parts of the lung.

Biological contaminants such as fungi, pollen, bacteria, and viruses also play a role in the sick building syndrome. These contaminants may breed in stagnant water accumulated in ducts, humidifiers and drain pans or where water has collected on ceiling tiles, carpeting, or insulation. Bacteria Legionella has caused both Legionnaire's Disease and Pontiac Fever /6/. It can be found in ducts that have accumulated water from the humidifiers /7/. Fungi play a negative role as pathogens to humans, plants, and animals, as allergens, producing secondary metabolites, mycotoxins, fungal VOCs, and glucans, which are detrimental to building occupants. The concentrations of fungi and bacteria are likely to increase in buildings with high temperatures and moisture /6/. Also, the fungal species may contaminate ductwork, which means that the heat exchanger may become contaminated. Fungi cause allergies and respiratory diseases.

4 METHODS

Several research methods are employed in this Bachelor’s thesis, such as literature reviews, comparisons, and analysis.

HVAC systems have the most direct indoor air quality, which means that they must be designed well and have excellent maintenance and operation. Therefore, most of the symptoms people experience due to polluted air can be resolved very quickly by following all the maintenance requirements of the HVAC system.

Another method is analyzing design mistakes how they affect indoor air quality, people inside the building and equipment. Moreover, the most important issue is to examine how poorly designed systems affect maintenance.

5 HOW TO TAKE CARE OF THE HVAC SYSTEM TO AVOID SBS

The SBS can be caused by many different factors working together. If the maintenance of HVAC systems in a building is carried out carefully and effectively, some problems can be avoided or easily eradicated. However, although eradicating one problem may help several people, it will not guarantee a comfort level to all building occupants.

5.1 Inspection plan

The best way to ensure that the HVAC systems are working correctly is to create an inspection plan. The maintenance plan should depend on several factors such as the age, size, location, condition and frequency of use of HVAC systems. For example, the older and bigger systems should be checked more often. Also, if the systems have both a heating and cooling unit, they should be inspected twice a year before switching the systems from one use to the other.

The maintenance checklist in spring or early summer of the systems with both heating and cooling units includes: filters replacement, cleaning evaporator coils and condensers, clearing clogs and cleaning drain lines to ensure proper flow, removing standing water from drain pans to avoid overflows, an inspection of the ducts for dust, mould or debris, checking the refrigerant charge for any possible leaks, checking thermostats and their controllers, inspect blowers and blades to maintain proper airflow and removing any debris from around the unit if it is outdoors /8/.

In the autumn or early winter, the maintenance checklist includes: replacing filters at least in autumn, carefully inspecting the heating exchanger if it is damaged it could lead to problems with carbon monoxide, if there is a gas furnace checking that there are no gas leaks, replacing frayed belts and pulleys, clearing drain lines and pants for standing water, checking thermostats and heat pumps /8/.

The list of the things that should be checked in spring and autumn could change based on the factors mentioned above, but it gives the idea of how preventive maintenance should look. It helps avoid the SBS and lower energy bills, reduce the chance for HVAC systems to break down, equipment lasts longer, and indoor air quality increases. Although most of these things are required for quality HVAC systems technicians, the house owner can do some things. For example, changing filters to increase the efficiency of the HVAC unit, clearing debris around the units that are outside, making sure that the system is level and not tilted, in summer the water for the furnace's humidifier should be turned off and when the weather gets colder install a new filter and set humidity around 40 per cent /8/.

5.2 Maintenance of the equipment

It is crucial to ensure that all equipment runs properly and is maintained to keep comfortable conditions in buildings for the occupants. In addition, most parts of the equipment have rules that must be followed to ensure that the indoor air quality will be good for most people.

5.2.1 Air filters

Filters must be maintained to the manufacturer's specification at the recommended time intervals no matter what type the air filter is. The filters should be able to filter the pollutants in the intake, including dust and chemicals. Dry and wet filters must be changed and cleaned at recommended intervals, while electrostatic filters, which remove dust and bacteria, must be switched off when the plan is shut down. Also, all filters must be fitted correctly so that no air can bypass it, and only specified filters must be used. Poorly maintained filters can become a reason to pollute an airstream, drastically reduce airflow through the system, and become a source of carbon dioxide storage. /9, p.87-101./

5.2.2 Cooling and heating coils

The cooling coil cools the airflow as it passes, causing condensation to form. The water runs down to a drip tray in which stagnant water can aid bacterial growth and be carried back into the airflow. For this reason, these points for maintenance should be followed. The drip tray and falls to the drain should always be kept clean. A blocked drain with no air brake is the reason for bacterial growth. All fittings in the cooling coil carrying water are watertight, and no plant water is carried into the air stream, and all deposit build-up from previously leaking joints is removed. /9, p.87-101./

Opposite to the cooling coil in the heating coil, the air is heated as it passes over, and the main points for maintenance to ensure indoor air quality are: making sure that the coil is not leaking at joins causing plant water to enter the air stream, control valves are calibrated and controlled correctly with no leaks on the gland. The control valves should receive correct information to act on, and it depends on whether the sensors and thermostats operate correctly. If units provide heating individually, the maintenance should follow the manufacturer's specifications. No matter what type of heating unit they are in, all thermostats should be placed correctly. The cold spot on a wall, thermal gain from electrical equipment or solar activity, cover by files or books, damage or neglect, or area that is not representative of the human occupation regime can be the reason for incorrect information from thermostats plant the room will be serviced incorrectly. /9, p.87-101./

5.2.3 Fans and ducts

According to the book "Sick Building Syndrome. Concepts, issues and practice ", the maintenance of fans and ducts is often neglected. A simple piece of equipment like a fan that pushes air around the plant and ductwork can cause problems. If the fan is not sealed, the bearings should be lubricated, and all excessive grease must be removed to stop them from entering the air system. The fan that is not balanced correctly can vibrate and become the noise source, which is one reason for the SBS. The balance of the fan and badly adjusted and worn belts can be the source of the noises. Excessive dirt and grease can affect the balance of the mechanism. The fans are for inlet or outside air, both types need maintenance, but exhaust air fans need more, as they operate in dirtier conditions. If the fan rotates less time in the minute than specified mean less air enters the building. /9, p.87-101./

Ducts need to be inspected periodically to ensure the system's integrity, although the possibility for a pollutant to enter the duct is slight. However, all joints must be airtight to prevent air from being lost into the roof voids, ceilings, and plant rooms. All holes, rips, pressure, and air temperature sensors must be sealed. If there are any signs of corrosion, the ducts must be investigated for leaks from the plant in the system, from the building's outer skin, from hot and cold-water services to toilets. If there is noticeable dust in the duct, there is a problem with filtration. /9, p.87-101./

6 BACTERIAL GROWTH IN HVAC SYSTEM'S PARTS

Poorly maintained HAVC system equipment such as air filters can remove particles of the given size and become the source of bacterial growth. It is not possible to avoid bacteria in the systems, but the system can be maintained and it is possible to keep them to a minimum. Bacteria in the system usually cause unpleasant symptoms or even diseases to humans.

6.1 Air filters

The air filters are used to remove the air pollutants from the air. As the filter loads up with the particles, it becomes less efficient, and the pressure in the system drops, therefore reducing airflow. The filters usually are made of porous filter material to retain biological particles and dust from the gas-solid two-phase flow. Different filters depending on their thickness and water retention, can affect fungal growth during filtration. The glass fiber surface with higher water content is suitable for various fungal or bacterial survival and growth. The hygroscopic materials' effect on suppressing growth in time decline. The reason for that is that hygroscopic materials absorb water and limit microbial growth initially, but when they are saturated, the effect disappears. The microorganisms grow in the filters when relative humidity (RH) is higher than 80 per cent /10/.

Martin Möritz, Hans Peters, Bettina Nipko, Henning Rüden did the experiment with F6, F7 class filters for 15 months. HVAC system 1 in the library with filter F7 and HVAC system 2 in the conference center with filter F6 reduce similar moulds. However, the results for bacterial filtration were different. Even though higher concentrations were found before the prefilters in system 2 than in system 1, the value behind filters was significantly lower in system 2. In system 1, the number of bacteria increases after filtration. Retention capability rates for bacteria depends on the season in HVAC system 1. In the dry and warm seasons remove more bacteria than in the winter or spring months. There is no seasonal influence with moulds. Their concentration reduced over the entire observation. Opposite to system 1 in HVAC system 2, there was no lower efficiency in retaining bacteria during cold and damp seasons. Both filters have a high capability to retain microorganisms under higher than 12°C temperatures and less than 80 per cent RH conditions. If the RH is over 80 per cent for more than 3 days and the temperature is lower than 12° C the bacterial number increase in the system after filtration. The concentration of bacteria and molds in the air of both systems are presented in figure 1. This was only observed in HVAC system 1 because the air filters directly contact outside air. In system 2, high HR was avoided by two preheaters installed in front of the air filters. Preheaters reduce RH so that microbial growth cannot occur anymore on the filters. The microorganisms that grow on the filters or go through them are tiny and can be easily carried into the ventilation system and cause bronchitis, asthma or allergies to persons who stay in the rooms with mechanical ventilation for a more extended period. There are only two ways to prevent bacterial growth after filtration. One is to install preheating, and two is to change air filters more often in winter and spring /11/.

	Airborne microorganism concentration [CFU m^{-3}]					
	Before filters		Behind filters		Difference	
HVAC system 1	a. m.[1]	s. d.[2]	a. m.	s. d.	a. m.	s. d.
Bacteria	256	± 373	269	± 375	−13	± 475
Molds	599	± 848	95	± 160	504	± 827
HVAC system 2	a. m.	s. d.	a. m.	s. d.	a. m.	s. d.
Bacteria	1143	± 3461	158	± 276	985	± 3264
Molds	555	± 527	87	± 97	468	± 498

[1] arithmetic mean.
[2] standard deviation.

Figure 1. Concentration of bacteria and molds in the air before and behind filters in HVAC systems 1 and 2

The fungi including Alternaria, Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger, Aspergillus ochraceus, Aspergillus Versicolor, Botrytis cinerea, Cladosporium herbarum, Epiccocum purpurascens-sterile, and Penicillium, A.

fumigatus and also bacteria Propionibacterineae, Staphylococcus, Streptococcus, and Corynebacterineae can be found in air filters or air conditioning systems /6/. Although most microorganisms in air filters and air conditioning systems cannot cause any damage to human health, some of them can cause hay fever, asthma, opportunistic infections, aspergillosis, pink eye, meningitis, or bacterial pneumonia for humans.

6.2 Legionella

Legionella can cause pneumonia or Legionnaires' disease, and symptoms are fever, muscle pain, coughing and shortness of breath. In more severe cases, symptoms include nausea, vomiting and diarrhea. Mostly Legionella is found in the water systems, but it can also be found in the air. Legionella grows at a temperature between 20 and 45°C. In wrongly designed ducts with humidifiers, water can condensate and accumulate for an extended period. With the right temperature, Legionella bacteria can grow in the ducts and be transmitted to the air. For this reason, it is possible that HVAC systems could become the source of legionellosis /6/. Therefore, to avoid an outbreak of Legionella, the operation and maintenance of water and air distribution systems become essential.

In air distribution systems, steam humidifier units give better results for avoiding Legionella than cold-water humidifiers. Steam units operate at higher temperatures creating steam. The temperature is too high for Legionella. Steam humidifiers, when not operating, require periodic descaling and draining. If steam is not an option, cold-water humidifiers should be operated with water temperatures of 20°C or below and sourced from a domestic water supply and drain line. To avoid Legionella, humidifiers should be cleaned and inspected for leaks regularly. Pipes should be maintained to prevent contaminated water from entering ducts. The drain lines with installed trap and air brake prevent bacteria from being a drawback in the system, and leak-free coils prevent contaminated water from spraying into ducts. Condensate drain pans should always be kept clean. If they are clean it is almost impossible for legionella bacteria to survive. /6/.

7 RESULTS

Building Information Modelling (BIM) links people, technology, and processes to improve outcomes in building and construction. BIM lets us use coherent 3D models for building designing, building, and operating process. BIM incorporates people and technology to streamline time and cost and improve efficiency. In BIM, not only 3D models can be found, but they also contain much information that makes up the project and lets exchange information with other involved parties.

When the construction teams move from one project phase to another, some information can be lost. However, using BIM, all information is collected digitally. With BIM, every phase of information from early planning, designing, construction, operation, maintenance, and recycling is digitally captured in one place. Thus, BIM opens new possibilities for efficiency, accuracy, and cooperation between the parties.

As is shown in figure 2, with the help of BIM, most of the design is done at the detailed design stage, where the potential to affect project performance is high, and the cost of design changes is low. This allows engineers to spend more time designing, collaborating with installation and maintenance professionals to avoid mistakes and make the job easier for everyone /13/.

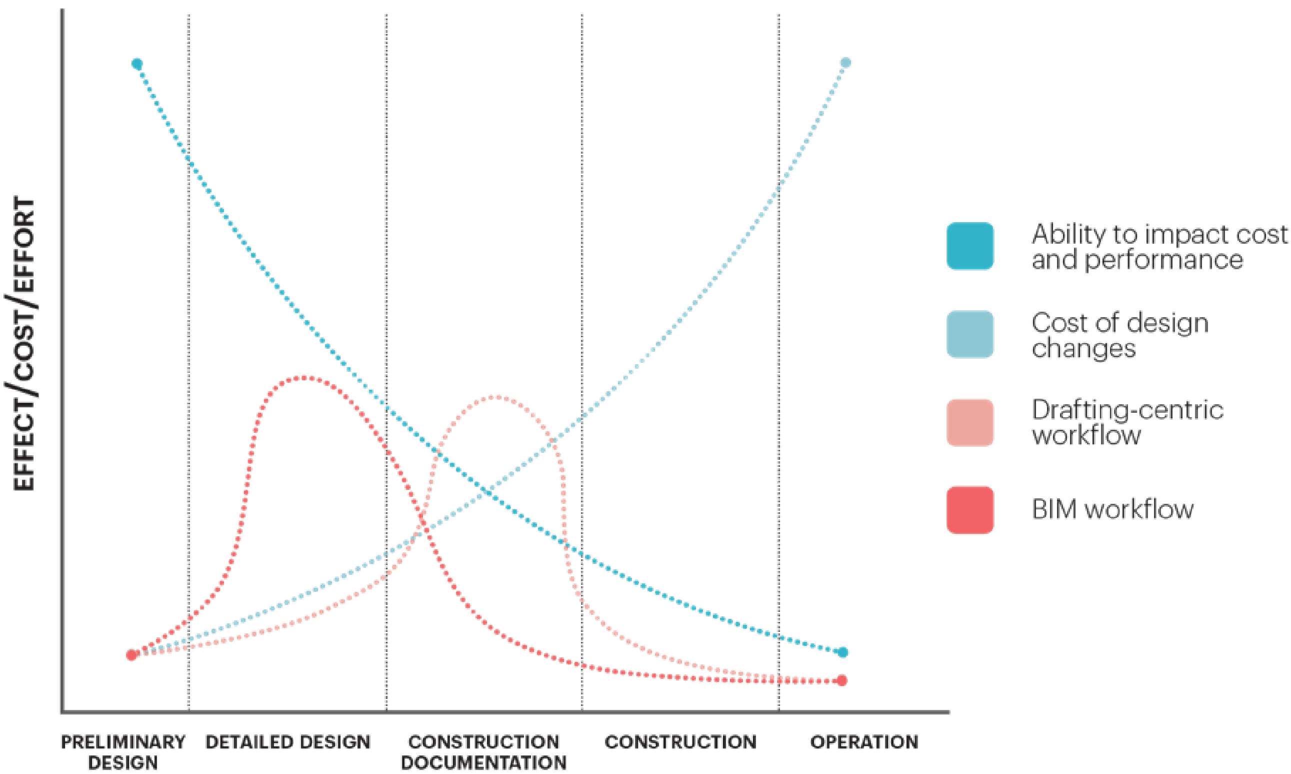

Figure 2. BIM design phases and how changes effectively can be made.
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Many HVAC system design mistakes that affect systems' maintenance can be avoided with BIM when all parties are involved earlier in the process.

7.1 HVAC maintenance

HVAC systems' maintenance is classified in periodic or routine, preventive, and breakdown maintenance. Periodic or routine maintenance is done in the same operating hours, monthly, seasonally, or annually. It also includes systems' start-ups and shut-downs. Preventive maintenance includes operations that detect, restore, or prevent deterioration. Preventive maintenance includes specific tasks such as painting a coil drain to stop corrosion, replacing valves to stop drips, and others. Breakdown maintenance is performed only after a failure in system operations has been detected. Breakdown maintenance involves a single component or entire system replacement. /14, p.75-76./

This chapter will discuss the mistakes that were made during system design which may affect system maintenance. Most of these mistakes can be corrected by noticing them during installation, but if it is not done, they can increase system failures until the systems stop working.

This chapter analyzes the design mistakes presented in the Hal Finkelstein book "Avoiding 101 serious HVAC system design mistakes " /15/. Those mistakes can affect the individual parts of the system or the entire system. There are several ways to solve the problems that can be done with different maintenance for each mistake.

All design mistakes can be classified into four problems related to air distribution, air movement, controls, equipment and hydronic. This is the way how the effect of design mistakes on maintenance will be analyzed.

7.1.1 Air distribution

Maximum and minimum supply air quantities for each VAV terminal unit should be listed on the design drawings.

If there are no minimum and maximum supply air values on the construction drawing for each diffuser connected to the VAV (Variable air volume) terminal box, usually, the contractor will set the minimum value at 30 to 33 per cent of the maximum value. This method can be close to the designed value, but it may lack the required amount of air for good IAQ or humidity control and low load.

Several situations reported by Sheet Metal and air Conditioning Contractors' National Association (SMACNA) where drawing did not show minimal requirements for VAV terminal boxes, and contractors elected to set devices at 30 per cent of maximum value. When the comfort problems developed and occupants started complaining due to ill health, it was found out that the actual design was set at 50 per cent of the maximum value. Many times, when mistakes are made, the humidity levels are excessive.

In that time, the air conditioning system needs to work harder to remove moisture from the air and cancel out the cooling effect. The musty odour and growth of the mould inside the ducts will become unpleasant problems in the house. If the wrong terminal boxes' value has not been noticed, then the dehumidifier needs to be installed in the HVAC system.

It is not easy to make corrections after installation. From the information given above, it is clear that when the relative humidity is greater than 80 per cent for a longer time, the respirable bacteria will start growing in the filters. To sum up, if the maximum and minimum supply air quantities for each VAV terminal unit are not listed in the design drawing, the solution is to set up again the minimum flow or if the mistake has not been noticed install a dehumidifier, clean ducts, and filters more often when RH is higher.

Bad duct layouts and excessive system duct leakage after leak test.

Ducts shall be designed to avoid largely or at least maintain uniform pressure drop differences between branches, especially in VAV systems under part load modes. This makes it easier to balance and maintain a balanced, symmetrical system, as the loads in them change along with the air flows. Duct systems with significant pressure differences in the branches will not remain balanced and will create large differences in airflow from one branch to another.

Unbalanced systems reduce energy efficiency and recirculate air. Spaces with more air also receive more mould and dust found in dirty ducts. Other rooms with insufficient airflow will have higher humidity problems. The pressure difference in the branches can often be caused by the low-pressure ducts not being inspected and the medium or high-pressure ducts being inspected in sections.

When the system is fully installed and operational, a leak can be found on the sides of the return or exhaust ducts. Whether the system is asymmetrical or has been checked for leaks, the duct collar connections above the ceiling must first be checked and sealed. If the system has been operating correctly for some time and has become unbalanced, the diffusers should first be inspected and cleaned. The maintenance specialist should also check the duct for holes. Especially at the collar joints, as there may be gaps left by improperly sealing the duct from the inside, because they may never be leak tested.

Variable air volume terminal.

Variable air volume terminals can become the reason for insufficient airflow. Dampers' shaft arrows should be wide open. If not, there is probably insufficient static pressure in the terminal boxes. Terminal boxes must be able to open and close properly. The defective controllers can be discovered by turning both MAX and MIN settings to the max or zero position. In the max setting position, terminal boxes should be open and in zero – fully close. All defective devices should be repaired or replaced by new ones.

Moisture from duct humidifiers accumulate in ducts.

The prime importance in HVAC systems is humidification. Moisture from duct humidifiers can gather in the ducts and become the reason for fungi and bacteria growth development. Humidifiers usually have horizontal delivery manifolds, which are placed in the horizontal position in the ducts. In this position, the discharge holes face the direction of airflow. Thus, the steam is injected into the air stream against the flow.

The system with duct humidification should be designed to prune down the chance of condensate collecting in the ducts. For eliminating water, it is vital to know, define and evaluate the vapour dissipation stage. Firstly, the steam will change from invisible gas into a moist vapour with 8 microns or bigger size droplets. Next, the steam is discharged against the airflow. After the vapour flows along with the air, it will again re-evaporate into invisible steam. The latent heat of 4186.8 kJ/(kg×K) of vapour will be given to the duct air when the first steam will condensate out. The latent heat will warm the air slightly. It is crucial that the re-evaporation occurs at a distance with no obstructions or other devices that could be the reason for condensate particles dropping out of the air and causing the wetness in the ducts.

The humidifiers' controllers must be installed out of the area where the visible vapour zone occurs. This is because the combination of locally warmer air and moisture vapour particles will create a false indication for the controllers. After the first three months of duty, humidification system controllers and the ducts should be inspected to determine future inspection and maintenance requirements. It is also essential to talk to building occupants because if the system operates to a more significant value than designed, the absorption distance becomes inadequate, and wetness will increase. The rule of thumb installing a controller is that the distance should be at least 4.5 meters downstream of the humidifier manifold.

Duct temperature should also be considered when selecting humidifiers. The visible vapour zone of about 30 centimetres are in a duct with 24°C temperature air, and it can increase to as much as 4.5 metres with 13°C temperature air. The higher the air velocity in the ducts is, the longer the visible vapour zone length should be. In the more extended zone, the possibility for the equipment such as controllers, insulation, air filters to become saturated with water and begin to fail, and the growth of bacteria and fungi are much higher than in the short distance.

If the system is already installed and the moisture problems created by humidification systems begin to show, the practical method for reducing the visible moisture zone length is to utilize multiple manifolds. When there are space constraints, airflow temperature is below 21°C, air filters are downstream of the humidifier, velocity in the ducts is bigger than 2.54 m/s the visible vapour length may impinge upon coils, fans, filters, dampers, internal insulation, turning vanes and others located downstream of the humidifier and be the reason for their tear and fail and energy demand for the system will increase. Installing more manifolds is not the only way to make sure that the humidification system works appropriately. The humidifier reservoir must be cleaned and checked regularly. The check for leaks and standing water around humidifiers should also be done regularly.

7.1.2 Controls

Static pressure controllers mainly adjust the supply fan. However, if the controller is installed near the elbows or other duct fittings, the air turbulence will cause the fan to over-work. The controllers must be installed about 7 duct diameters from the elbow or some other fittings. If the fan works inappropriately, it will mainly create a lot of noise and the fan belts will constantly break and cause much more mechanical problems, such as vibration, duct heating, and increasing torque. All the fans should be checked every 6 months, and if there are any discrepancies in the work curve, they must be changed. Also, the duct system after this should be inspected more carefully.

7.1.3 Equipment

HVAC unit vibration

Concentrating HVAC units' weight between the beams of the building will cause noise and vibration—no matter what type of vibration eliminators are installed. The vibration causes the excessive wear of the system's equipment. The system's control components such as fire safety thermostats, smoke detectors in air handling systems, and refrigerant high-low pressure cut-outs on refrigerant compressors can be easily damaged by vibration. The changes in accuracy and inability to maintain calibration can lead to all system operation failure. Control devises should be periodically tested or be replaced by new ones. All control devices located on the air handling unit, fans, ductwork, piping, and compressors should be relocated to the point where there is no vibration. /14, p.82-83. / If relocation is impossible, the units should be reinstalled on a steel frame supported by column extensions or adding an extra stiffening slab under the unit. Both methods of reinstallation are shown in figures 3 and 4.

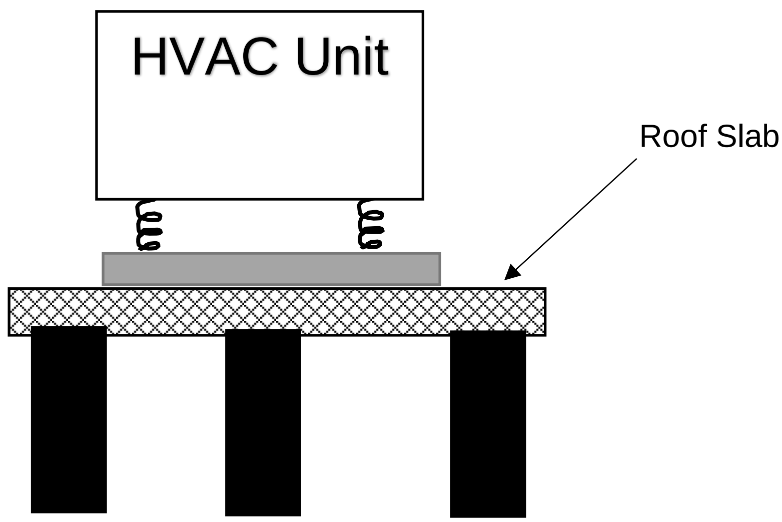

Figure 3. HVAC unit reinstalled with steel frame supported by column extensions

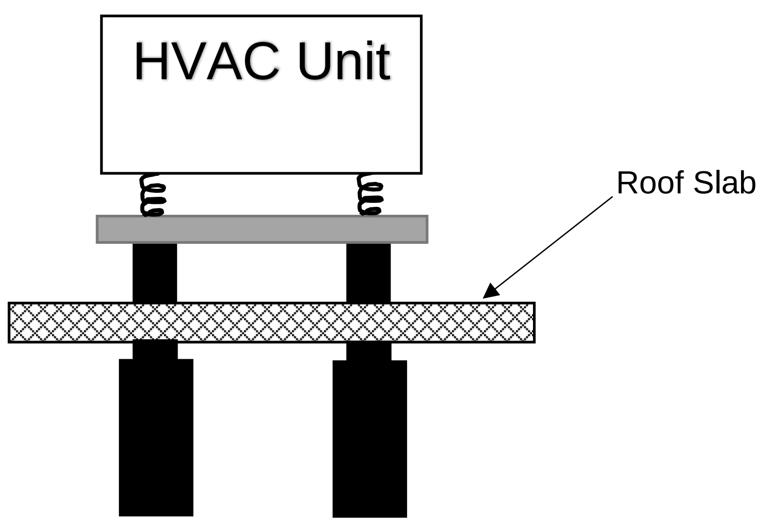

Figure 5. HVAC unit reilstalled with extra stiffening slab.

Low Pressure heating boiler shows signs of corrosion.

Using low-pressure boilers can show the pitting type of corrosion caused by the dissolved gases in the boiler water. Carbon Dioxide and Oxygen are the most prominent causes. It can be solved by adding alkali to the boiler water. For neutralizing Carbon Dioxide, the 400ppm CaCO3 in the boiler water should be maintained. The Sodium Chromate chemicals or other Oxygen reducing chemicals approved by the EPA (Environmental Protection Agency) can be used to protect a large amount of Oxygen and Carbon Dioxide. All the chemicals permitted to use in the system and instructions for putting them in the boiler water should be listed in manufacturer instructions.

7.1.4 Hydronics

Corrosion in chiller absorber and condenser tubes.

Poorly maintained water circuits in a chiller system can be the reason for the rapid corrosion of the chiller absorber and condenser tubing. The corrosion could destroy a new chiller in ono to three years. The absorber and condenser tubes can be attacked in internal areas by the different corrosion cells. Sand, algae, and debris build up to cause fouling, progressing fouling from corrosion cells.

As the corrosion progresses, copper material wears out. Copper then plates out on the interior surface of the steel piping material. Corrosion can progress to the steel piping due to low Ph value, approximately 6 to 7, and warm condenser water. Tubercle material develops from the corrosion process, and it breaks off and ends up in the cooling tower water circuit.

Iron oxide enters into the cooling tower water circuit and increases fouling to the absorber and condenser tubes full of algae, spores, and sand. Once the fouling in tubes accelerates, the cleaning brushes in the chillers become ineffective. The effectiveness of the brushes also increases as the water flow and velocity decrease.

This corrosion cycle becomes self-feeding. The more corrosion, the more fouling increase and create increased corrosion and more of the same. The complete system cleaning must be done to stop the process, and the water pH should stay about 8 or 8.5. Corrosion inhibitors or glycol can also be used for stopping the process. If it is possible, the side stream filter system should be installed. It will filter the water through a side stream loop and can also add chemicals periodically. If the water temperature in the system is above 7°C, the molybdate based corrosion inhibitor should be added to the system. Nitrite based corrosion chemicals may be the food source for bacteria development above 7°C.

Corrosion in hydronic heating systems.

Hydronic heating systems, the same as chiller systems, experience corrosion and gas generation. Water cleanliness and pH are essential in preventing pipes' corrosion. Before system start-up, when there is no water, the system interior must be cleaned with commercially available cleaning products. During operation, the water pH must be checked periodically and maintained not to go lower than 8. If it is lower, corrosion will occur. Air should be vented from the system. The methane gas in the system forms because of the debris, low pH, and air in the water. Air venting should be done only from centrifugal air eliminators in the mechanical room or from manual air vents at the high points in the system. Automatic vents cannot be used in air venting because they can suck more air into the system than vent out.

7.2 Occupants and HVAC maintenance

All buildings have different HVAC systems, and none of them has the same problems. However, a big part of the problems depend on the occupants because they regulate indoor air. If they set the humidity and temperature to be higher or set the supply air to be lower, the system will be working in the way it should not. In addition, systems usually break up because all parts work together, and if one part fails, other parts need to work harder. So, the system longevity depends not on only maintenance professionals but also on the occupants. Therefore, every occupant should be familiarized with the designed system work and capacity of the system and what they can do to ensure that the system works properly and does not become the reason for their unwell feeling.

Occupants also need to be sure that the company which takes care of their building's HVAC systems, no matter what the purpose of the building is, do these listed things. There is no legislation for HVAC system maintenance, so every HVAC maintenance company does things by their inside rules, but the good practice is:

At least once a week: check substation heating and domestic hot water systems and modes in the heating season.

At least once a month: check the air conditioning system, when it is working, check substation heating and domestic hot water systems and modes, in not heating season, water inlet check, ventilation chambers and their modes.

At least twice a year: changing or cleaning air filters.

At least once a year: cleaning of fan impellers and heat exchangers, cleaning of filters in air conditioning systems, coolers, as well as inspection of the condensate drainage system and AC modes, performing hydraulic tests of the heating substation, starting the system for the heating season, and stopping the system.

8 CONCLUSIONS

The systems must be correctly maintained and operating through the whole building use. Only good maintenance can ensure occupants' safety, health, and hygienic conditions. Humans spend more than 90 per cent of their time inside, so that the poor indoor air quality can affect them easily. /1/. One way how to control IAQ is to take care of HVAC systems.

Poor maintenance of the systems is the main reason for the sick building syndrome. Inadequate ventilation, when there is not enough fresh air, and the contaminants are not removed, chemical and biological contaminants from the air, furnishes, or HVAC system equipment can cause the SBS. The inspection plan, which depends on the system age, size, location, and frequency of use, ensures that the equipment is maintained correctly and will not become the reason for people's illnesses.

The main rules for HVAC system maintenance are: air filters must be changed regularly, or when the weather temperature drops and humidity rise above 80 per cent, then the bacterial growth begins on the filters. The heating and cooling coil need to be carefully checked every time for water in drip trays, there are no leaking at the joins and water cannot enter the system, and the thermostats for the coils are placed correctly. The fans should be placed correctly to make as little noise and vibrations as possible and all the excessive grease must be removed to stop entering the air system. Finally, the ducts must be airtight, and all holes sealed.

Many additional HVAC systems maintenance can be avoided if the systems are designed correctly. The mistakes made at the building design phase and unseen at other construction phases can significantly impact the maintenance of the system.

All important information such as airflows, distances, minimum and maximum supply air quantities must be listed in the design drawing so that the contractors can set the correct value. Later, when the occupants start complaining, it is hard to find the problems’ source and other problems can develop. For example, higher humidity, cooling systems shut down, mould, and bacterias inside air system parts can occur from not given values in the drawings. Then the additional system's parts such as dehumidifiers need to be installed, replacing systems, cleaning ducts, and filters must be done until finding the source of the problems.

High-pressure differences between duct branches, dirty ducts or vibration from AHU can unbalance the systems. Then the ducts must be carefully checked for holes, and collar connections must be sealed again if necessary. The vibration also causes the excessive wear of system equipment and control devices to disbalance.

Moisture from duct humidifiers causes fungi and bacteria growth development and duct corrosion. To prevent moisture in the duct, larger amounts of manifolds must be installed, and the humidifier tank must be cleaned and inspected regularly. It is also necessary to regularly check for leaks and standing water around the humidifier.

The corrosion in an HVAC system can be avoided by adding chemicals to the system to reduce Oxygen and Carbon Dioxide concentration in the systems. Systems with corrosion have more dirt in them, they need to work harder and can shut down quicker.

All HVAC systems must be maintained throughout the year, not only by the maintenance company but also by the occupants. They can also contribute to the longevity of the system. Adequately controlled control devices, keeping system temperature and the humidity in the design range, dust removal from the devices help maintain the system.

9 DISCUSSION

This study shows that HVAC system maintenance is equally crucial to system as design and installation. Designing and installing systems are essential at the building production and construction stage. However, great maintenance is necessary for the building operation stage. HVAC systems’ maintenance can help save energy, attain sustainability goals and improve occupants' comfort.

One poorly maintained HVAC system part can be the reason for the whole system replacement. Many HVAC systems design mistakes affect air movement and cannot be solved without re-designing or reinstalling. However, the air distribution, controllers, equipment, and hydronic design mistakes can be avoided with proper maintenance.

While each device in the system has its own maintenance rules that the manufacturers can set, often, maintenance professionals set their maintenance schedule based on the purpose of the building and the load on the use of the systems. There is no legislation describing the HVAC systems' maintenance, and only a suitable practice method is applied to take care of the systems.

More detailed investigation can be made with the buildings requiring more specific checking, such as hospitals, laboratories, museums, and libraries. Where the bacteria, moulds and higher humidity have more impact on people's work or the condition of expensive items.

The Bachelor's thesis could be developed in the future by writing and analyzing the maintenance of HVAC systems in buildings of different purposes or by comparing how two similar systems are maintained equally in different locations and how this determines the building's microclimate and occupants' well-being. Little research has been done on such studies, which could help to harmonize the oversight of systems and help to develop legislation to ensure that HVAC systems are properly maintained. I am convinced that the legislation would make the work easier not only for maintenance professionals but also for HVAC system designers. By knowing the standards and rules of maintenance, they could make fewer mistakes and look more closely at the expected locations of devices when assessing planned maintenance. This would help for HVAC designers to become better professionals.

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LIST OF FIGURES