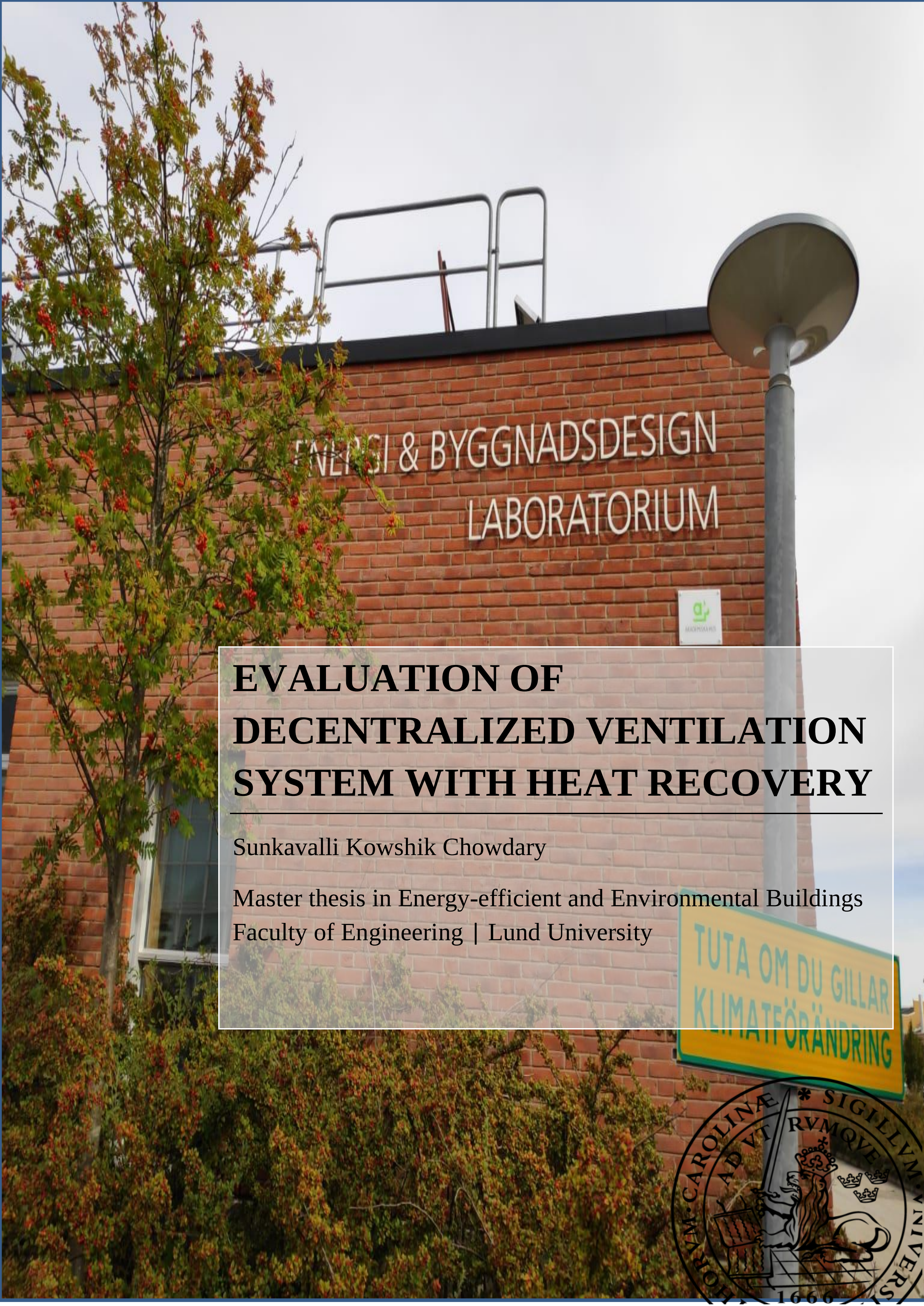


# EVALUATION OF DECENTRALIZED VENTILATION SYSTEM WITH HEAT RECOVERY

Sunkavalli Kowshik Chowdary

Master thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University

# Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280-degree programmes and 2 300 subject courses offered by 63 departments.

## Master Programme in Energy-efficient and Environmental Building Design

This international programme provides knowledge, skills and competencies within the area of energy-efficient and environmental building design in cold climates. The goal is to train highly skilled professionals, who will significantly contribute to and influence the design, building or renovation of energy-efficient buildings, taking into consideration the architecture and environment, the inhabitants' behaviour and needs, their health and comfort as well as the overall economy.

The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

Examiner: Birgitta Nordquist

Supervisor: Henrik Davisson (Division name), Dennis Johansson (Company or Division name)

Keywords:

Thesis: EEBD - # / YY

# Abstract

Humans spend 90% of their times indoors, and maintaining a pleasant indoor environment is essential. Factors like human behaviour, combustion sources, cleaning supplies, affect the indoor environment, which could potentially affect the human health.the most common answer to controlling the indoor environment is a good HVAC system. Ventilation systems with supply and exhaust are not standard in residential houses, natural ventilation with exhaust ducts or just mechanical exhaust system is conventional among the residential sectors. A cost-effective and an energy-efficient alternative could be a “Decentralized ventilation system” This report aims to provide knowledge of such innovation in the field of HVAC, to evaluate the performance of a decentralized ventilation window unit system.

The results aimed to declare the performance of a window unit decentralized ventilation system developed by SMARTVENT AB. The tests are done according to the standards that have to be followed, and the ventilation unit has performed up to those standards in various airflows. Nevertheless, it needs to be tested further to be released in the market. A separate control system must be built for this unit to do any further testings.



# Acknowledgements

pay my sincere thanks to my  Supervisors Henrik Davidsson and Dennis Johanson. Utmost gratitude towards Mattias from Smartvent for providing with equipment and information to move forward in this diploma work.

This report is dedicated to Henrik, who always pushed me and always being so patient, I wish we had a teacher like him during my bachelor degree days.

*"Hello Sunkavalli, for god's sake sit down,*

*I am going out of Sweden for a couple of days, Bhutan, Nepal, travel travel travel"*

***Henrik Davidsson***

# Table of content

# 1. Introduction

## 1.1. History

It all started during the time of early man when they discovered fire which they not only used for cooking food but also to keep them warm in the nights and during the cold weather. That is the first use of Heating Ventilation and Air Conditioning(HVAC) known to humankind.

During the era when Greeks, Romans, Indians, Egyptians were considered the heavyweights in terms of civilization, they lived without the modern state of the art equipment. They had their means of HVAC; for instance human workforce or rope fans, long piece of cloth attached to the ceiling attached to a rope for the humans to pull for the fan to swing manually, to produce enough air movement in those climates which was called punkah. The people of Rome and few other parts of Europe has been seen to use Hypocaust- where the whole floor in the house and in some cases wall constituted a heating system, which is an olden tile floor heating method. In India, they used a system called jail where the walls are designed with some designs which would allow some air and daylight enter the building, having natural ventilation but in a limited access[1].

Over the years, innovation came flowing. In the USA the franklin stove was created by Benjamin Franklin, later developed by David Rittenhouse in the 1700s [2].

In the 1800s, the discovery of latent heat by Joseph Black has changed the people’s view on temperature and heat, which believed to have paved the way for developing water heating systems. Dr John Gorrie developed the idea behind the ice-making machine, which could be used to cool the rooms by passing air through the machine. Unfortunately, he could not get his concept out to the marketplace but did pave a foundation in air conditioners [3].

However, the revolutionary breakthrough came during the time of the early 1900s, to exaggerate one can classify it as pre-Willis era and post-Willis era. Willis Carrier invention to condition the air and control temperature and humidity levels through coils and cooled the air. The patent was attained for the air conditioner, and in the late 1920s it found its way into homes and then into cars and took over the world over the years with various new products and developments. He was considered the father of air conditioning [4].

The pleasant indoor environment is determined by good lighting, temperature comfort and ventilation [5], removing of air indoor pollution. Heat pumps were one of the innovation towards better efficiency ventilation systems. With the competition to deliver better products for the people, many companies are coming up with various ideas. On the author's note, most of the improvements in the ventilation industry are towards the bigger scale, Big scale industries are developing equipment for big residential apartments of multiple storeys, malls or with large scale ventilation requirement.

A conventional ventilation system is good but not always an advantage for single-family dwellings; the costs will be high and the ducts and pipes will consume indoor space. In a renovation process, the building could potentially be made more airtight in order to reduce energy loss through cracks. In other words, it would reduce its air infiltration coming in and going out of the building and thereby lowering the air exchange. In these situations, people tend to open the windows and doors for better air, which is termed as natural ventilation. In that process, all the energy saved in the indoor air might be lost, and inhabitants have to re-heat or cool the building again according to their comfort. Smartvent AB developed a decentralized ventilation unit which aims at providing enough airflow and airchange inside the space, which can be integrated together with a window. There are other companies which have been developing products in the decentralized ventilation unit. However, a window integrated unit is less common.

## 1.2.Background problem and motivation

Over the years, the use of energy in the building sector has been increasing, early in this decade, the energy consumption in buildings are said to be around 40 % [6]. In the present, the increased energy use could reach 3 % anually. In 40 % of building energy consumption, space heating and cooling that is indoor comfort energy use, is around 30 % - 60 % [7], which is believed to be a hefty sum. The Swedish government aims to reduce primary energy by 20 % and 50 % by the year 2020 and 2050 respectively in comparison with 1995 energy demand[8]. With the future energy goals, the renovation industry taking steps with better insulation and windows, the building is made airtight, without the loss of any infiltration. EU have taken significant initiatives, By 2050 there should be energy-efficient buildings with low to no carbon emission[9].

Single-detached dwelling houses are generally equipped with an exhaust ventilation system or natural ventilation together with, district heating. It is less common to see typical mechanical supply and exhaust ventilation system. This could be due to various factors pipes and ducts passing all over the house, the usage of the equipment and most importantly the cost factor. The installation cost, equipment and maintenance could be a concern for the single-family houses[10].

In tropical countries like India, natural ventilation is the primary source of cooling. Over the last decade and a half, air conditioners have become a common household item for active cooling. The sales of such machines have increased drastically due to indoor comfort needs with the rise in global temperature [11]. One state of the art is the decentralized ventilation system. Compared to the typical ventilation Air Handling unit(A.H.U) system, decentralized systems are cheaper and compact.

Decentralized ventilation systems are being developed more in recent years [12]. All the units up until now have almost come as a separate unit, occupying an area of the window or a part on the wall, yet it served its purpose.

Deventralized ventilation system does not work on a big scale but on a tiny scale of single space at a time at its best. Different decentralized systems contribute on various types of a single system where for each cycle the air is sucked in. In the next, it is sent out, storing the heat and releasing it in the other cycle, others models have the exhaust and supply connected and works as a single port[13].

There would be certain advantages to decentralized ventilation systems: since these units come ready for ventilation, there would be little to no configuration work. The question mostly is mostly how one can evaluate if and when a decentralized ventilation is beneficial?

## 1.3 Aim and objective

The thesis aims to test the Smartvent decentralized ventilation system and its performance. The research question is to find how much airflow can be achieved, the efficiency of the heat exchanger, information of the tests conducted on a decentralized ventilation system. This paper is not just about providing the performance of the decentralized ventilation system.

## 1.4 Approach


*Figure 1 Energy and building design laboratory, Lund University, Lund, Sweden*

All the tests were done by measurements in Energy and Building Design(EBD) lab behind the A-building, Lund University, Sweden.

The evaluation of the Ventilation system is done by testing air exchange efficiency through tracer gas, heatexchange efficiency, draught inside the room, short-circuit and leakages around and inside the equipment. To evaluate actual airflow from the two compartments of the machine, the tests to be done at various speed of high medium and lowest possible, and for some more than three test speed is done.

## 1.5 Limitation

One main goal for the ventilation system is to remove pollutants from the indoor air. Using the same material/duct for both supply respectively exhaust air implies a risk for bringing back the pollutants collected by the exhaust air, to the suppy air. This aspect has not been examined in the present study

# 2 Methodology

Decentralized ventilation system came recently to the ventilation industry, and there is not much available information on how to accurately evaluate a system and deem it fit. There are many tests which can determine the performance of the ventilation systems based on the performance we are looking for. So in this report, it will cover the essential tests to perform to evaluate a decentralized system. This thesis contributes to various tests done on various ventilation systems and taking a particular factor to test and combine it all[14].

## 2.1 The geometry of the room and ventilation unit

### 2.1.1 Room

The allocated room has the dimensions of 2.7 m width × 4.2 m, length × 2.65 m height. with two windows on the south side see figure 2 of dimensions 1.13 m×1.17 m, and a single entry/exit door. This is one of the labs located inside the building of Energy and Building Design.

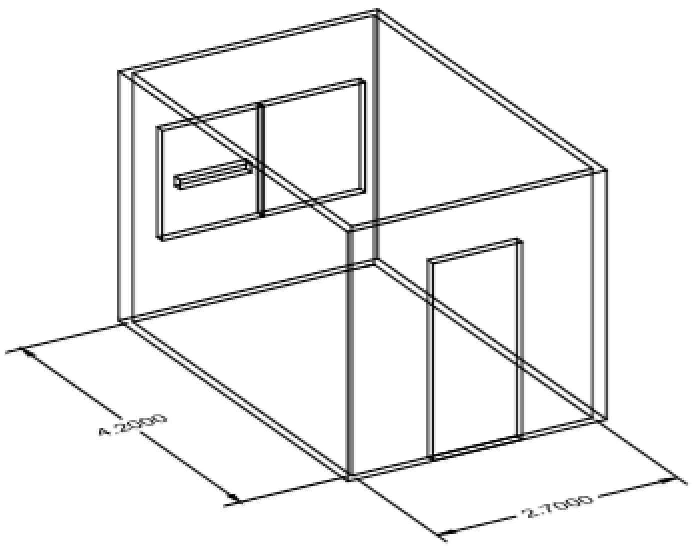


*Figure 2 Basic design of the single space test room*

### 2.1.2 Ventilation unit

The decentralized unit was on a wooden board that replaced one of the windows seen in the figure 2 where the equipment is located, with the outside hoods i.e the supply and exhaust face the south side.

The ventilation unit is divided in two parts, one for inlet air and one for outlet air of a fan each as shown in figure 3. The fans changes the air direction so that the inlet becomes the outlet and vice versa. On the entry and exit side of the room, regenerative ceramic heat recovery material is mounted.

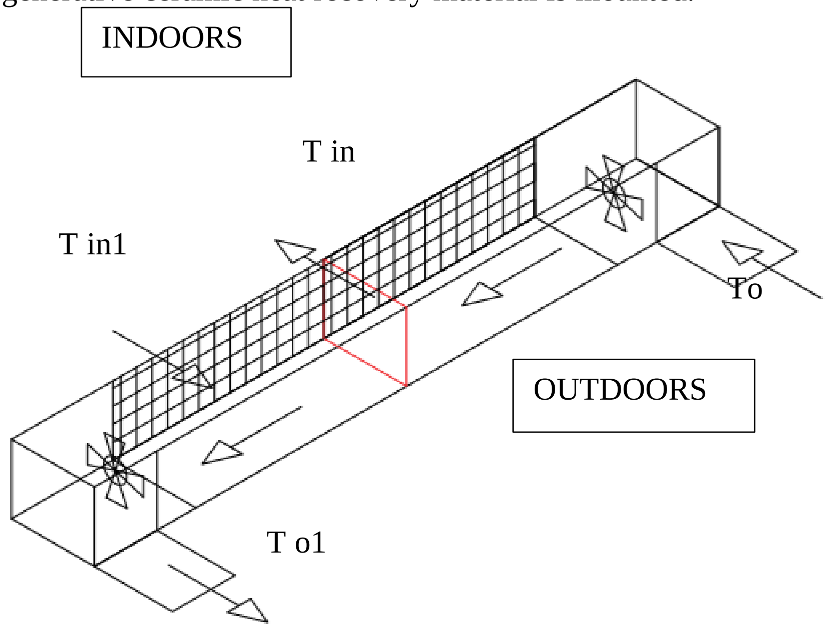


*Figure 3 ventilation unit wih airflow in and out of the unit, the redline indicating the separation of the unit in two parts*

The workflow of the unit have two cycles of seventy seconds each, i.e for one minute one side takes in air, and the other will let it out from the room. After that cycle the fan changes the direction of airflow where inlet becomes outlet and vice versa. A secondary unit will be delivered and tested for noise in future study, as the primary unit is fixed solidly to the lab window.

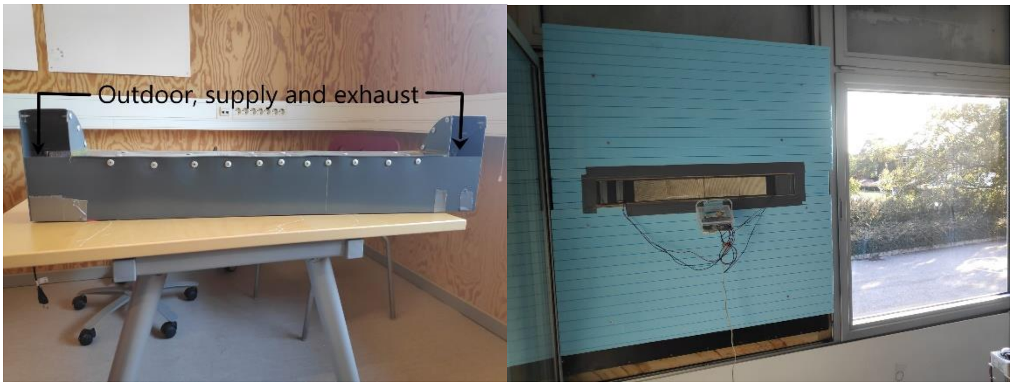


*Figure 4 ventilation equipment supply and exhaust*

Dimensions of the Decentralized ventilation unit (when placed horizontally), in the figure 4, it is 80 cm of length, 8.8 cm fo height and a width of 10.6 cm. as seen in the figure 6 the heatexchnagers size of 54 cm, 5 cm in height and a possible width of 8 cm.

#### 2.1.2.1 **Heat-exchanger**

A heat exchanger is a device used for transferring or exchanging heat between fluids, or solid surfaces or from solid to liquid or vice versa. The heat-exchangers are classified based on various types few are.

I. Transfer type – direct or indirect contact
II. Fluid quantity
III. Design and type
IV. Type of flow

Most of the heat-exchangers fall under the flow and the type.

There are two types of heat-exchangers I. Regenerative, II.Recuperative.

[I].Regenerative – in this type of heat exchangers, the heat from hot source is stored in the storage medium where the supply and the exhaust air slowed through the same area/duct for transfer of heat.

[II]. Recuperative – in this type, both the flows are separated and based on the need and scale it can be direct or indirect, like a barrier and the heat transfer is done through the exchange medium.

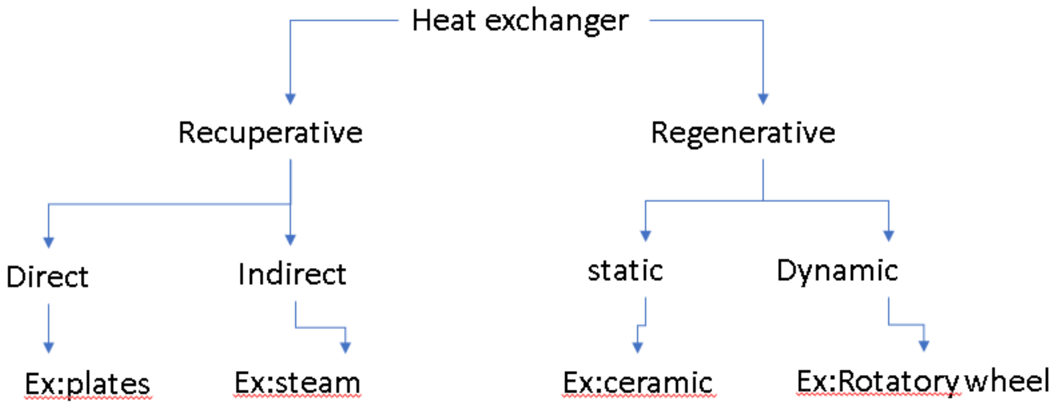


*Figure 5 types of heat-exhangers*

The new decentralized ventilation unit uses a ceramic material as the regenerative heat exchangers.

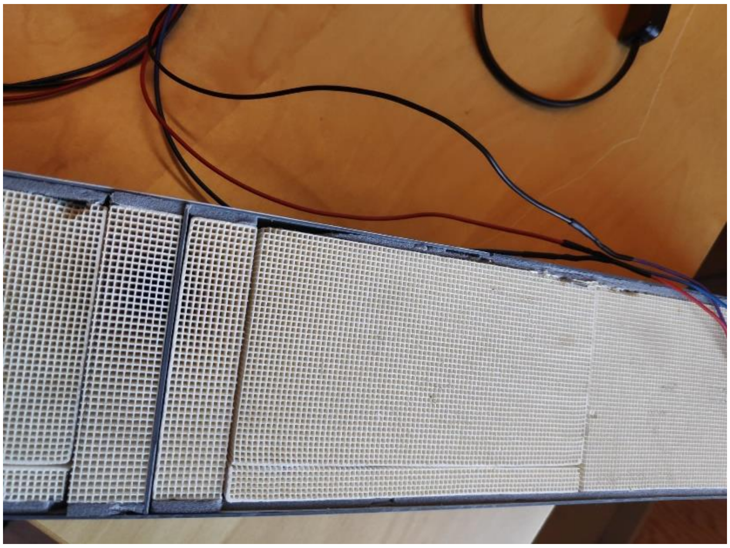

*Figure 6 heat exchnager*

Ceramic materials are used in this regenerative exchangers, and they can take in the cold as well as heat and store it. Ceramic heat exchangers can store in high temperature [15].

#### 2.1.2.2 **Working mechanics of the equipment**

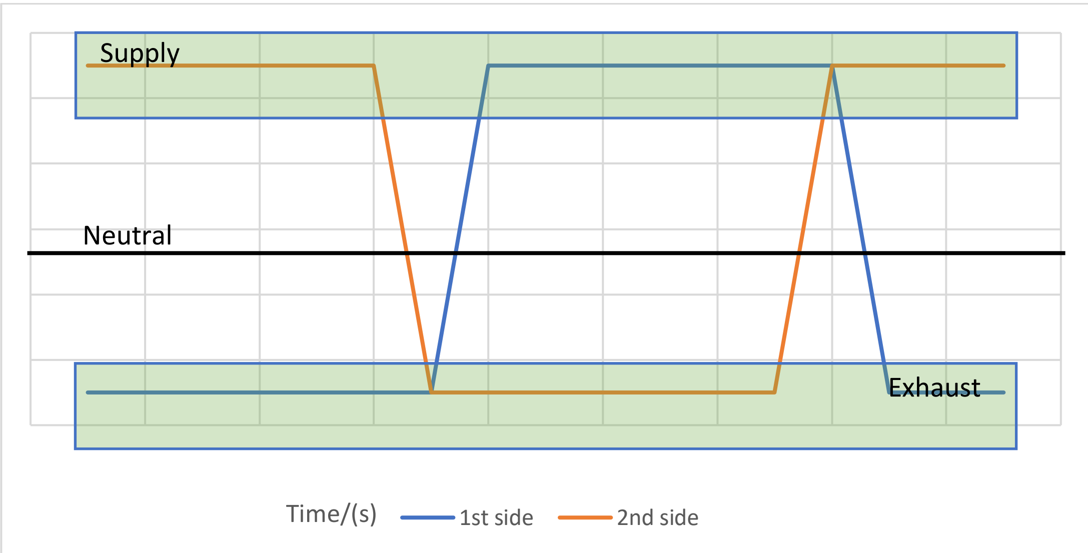


*Figure 7 Ventilation working*

Above figure 6 is a picture of the working time of the supply and exhaust.

First,  it takes sixty seconds to supply/exhaust, and the next ten seconds to ramp, to change direction. So, in total, a complete cycle of supply and exhaust would be exactly 160 seconds of supply and exhaust.

## 2.2 Measurements

The test materials were will be examined for temperature efficiency, copper and Constantine wires were taken and soldered exactly at the wires meeting point called the sensor point. This is to ensure which testing tool provides more accuracy temperature readings between thermocouples and psidac. The sensor was kept as thin as possible since a thicker sensor would be less sensitive to temperature changes. This is potentially important as the temperature changes continuously in the ventilation unit. Fast response in the temperature measurement is thus a nessessity for accurate measurements and conclusions. The developed thermocouples are later validated with TESTO temperature and airflow calculator for comparison, and the results varied no more than 0.2 °C to 0.5 °C in terms of temperature.

The ventilation unit was installed in a window at the Energy laboratory at Energy and Building Design. A wooden board is modified to hold the ventilation unit on the frame replacing the window, and the rest is covered with insulation material see figure 3. During the tests it is important to be able to place measurement divices in such way that the flow from the vntilation unit is directed to the measurement divice. If the flow can take alternative path, for instance on the side of the measurement device, then the readings will be wrong. It was therefore important to make sure that the ventilation unit was placed eavenly on the mounting board.

The following tests was performed for the unit

### 2.2.1 Tests to be conducted

I. Air flows
II. Draft
III. Air leakage
IV. Tracer gas (decay)
V. Short-circuiting
VI. Temperature efficiency

#### 2.2.1.1 Air flows

The Airflow is essential for HVAC. If the airflow is large enough indoor environment can be affected. Imperfect airflow can undermine the working performance of a ventilation unit [16].

### 2.2.1.2 **Draft**

The draft is the current of air present in the occupied space. The draft is felt when the bare skin like the neck, face, hands is exposed. According to the ASHRAE standards, the air velocity should not exceed 0.20/m/s and 0.15 m/s during winter time according to Swedish building regulation[17], [18]. Higher air movement than this limit might result in uneasiness.

### 2.2.1.3 **Tracer gas**

Tracer gas test is a commonly used ventilation test. There are various reasons to use this test [19],

1. Movement of air within the building
2. Building's airtightness
3. Air change per hour
4. Ventilation system's airflow rate

Moreover, the most significant tracer gas testing's are:

1. Decay test –
    - A certain amount of gas is released into the air, and a mixer fan ensures a constant concentration of the gas throughout the room. Then the ventilation system is turned on, the time it takes for the gas in the room decline measured[20].
2. A constant level of the flow-
    - The apparatus for the experiment remains the same, but the level of tracer gas is always maintained at the desired level. For example, 500 ppm is maintained at all levels when the levels go down some amount is again injected into the room[21].

Typical gases used in these tests are

A. formaldehyde
B. carbon di-oxide
C. dinitrogen oxide
D. sulphur hexaflouride
E. toluene

For a gas to be used as a tracer gas, it should have a particular set of physical and chemical properties. The gas should be, non-inflammable and should be non-toxic. Non-reactive with the construction materials of the ventilation unit. The density of tracer gas should be equal or lower than air so so that it does not just settle down to the floor right away. The gas used was dinitrogen oxide (nitrous oxide) in the Building physics department, and that will be utilized.

#### 2.2.1.4 Short-Circuiting

Just like current air flows in the path of least resistance. Short-circuiting occurs when airflow path from entry to exit in the room is shorter than its intended path occurring in the unit [22]. This is bad in terms of both air quality and heat recovery when the intake air is taken out without delivering the heat to the entire space. The total supply of air has been cut short, and the performance is affected, and the efficiency will be miscalculated. A short-circuit problem exists, addressing it takes precedence [23].

#### 2.2.1.5 Temperature efficiency

Testing the temperature efficiency is vital to calculate the efficiency of the Ceramic heat exchanger.measuring temperature efficiency helps us to calculate the heat transfer ratio of the heat exchnager. There are two methods to calculate the efficiency, (i)Log Mean Temperature difference(LMTD), (ii)Number of Transfer Units(NTU).

NTU concept is used in the case when there is too little information available to proceed with LMTD, when the inlet and the outlet temperatures are not mentioned [24].

## 2.3 Measurement equipments

#### 2.3.1.1 Thermocouples & PSIDAC

The thermocouple was construcred with copper and Constantan( a copper-nickle alloy). Some of these thermocouples broke during measurements and had re-soldered to continue measurements. The material used was led free[25].

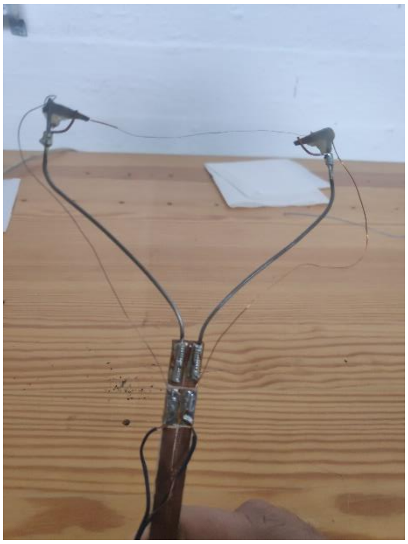

*Figure 8 Thermocouple repaired*

This is the soldering station to solder the thermocouples and whatever soldering to be done in the future.

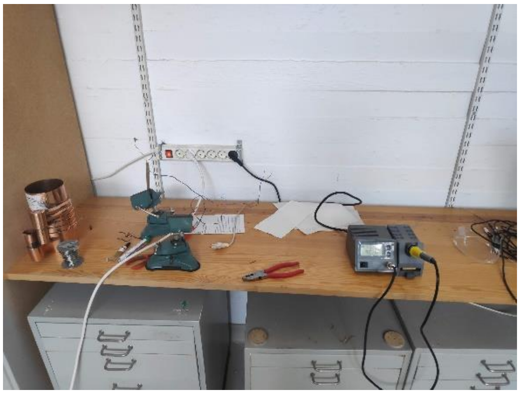

*Figure 9 Soldering workstation*

### 2.3.2 Initial Temperature change

The temperature change rate and efficiency of the thermocouple was tested under the following condition.

(i) in a duct with constant airflow

(ii) in a heated atmosphere of a box.

### 2.3.3 Temperature change in a box

*Figure 10 Thermocouple test station, Box and Duct*

The inside air of the box was heated to a known temperature, and the thermocouple was inserted to record the temperature reading.

### 2.3.4 Temperature and Relative humidity equipment speed test

PSIDAC is a moisture and temperature sensor. This sensor was also tested and calibrated

## 2.4 Measurement performance

### 2.4.1 Thermocouple

The test duct was sealed with a hairdryer to supply hot air. The equipment is set up with the CR1000 datalogger connected to a computer with the control software for CR1000 datalogger, with at least a 12volt battery backup for the current supply.

The tests were repeated atleast thrice to achieve statistical significance in the measured data.

The readings should be taken from loggernet application from the computer. For this process, a program is written through the shortcut option, as shown in the figure 11.

The equipment should be turned on and wait for the blower to heat the duct for approximately three minutes and the thermocouple is recorded in the room temperature first, and then it is placed in front of the duct for two minutes initially, and then to the room. This procedure was done a couple of times per each round of testing.

*Figure 11 Duct test work station*

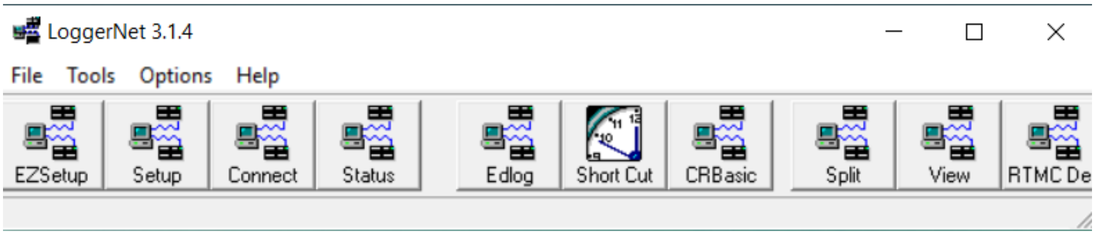


*Figure 12 Logger net Computer software*

### 2.4.2 Air supply and exhaust

This is one of the main experiments to be conducted for the determination of efficiency of the ventilation unit. An objective of this test is to measure airflow speed compared to the actual flow and the flow set in the website application.

Swema 125D is the tool used for this experiment; it is an excellent piece of machinery to measure the exhaust and supply air of the ventilation system. The hood dimension is about 650 mm×650 mm and it is to be to be attached to the supply and exhaust openings.

The equipment can measure airflow, Temperature and barometric pressure.

Air flow range – 1.5 l/s to 125 l/s, 5.4 m3/h to 450 m3/h, and in 2.3 CFM to 260 CFM.

It is equipped with a display, to toggle between l/s, m3/h, 0c, hPa.

In this equipment, the flow is influenced by the hood, and the flow can be restrained from its full potential. In this case, BackPressure(BP) is used in both the supply and exhaust cases. When the reading is taken, the throttle ring is placed on the opposite side of the flow direction, and most importantly, two readings should be taken one with the throttle ring and one without it. The Swema 125D calculates both the flows and gives the most accurate value, which determines the actual airflow rate of the ventilation unit.


*Figure 13 (a):Ring placement, (b):actual equipment*

### 2.4.3 **Drought**

The test room was emptied of all obstacles and was divided equally into 30 points that are half a meter apart. See figure 13,  This equipment is omnidirectional, and can catch a range of air velocities from 0.05 m/s to 3 m/s

*Figure 14 Swema 3000 Draught tester*

*Figure 15 Swema draft equipment and the space with measurement points marked on the floor*

The point starts at half a meter from the middle of the air openings in the equipment. It is then extended on all the sides with the same pitch.

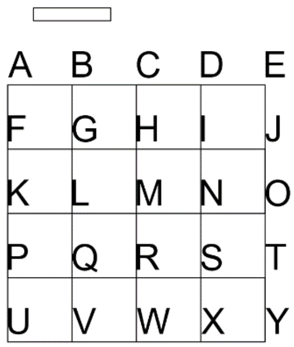


*Figure 16 measurement points and its labels*

Addressing the standards, the Swema equipment was fixed on to a tripod and was held at the height 1.7 m, 1.1 m, 0.6 m, and 0.1 m. The airflow was varied and the draft was measured under the following conditions, minimum flow(7 l/s), the medium (13l/s) and high flow (19l/s).

### 2.4.4 **Tracer gas**

Decay test and pulse test are the easiest to conduct, while constant injection tedious tests to perform while performing the tracer gas experminets [26]. Based on the information available, the decay tracer gas test was chosen. It is better to be considerate and make the process as simple as possible. The setup here comprises of two electronic machines from INNOVA air measurements (i) Innova 1303, (ii) Innova 1312 as seen in the figure 17.

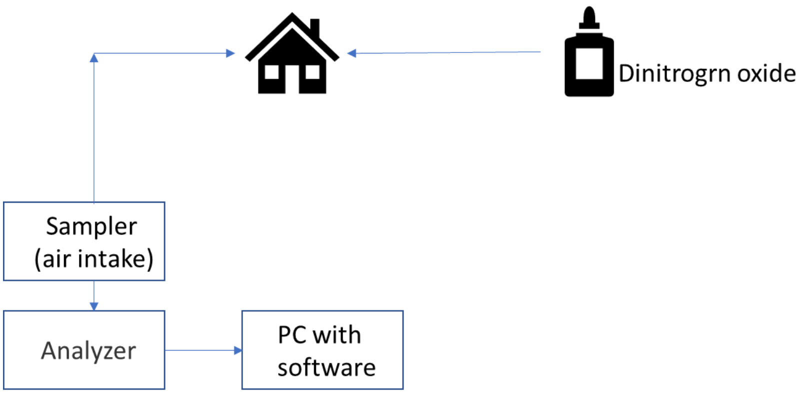


*Figure 17Layout of Tracer gas experiment*

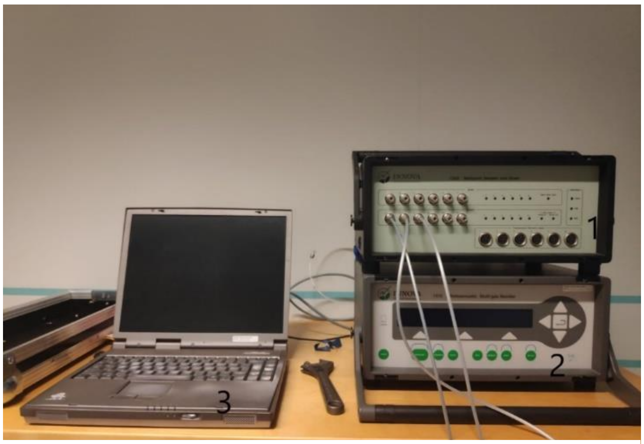


*Figure 18 1.Air sampler, 2.Analyzer, 3.PC with innova software. Tracer gas setup*

1. Air sampler - this equipment can hold up to six tubes for the sampling of intake gas. For more accurate and reading, all six ports are used for maximum accuracy of the gas readings inside the room.
2. Analyzer – it is connected to the sampler to calculate the concentration of gas and produce values connected to the pc.
3. PC – software installed for output of the results.

Six tubes of equal length are connected to the equipment in order to have an uniform gas intake. In this scenario, if there persists any delay or quick movement of the gases due to any external or internal factors, the equal length tubes will almost act at the same rate, which results in minimizing the error.

This experiment was conducted in the single space room of 29.5 cubic meters of a room. Nitrous oxide was used as the tracer gas and is, also known as laughing gas, which is used as a dental anesthetics[27].

200-500 ppm is the suggested range to be used for a small scale test, 200ppm was chosen as the benchmark value based on the room size, space, and the amount of human activity.proper care was taken so that the gas concentration never rises above 10,000 ppm.

Decay test is conducted under two circumstances, with fan on throughout the experiment for constant mixing of air. With the fan off after the initial mixing of air, where the ventilation unit was solely dependent on its function.

The whole experiment is conducted on three to five airflows of high, medium and low.

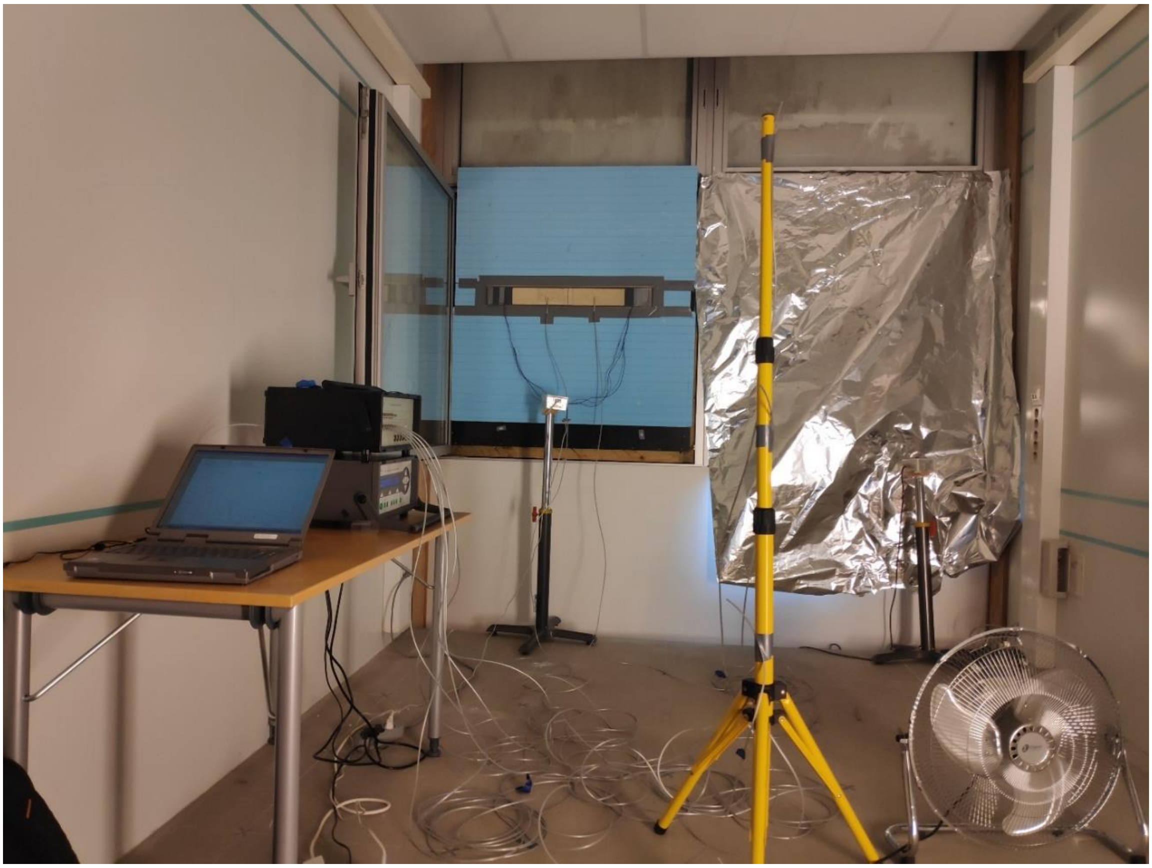

*Figure 19 Tracer gas room setup*

The room was completely sealed from all the possible points through with air can enter or exit; the ventilation systems were turned off and sealed with plastic covers and tapes. The decentralized ventilation unit was entirely closed, and the test is run to evaluate the airtightness of the room. The experiment was conducted with the fan turned on and- the space is completely sealed before the adequate amount of gas is released with no human presence. Then the fan is turned on for mixing of gas into the air all around the room for consistency. The software is set up before the ventilation is turned on, and the gas inlet tube placed into the sampler and other necessary details are entered in the software. The first airspeed from the ventilation unit is selected, and the equipment is turned on, and the experiment ran for 45-60 mins in total.

The experiment was repeated with the same ventilation airspeed for statistical significance before moving on to a different airspeed and to the second set of experiments with the fan off.

The values are taken and represented with a formula [26].

$$n = \frac{Ln(C1) - Ln(C2)}{t0 - t1}$$

Ln – log

C1 – Initial value

C2 – secondary value

T0 – time at reading one

T1 – time at reading two.

The formula takes the logarithmic values of the first, and the last and the slope value is provided, and the air change is calculated. In this modified formula, the values are taken from each value of the time gap of 40 seconds to acquire a more accurate decline of the gas.

### 2.4.5 Short-circuiting

This experiment is similar to that of the tracer gas equipment setup. The gas was continuously injected for approximately 8 minutes. Since the equipment has switching fan mechanism, summer mode is activated. First two minutes the air in the room was thoroughly mixed, and the next 8 minutes, the gas was injected at a low level, in the effort to maintain required tracer gas concentration. Moreover, for the rest of the time the air was circulated and record the exhaust system.

### 2.4.6 Temperature efficiency

Figure 20 thermocouples on the heat-exchangers and outside near the fans

Out of eight available thermocouples, four were placed as close as possible without touching the heat exchanger as shown in the figure 19, for an accurate reading. Two sensors were placed on each side of the heat exchanger, one each on the outside for entry/exit reading.

One thermocouple is placed outside for outdoor temperature and on the inside for indoor temperature, for the comparison of the room temperature and the exhaust air temperature, would give a brief understanding how well the temperatures vary.

The Eight thermocouples were fixed in the Datalogger CR1000, as shown in the figure 18.

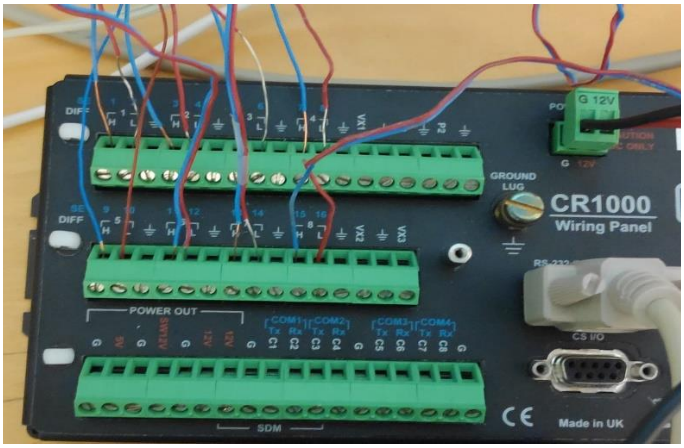


*Figure 21 CR 1000 with thermocouples connected*

The code is written through the shortcut option in the loggernet application in a computer, and the required details are entered. The datalogger can take in temperature differences ranging from -270°C to 400°C. The reading interval is recorded at 1 second, as shown in the software and the above picture the blue colour wire consisting of copper is attached to the High's and the Constantan in the red wire is connected to the Low's.

After all the data is entered and saved, the code is sent to the datalogger, the time should be synced, and the test is run for 24 hours. A heater is placed in the test space to raise temperature inside the room as the room was devoid of any heat sources. It is beneficial to have a heat source inside the room when the temperature is high as it would provide more explicit details of the heat exchanger capacity and efficiency.

$$\eta = \frac{Tin - To}{Tin1 - To}$$

Tin – temperature

To – Temperature outside

Tin1 – Temperature exhaust

# 3 Results

The results of the experiments conducted on Smartvent Decentralized ventilation unit is collected in this chapter.

## 3.1 Thermocouples

First step, the response time of the thermocouples were tested.

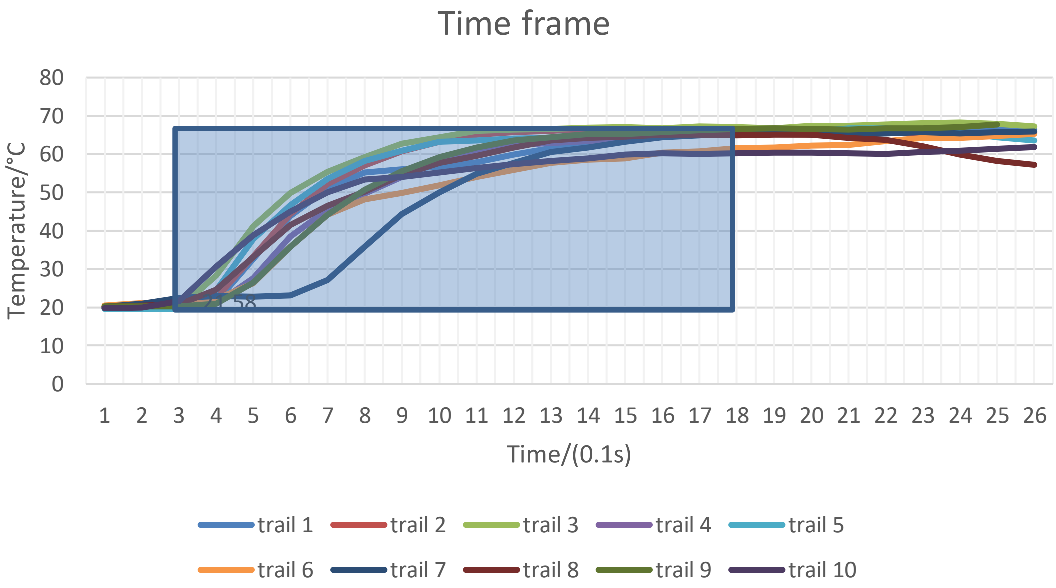


*Figure 22 Thermocouples response time (0.1s × x-axis)*

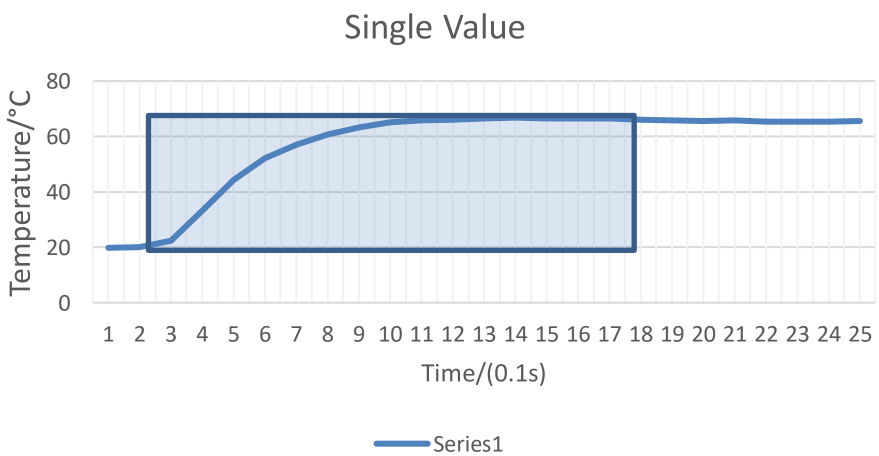


*Figure 23 Thermocouple 1 response time*

The average temperature of the room was measured to be around 21 °C, and in the duct it was 66 °C. So the average time for the temperature to go from room temperature to 66 °C – 1.53 seconds

Over ten trials, the temperature in the duct has reached a value ranging between 65 °C – 67 °C.

For the lowest temperature reaction reading, the overall average time 1.53 seconds allowed the temperature to reach only 71.5 % of the average measured duct temperature. In the best-case scenario, the average duct temperature is reached already at 1.2 seconds.

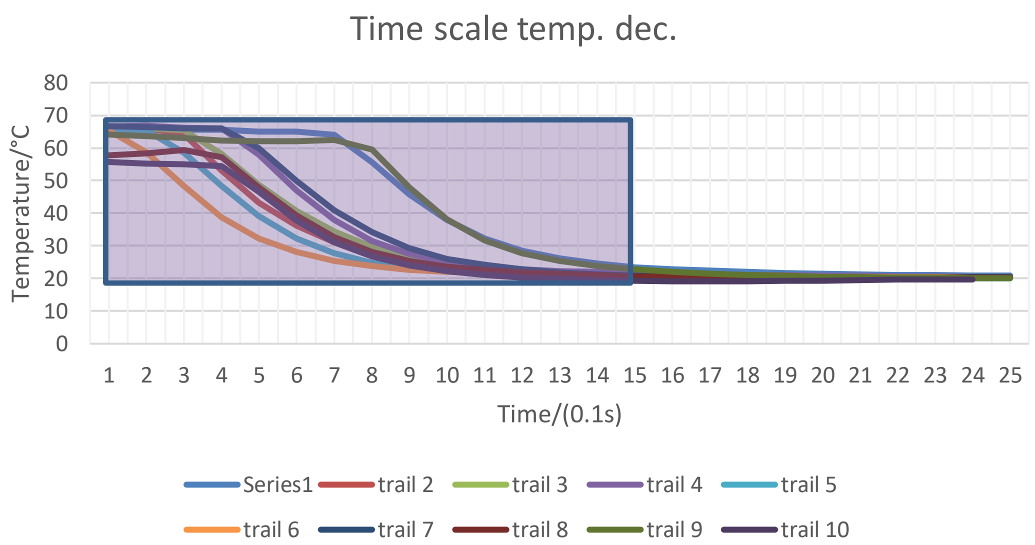


*Figure 24 Dcline temperature response time*

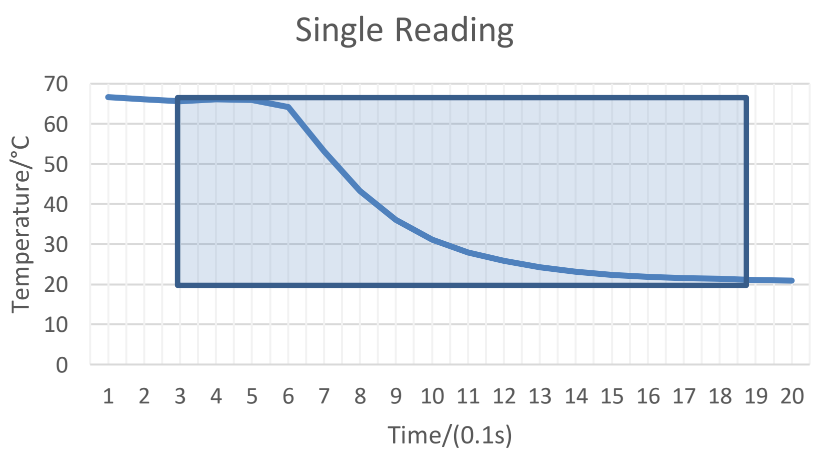

*Figure 25Thermocouple 1 Decline Tepmerature response time*

In the same setup, another experimental reading was to know the time  scale for the thermocouple to cool down to room temperature after exposure to high temperature.

Average time to reach to room temperature after exposure – 1.49 seconds, In the worst-case scenario, it required 25 % excess time to reach the optimal room temperature, i.e. is 2 seconds. Moreover, in the opposite case, the least time to reach the average is 1.2 seconds.

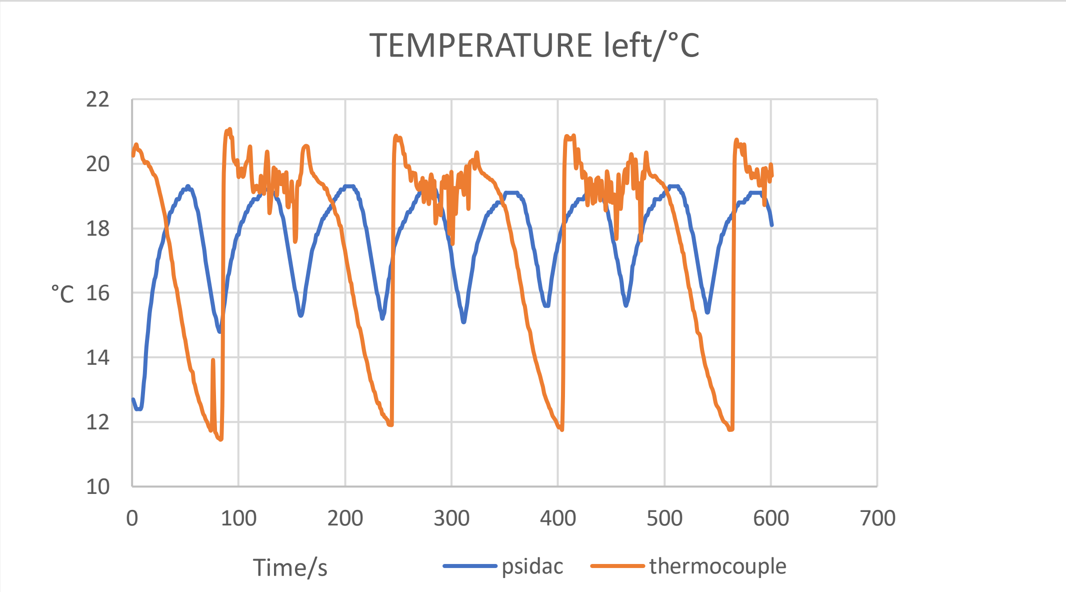


*Figure 26Temperature Reading difference between Psidac and thermocouples*

## 3.2 Psidac equipment tests

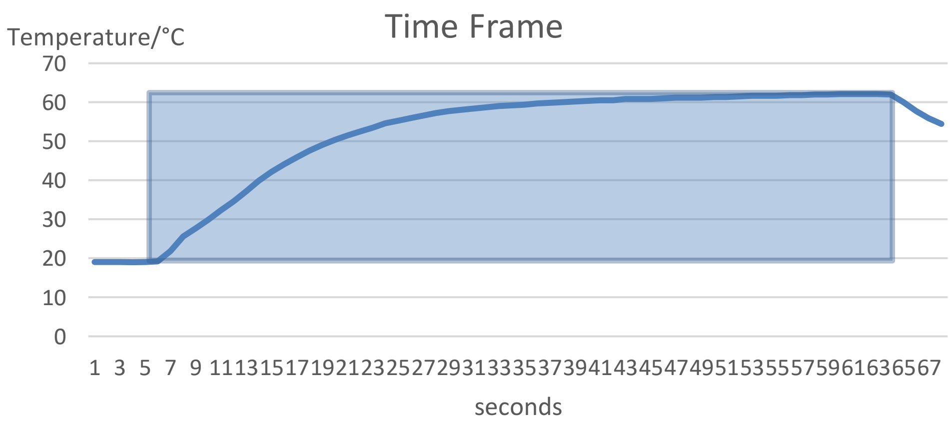


*Figure 27PSIDAC unit test time*

The average time for the Temperature and the moisture equipment to rise from room temperature inside the room to hit the peak readings  is approximately 1 minute.

There is a difference in the response curves of psidac and the thermocouples; the thermocouples follow the thermal profile of the ventilation unit. Whereas psidac has different temperature readings, due to the reaction time of the sensors.

## 3.3 Airflow supply and exhaustflow test

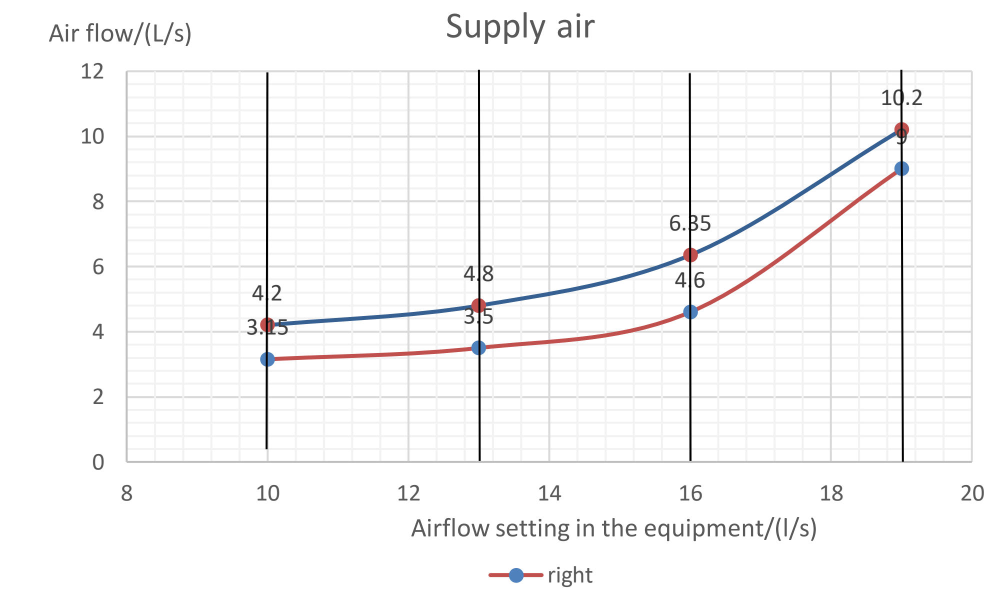


*Figure 28 Supply airflow*

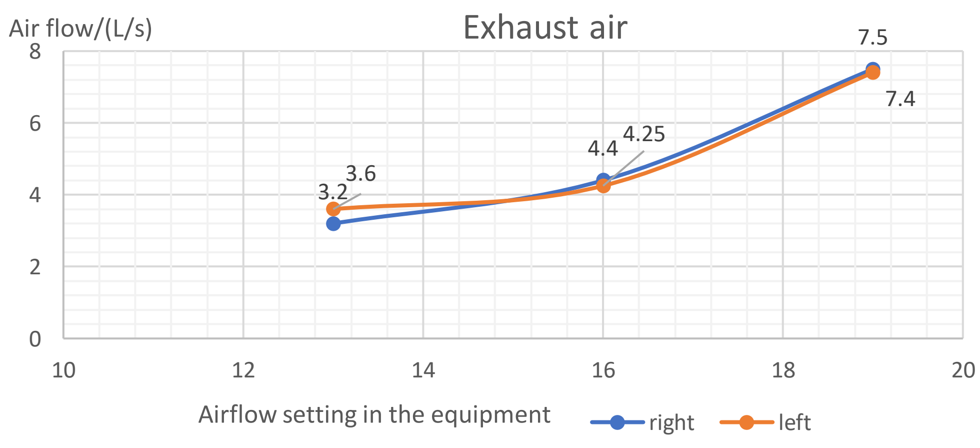


*Figure 29 Exhaust air flow*

*Table 1Actual airflow in comparision with the web application settings*

| Supply flow/(l/s) | Right flow/(l/s) | Left flow/(l/s) |
|---|---|---|
| 19 | 9 | 10.2 |
| 16 | 4.6 | 6.35 |
| 13 | 3.5 | 4.8 |
| 10 | 3.15 | 4.2 |
| Exhaust | right | left |
| 19 | 7.5 | 7.4 |
| 16 | 4.4 | 4.25 |
| 13 | 3.2 | 3.6 |

The airflow chosen in the controller application varies a lot during the testing phase. This is due to the unavailability of a control system for the new device, so the old control system was linked for the time being.

The variation of airflow from the chosen value and the actual output flow varies from 50 % to 75 %. Since the swema equipment cant read any airflow below 2 l/s the exhaust airflow varies at a rate of 80 %.

## 3.4 Air Velocity, draught tests

This test is performed to examine the airvelocity in the room and record the presence of draft inside the room. The swema equipment is first placed in front of the equipment half a meter apart, and the readings were taken following the standards. Total draft from each airspeed varies, for some airspeed, the draft is negligible and non-existent.

The highest values according to the test height

*Table 2Draft in accordance to height and airflow*

| Airflow | 19/(l/s) | 13/(l/s) | 7/(l/s) |
|---|---|---|---|
| Height above floor | | | |
| 0.6 | 0.0108 | 0 | 0.00087 |
| 1.1 | 0.01 | 0.0101 | 0.01 |
| 1.7 | 0.010 | 0 | 0 |

## 3.5 Short-circuiting

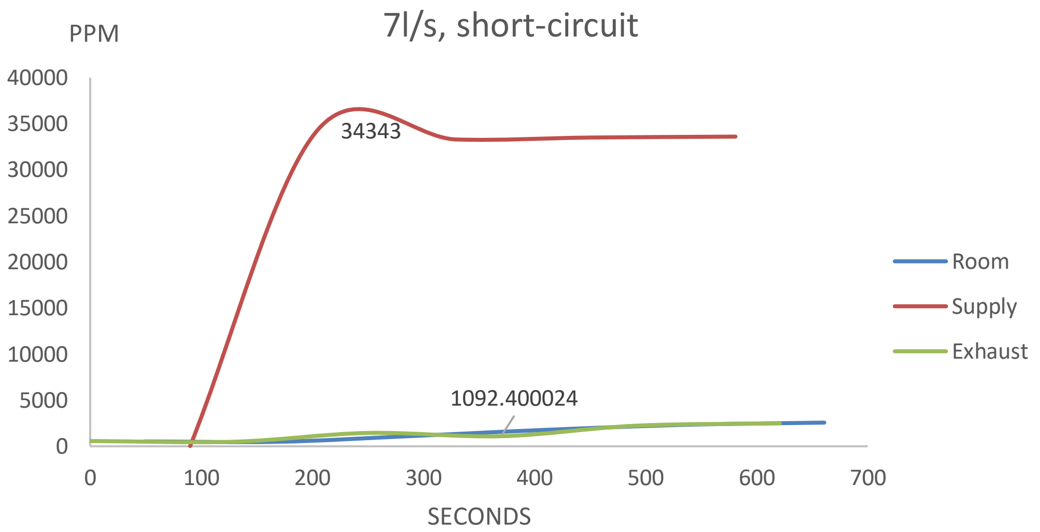


*Figure 30Lowest airflow short-circuit test*

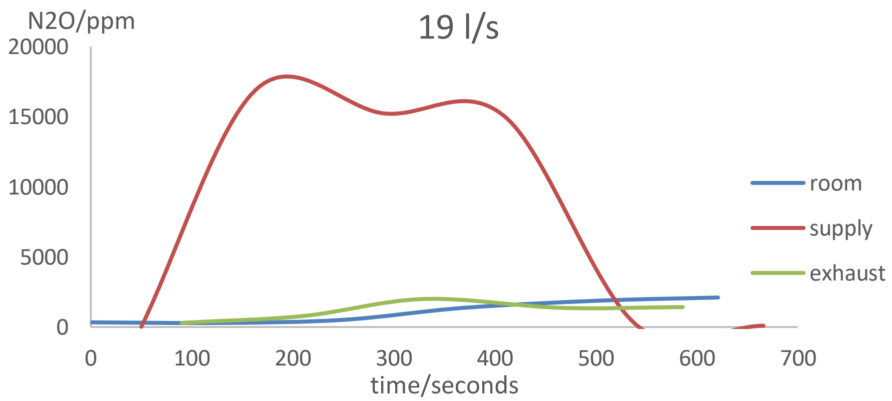


*Figure 31high airflow short-circuit test*

The results indicate the rise of supply concentration due to constant injection, the gas reading inside the room and the reading at the exhaust are at par at the same level. The equipment records the data every 40 seconds between each value, so there is an increase in forty seconds from room to the exhaust values due to a constant injection of the tracer gas. As seen in the figure 30 and 31, there is no or less probability of short-circuiting.

## 3.6 Air leakage

The air escaping the room through leaks, cracks. This test results indicate the airchange without using the ventilation unit, this value is then deducted from the actual ACH of the airflow values

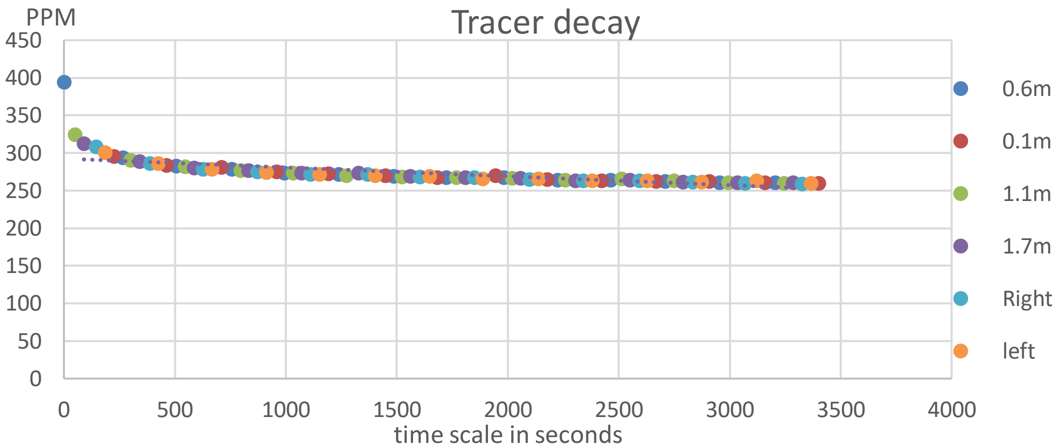


*Figure 32 ACH in airtight room*

Air leakage average value = 0.22

## 3.7 Tracer gas

Two types of test results is presented one being fan-on where the air is constsntly mixed with the help of a portable fan, and the second without the mixing of air.

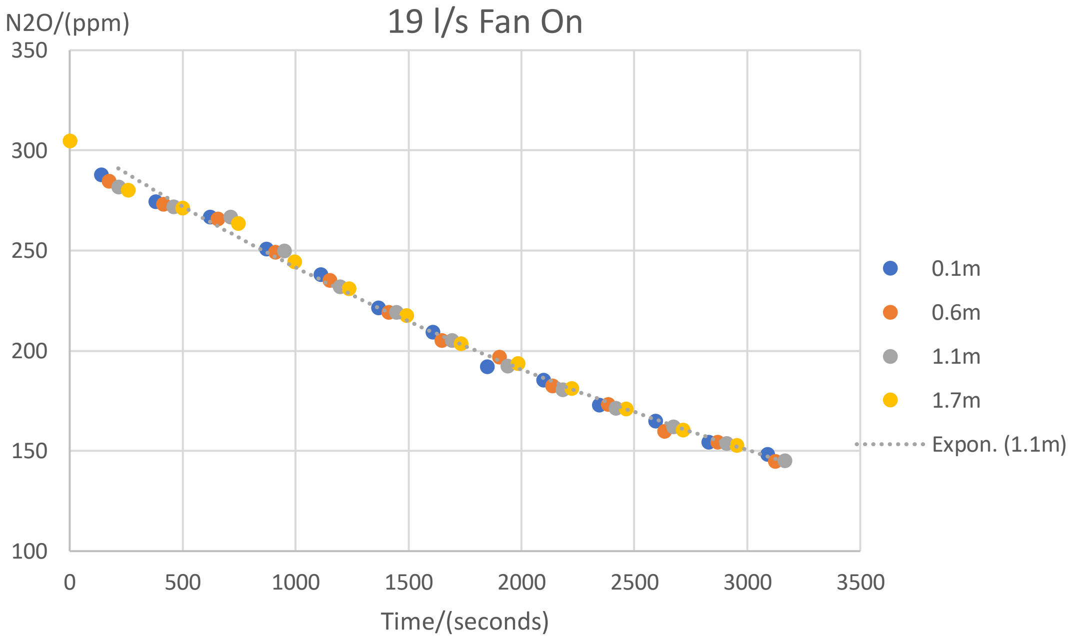


*Figure 33 ACH with mixing fan turned on*

Mixing fan-on air change value – 0.84

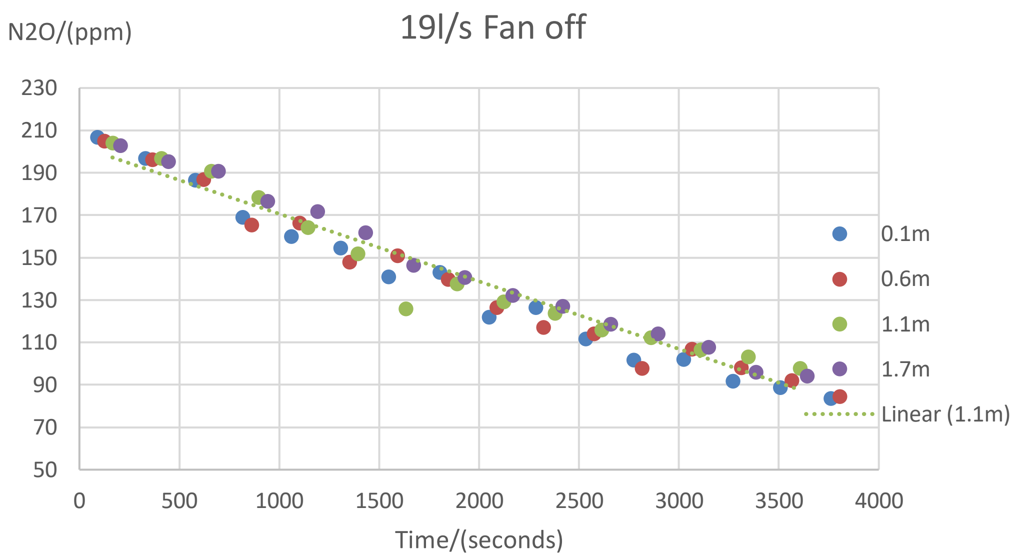


*Figure 34 ACH with mixing fan turned off*

Mixing Fan off-air change value – 0.84

Comparing the fan-on and fan-off, which contributes to the mixing of air, the overall decay of the gas concentration inside the building does not vary significantly. The rate of change is not consistent at different levels of the room**.**

Table 2 and figure 25 describes the average air change rate per hour concerning the airflow accordingly.

*Table 3air change per hour according to the airspeed*

| Airflow/(l/s) | Mixing fan-on/(ACH) | Mixing fan-off/(ACH) |
|---|---|---|
| 7 | 0.33 | 0.325 |
| 10 | 0.499 | 0.405 |
| 13 | 0.455 | 0.46 |
| 16 | 0.54 | 0.44 |
| 19 | 0.8 | 0.825 |

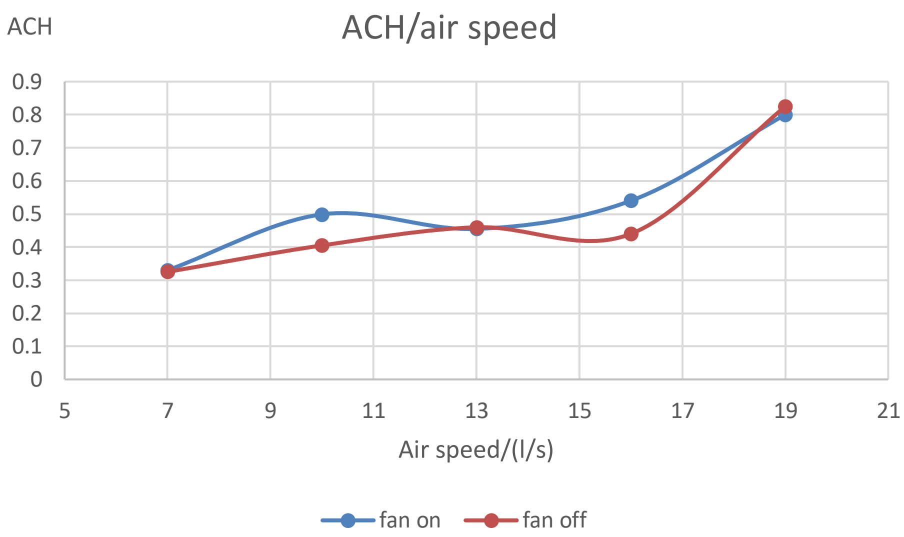


*Figure 35 airspeed difference of mixing fan(on and off)*

## 3.8 Temperature efficiency

*(the test values are still uncertain, it will be examined and presented in the later report with more accuracy)*

In Figure 36, it depicts the air supply heat-exchanger efficiency, on the left blue represents the left supply and exhaust rea of the ventilation unit and the red represents the right side.. The efficiency varies due to the difference in the airflow. From the left supply the full running time of 60 seconds the efficiency is about 68 % and during its ramp down the efficiency is about 21 %. From the right supply full running time efficiency would be 85 % and the revamp time is about 46 %.

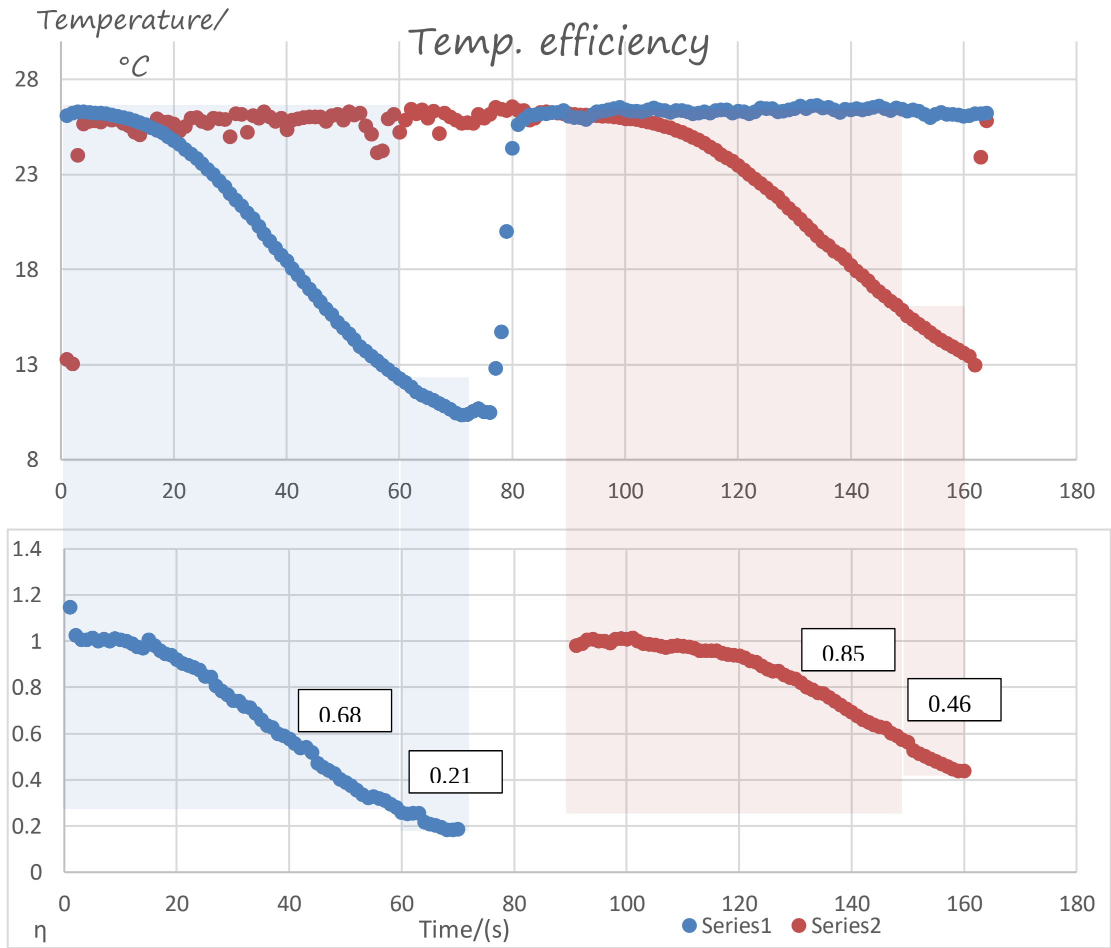


*Figure 36 19L/S Heat exchanger efficiency*

| Airflow | Left efficiency | Right efficiency |
|---|---|---|
| 19 L/s | 45 % | 65 % |
| 13 l/s | 62 % | 77 % |
| 7 L/s | 54 % | 66.5 % |
| | | |

# 4 Discussion & conclusion

An important thing to notice here is that during the extra seconds of exhaust, there are almost twenty seconds of no full potential of air supply and only exhaust will lead to under pressure inside the space. Vice versa, when there is excess supply, there is going to be overpressure.

## 4.1 Thermocouples

It was an arduous task to solder the ultra thin wires for the thermocouple, but the ultra thin thermocouples provided accurate temperature readings with a short recovery time. During the initial times to soldering these materials, it was hard to handle the fragile material. To find the differences between a thermocouple wire and a strand of hair would be difficult, we had to find new material.

In conclusion, the copper and constantin thermocouple temperature change happens in a range of 1.5 seconds to a maximum of 2 seconds was its reaction time, and deemed to be the most reliable compared to the PSIDAC 40 seconds to 60 seconds reaction time.

## 4.2 Airflows

This test was the first and foremost important thing to consider to evaluate a ventilation system when details were unknown beforehand. It is noted from the results that one fan performs approximately 10 % better than the other, and there could be various reasons differences in the fan and its power, misplaced fans, no equal power supply. Regarding its electrical wire connections, we do not have any information, of the internal wiring schematic,and it is not to tamper with it. The airflows are relatively very small to its web application control settings, so the maximum potential of airspeed of this ventilation system is hard to measure unless there is a change in the application airspeed setting. The maximum speed is 10.2/(l/s). The controls in web application of the ventilation unit was developed for a previous ventilation unit, a totally different machine created by Smartvent, that was the reason of the drastic difference.

## 4.3 Draught

A cold draft is a common issue when the airflow doesn't follow the intended flow pattern and the movement of air is not proper. The results suggest that the draft is at all par way below the normal limit in the occupancy zone in the room. The draft may vary in terms of room size, the placement of the equipment on the wall and the things surrounding it and the indoor environment.

## 4.4 Air leakage

The average airleakage is 0.22, which then would be reduced from the actual ACH from the results, so the maximum ACH of the highest airflow would be around 0.6.

## 4.5 Tracer gas air change rate

The quality of the indoor environment is the prime factor to use any technology for comfort, the measurements of tracer gas concentrations is one measure that is important for air quality. Air change per hour simply means the percentage of air replaced in a space in one hour and the minimum advised air change per hour according to the ashrae standards is 0.35. This ventilation equipment in a room size of 33 cubic meters is around 0.6 which is good quality indoor environment [28]. During the testing phase, there have been drawbacks which lead to redoing the same tests again. Firstly the room was not adequately sealed; secondly, the pre-existing ventilation system wasn't examined of its working conditions due to inadequate inspection, which led to overestimation of performance of the ventilation unit. This error correction was after a precise inspection, which resulted in the correct values.

## 4.6 Short-circuiting

The performance of the ventilation will be affected if there exists a short-circuiting. The supply and the exhaust is located at close proximity to each other, due to which the air movement and speed the airflow into the room can be short-circuited, thereby affecting the air change and the indoor environment. During testing, it has been proved that there is almost low to no short circuit of air, which hows that the equipment performs better in many aspects. Considering the airflows, the higher the speed, the lower the short-circuit due to the force the air is pushed into the room and vice versa. It was expected if the room values correspond to the exhaust at a particular period of gas deacy values.

## 4.7 Temperature efficiency

Due to the rotating fans, it was hard to derive a formula that can be used to calculate the temperature efficiency of the decentralized ventilation system. It is hard to derivate how accurate the values and efficiency are due to the different air flows between the heatexchnagers, and mostly due to rotating fans. After many attempts, the most reasonable and accurate values have been derived. The supply and exhaust airflow have different revamp time and the speed during that period made it difficult to formulate to derive efficiency. Therefore, the values are taken manually and calculated, and many doubts and inaccuracy have emerged. Based on the performance study it cant be concluded yet on the performance of this parameter. Further research is needed.

## References


[1] "HVAC: A Brief History of Heat, Cooling, and Air Conditioning," *HVAC Tech*, 07-Jan-2015. [Online]. Available: https://www.hvac-tech.com/hvac-a-brief-history-of-heat-cooling-and-air-conditioning/. [Accessed: 08-Mar-2020].

[2] "Ben Franklin's inventions: the Franklin stove." [Online]. Available: https://www.ushistory.org/franklin/science/stove.htm. [Accessed: 17-Mar-2020].

[3] "History of Air Conditioning," *Energy.gov*. [Online]. Available: https://www.energy.gov/articles/history-air-conditioning. [Accessed: 08-Mar-2020].

[4] "Who Invented Air Conditioning?," *Time*. [Online]. Available: https://time.com/4423959/air-conditioning-invention/. [Accessed: 08-Mar-2020].

[5] Y. Al horr, M. Arif, M. Katafygiotou, A. Mazroei, A. Kaushik, and E. Elsarrag, "Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature," *Int. J. Sustain. Built Environ.*, vol. 5, no. 1, pp. 1–11, Jun. 2016, doi: 10.1016/j.ijsbe.2016.03.006.

[6] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," *Energy Build.*, vol. 40, no. 3, pp. 394–398, Jan. 2008, doi: 10.1016/j.enbuild.2007.03.007.

[7] X. Cao, X. Dai, and J. Liu, "Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade," *Energy Build.*, vol. 128, pp. 198–213, Sep. 2016, doi: 10.1016/j.enbuild.2016.06.089.

[8] M. Åberg and D. Henning, "Optimisation of a Swedish district heating system with reduced heat demand due to energy efficiency measures in residential buildings," *Energy Policy*, vol. 39, no. 12, pp. 7839–7852, Dec. 2011, doi: 10.1016/j.enpol.2011.09.031.

[9] fernbas, "Energy performance of buildings directive," *Energy - European Commission*, 16-May-2019. [Online]. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en. [Accessed: 17-Mar-2020].

[10] "Why I'm Not a Fan of Positive Pressure Mechanical Ventilation," *Energy Vanguard*. [Online]. Available:

https://www.energyvanguard.com/blog/54084/Why-I-m-Not-a-Fan-of-Positive-Pressure-Mechanical-Ventilation. [Accessed: 17-Mar-2020].

[11] 1201 New York Avenue and NW, “Cooling Your Home but Warming the Planet: How We Can Stop Air Conditioning from Worsening Climate Change,” *Climate Institute*. [Online]. Available: https://climate.org/cooling-your-home-but-warming-the-planet-how-we-can-stop-air-conditioning-from-worsening-climate-change/. [Accessed: 09-Jan-2020].

[12] F. Engdahl, “Evaluation of Swedish ventilation systems,” *Build. Environ.*, vol. 33, no. 4, pp. 197–200, Jul. 1998, doi: 10.1016/S0360-1323(97)00040-1.

[13] F. Coydon, S. Herkel, T. Kuber, J. Pfafferott, and S. Himmelsbach, “Energy performance of façade integrated decentralised ventilation systems,” *Energy Build.*, vol. 107, pp. 172–180, Nov. 2015, doi: 10.1016/j.enbuild.2015.08.015.

[14] “03_Reqs_and_testing_procedures_ventilation_en.pdf.” .

[15] B. Sunden, “High Temperature Heat Exchangers (HTHE),” p. 13.

[16] “How to Check Your HVAC Airflow and What It Means,” *Detmer and Sons*, 16-May-2019. [Online]. Available: http://www.detmersons.com/how-to-check-your-hvac-airflow-and-what-it-means/. [Accessed: 03-Mar-2020].

[17] “ANSI/ASHRAE Addendum d to ANSI/ASHRAE Standard 55-2013,” p. 8.

[18] A. Aganovic, M. Steffensen, and G. Cao, “CFD study of the air distribution and occupant draught sensation in a patient ward equipped with protected zone ventilation,” *Build. Environ.*, vol. 162, p. 106279, Sep. 2019, doi: 10.1016/j.buildenv.2019.106279.

[19] C. Afonso, “Tracer gas technique for measurement of air infiltration and natural ventilation: case studies and new devices for measurement of mechanical air ventilation in ducts,” *Int. J. Low-Carbon Technol.*, vol. 10, no. 3, pp. 188–204, Sep. 2015, doi: 10.1093/ijlct/ctt025.

[20] S. Cui, M. Cohen, P. Stabat, and D. Marchio, “CO2 tracer gas concentration decay method for measuring air change rate,” *Build. Environ.*, vol. 84, pp. 162–169, Jan. 2015, doi: 10.1016/j.buildenv.2014.11.007.

[21] G. Remion, B. Moujalled, and M. El Mankibi, “Review of tracer gas-based methods for the characterization of natural ventilation performance:

Comparative analysis of their accuracy," *Build. Environ.*, vol. 160, p. 106180, Aug. 2019, doi: 10.1016/j.buildenv.2019.106180.

[22] P. H. Improvement, "What is Short-Circuiting? - Pro Home Improvement." [Online]. Available: https://prohomemi.com/what-is-short-circuiting/. [Accessed: 02-Mar-2020].

[23] H. Manz, H. Huber, and D. Helfenfinger, "Impact of air leakages and short circuits in ventilation units with heat recovery on ventilation efficiency and energy requirements for heating," *Energy Build.*, vol. 33, no. 2, pp. 133–139, Jan. 2001, doi: 10.1016/S0378-7788(00)00077-3.

[24] A. Fakheri, "Heat Exchanger Efficiency," *J. Heat Transf.*, vol. 129, no. 9, pp. 1268–1276, Sep. 2007, doi: 10.1115/1.2739620.

[25] M. Radajewski, S. Decker, and L. Krüger, "Direct temperature measurement via thermocouples within an SPS/FAST graphite tool," *Measurement*, vol. 147, p. 106863, Dec. 2019, doi: 10.1016/j.measurement.2019.106863.

[26] M. H. Sherman, "Tracer-gas techniques for measuring ventilation in a single zone," *Build. Environ.*, vol. 25, no. 4, pp. 365–374, Jan. 1990, doi: 10.1016/0360-1323(90)90010-O.

[27] "Nitrous Oxide: Can You Overdose? How Much Is Lethal? - Oxford Treatmen," *Oxford Treatment Center*. [Online]. Available: https://www.oxfordtreatment.com/prescription-drug-abuse/nitrous-oxide/overdose/. [Accessed: 03-Mar-2020].

[28] O. US EPA, "How much ventilation do I need in my home to improve indoor air quality?," *US EPA*, 19-Feb-2019. [Online]. Available: https://www.epa.gov/indoor-air-quality-iaq/how-much-ventilation-do-i-need-my-home-improve-indoor-air-quality. [Accessed: 08-Mar-2020].

LUND UNIVERSITY

Dept of Architecture and Built Environment: Division of Energy and Building Design

Dept of Building and Environmental Technology: Divisions of Building Physics and Building Services