KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING & DESIGN FACULTY

Srinivasan Sekar

DESIGN AND ANALYSIS OF A COMPACT WASTE HEAT RECOVERY UNIT FOR SMALL PREMISES

Final project for Master degree

Supervisor
Assoc. Prof. Dr. Sigitas Kilikevičius

KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING & DESIGN FACULTY
MECHANICAL ENGINEERING DEPARTMENT

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Final project for Master degree
Master's in Mechanical Engineering (621H30001)

Supervisor
(signature) Assoc. Prof. Dr. Sigitas Kilikevičius
(date)

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KAUNAS, 2015

KAUNAS UNIVERSITY OF TECHNOLOGY

Mechanical Engineering & Design Faculty

Srinivasan Sekar

Master’s in Mechanical Engineering, 621H30001

Design and analysis of a compact waste heat recovery unit for small premises

DECLARATION OF ACADEMIC HONESTY

12 June 2015

Kaunas

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Approved:

Head of Mechanical Engineering Department

(Signature, date)

Vytautas Grigas
(Name, Surname)

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Design and analysis of a compact waste heat recovery unit for small premises

Approved by the Dean 2015 y. May m.11d. Order No.ST17-F-11-2

2. Aim of the project

To design a compact waste heat recovery unit for small premises and to investigate the airflow characteristics.

3. Structure of the project

Summary
Introduction, Literature review (Selection of heat exchanger type and the materials), Waste heat recovery unit (Selection of filter and fan), Investigation of airflow characteristics (Calculation of heat recovery efficiency, Airflow in full room, Experimental study & Numerical simulation of the airflow produced by the unit)

4. Requirements and conditions

1. A waste heat recovery unit should be suitable for use in premises of an area up to 45 m^2
2. The waste heat recovery unit should not exceeded the dimensions of 400x365x120 mm
3. A possibility to change the volume of the produced airflow

5. This task assignment is an integral part of the final project

6. Project submission deadline: 1^{st} June 2015

Given to the student
Srinivasan Sekar

Task Assignment received	Srinivasan Sekar (*Name, Surname of the Student*)	(*Signature, date*)
Supervisor	Sigitas Kilikevičius (*Position, Name, Surname*)	(*Signature, date*)

Sekar Srinivasan. Design and analysis of a compact waste heat recovery unit for small premises. *Master's in Mechanical Engineering* final project / supervisor Assoc. Prof. Dr. Sigitas Kilikevičius; Kaunas University of Technology, Mechanical Engineering & Design faculty, Mechanical Engineering department.

Kaunas, 2015. 51p.

SUMMARY

The work deals with simple heat recovery system which is reliable in providing warm & fresh air to the small room with low cost and low maintenance. The purpose of this work is to design a compact waste heat recovery unit for small premises and investigate the airflow characteristics. A design of the unit is proposed and a prototype is manufactured, which was tested in both numerical simulation & experiments using a pressure chamber to obtain airflow- static pressure curves. The unit was designed using SolidWorks computer aided design software and the simulation was carried out using SolidWorks Flow Simulation computational fluid dynamics software. The experiments & simulation were carried out with a use of different fans to see the difference in airflow, static pressure. The numerical simulation results show a good agreement with the results of experimental investigation. Also, the numerical simulation shows that depending on the fan or its speed, the heat recovery efficiency of the device can be achieved up to 55 %. The research indicates that the device is suitable for use in a small residential building up to 45 m^2.

Keywords: Waste Heat Recovery, Heat Exchanger, Heat Recovery Ventilator Systems

Sekar Srinivasan. Kompaktiško šalinamo oro šilumą grąžinančio įrenginio mažų patalpų vėdinimui projektavimas ir tyrimas. *Mechanikos inžinerijos magistro* baigiamasis projektas / vadovas doc. dr. Sigitas Kilikevičius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas, Mechanikos inžinerijos katedra.

Kaunas, 2015. 51 psl.

SANTRAUKA

Darbe nagrinėjama paprasta pigi, nereikalaujanti intensyvios priežiūros, šalinamo oro šilumą į patalpas grąžinanti ventiliacijos sistema. Darbe tikslas suprojektuoti kompaktišką šalinamo oro šilumą grąžinantį įrenginį, skirtą mažų patalpų vėdinimui ir ištirti jo sukuriamų oro srautų parametrus. Pasiūlytas įrenginio projektas ir pagamintas prototipas, kuris išbandytas atliekant skaitinį modeliavimą ir eksperimentinius tyrimus naudojant slėgio kamerą tam, kad būtų nustatytos įrenginio sukuriamo oro srauto priklausomybės nuo slėgio. Įrenginys suprojektuotas naudojant SolidWorks kompiuterinio projektavimo programinę įrangą, o skaitinis modeliavimas atliktas SolidWorks Flow Simulation skaičiuojamosios skysčių dinamikos programine įranga. Modeliavimas ir eksperimentai atlikti naudojant keletą ventiliatorių tam, kad nustatyti oro srauto ir slėgio pokyčius. Atliktų skaitinių ir eksperimentinių tyrimų rezultatai gerai sutapo. Taip pat, skaitinis modeliavimas parodė, kad priklausomai nuo naudojamo ventiliatoriaus ar jo greičio, šilumos grąžinimo naudingumo koeficientas gali siekti iki 55 %. Atlikti tyrimai parodė, kad įrenginys yra tinkamas naudoti nedidelėse patalpose, kurių plotas yra iki 45 m^2.

Raktiniai žodžiai: šalinamo oro šilumos grąžinimas, šilumokaitis, ventiliacinės sistemos

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is then “dumped” into the environment and not reused for useful and economic purposes. The essential fact is not the amount of heat, but rather its “value”. The mechanism to recover the unused heat depends on the temperature of the waste heat gases and the economics involved. Large quantities of hot flue gases are generated from boilers, kilns, ovens and furnaces. If some of the waste heat could be recovered then a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and adopting the following measures as outlined in this chapter can minimize losses. For so waste heat recovery unit is used. Waste heat recovery unit offer many advantages to small home, small office, and society as a whole [1].

In general, Heat recovery ventilation system (HRV) and other ventilator systems provide significant amount of warm air to the room with a high cost with low heat recover efficiency. But in this case, the project is a simple heat recovery system which is reliable in providing warm & fresh air to the small room (45 m^2) with low cost, low maintenance & aiming to achieve high heat recovery. The main role of this unit is heat recovery and the core of heat recovery is the heat exchanger and it uses the exhaust airflow to pre-heat or pre-cool the incoming fresh air, without mixing of two airstreams. Heat recovery is the valuable alternative advance to improve overall efficiency and reclaim the waste heat.

The main aim of this work is to **design a compact waste heat recovery unit for small premises (approximately 45 m^2) and to investigate the airflow characteristics**. The major tasks raised to reach the main aim are:

1. literature on the topic has to be reviewed for the selection of heat exchanger type and the material as a whole;
2. a prototype of waste heat recovery unit has to be designed and manufactured;
3. simulation of airflow in the unit has to be done for the calculation of heat recovery efficiency;
4. airflow – static pressure characteristics of the unit has to be obtained by an experimental study and numerical simulation;
5. comparison of experimental study results and numerical simulation results has to be carried out;
6. the simulation of airflow in design unit inside the room has to be carried out.

1 LITERATURE REVIEW

1.1 Energy Recovery Technology

Heat exchangers can be classified into two basic categories based on the process of heat transfer: recuperative and regenerative. Recuperative heat exchangers are characterized by one fluid continuously recovery heat directly from the other fluid, either by direct contact between the fluids or, in the case of ventilation heat recovery, through a separating wall. Regenerative heat exchangers use an intermediate storage medium to transfer energy to and from the two airstreams. The airstreams may alternately occupy a single flow passage containing the storage medium or the storage medium may move between the two airstreams [2].

Heat exchangers used for ventilation heat recovery can be further classified into those which recover sensible energy only (commonly referred to as “heat recovery ventilators” or HRVs) and those which recover sensible energy and latent energy (commonly referred to as “energy recovery ventilators” or ERVs). ERVs are most commonly used in hot climates where the latent portion of the cooling load dominates, while HRVs are common in cold climates where heating load dominates [2].

1.2 Existing Heat Recovery Devices

1.2.1 Heat Recovery Ventilation (HRV)

Heat recovery ventilation (HRV) is in some ways similar to a balanced ventilation system, it uses the extracted warm air to heat the incoming cold air flow, without both streams being mixed [3]. Generally, such heat transfer unit consists of two fans:

- draws air outside from the premise;
- lets in the fresh air [3].

What makes HRV unique is the heat exchange unit. The heat exchange unit employs a counter-flow heat exchanger (counter current heat exchange) between the inbound and outbound air flow, in the same manner as does the radiator in your vehicle; conveying the heat from the engine to the external environment. The HRV consists of a narrow channel changing series through which air flows enter and leave. The incoming cool air flowing from the outside into the house is being heated by the warm air flow, but the air flows do not mix (see Fig 1.1) [3].

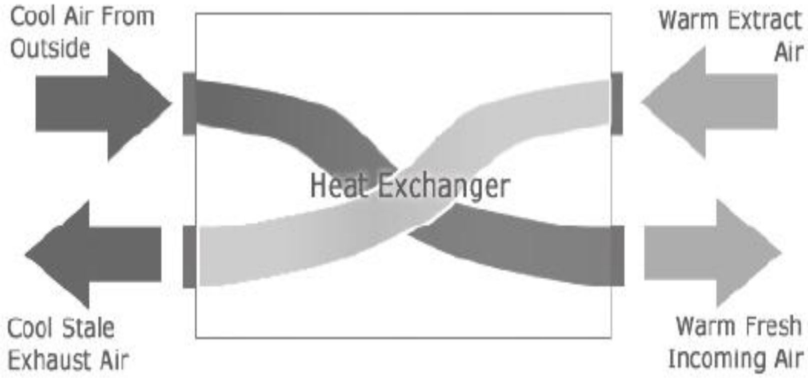

Figure 1.1-Heat exchanger unit activity diagram [3]

1.2.2 ERV

Energy recovery ventilation (ERV) is a heat and humidity exchanger, where the two incoming air-streams are fresh outside air (feed) and stale room exhaust air (sweep). The ERV use the energy difference between the two air streams and no external energy is supplied to the unit. Since the ERV is a passive component, it requires a differential of heat and humidity between the air-streams to have something to exchange. The only thing that separates the air-streams is a thin membrane layer which is vapour-permeable, so both heat and humidity are able to pass through the membrane when they flow through the unit. In the winter, heat and humidity will be recovered from the exhaust air and in the summer, heat and moisture in the incoming air will be transferred to the exhaust air-stream to cool and dehumidify the incoming air [4].

1.3 Commercial Waste Heat Recovery Devices

1.3.1 Recuperators

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Ducts or tubes carry the air for combustion to be preheated, The other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in Fig 1.2 [5].

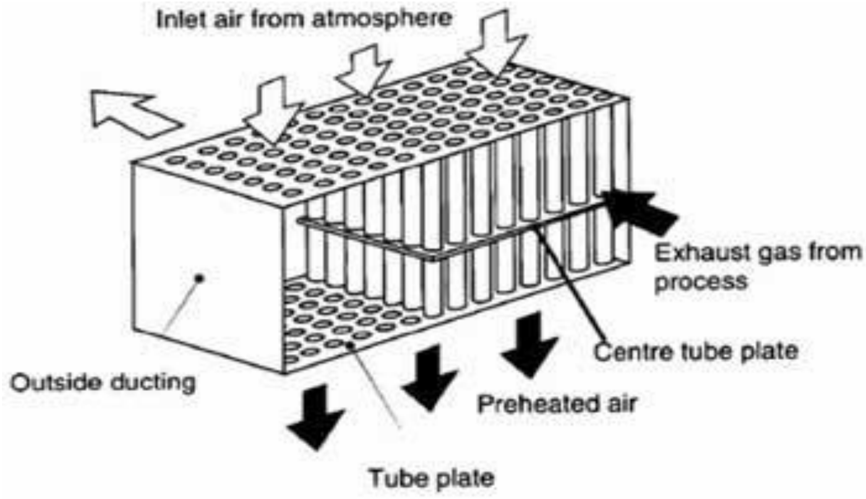

Figure 1.2-Waste Heat Recovery using Recuperator [5]

Recuperators are available in a wide variety of types and designs and are also categorized according to several other variables, including the following:

- type of flow arrangement (cross, counter, parallel, single pass, multipass);
- materials used in construction (metal, ceramics, hybrid);
- type of construction (modular);
- heat transfer configuration (tube. shell-and-tube, plate-fin, etc.) [6].

The most commonly used type is the recuperative heat exchanger and they can classified by flow arrangement, where numerous possibilities exist for flow arrangement in heat exchangers

- **Parallel Flow**: in parallel flow heat exchanger configuration, the hot and cold fluids enter at the same end of the heat exchanger, flow through in the same direction (i.e. in parallel to one another to the other side),and leave together at the other end, as illustrated in Fig 1.3a.
- **Counter Flow**: in counter flow heat exchanger configuration, the hot and cold fluids enter in the opposite ends of the heat exchanger and flow through in opposite directions, as illustrated Fig 1.3b.
- **Cross Flow**: in the cross flow heat exchanger configuration, the two fluids usually flow at right angles to each other, as illustrated Fig 1.3c.In the cross-flow arrangement; the flow may be called mixed or unmixed, depending on the design. The counter current design is most efficient, in that it can transfer the most heat. In a cross-flow heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger [7].

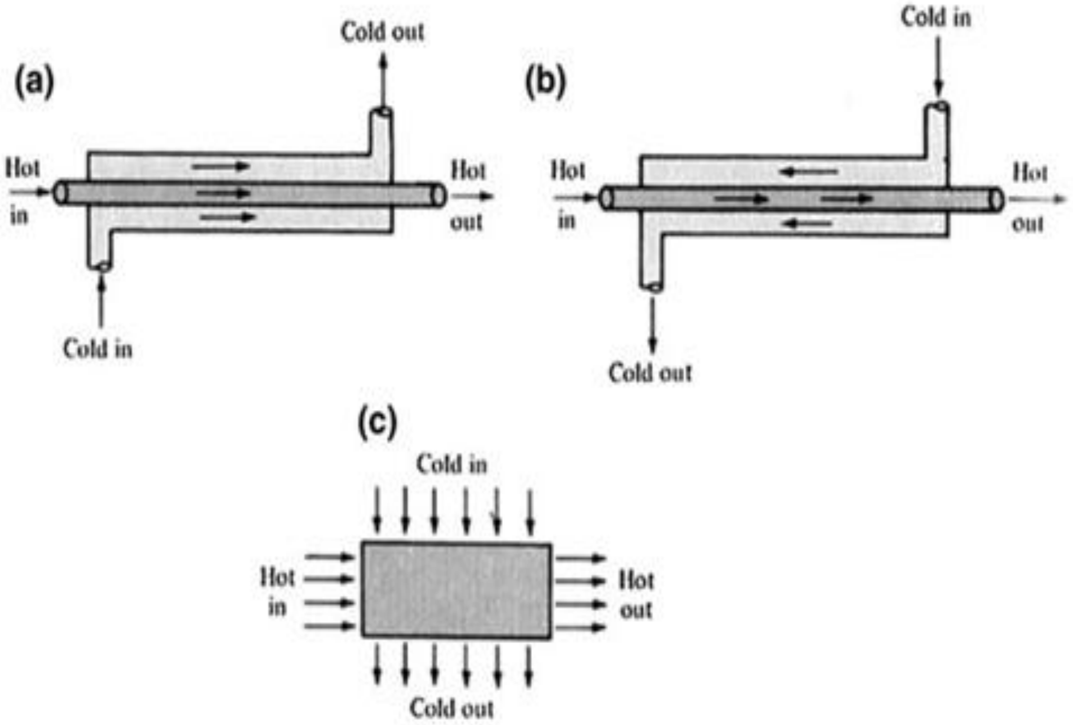

Figure 1.3-Flow Arrangements

a) Parallel-flow, b) Counter flow, and c) Cross flow [7]

Fig 1.4b illustrates a typical temperature profile for the outlet temperatures when both fluids are unmixed, as shown in Fig 1.4a. The inlet temperatures for both fluids are assumed to be uniform, but the outlet temperatures exhibit variation transverse to the flow [7].

In the flow, arrangement shown in Fig 1.4c, the cold fluid flows inside the tubes and so is not free to move in the transverse direction. Therefore, the cold fluid is said to be unmixed .However, the hot fluid flows over the tubes and is free to move in the transverse direction. Therefore, the hot fluid stream is said to be mixed. The mixing tends to make the fluid temperature uniform in the transverse direction; therefore, the exit temperature of a mixed stream exhibits negligible variation in the crosswise direction [7].

In general, in a cross flow exchanger, three idealized flow arrangements are possible:

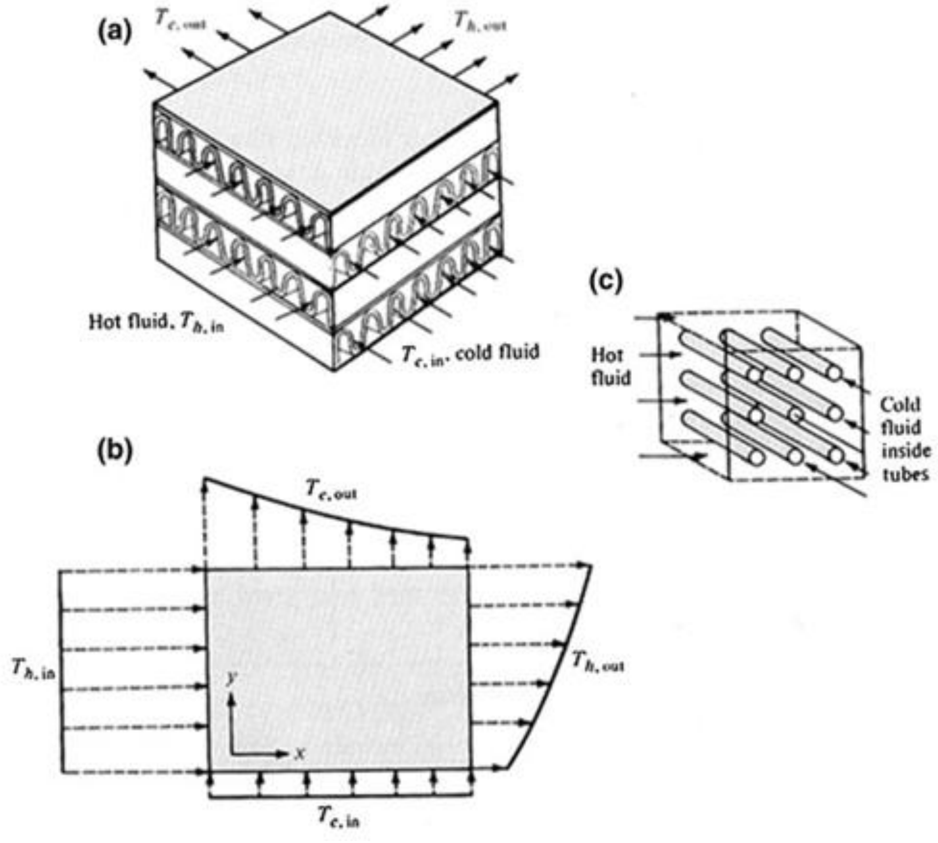

Figure 1.4-Cross-flow arrangements

a) both fluids unmixed; b) Temperature Profile when both fluids are unmixed; c) Cold fluid unmixed, hot fluid mixed [7]

1.3.2 Heat Pipe

The heat pipe is a heat-transfer element that is assembled into arrays which are used as compact and efficient passive gas-to-gas heat exchangers. Fig 1.6 shows how the bundle of finned heat pipes extend through the wall separating the inlet and exhaust ducts in a pattern that resembles the conventional finned tube heat exchangers. Each of the separate pipes, however, is a separate sealed element. Each consists of an annular wick on the inside of the full length of the tube, in which an appropriate heat-transfer fluid is absorbed. Fig 1.7 shows how the heat transferred from the hot exhaust gases evaporates the fluid in the wick. This causes the vapor to expand into the center core of the heat pipe. The latent heat of evaporation is carried with the vapor to the cold end of the tube. There it is removed by transferral to the cold gas as the vapor is recondensed [8].

The condensate is then carried back in the wick to the hot end of the tube. This takes place by capillary action and by gravitational forces if the axis of the tube is tilted from the horizontal. At the hot end of the tube the fluid is then recycled. The heat pipe is compact and efficient for two reasons. The finned-tube bundle is inherently a good configuration for convective heat transfer between the gases and the outside of the tubes in both ducts. The evaporative-condensing cycle within the heat tubes is a highly efficient method of transferring heat internally. This design is also free of cross-contamination. However, the temperature range over which waste heat can be recovered is severely limited by the thermal and physical properties of the fluids used within the heat pipes [8].

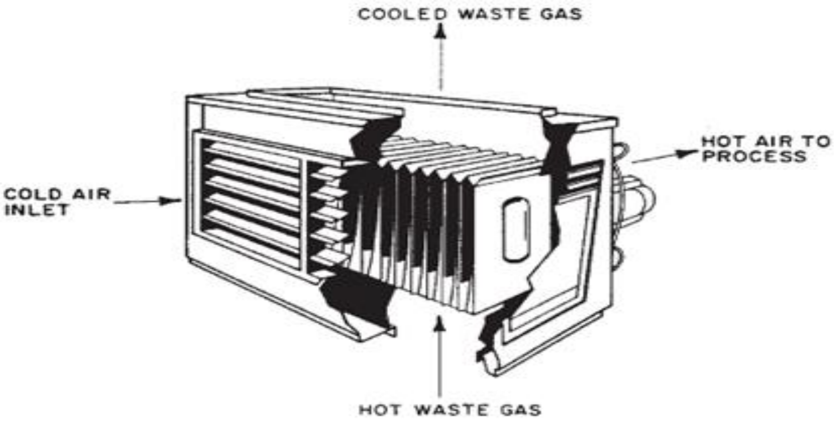

Figure 1.5-Passive gas to gas regenerator [8]

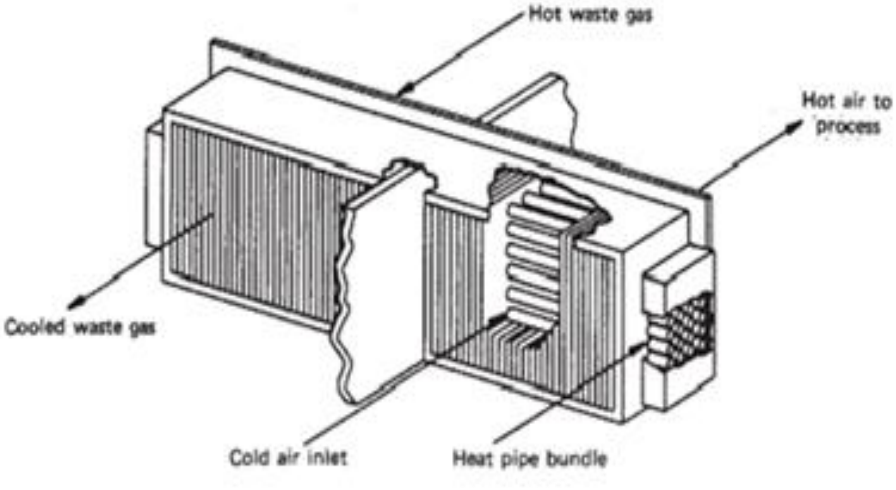

Figure 1.6-Heat Pipe [8]

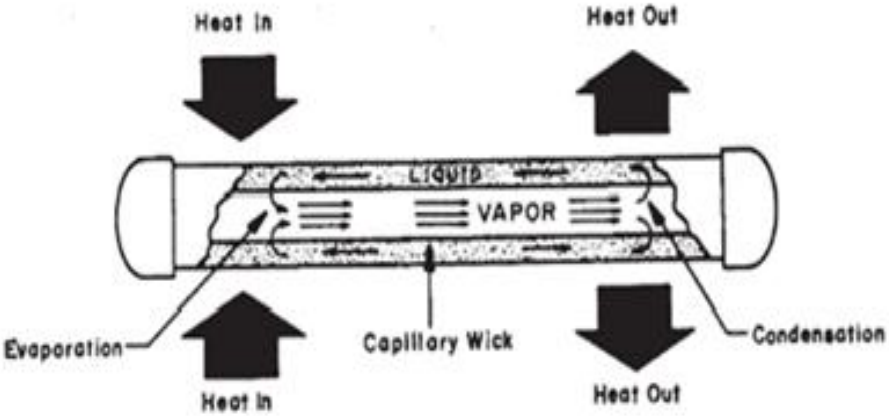

Figure 1.7-Heat Pipe operation [8]

1.3.3 Heat Wheels

A rotary regenerator, also called an air preheater or hear wheel, is used for low-to moderately high-temperature waste-heat recovery. Typical applications are for space heating, curing, drying ovens, and heat-treat furnaces. Originally developed as an air preheater for utility steam boilers, it was later adapted, in small sizes, as a regenerator for automotive turbine applications. It has been used for temperatures ranging from 20 °C to 1371 °C. Fig 1.8 illustrates the operation of a heat wheel in an air conditioning application. It consists of a porous disk, fabricated of material having a substantial specific heat. The disk is driven to rotate between two side-by-side ducts. One is a cold-gas duct and the other is a hot-gas duct. Although the diagram shows a counter flow configuration, parallel flow can also be used. The axis of the disk is locating parallel to and on the plane of the partition between the ducts. As the disk slowly rotates, sensible heat (and in some cases, moisture-containing latent heat) is transferred to the disk by the hot exhaust gas. As the disk moves into the area of the cold duct, the heat is transferred from the disk to the cold air. The overall efficiency of heat transfer (including latent heat) can be as high as 90% [9].

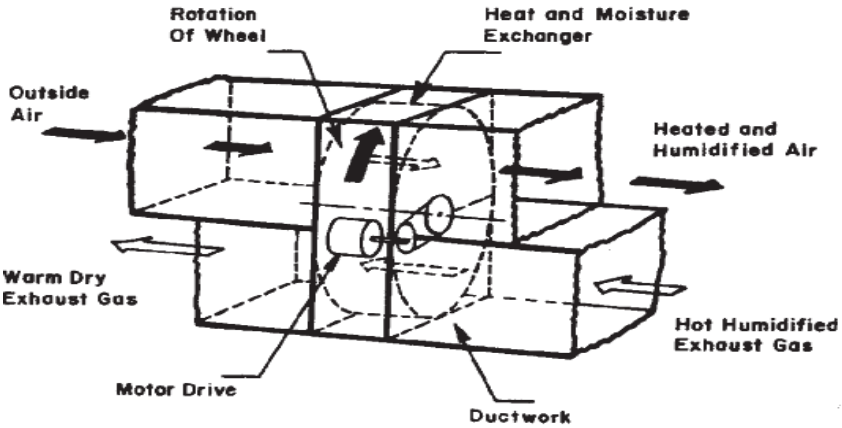

Figure 1.8-Heat wheel [9]

1.3.4 Plate Heat Exchanger

This gas/gas or liquid/liquid heat exchanger is a system that consists of a metal frame in which a variable number of corrugated metal sheets are clamped together. Adjoining plates are spaced apart and sealed against leakage and intermixing by gasketing. The two fluids flow in alternate interplate channels, usually in a countercurrent direction. Plate corrugations produce turbulence and an increased surface area, thus providing high heat transfer and high effectiveness.

Hot liquid passing through a bottom port in the head is permitted to pass upwards between every second plate while cold liquid at the top of the head is permitted to pass downwards between the odd plates. When the directions of hot & cold fluids are opposite, the arrangement is described as counter current. A plate heat exchanger is shown in Fig 1.9 [10].

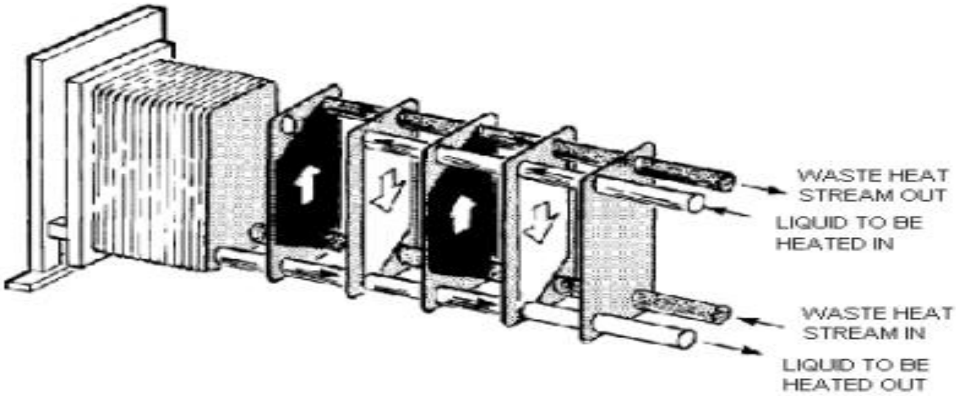

Figure 1.9-Plate Heat Exchanger [10]

1.3.5 Metallic Radiation Recuperator

Radiation recuperator is a class of indirect contact heat exchanger widely used for waste heat recovery in high temperature industrial applications. At higher temperatures heat loss is higher and as the cost of energy continues to rise, it becomes imperative to save energy and improve overall energy efficiency. In this light, a radiation recuperator becomes a key component in an energy recovery system with great potential for energy saving [11].The simplest configuration for a recuperator is shown in Fig 1.10 which consists of two concentric lengths of metal tubing [12].

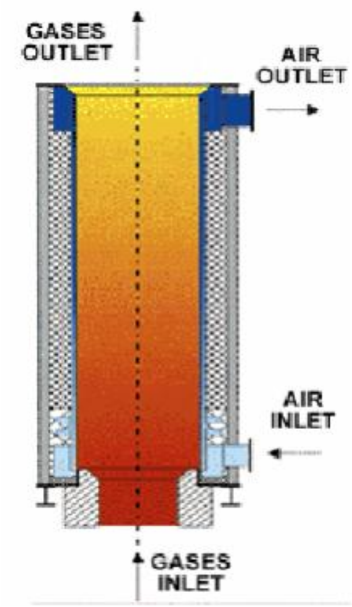

Figure 1.10-Metallic Radiation Recuperator [12]

The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air, which now carries additional energy into the combustion chamber. This is the energy, which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading. The saving in fuel also means a decrease in combustion air and therefore, stack losses are decreased not only by lowering the stack gas temperatures but also by discharging smaller quantities of exhaust gas. The cold air in the annuals, however, is almost transparent to infrared radiation so that only convection heat transfer takes place to the incoming air. As shown in the diagram, the two gas flows are usually parallel, although the configuration would be simpler and the heat transfer would be more efficient if the flows were opposed in direction (or counter flow). The reason for the use of parallel flow is that recuperators frequently serve the additional function of cooling the duct carrying away the exhaust gases and consequently extending its service life [12].

1.3.6 Convective Recuperator

A second common configuration for recuperators is called the tube type or convective recuperator. As seen in the figure below, the hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in the direction normal to their axes. If the tubes are baffled to allow the gas to pass over them twice, the heat exchanger is termed a two-pass recuperator; if two baffles are used, a three-pass recuperator, etc. Although baffling increases both the cost of the exchanger and the pressure drop in the combustion air path, it increases the effectiveness of heat exchange. Shell and tube type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases [13].

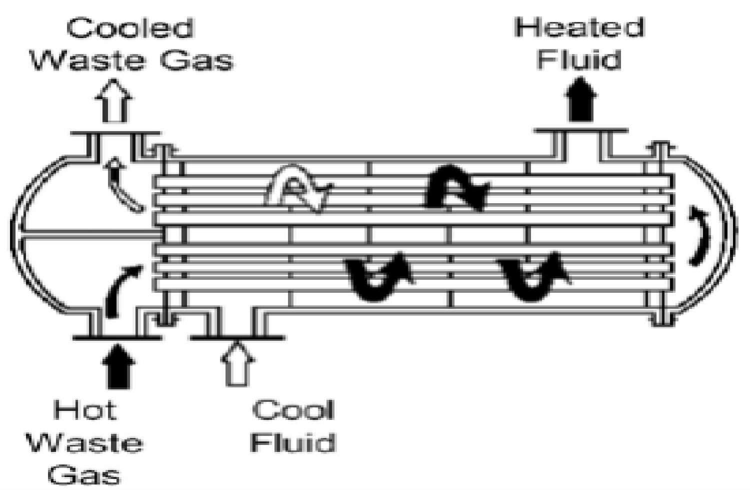

Figure 1.11-Convective Recuperator [13]

1.3.7 Shell and Tube Heat Exchangers

When the medium containing waste heat is a liquid or a vapor which heats another liquid, then the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluids. The shell contains the tube bundle, and usually internal baffles, to direct the fluid in the shell over the tubes in multiple passes. The shell is inherently weaker than the tube, so that the higher-pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell. When a vapor contains the waste heat, it usually condenses, giving up its latent heat to the liquid being heated. In this application, the vapor is almost invariably contained within the shell. If the reverse is attempted, the condensation of vapors within small diameter parallel tubes causes flow instabilities. Tube and shell heat exchangers are available in a wide range of standard sizes with many combinations of materials for the tubes and shells. A shell and tube heat exchanger is illustrated in Fig 1.12 below [14].

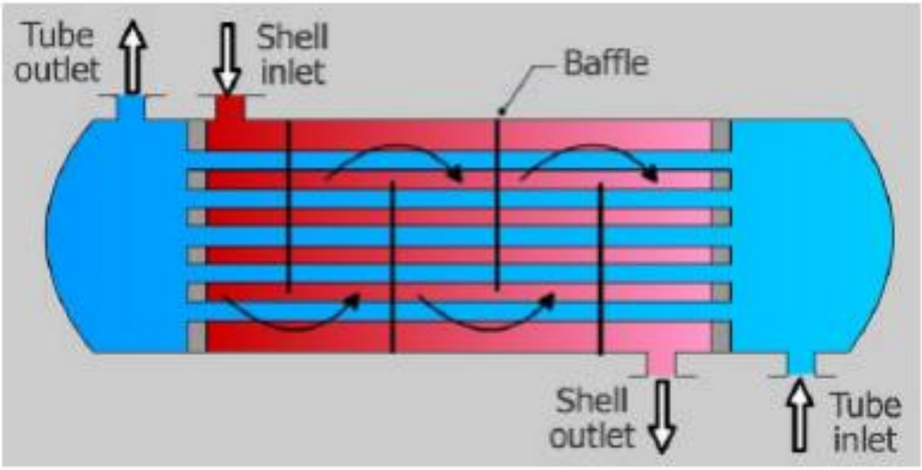

Figure 1.12-Shell & Tube Heat Exchanger [14]

Typical applications of shell and tube heat exchangers include heating liquids with the heat contained by condensates from refrigeration and air-conditioning systems; condensate from process steam; coolants from furnace doors, grates, and pipe supports; coolants from engines, air compressors, bearings, and lubricants; and the condensates from distillation processes [14].

1.3.8 Waste Heat Recovery Boilers

Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases .From gas turbines, incinerators, etc., pass over a number of parallel tubes containing water. The water is vaporized in the tubes and collected in a steam drum from which it is drawn out for use as heating or processing steam. Because the exhaust gases are usually in the medium temperature range and in order to conserve space, a more compact boiler can be produced if the water tubes are finned in order to increase the effective heat transfer area on the gas side. Fig 1.13 shows a mud drum, a set of tubes over which the hot gases make a double pass, and a steam drum which collects the steam generated above the water surface. The pressure at which the steam is generated and the rate at which steam is produced depend on the temperature of waste heat. The pressure of a pure vapor in the presence of its liquid is a function of the temperature of the liquid from which it is evaporated. The steam tables tabulate this relationship between saturation pressure and temperature [15].

These are the water tube boilers that use medium to high temperature exhaust gases to generate steam.In cases where the waste heat is not sufficient for producing desired levels of steam, auxiliary burners or an afterburner can be added to attain higher steam output. The steam can be used for process heating or for power generation [15].

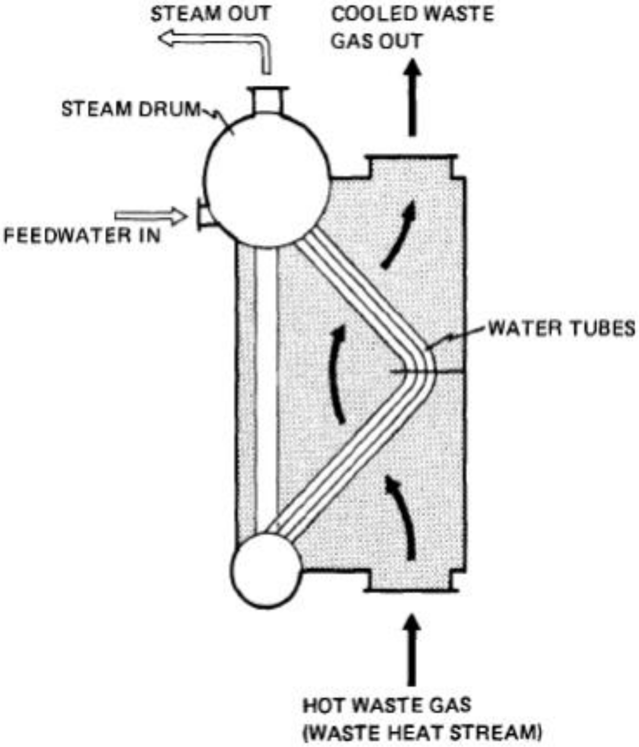

Figure 1.13-Two-Pass Water Tube Waste Heat Recovery Boiler [15]

1.4 Materials used for the Construction

1.4.1 Polyurethane Foam

Polyurethanes are one of the most versatile materials in the world today. The unique properties of PU deserve popularity as PU offers the elasticity of rubber combined with the toughness and durability of metal, it is resistant to oils, solvents, fats. Products, coated with PU last longer, PU adhesives provide strong bonding advantages, PU elastomers can be molded into any shape, they are lighter than metal and offer a good resistance to environmental factors [16].

Polyurethane Polyurethanes are any type of polymer containing a urethane linkage. The urethane linkage is -NH-CO-O-. The way to form polyurethanes is done by reacting isocyanates with compounds that have an active hydrogen, such as diols, that contain hydroxyl-groups, in the presence of a catalyst. Since there are many compounds containing active hydrogens and many different diisocyanates, the number of polyurethanes that can be synthesized is also large. The specific properties of the polyurethane can be tailored to a specific need by combining the appropriate compounds. Polyurethanes can exist as both rigid and flexible foams, and as a coating or adhesive material. Since polyurethanes come in so many forms and can have a wide variety of properties, it is also used in many different applications. Rigid polyurethanes are used as insulation and flotation, while flexible ones are used for cushioning and packaging. In addition, they are used as adhesives in construction and transportation [17].

1.4.2 Hard Polystyrene Foam

Polystyrene Insulation Types There are two types of rigid polystyrene foam plastic insulation, extruded (XPS), and expanded (EPS) [18]

- XPS is manufactured in a continuous extrusion process that produces a homogeneous closed cell cross section (Fig-1.14).
- EPS is manufactured by expanding spherical beads in a mold, using heat and pressure to fuse the beads together where they touch, leaving open spaces between the beads where they don’t touch (Fig-1.15). Although both types are comprised of polystyrene, the two types of manufacturing processes produce finished products with very different performance properties. This bulletin explains the important difference between XPS and EPS and demonstrates that extrusion matters. Actually, the

extrusion process is the most important difference between EPS and XPS and it results in one of the most important performance differences which is water absorption. Both XPS and EPS are manufactured using polystyrene which is a hydrophobic polymer that repels water. The big difference that causes EPS to absorb more water than XPS is a result of the manufacturing process. The XPS continuous extrusion process produces a homogeneous “closed cell” matrix with each cell fully enclosed by polystyrene walls. The EPS bead molding process, although individual beads are closed cell, leaves open voids between beads where water enters [18].

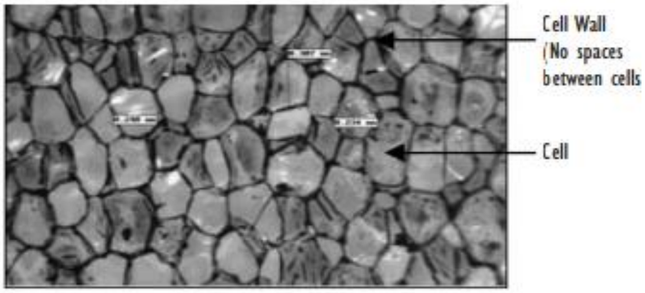

Figure 1.14-Two-Pass **Extruded Polystyrene Cell Structure [18]**

Compare XPS (Fig-1.14) to EPS (Fig-1.15). Because of the homogeneous cross section of XPS, very little water is absorbed into the cell structure. “Closed cell” means very little R-value reducing water will be absorbed into the insulation board. The XPS extrusion process produces that closed cell structure. The EPS expansion process does not, therefore, EPS should be considered an open void structure [18].

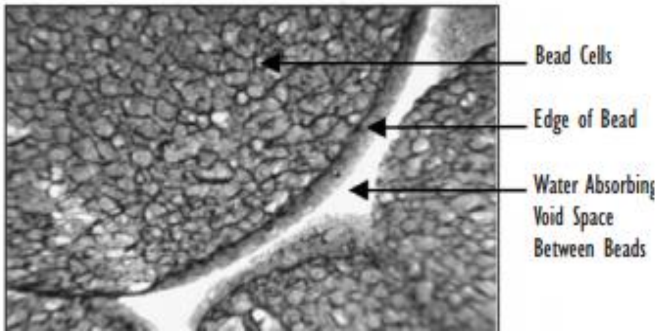

Figure 1.15**-Expanded Polystyrene Cell Structure [18]**

Foam Materials made of Polystyrene contains nearly 98% air. The solid phase (foam skeleton) that conducts the heat takes 2% of the total volume. In addition to this, the polystyrene material that transfers the heat is a very insulating material. Because of the fact that Polystyrene Foam Material takes form from very little (1m3 EPS Polystyrene Foam material consists of 3-6 billion cells) closed cells: 0.01-0.1 mm in diameter (See Fig – 1.16), the conduction rate of heat by air movement decreases with more little cell volumes thus from the side of insulation technique, it is good insulating material. Heat rays can be prevented best by more number of laminates. First of all; the property that takes attention is the unit weight of polystyrene foam material is less. The weight of foam material that is obtained by kinds of methods with pre swelling is varying from 10-100 kg/m3. Also thermal conductivity value varies according to production density. Generally the standard foam material that is used at construction sites has a density of 10 - 30 kg/m3 [19].

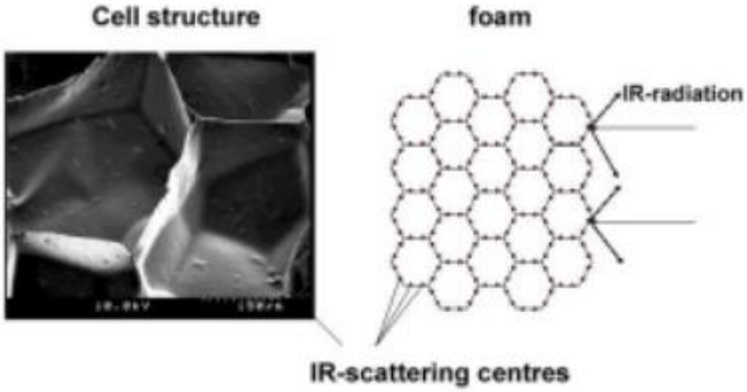

Figure 1.16 -Reduced heat conductivity – microstructure [19]

The most general usage area of polystyrene foam for heat insulation purposes are at Constructions; wall, ceiling, roof and prefabricated elements. Other areas of usage are for noise insulation, decorative ceiling boards and placing holes in concrete molds. The polystyrene that is pre swelled is used also at production of light concrete and light brick. In cooling technology, Polystyrene Foam material is being used at insulation of cooled warehouses, railway cars, ships, trucks and also at insulation of pipes. Durability of this material exposed to heat varies according to period and degree centigrade under exposure. Despite of the fact that it is durable against heat up to 100 ˚C for a short period, it is durable and can be used up to 75 - 85 ˚C according to its density for a long period [19]

In above literature sources related to the heat exchanger and the foam materials. From this, the cross- flow heat exchanger is selected on the basis of cheap price as well as it provides good heat recovery. It is easy to make when it compares with other heat exchangers.

The extruded polystyrene material is selected according to the following properties such are:

1. thermal insulation;
2. resists water and inorganic chemicals such as acids and alkaloids;
3. releases no gases or particles that are harmful to health;
4. insulation capacity is excellent even with light structures, leaving more square metres for actual use;
5. does not crumble, sting or produce dust. In short, it is pleasant to use;
6. it can be glued using different types of polyurethane and epoxy glues and construction adhesives [21].

2. WASTE HEAT RECOVERY UNIT DESIGN

2.1 Project Description

The compact waste heat recovery unit design uses the efficient heat exchanger to improve the heat recovery efficiency and to provide air circulation for small premises. It also provides clean fresh air to the room with the help of filter which is selected according to the filter specifications shown in below chapter. The design is based on small size room; approximately 45 m^2.

And in case the supply air at zero degrees Celsius (it operates a temperature range from 25 to 50 °C) is too cold and needs to be warmed. In order to transform the cold to warm solution is key concept is that of heat recovery. The core of heat recovery is the heat exchanger and it uses the exhaust air to pre-heat or pre-cool the incoming fresh air, without mixing of two airstreams. The heat exchanger recovers a significant amount of the heat which the air had obtained by various means, inside the premises. According to the construction technical regulations STR 2.09.2:2005 [20], 1 m^2 require 1.8 m^3/h air volume to the living room and for that reason the unit design has to attain air volume of 81 m^3/h to the room to meet the project goal (45 m^2).

Compact waste heat recovery unit for small premises offer many advantages, including:

- low price;
- low maintenance;
- simple operation;
- high availability;
- no gaseous or liquid emissions.

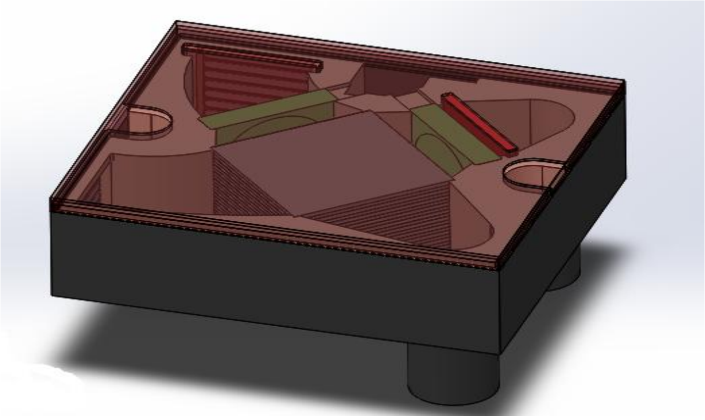

Figure 2.1 -Waste Heat Recovery Unit Design

Designed in accordance with the selected frame construction:

- the heat exchanger is mounted in the center part;
- the filter installation location provides the air intake from the room and from the outside openings to clean the air before being fed to the heat exchanger and into the room that would be supplied already cleaned and unpolluted air;
- the fan is placed near the air exhaust nozzles;

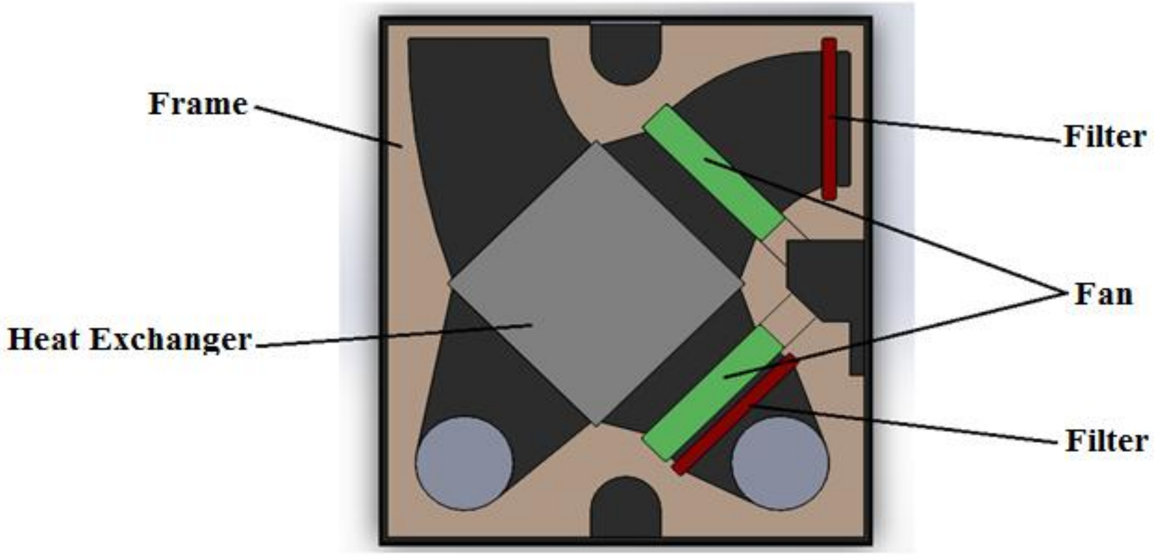

Figure 2.2-Model Design

2.2 Selection of Materials for the Unit

2.2.1 The Frame and Casing Material Selection

The frame and casing material selection key requirements as follows:

- stability;
- strength;
- weight;
- thermal insulation;
- sound insulation;
- resistance to the interaction with the ambient atmosphere.

Finnfoam is a cell plastic primarily made of polystyrene. Finnfoam is an extrusion-compressed polystyrene (XPS) thermal insulation material. Its excellent characteristics are based on its cell structure, which is completely homogenous and closed. Finnfoam releases no gases, particles or fibres harmful to health. Finnfoam is classified as M1 – the best indoor emissions classification in Finland [21].

Extruded polystyrene material characteristics are presented in Table 2.1

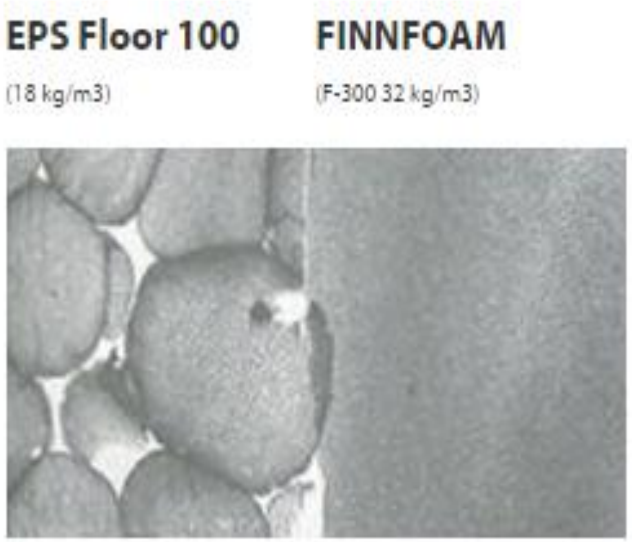

Figure 2.3-Pore structure [21]

Table 2.1-Extruded Polystyrene Material Characteristics [21]

Thermal conductivity, W/(m K)	0,035
Modulus of elasticity, kPa	15 000
Weight, kg/m^3	32
Operating temperature, °C	From -150 to +75

In order to reach these requirements, extruded polystyrene material is used and it is cut by hot wire to bring into frame construction (Fig 2.4). A.B.S (Acrylonitrile, butadiene, and styrene) plastics are fitted all over the outer layer of extruded polystyrene, A.B.S plastics is to comfort for the material.

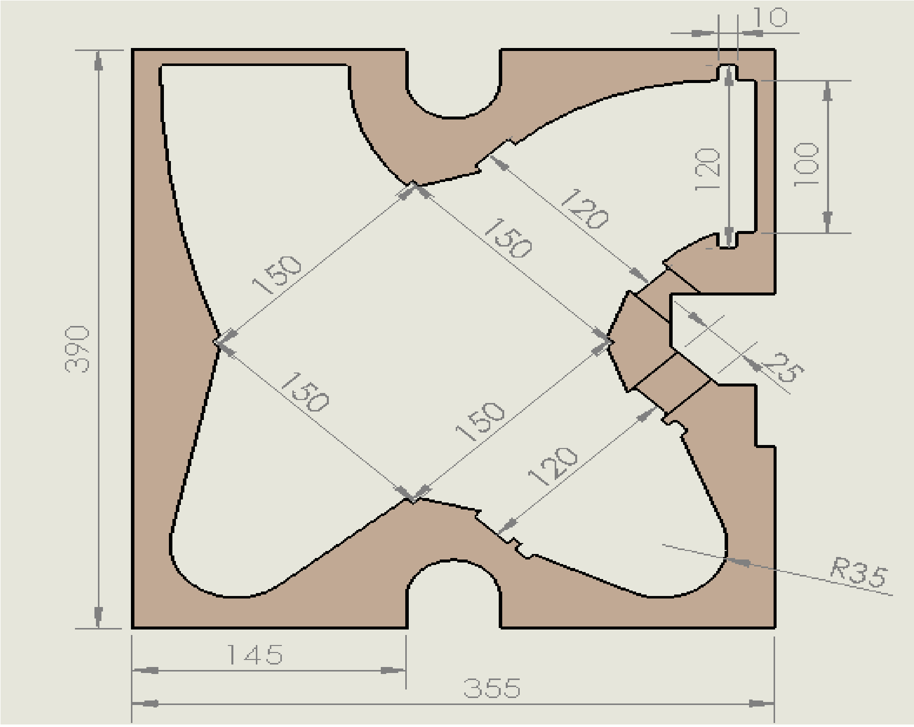

Figure 2.4-Frame Construction

2.2.2 Selection of Heat Exchanger and its Material

Heat exchanger selection is based on how much the heat can reclaim from extract air, according to the literature study the cross flow plate heat exchanger is very much helpful for the project work.

Heat exchanger cartridge, different airstream flows separate a place of conventional metal plates to use a special hygroscopic paper. The hygroscopic paper is able to return back to the room with the incoming outside air heat whereas moisture generated from the exhaust air. The return of moisture is mostly considerable during the cold period, when the weather dries out very much. It does not dry out the room air. And at the same time, moisture condensation return solves the heat exchanger cartridge problem and increases the frost protection up to minus 25 °C cold.

The paper has many unique properties:

- fire-resistant and strong;
- moisture absorbent that permits the way of only water vapor;

- it has a gas barrier property that does not allow gases such as CO2 from entering the conditioned area [22].

In order to reinforce the structure of the heat exchanger, the layers of absorbent cellulose fitted with an aluminum foil in wave-like shape layer (Fig 2.5). This shape is not only reinforces the structure, but also smoothes the flow of air in the heat exchanger (150x150x110 mm).

Figure 2.5-Heat exchanger

2.2.3 Heat Exchanger Design

Cross-flow heat exchanger (Fig 2.6) is selected with comprising of 24 media layers. The heat exchanger provides for the purchase of large work pieces made from a saw cut design provides dimensions (150x150x110 mm). That it is more rigid and have a smooth and flat surface for fixing to the frame.

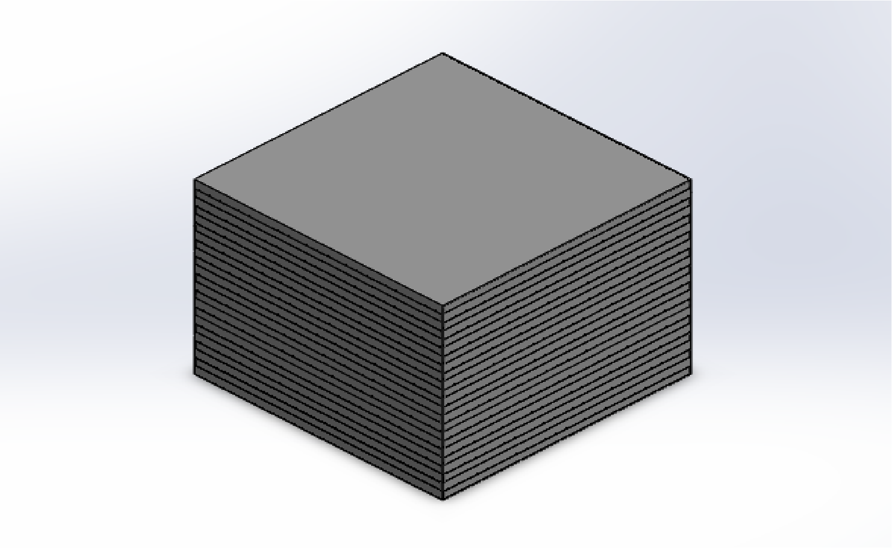

Figure 2.6-Heat Exchanger Design

2.2.4 Filter Selection

Structure selection of the filter is panel filter (Fig-2.7). The selection based upon assumption of F5 class filters and it is made of polyester media. These structures are the main filters and ventilation air conditioning filter type. Compared with other types of filters, panel filters are lighter, more compact, and their efficiency is higher. The particle size and their efficiency of these filter properties are from F5 class filter [23]. Table 2.2 shows the filter characteristics and Fig-2.8 shows filter curve which is an assumption of similar filters curve of F5 filters.

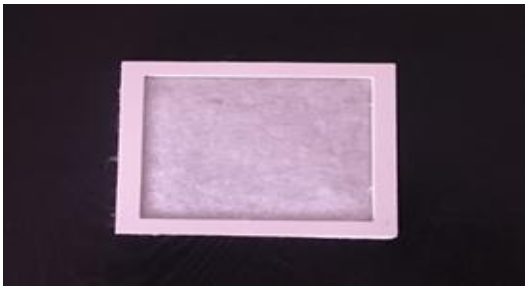

Figure 2.7- Panel Filter [23]

Table 2.2-F5 Filter Characteristic [23]

Particle size, µm	0.1	0.3	0.5	1	3	5	10
Capture, %	0 - 10	5 – 15	15 – 30	30 – 50	70 – 90	90 – 99	> 98

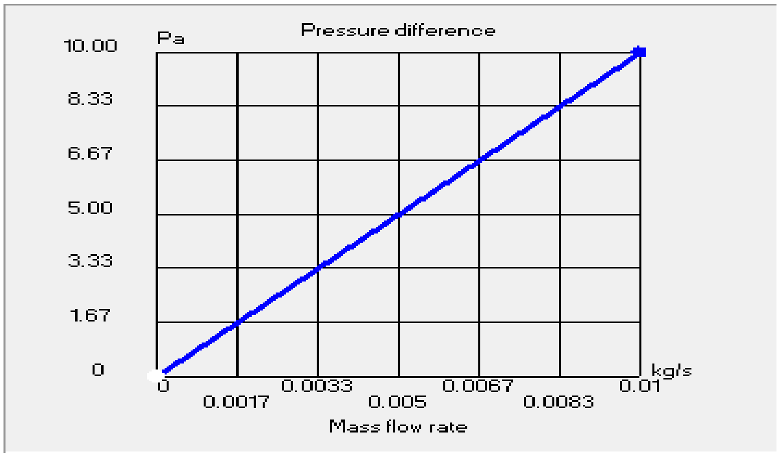

Figure 2.8-Filter Curve [23]

2.2.5 Fan Selection

Fan capacity directly influences the performance of the unit. In addition to the fan working reliability is one of the most important indicators of the long life of the total component. It also strongly influences the noise level. For these reasons, the fan is selected, high quality, which makes it possible to increase the total duration of the working device. The technical characteristics of Sunon Company - PMD1212PTB1-A fan is presented in Table 2.3 & Noise blocker company- M12-PS fan is presented in Table 2.4.

Figure 2.9, 2.10 shows the static pressure-airflow fan curve of PMD1212PTB1-A fan & M12-PS fan

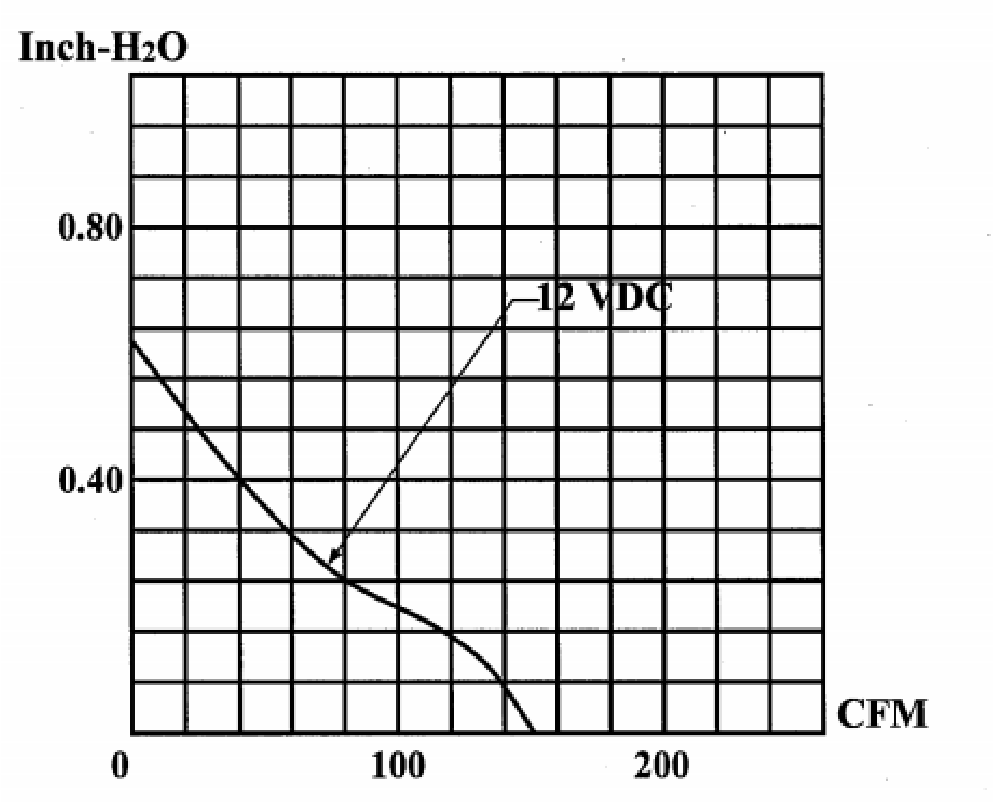

Figure 2.9-PMD1212PTB1-A Fan Curve [24]

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Table 2.3-PMD1212PTB1 A-Fan Technical Characteristics [24]

Voltage - Rated	12VDC
Size / Dimension	Square - 120mm L x 120mm H x 25mm
Air Flow	150.0 CFM ($4.24m^3/min$)
Static Pressure	0.620 in H2O (154.4 Pa)
Bearing Type	Ball
Fan Type	Tube axial
Noise	54 dB(A)
Power (Watts)	12.0W
RPM	4500 RPM
Termination	2 Wire Leads
Weight	0.485 lb (219.99g)
Operating Temperature	14 ~ 158°F (-10 ~ 70°C)

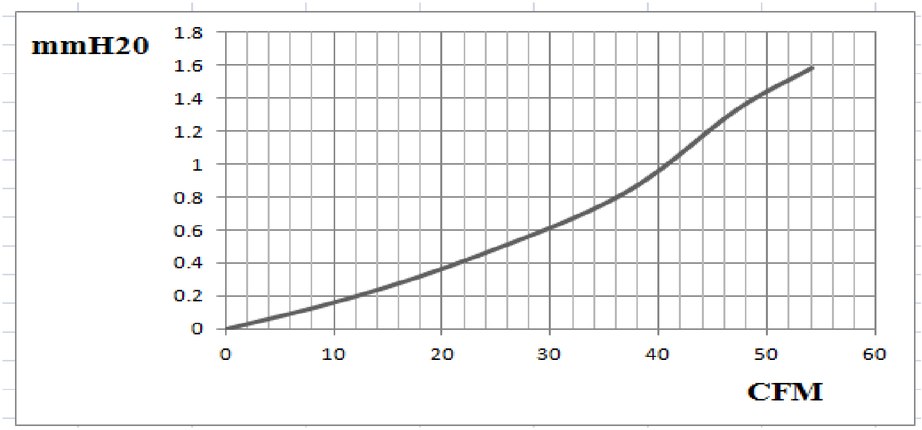

Figure 2.10-M12-PS Fan Curve [25]

Table 2.4-M12-PS Fan Technical Characteristics [25]

Rated Voltage	VDC	12
Voltage Range	VDC	5-13,8
Start Voltage	VDC	5,5
Rpm	U/min	600-1500
Input Power	Watt	1,2
Airflow	m3/h	40-100
Static Pressure	mmH2O	1,460 max.
Noise Pressure	dB/A	7-22,1
Loudness	S one N	0,323 max.
Temp. Range	°C	-10° ~ +65
Size		120x120x25 mm
Weight		140 g
Bearing Type		NB-NanoSLI magnetic nano bearing

2.3 Design Construction

Cross-flow heat exchanger is selected with comprising of 24 media layers. The heat exchanger provides for the purchase of bulky work pieces made from a saw cut design provides dimensions (150x 150x110 mm).

The frame construction with a dimension of (390x355x115 mm) and also made of extruded polystyrene material. In order to attain this, choose 50 mm high and 65 mm thick plate, by gluing them to obtain the necessary height of the frame to 115mm which in turn cut by hot wire to bring into one piece frame. This ensures the thermal and acoustic insulation. As well as cutting of three parts on the same material: the first is casing with dimensions of (400x365x120 mm) and in addition to, it will give support to the stationary frame. The other two is inner cover made of dimension (397x362x15 mm) & outer main cover made of dimension (400x365x120 mm).

Fig 2.11, below shows the prototype model of compact waste heat recovery unit, which is manufactured according to the material specified above. The experiments are done with this unit.

Figure 2.11- Prototype unit

3. INVESTIGATION OF THE AIRFLOW CHARACTERISTICS

3.1 Mathematical Background of Airflow Simulation

The airflow produced by the design unit was modelled using Solidworks Flow Simulation - computational fluid dynamics (CFD) software.

Flow Simulation enables the analysis of various types of fluid flow and heat transfer phenomena as:

- External and internal fluid flow;
- Constant and time varying fluid flow;
- Compressible fluid flows;
- Subsonic, transonic and supersonic speed fluid flows;
- Free, forced and mixed convection;
- For laminar and turbulent fluid flows;
- Fluid flows with boundary conditions, including the wall roughness, etc.

For these calculations the fluid’s motion is modelled using the Reynolds Averaged Navier Stokes (RANS) equations [26]. The equations are given below (the bar is dropped for averaged quantities):

$$\frac{\partial \rho}{\partial t} + \frac{\partial u_j}{\partial x_j} = 0, \qquad (1)$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\tau_{ij} - \rho\overline{u_i u_j}\right) + S_i, \qquad (2)$$

where ρ is the fluid density, u is the fluid velocity, p is the static pressure, τ_{ij} is the molecular stress tensor, $\rho\overline{u_i u_j}$ is the Reynolds stresses, S_i is a mass-distributed external force per unit mass.

The energy equation [27]:

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial x_i}\left(u_i\left(\tau_{ij} - \rho\overline{u_i u_j}\right) + q_i\right) + \frac{\partial p}{\partial t} + \rho\overline{u_i u_j}\frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H , \qquad (3)$$

where $H=h+u^2/2$, h is the thermal enthalpy, q_i is the diffusive heat flux, Q_H is a heat source or sink per unit volume, ε is the turbulent dissipation.

3.1.1 The Principle Scheme Operation

Fresh air from outdoor is supplied to the system through a filter. Compact waste heat recovery unit uses efficient cross- flow heat exchangers to recover heat from extract air and to warm up the incoming fresh air to room temperature .The heat taken from the extracted air is used to warm the fresh filtered air in the exchanger and then flows to the room. Fig 3.1- shows the principle operation of compact waste heat recovery unit.

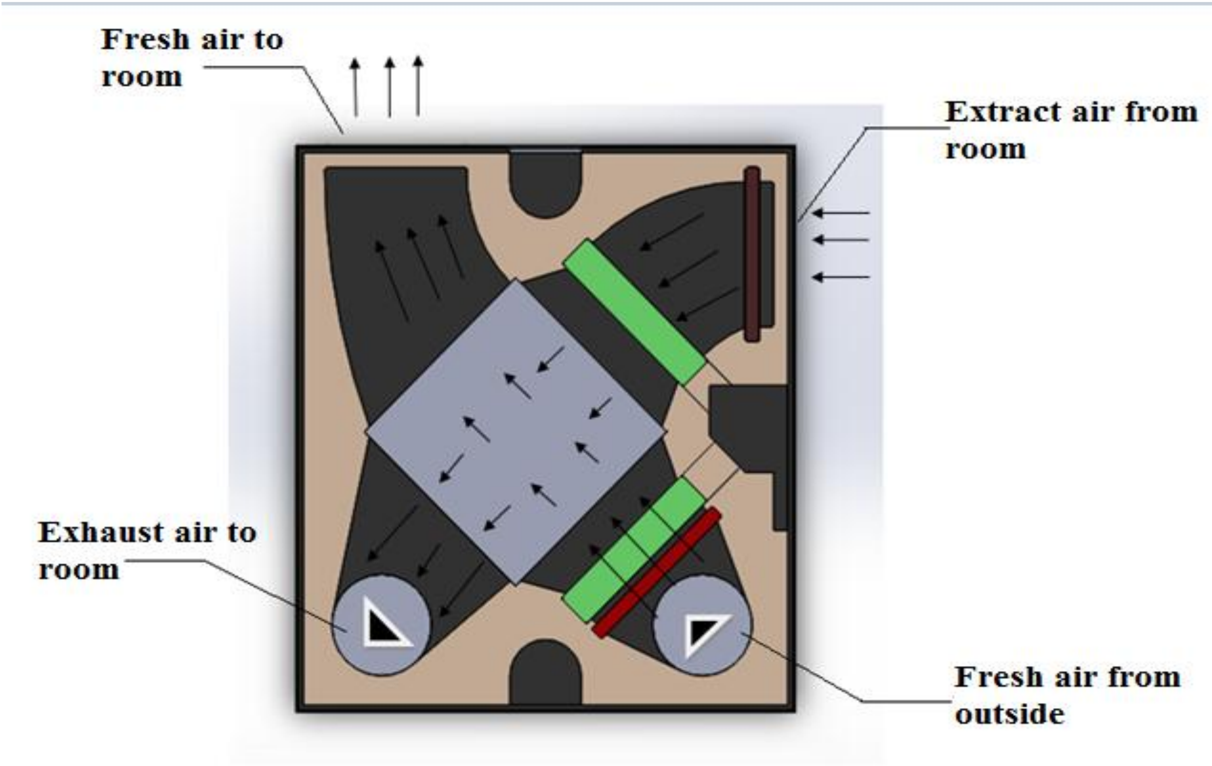

Figure 3.1 -The Principle Scheme Operation of the Waste Heat Recovery Unit

3.1.2 Computational Model

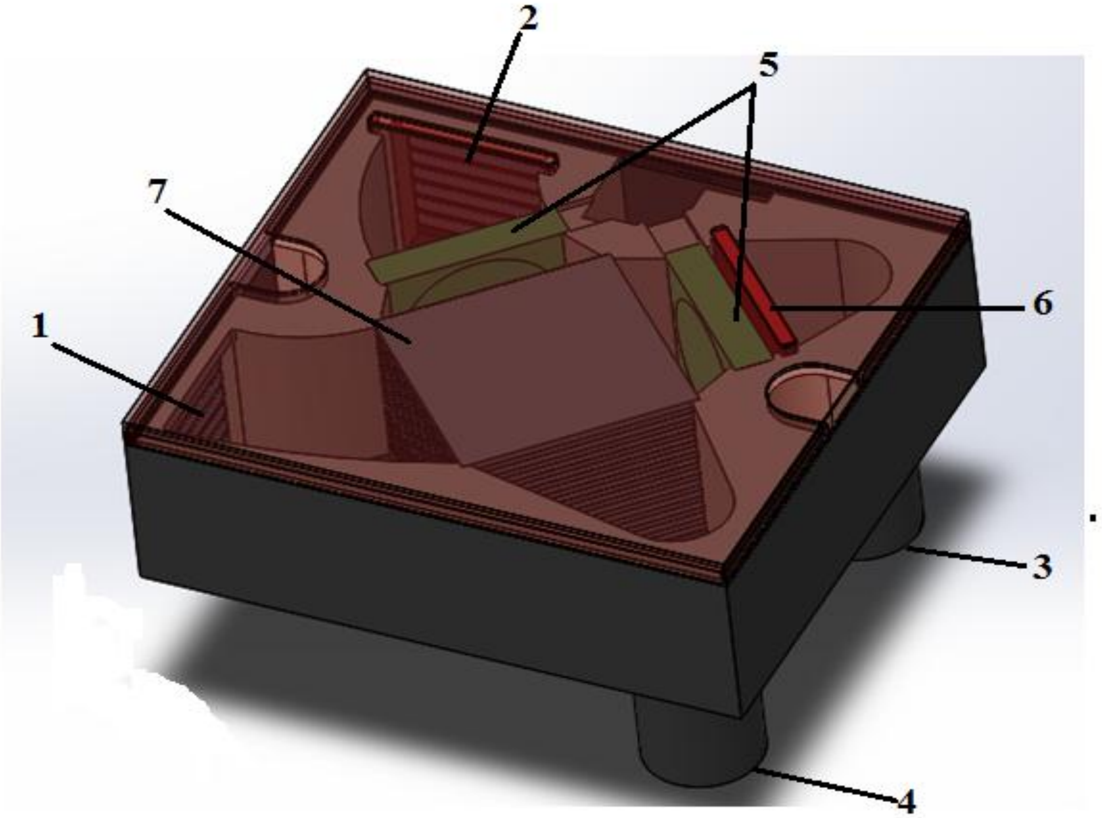

Figure 3.2 -Computational Model

1 - Supply air to the room; 2 - Extract air connection in the room; 3 - Supply of outdoor air nozzle; 4 - Exhaust air to the outside nozzle; 5 -Fans; 6 - Filters; 7 - Heat exchanger

Heat exchanger modelled as twenty four porous media layers separated by a single material layer. The pore size in the actual heat exchanger of this project is triangular and it is calculated in terms of hydraulic diameter.

The concept of hydraulic diameter D_H allows the use of relationships developed for circular pipes with non-circular tube or duct. Frequently it is calculated as 4 times the flow area divided by the wetted perimeter of the duct or other tubes of any form. Also it is calculated according to triangle-flow channel geometry [28]. In this work, the porous medium layer modelled as the channel with a hydraulic diameter of 5mm and 0.9 orthotropic porosity (in which it is calculated according to equation below) in order to simulate airflow in the direction (from the outdoor air supplied to the room is limited to y-axis direction, and the extract air from the room is limited to x-axis direction).

Solid modelling material properties applied as copper, given the fact that the Mitsubishi Company declares that heat exchanger thermal conductivity properties are close to copper [22].The pore size is calculated from the below equation

$$D_{H}=\frac{1}{2}B^{2}\mathrm{Sin}\theta$$

Where B=3.5mm, $\theta=60^{\circ}$

=5mm

Table 3.1-Porous Material Characteristics for Heat Exchanger [22]

Porosity	0.9
Permeability type	Orthotropic
Pore Size (D)	5e-005m
Density of porous matrix	0.15 kg/m^3
Specific heat capacity of porous matrix	100 J/(kg*K)
Conductivity type	Isotropic
Thermal Conductivity	400 W/(m*K)

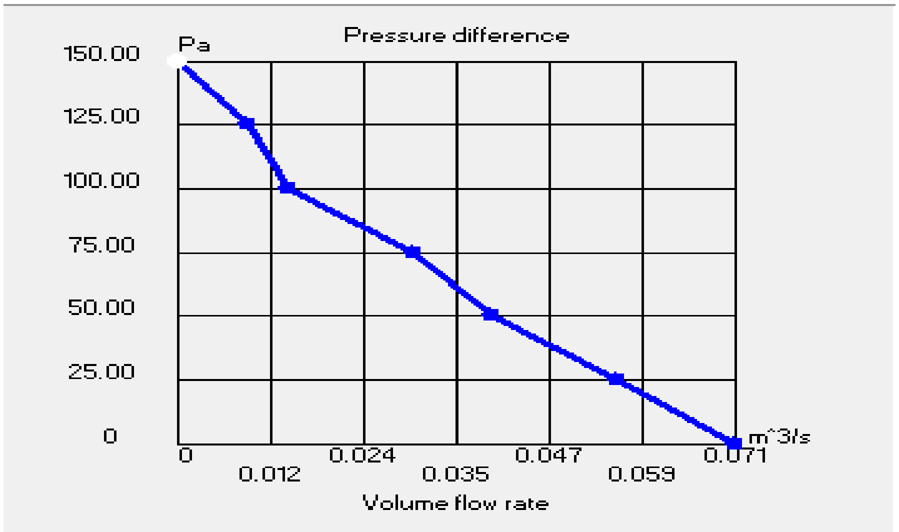

Figure 3.3 -PMD1212PTB1-A Fan Curve [24]

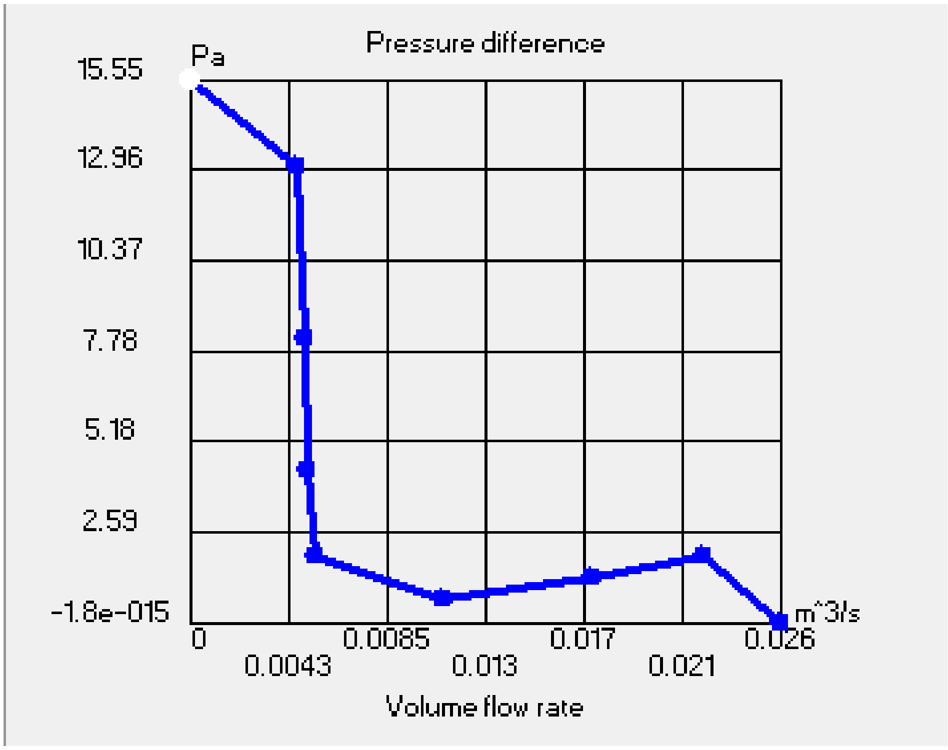

Figure 3.4 -M12-PS Fan Curve [25]

A porous material characteristic for the filters (Table 3.2) is an assumption almost related to similar filter characteristics

Table 3.2-Porous Material Characteristics for Filters [23]

Porosity	0.8
Permeability type	Isotropic
Pressure Drop vs. Flow rate	Mass Flow Rate
Length	0.1m
Area	0.01m^2

Boundary conditions: Supply air to the room connections (Fig- 3.2, 1) indicates the room temperature 22 °C, and atmospheric pressure 101325 Pa. Air intake from the room connections (Fig- 3.2, 2) indicates the temperature 22 °C, and atmospheric pressure 101325 Pa. Air intake from outside nozzle (Fig- 3.2, 3) indicates the temperature 0 °C, and atmospheric pressure 101325 Pa. Exhaust air to outside nozzle (Fig- 3.2, 4) indicates the temperature 0 °C, and atmospheric pressure

101325 Pa. It is also assumed that the device will be in the room, it indicates the room temperature is about 22 °C and the heat transfer coefficient is 5.5 W/(m^{2}K).

3.2 Simulation Results

Airflow speed & airflow temperature line of PMD1212PTB1-A fan in the waste heat recovery unit is shown in Fig-3.5, 3.6. Temperature distribution (PMD1212PTB1-A Fan) & the pressure distribution (PMD1212PTB1-A Fan) presented in Fig-3.7, 3.8, along with the temperature distribution and temperature distribution in the horizontal section of M12-PS fan in the waste heat recovery unit is shown in Fig- 3.9, 3.10.

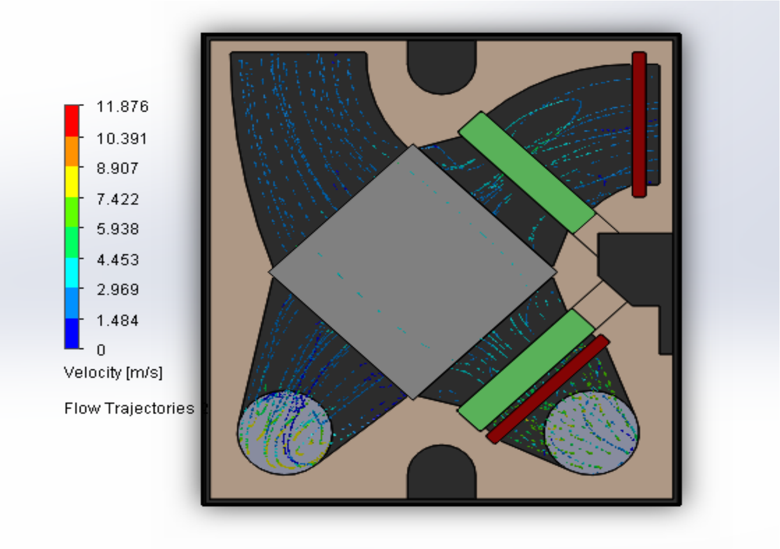

Figure 3.5 -Airflow Speed (PMD1212PTB1-A Fan)

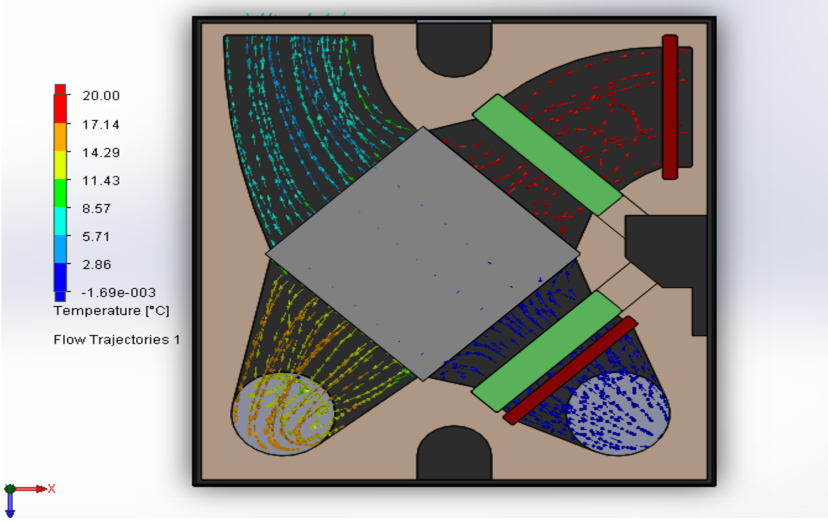

Figure 3.6 -Airflow Temperature Line (PMD1212PTB1-A Fan)

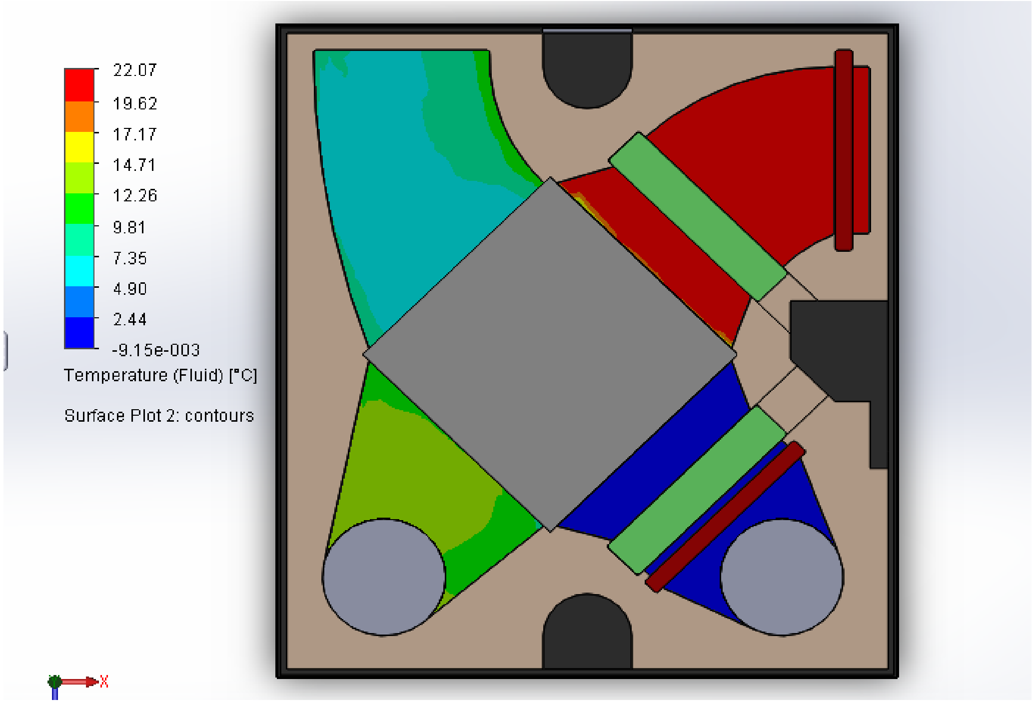

Figure 3.7 -Temperature Distribution (PMD1212PTB1-A Fan)

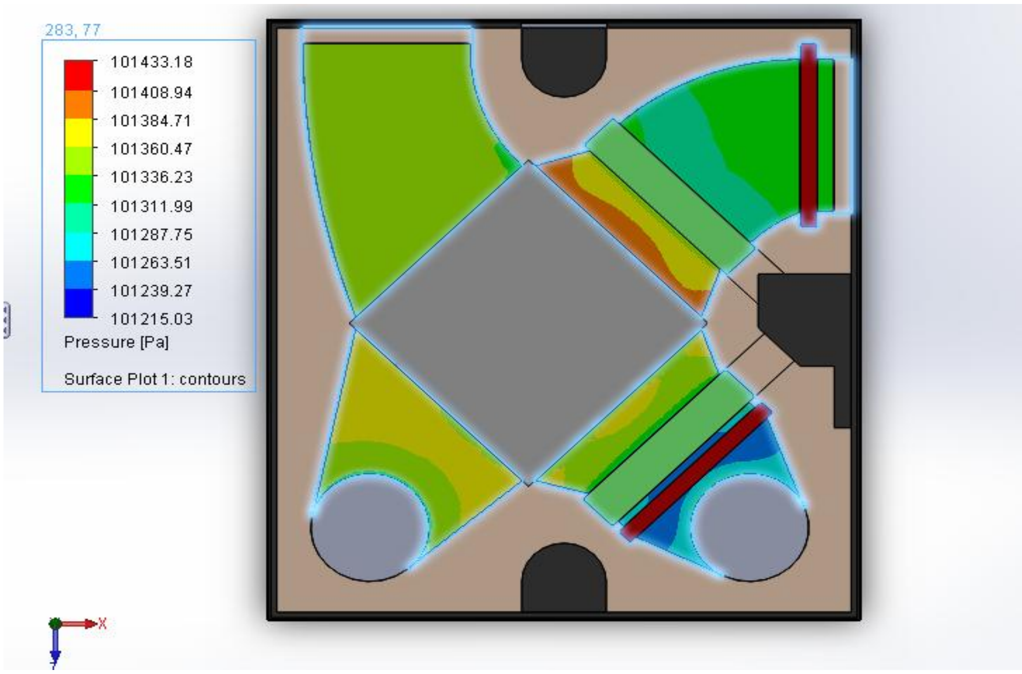

Figure 3.8 -Pressure Distribution (PMD1212PTB1-A Fan)

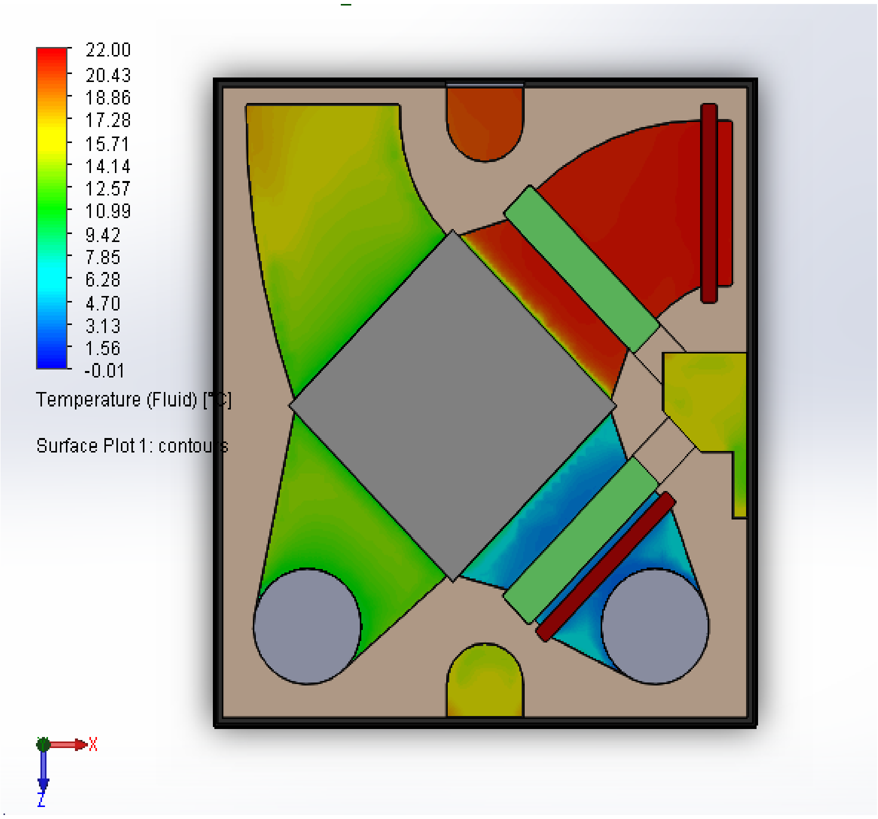

Figure 3.9 -Temperature Distribution (M12-PS Fan)

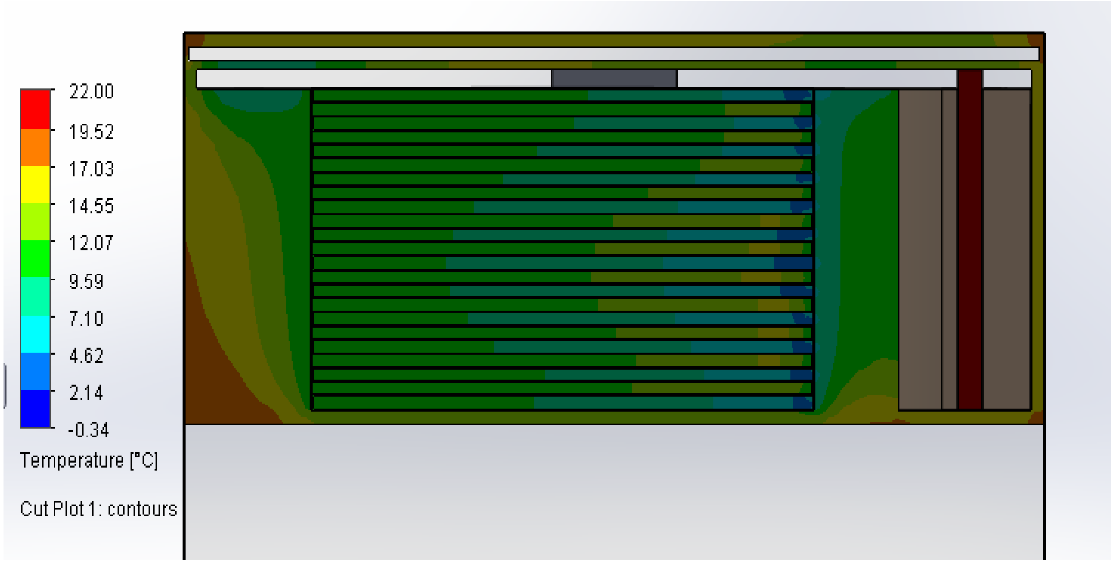

Figure 3.10-Temperature Distribution in the Horizontal Section (M12-PS Fan)

After the calculation, the results presented in Table 3.3 & Table 3.4.

Table 3.3- The Results of Calculation [PMD1212PTB1-A Fan]

Title	**Units**	**Average Value**	**Minimum Value**	**Maximum Value**
Room supply air	[m^3/h]	96.24	96.26	96.22
Room air temperature	[°C]	6.61	6.61	6.61
Exhaust air temperature	[°C]	13.31	13.26	13.34

Table 3.4- The Results of Calculation [M12-PS Fan]

Title	**Units**	**Average Value**	**Minimum Value**	**Maximum Value**
Room supply air	[m^3/h]	12.40	12.41	12.40
Room air temperature	[°C]	12.10	12.06	12.19
Exhaust air temperature	[°C]	9.58	9.46	9.69

3.3 Heat Recovery Efficiency Calculation

This work evaluated the heat propagation in solids. And therefore I selected few fans for simulation to find which fan can produce good heat recovery efficiency. When it comes to simulation, the modeling assumed that all fans are working at maximum capacity and the condition of outer wall heat exchanger heat transfer coefficient is 5.5 $W/(m^2K)$. Below shows the heat recovery calculation and as well heat recovery efficiency in Table 3.5.

Heat Recovery Efficiency $=\frac{(t1-t2)}{(t1-t3)}$ *100 %……………………………………………………… [22]

t_1 = temperature outside air before the heat exchanger (^oC)

t_2 = temperature outside air after the heat exchanger (^oC)

t_3 = temperature inside air before the heat exchanger (^oC)

Heat Recovery Efficiency for M12-PS fan $=\frac{(0-12.10)}{(0-22)}$ *100 % = 55 %

Heat Recovery Efficiency for PMD1212PTB1-A fan =$\frac{(0-6.61)}{(0-22)}$ *100 % = 30.0 %

Table 3.5- Heat Recovery Efficiency

	Fan Type	**Heat Recovery Efficiency %**
Low airflow fan	B12-4	35.5
	B12-3	38.6
	B12-P	38.09
	Pro-Pk3	37.18
	M12-PS	**55**
High airflow fan	**PMD1212PTB1-A**	**30**

After calculation, in which it clearly shows that M12-PS fan produce good heat recovery around 55% and PMD1212PTB1 -A fan produce around 30%.

3.4 Airflow in Full Room

This is same as previous simulation study but here simulation of airflow done in design unit in the room to see the actual airflow velocity produces in the full room of 45m^2.The fan used here is PMD1212PTB1-A **.**

Boundary conditions: The atmospheric pressure 101325 Pa is applied on the openings of exhaust air nozzle & the openings of air intake from outside nozzle. The temperature 22 ^{o}C is applied on the openings of exhaust air nozzle.

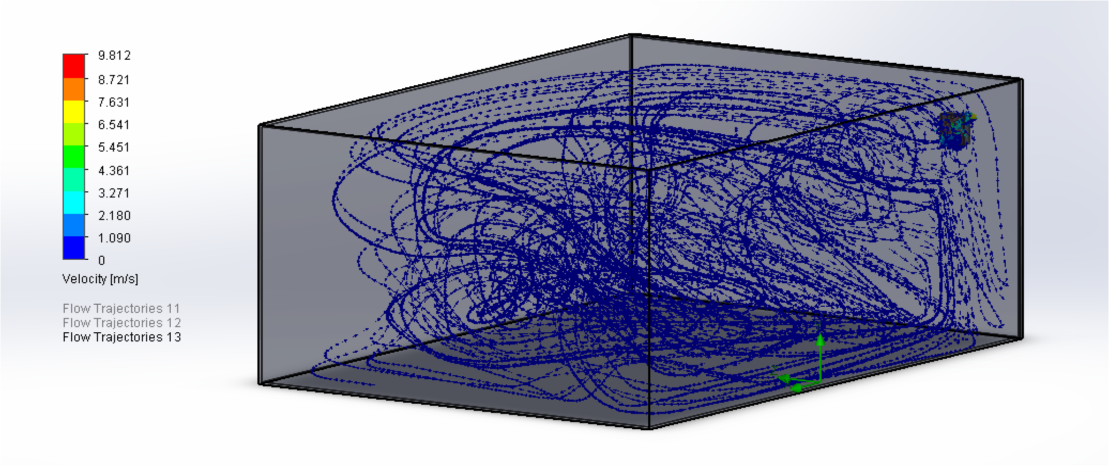

Figure 3.11-Airflow in 45 m^2 Room

Fig 3.11 shows the airflow velocity in a room. According to the results obtained from the simulation accomplished that this fan can provide air volume (82 m^3/h) to the room.

The graph (Fig 3.12) shows the air velocity dependence of the distance traveled from the unit to the end of room (Horizontal lines is drawn to check the velocity and according to the distance traveled the velocity varies). Horizontal lines is drawn from the unit to the end of the room (dimensions are 5400mm, 7000mm, 7200mm, and 7300mm), whereas one line (7300mm) is drawn close to the unit and other lines is drawn next to next to see the variation in velocity.

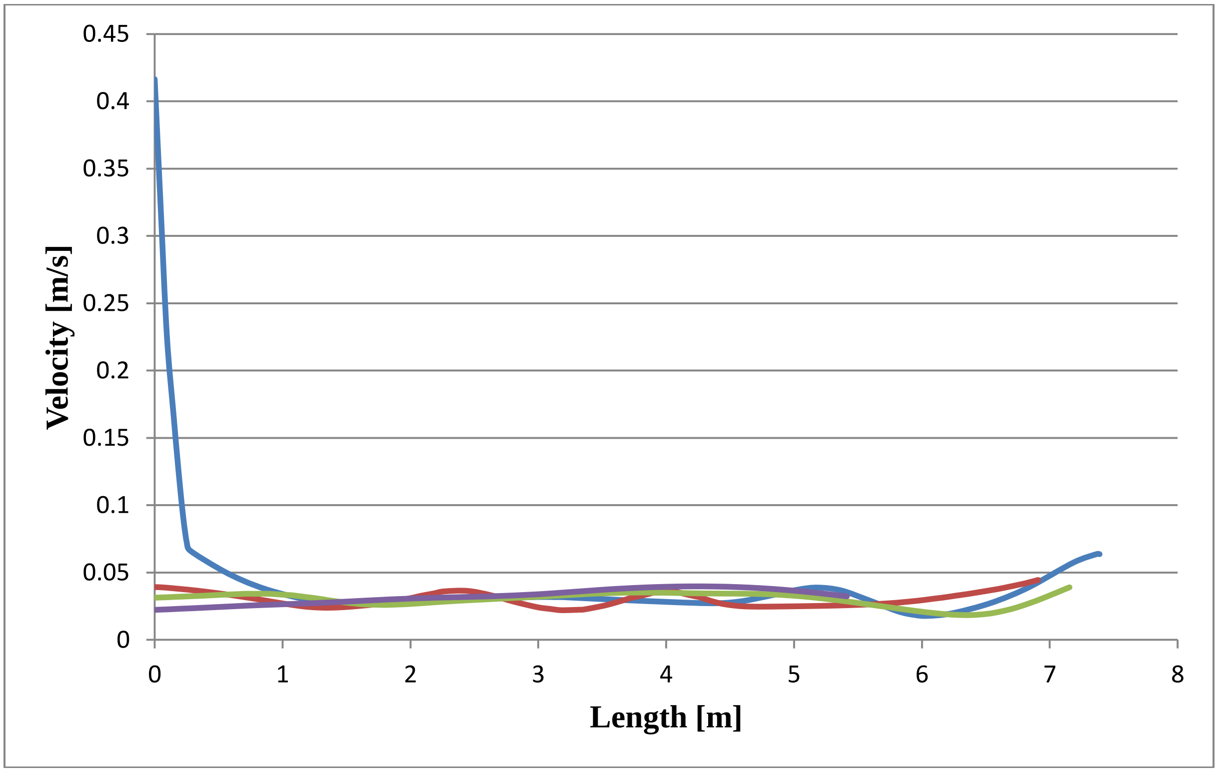

Figure 3.12-Air velocity dependence of the distance traveled through the unit

On the basis of these graph related to the velocity speed, the Beaufort scale stated that no noticeable wind at 0.2–1.0 m/s and wind felt on face at 1.1–2.3 m/s [29]. According to the curve (Fig 3.12) it is possible to state, that a person could not feel any noticeable wind at a distance greater than 0.35 m from the unit. By way the light wind speed will be good for home, whereas people will be more comfort on this particular wind speed.

3.5 Air Flow Dependence on the Static Pressure Measurement Method

Measuring the airflow and static pressure with the device is done according to industrial standards [22]. In order to investigate the air flow generated by the unit's dependence on the static pressure necessary to create a test bench. Studied principle scheme is presented in Fig 3.13. Also, the Q-H curve is demonstrated in Fig 3.14. Q and H is the term for airflow and static pressure.

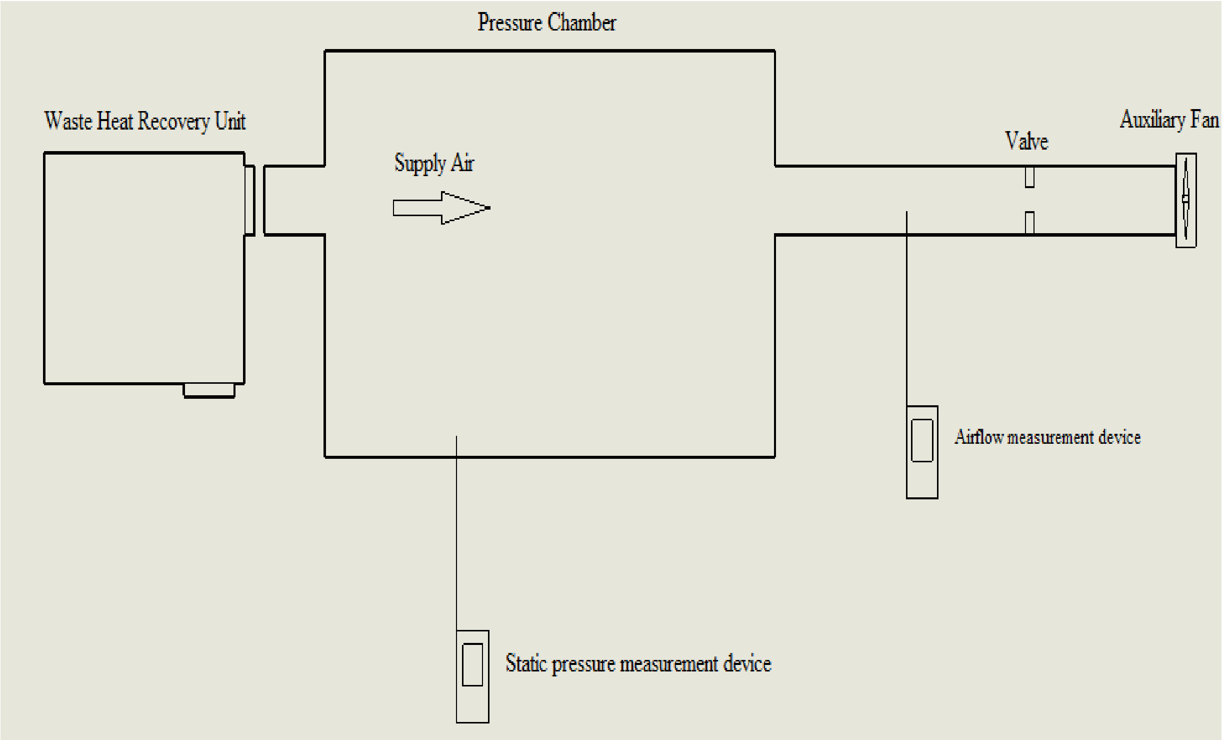

Figure 3.13--Studied Principle Scheme

Fig 3.14 demonstrates the static pressure plotted against the airflow curve obtained when the device is operating at full capacity and the valve is fully closed, then there is no air flow and static pressure reaches a maximum point (A). Next, the valve gradually opened, the auxiliary fan is operated and the median points (Points B, C and D) are obtained, where as in this points there will be little airflow and static pressure drops. Finally, when the valve is fully opened and starts the auxiliary fan in order to achieve zero static pressure in the pressure chamber, thus maximum air flow is obtained at the point (E).In this way Q-H curve is obtained [22].

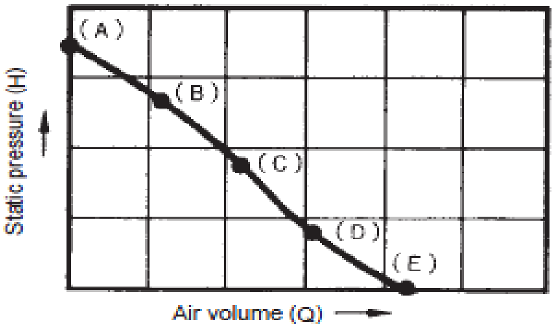

Figure 3.14--Q-H Curve [22]

3.6 Experimental Investigation of the airflow produced by the unit

The figure shows the experimental setup (Fig 3.15) in which consists of a duct (100 mm diameter), prototype (Fig 3.15-2) and a pressure chamber (Fig 3.15-1) has a length of 250 mm and it is made of 1000x750x750 mm design dimensions. The duct length of the pressure chamber up to the valve duct (Fig 3.15-4) provides 1000 mm; the length of the valve duct to the auxiliary fan (Fig 3.15-3) is 1300 mm.

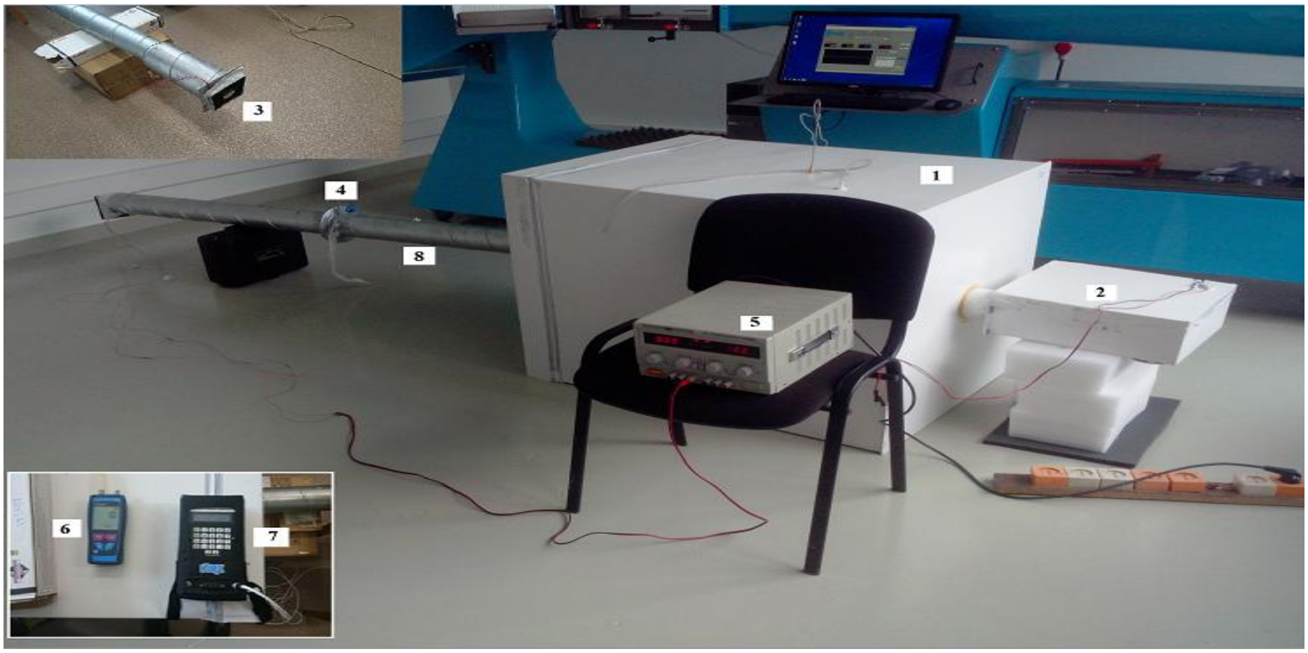

Figure 3.15-Experimental Setup

Where 1 – Pressure chamber; 2 - Prototype; 3 – Auxiliary fan;

4 - Valve; 5- Power supply; 6-Manometer; 7-Thermal Anemometer; 8 - Exhaust air duct;

The auxiliary fan is used, in order to attain zero static pressure in a pressure chamber. And it is powered by an external power source (Fig 3.15-5). In experimental part, an additional one PMD1212PTB1-A fan is used as auxiliary fan. Thermal anemometer & manometer is used in experiments for measuring the airflow and static pressure. Both thermal anemometer and manometer is shown in Fig 3.15-7, & Fig 3.15-6.

An investigation carried out by the method described; where two fan M12-PS & PMD1212PTB1-A is tested. The results are obtained during experiments is presented in Table 3.6.

3.6.1 Experimental Results

Table 3.6- During the Experiment, the Results obtained

M12-PS Fan		**PMD1212PTB1-A Fan**	
Volumetric Flow Rate (m^3/h)	**Static Pressure (Pa)**	**Volumetric Flow Rate (m^3/h)**	**Static Pressure (Pa)**
10.5	0	82	0
8.5	0.6	74	10
7.1	1	68	20
5.2	1.5	55	30
3.6	1.8	47	35
1.27	2.23	38	40
0	2.5	29	45
-	-	18	55
-	-	5	60
-	-	0	65

Done air flow dependence on the static pressure curve presented in Fig 3.16 & Fig 3.17.

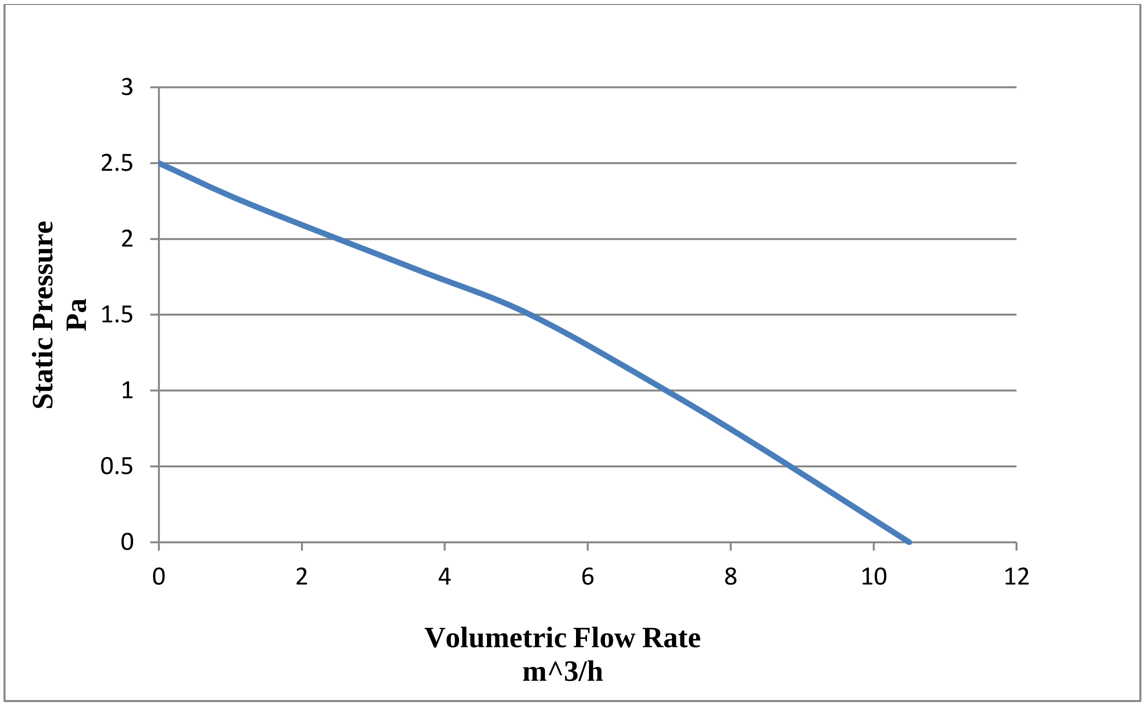

Figure 3.16- Airflow-Static Pressure Experimental Graph (M12-PS fan)

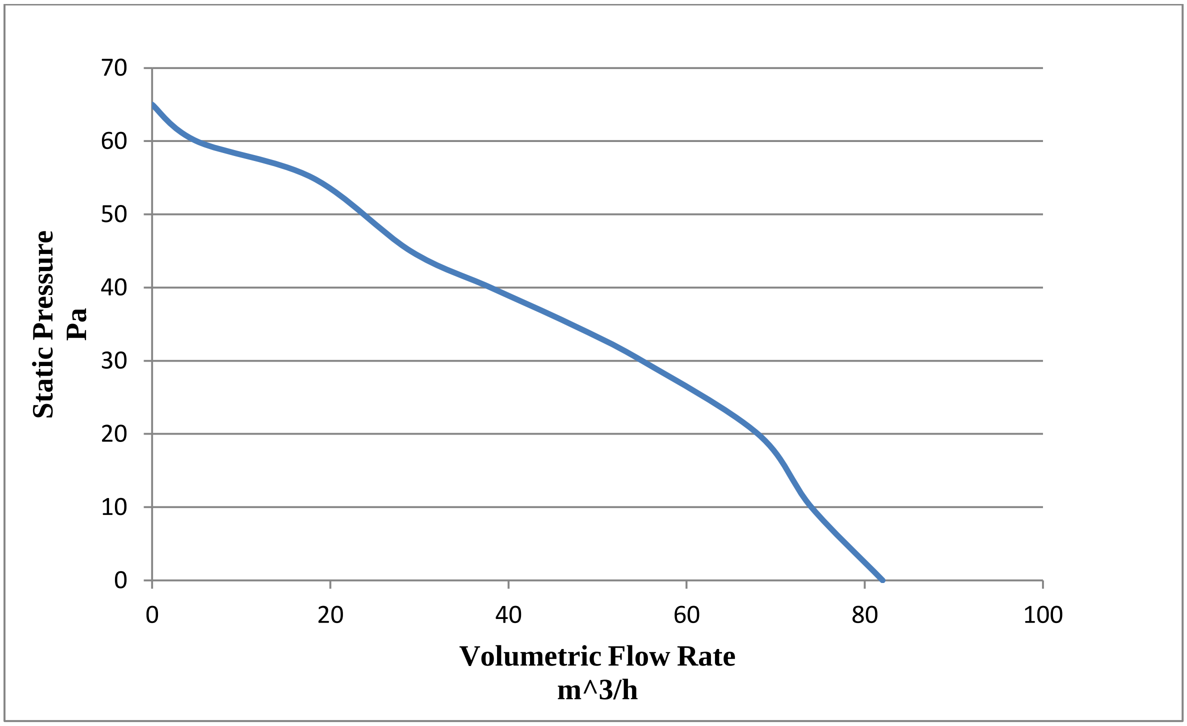

Figure 3.17--Airflow-Static Pressure Experimental Graph (PMD1212PTB1-A fan)

3.7 PMD1212PTB1-A Fan Experiments under Variation of Speeds

The experiments are done in the design unit with PMD1212PTB1-A fan in a pressure chamber, on the basis of speed variation by changing of voltage in the power supply. This is same as airflow-static pressure method study. The fan filters and heat exchangers are also the same as airflow dependence on static pressure method study. This is done to know how much it can produce the airflow & static pressure on different speeds. Therefore the different speeds are achieved by changing the different voltage that are 12V, 10V, 8V.Investigation carried out by the method described and the results presented in Table 3.7.

Table 3.7- Comparison of PMD1212PTB1-A Fan under Different Speeds

PMD1212PTB1-A Fan-Speed I, 12V		**PMD1212PTB1-A Fan-Speed II, 10V**		**PMD1212PTB1-A Fan-Speed III, 8V**	
Volumetric Flow Rate (m^3/h)	**Static Pressure (Pa)**	**Volumetric Flow Rate (m^3/h)**	**Static Pressure (Pa)**	**Volumetric Flow Rate (m^3/h)**	**Static Pressure (Pa)**
82	0	51	0	41.5	0
74	10	48.5	5	37.5	5
68	20	46	10	34	10
55	30	42.8	15	26.3	20
47	35	32.9	30	22.4	25
38	40	30	35	17.5	30
29	45	24.5	40	13.8	35
18	55	19.4	50	0	45
5	60	10	60	-	-
0	65	0	67	-	-

Done air flow dependence on the static pressure curve presented in Fig 3.18.

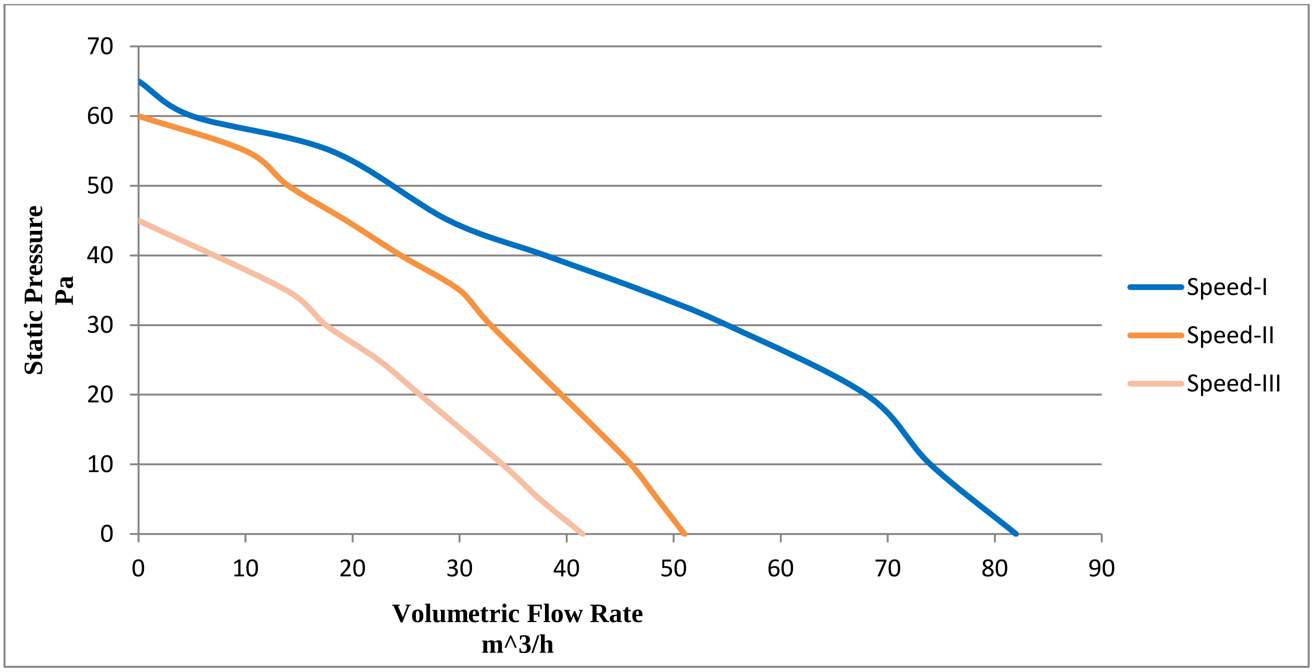

Figure 3.18- Airflow-Static Pressure Experimental Graph (PMD1212PTB1-A Fan)

From above Fig-3.18 shows the airflow-static pressure graph which demonstrates speed I, speed II, speed III of PMD1212PTB1-A fan. Depend on this graph, the customer can get a chance of choosing any type of PMD1212PTB1-A Fan speeds.

3.8 Numerical Simulation of the airflow produced by the unit

Computational model is shown in Fig 3.19. It consists of a frame (2), the heat exchanger (1), the fan (3), the filter (4), and the pressure chamber (6) with a 100 mm diameter duct (9) and a valve (7). Assumption of temperature 22 °C & pressure of 101325 Pa is applied for the openings to the atmosphere (5, 9). Fan, filters, heat exchanger is the same as in the heat recovery study. In order to determine the dependence of the airflow- static pressure carried out by the method described .The valve from fully closed is opened gradually to fully open position.

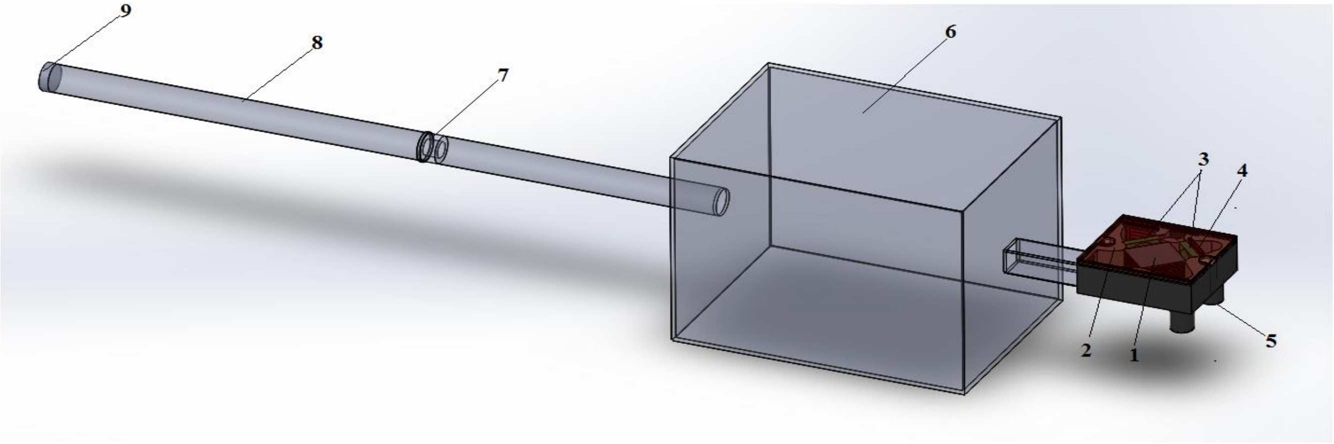

Figure 3.19-Computational Model

1 - Heat exchanger; 2 - Frame; 3 - Fan; 4 - Filter; 5 – opening to the outside air;

6 – Pressure chamber; 7 - Valve; 8 - Exhaust air duct; 9 - opening to the room

3.8.1 Numerical Simulation Results

Table 3.8-During the Simulation, the Results obtained

M12-PS Fan		**PMD1212PTB1-A Fan**	
Volumetric Flow Rate (m^3/h)	**Static Pressure (Pa)**	**Volumetric Flow Rate (m^3/h)**	**Static Pressure (Pa)**
10.73	0	84.72	0
9.93	0.38	83.1	11.22
9.0335	0.6	79.89	13.91
7.626	0.92	72.66	18.52
5.474	1.39	62.42	26.77
3.376	1.83	48.28	36.1
1.43	2.21	32.41	44.86
0.35	2.41	19.13	51.28
0	2.48	8.12	56.91
-	-	0	61.09

Done air flow dependence on the static pressure curve presented in Fig 3.20, Fig 3.21.

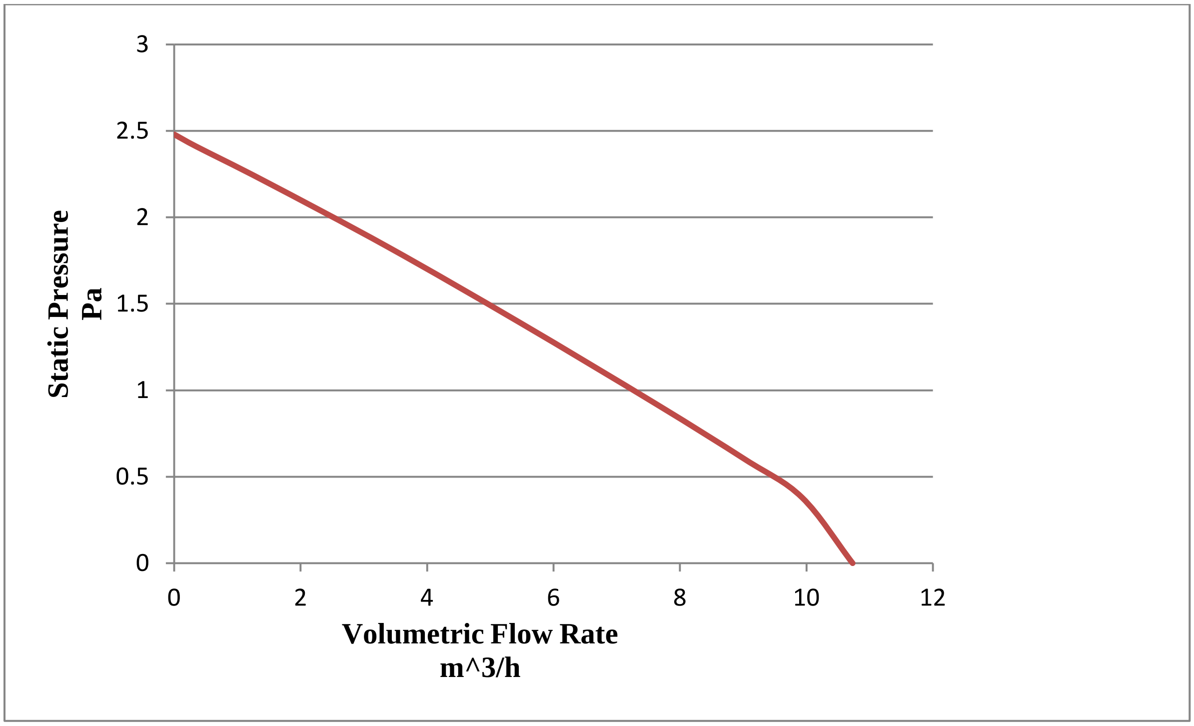

Figure 3.20--Airflow-Static Pressure Simulation Graph (M12-PS fan)

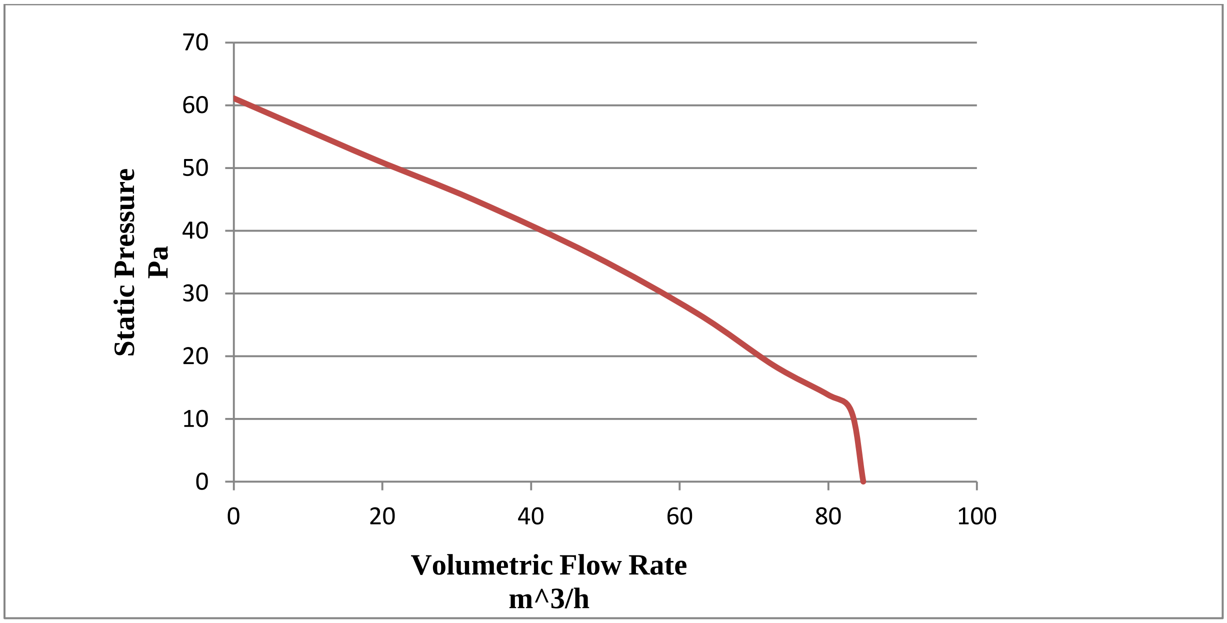

Figure 3.21-- Airflow-Static Pressure Simulation Graph (PMD1212PTB1-A fan)

3.9 Comparison of Results

The comparison of results of experimental study and numerical simulation of both the fan are presented in Table 3.9 & 3.10

Table 3.9- Comparison of results, M12-PS Fan

Experimental Results		**Simulation Results**	
Volumetric Flow Rate (m^3/h)	**Static Pressure (Pa)**	**Volumetric Flow Rate (m^3/h)**	**Static Pressure (Pa)**
10.5	0	10.73	0
8.5	0.6	9.93	0.38
7.1	1	9.0335	0.6
5.2	1.5	7.626	0.92
3.6	1.8	5.474	1.39
1.27	2.23	3.376	1.83
0	2.5	1.43	2.21
-	-	0.35	2.41
-	-	0	2.48

Comparison results of airflow- static pressure curve presented in Fig 3.22.

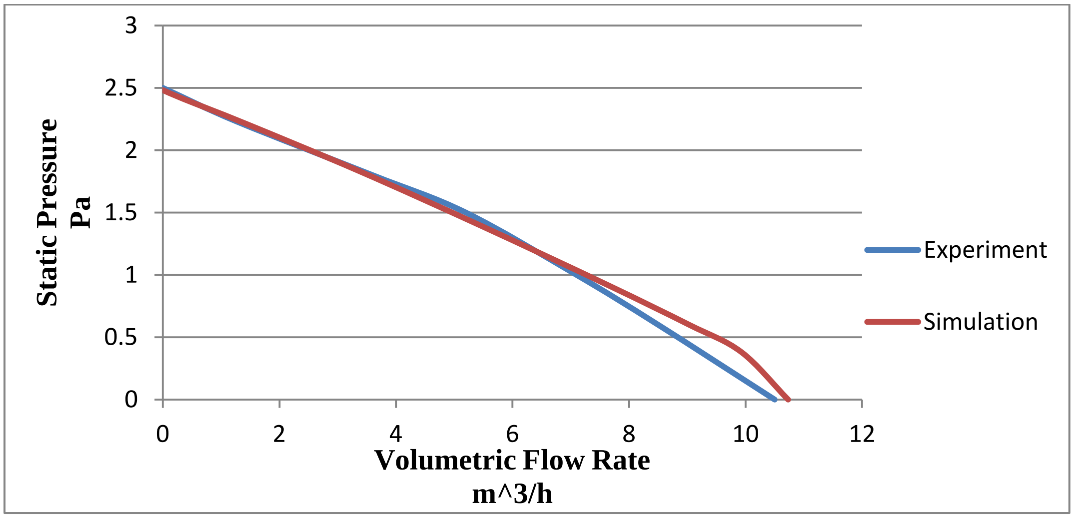

Figure 3.22- Comparison of Results, Airflow-Static Pressure Graph (M12-PS Fan)

Table 3.10 - Comparison of Results, PMD1212PTB1-A Fan

Experimental Results		**Simulation Results**	
Volumetric Flow Rate (m^3/h)	**Static Pressure (Pa)**	**Volumetric Flow Rate (m^3/h)**	**Static Pressure (Pa)**
82	0	84.72	0
74	10	83.1	11.22
68	20	79.89	13.91
55	30	72.66	18.52
47	35	62.42	26.77
38	40	48.28	36.1
29	45	32.41	44.86
18	55	19.13	51.28
5	60	8.12	56.91
0	65	0	61.09

Comparison results of airflow- static pressure curve presented in Fig 3.23.

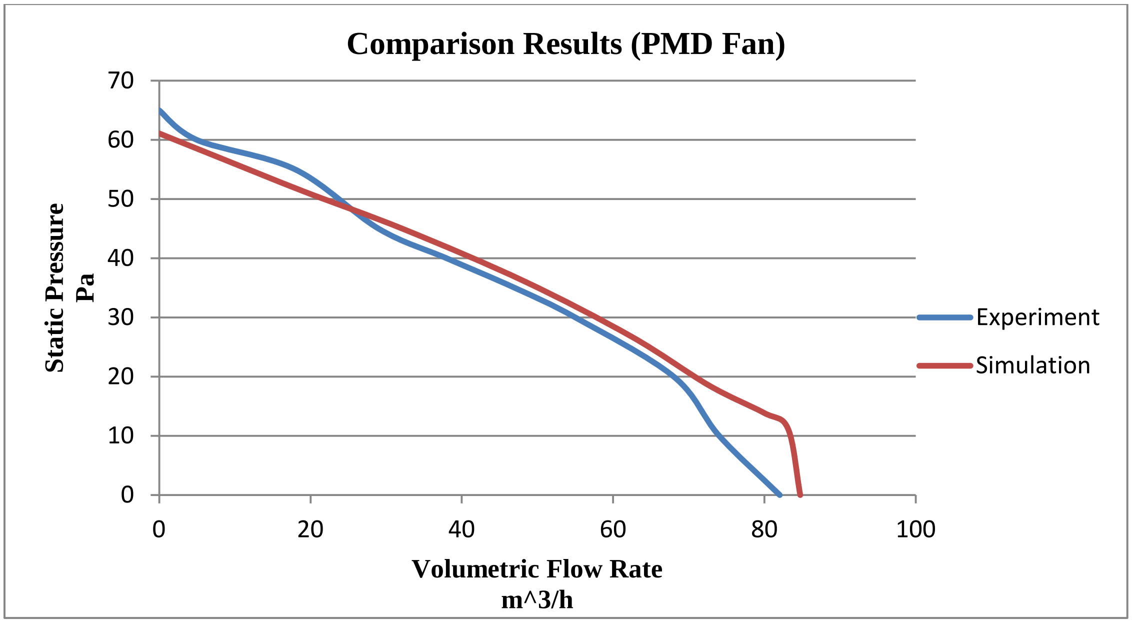

Figure 3.23- Comparison of Results, Airflow-Static Pressure Graph (PMD1212PTB1-A Fan)

4. CONCLUSION

1. An examination of the literature sources related to the heat exchanger and its design to identify their strength and weakness of waste heat recovery unit decided to use of cross-flow heat exchanger. Extruded polystyrene material was also selected on the basis of thermal insulation, strength and other properties, so that the structure can be easily designed and manufactured.
2. A prototype of waste heat recovery unit was designed and manufactured.
3. Numerical simulation of airflow temperature result is calculated and the results shows heat recovery efficiency for M12-PS fan is 55 %, PMD1212PTB1-A fan is 30.0 % ,Pro-PK3 fan is 37.18 % , B12-P fan is 38.09 %, B12-3 fan is 38.86 % and B12-4 fan is 35.5 %. The volumetric flow rate results for PMD1212PTB1-A fan is 96.24 m^3/h and M12-PS fan is 12.40 m^3/h, Pro-PK3 fan is 37.4 m^3/h, B12-P fan is 33.52 m^3/h, B12-3 fan is 30.0 m^3/h and B12-4 fan is 44.24 m^3/h.
4. Computational model and digital simulation carried out air volume dependence on the static pressure method. It was found that device can produce the air flow for M12-PS fan up to 10.7 m^3/h & PMD1212PTB1-A fan is 84.7 m^3/h. Experimental study carried out air volume dependence on the static pressure method. It was found that the device can produce the air flow for M12-PS fan up to 10.5 m^3/h & PMD1212PTB1-A fan is 82 m^3/h. The PMD1212PTB1-A fan was investigated under different speeds, in addition to airflow -static pressure curve was obtained.
5. The experimental results show a good agreement with the results of digital simulation of both the fan (M12-PS & PMD1212PTB1-A)
6. Airflow in the full room achieves 82 m^3/h which indicates that the device is suitable for use in a small residential building up to 45 m^2.

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FORMAT	ZONE	NO.	DESIGNATION	NAME	QUANTITY	NOTES
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			Assembly Units			
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			Parts			
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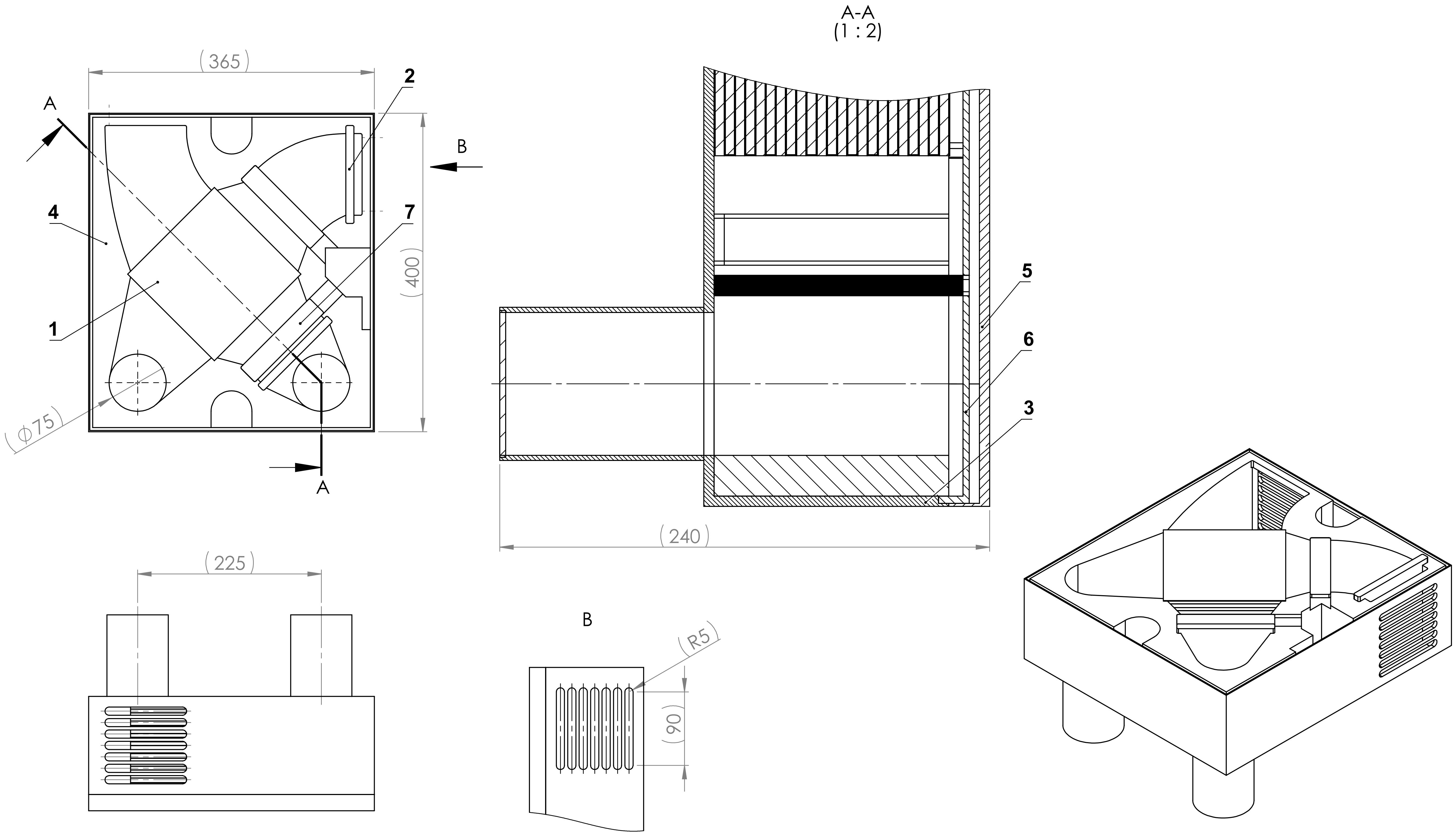
		4	*RU-00.00.004*	*Frame*	*1*	
		5	*RU-00.00.005*	*Front Cover*	*1*	
		6	*RU-00.00.006*	*Inner Cover*	*1*	
			Other Items			
		7	*RU-00.00.007*	*Fan PMD1212PTB1-A (Sunon)*	*2*	

Resp. department *MED*	*Technical reference*	*Document type* *Parts list*	*Document status* *Training*
Legal owner *KTU*	*Created by* *Srinivasan Sekar* *Approved by* *Sigitas Kilikevicius*	*Title, Supplementary title* *Waste Heat Recovery Unit*	*RU-00.00.000* *Rev.* *A* · *Date* *2015-06-12* · *Lang.* *En* · *Sheet* *1/1*



1. Unspecified tolerance limit according LST EN 22768.
2. The front cover and inner cover is not shown in front view and isometric view

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Resp. department MED	Technical reference	Document type Assembly drawing		Document status Training
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