TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Electrical Power Engineering and Mechatronics

DEVELOPMENT AND SIMULATION OF AIR FLOW FOR EXTENSION R4-R5 OF DRIVE ACS580-07

ÕHUVOOLU ARENDAMINE JA SIMULEERIMINE AJAMI ACS580-07 LAIENDAMISEKS R4-R5

MASTER THESIS

Student: Andrei Holtsman

Student code: 204809MAHM

Supervisor: Tanel Jalakas, Senior Researcher

Co-Supervisor: Oleg Kudrjavtsev
                  Technical product manager

Tallinn, 2024

(On the reverse side of title page)

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

"......." .... 202.....

Author: ....
         /signature /

Thesis is in accordance with terms and requirements

"......." .... 202....

Supervisor: …........................
             /signature/

Accepted for defence

"......."...................202… .

Chairman of theses defence commission: ....
                                          /name and signature/

Non-exclusive Licence for Publication and Reproduction of Graduation Thesis[1]

I, Andrei Holtsman 16.01.1997 hereby

1. 58
Development and simulation of air flow for extension of drive ACS580

,

supervised by

_____,

(*Supervisor's name*)

1.1 reproduced for the purposes of preservation and electronic publication, incl. to be entered in the digital collection of TalTech library until expiry of the term of copyright;

1.2 published via the web of TalTech, incl. to be entered in the digital collection of TalTech library until expiry of the term of copyright.

1.3 I am aware that the author also retains the rights specified in clause 1 of this license.

2. I confirm that granting the non-exclusive license does not infringe third persons' intellectual property rights, the rights arising from the Personal Data Protection Act or rights arising from other legislation.

_____ (*da*

---

[1] *The non-exclusive licence is not valid during the validity of access restriction indicated in the student's application for restriction on access to the graduation thesis that has been signed by the school's dean, except in case of the university's right to reproduce the thesis for preservation purposes only. If a graduation thesis is based on the joint creative activity of two or more persons and the co-author(s) has/have not granted, by the set deadline, the student defending his/her graduation thesis consent to reproduce and publish the graduation thesis in compliance with clauses 1.1 and 1.2 of the non-exclusive licence, the non-exclusive license shall not be valid for the period.*

Department of Electrical Power Engineering and Mechatronics

THESIS TASK

Student: **Andrei Holtsman 20480MAHM**

Study programme,   MAHM02/18, Mechatronics

main speciality:

Supervisor(s):   Tanel Jalakas, Senior Researcher, +3726203703

Co-Supervisor: Oleg Kudrjavtsev Technical product manager
                                               ABB AS, oleg.kudrjavtsev@ee.abb.com

Thesis topic:

 (in English) Development and simulation of air flow for extension of drive ACS580-07

 (in Estonian) Õhuvoolu arendamine ja simuleerimine ajami ACS580-07 laiendamiseks

Thesis main objectives:

 1. Optimization of the cabinet cooling system to reduce the cost of the cabinet by at least 5% of the total cost.

 2. Assembly process improvements to reduce cabinet assembly cycle time.

 3. Minimal change in physical cabinet gabborites

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Studying the necessary standards and searching for literature	01.02.24
2.	Writing first draft the theoretical part	07.02.24
3.	Research cabinet components, looking for possible design changes	26.02.24
4.	Second draft of theoretical part	06.03.24
5.	Simulation of air flow cooling of current models	18.03.24
6.	First data analysis	20.03.24
7.	Adjustment of cabinet design considering new data	01.03.24
8.	Analysis of the result	06.04.24

9.	Cost analysis	16.04.24
10.	Final draft of the thesis	26.04.24
11.	Final corrections in the thesis work	10.05.24
12.	Submission of the thesis	13.05.24

Language: ………… **Deadline for submission of thesis:** "……."………20….a

Student: ………………….. ……....…....... "……."…….….....................20….a

/signature/

Supervisor: ………………… ……………………….. "……."......................20….a

/signature/

Consultant: ………………… …...................... "……."......................20….a

/signature/

Head of study programme: …………… …..................."……."......................20…..a

/signature/

Terms of thesis closed defence and/or restricted access conditions to be formulated on the reverse side

CONTENTS

PREFACE

This thesis was published at the initiative of the author, and the topic was chosen jointly with ABB AS. The thesis was compiled at ABB and all key data used in it was provided by ABB databases. The thesis is based on the idea of improving air cooling systems for electric drives of the ACS580-07 series.

The thesis' author would like to thank the engineers at ABB for the guidance and the coursemates at Tallinn University of Technology for the assistance with the formalization of the work. Most of all the author would like to thank co-supervisor Oleg Kudrjavtsev and supervisor Tanel Jalakas who both helped with the finishing of the thesis.

LIST OF ABBREVIATIONS AND SYMBOLS

- 3D - Three-dimensional space
- AC – air conditioning
- CAD - Computer-aided design
- IEC - International Electrotechnical Commission
- IP - Ingress protection
- UL - UL Solutions company
- IEC - International Electrotechnical Commission

1. INTRODUCTION

The purpose of this chapter is to tell more about the topic of this thesis. To achieve this, it is necessary to consider the background and reasons that caused the need for this thesis. Since the work was written jointly with ABB AS, some of the data was hidden to protect commercial interests and maintain confidentiality. The data is covered with red rectangles. Calculations are presented in percentage terms.

1.1 Background

Electric drives play an important role in a large number of industrial applications, electric vehicles, elevators, pumps and robotics. An electric drive is a system, where an electric motor or generator is controlled using a power-electronic converter. A properly selected drive can extend the life of the motor, increase its efficiency and reduce energy consumption.

One of the largest manufacturers of electrical drives in the world is ABB company. Two different series of drives families are produced in Estonia and Finland. Their names are ACS880 and ACS580. Both drives have their own sub-classifications and various modifications. For this thesis, the ACS580 series will be most important. (A more detailed comparison can be found in the next chapter of the thesis) [1] [2]

1.2 Problem statement

Due to the change in UL standards, the old ventilation system cannot be used. Due to the design features of the cabinet, it is necessary to create a simulation of air flow in the cabinet to create a new ventilation system. During the simulation process, the following questions must be answered:

1) How air flows inside the cabinet

2) Which components require more attention when cooling

3) How it is possible to meet the requirements of all necessary standards

4) How to improve the previous ventilation system

5) How changing the position of the fans affects on the air movement.

6) Temperature rise

1.3 Objective of the research

The objective of this research is to update the cooling system of cabinets of the ACS580-07. To achieve this goal, it is necessary to create a computer simulation of the air flows inside the cabinet. Then make the necessary changes to the design of the cabinets. The final goal should be to improve the cabinet cooling system to reduce the cost of the final solution by 5%. It will also be a positive achievement to facilitate the design of the cabinet and reduce assembly time.

• Optimization of the cabinet cooling system to reduce the cost of the cabinet by at least 5% of the total cost.

• Assembly process improvements to reduce cabinet assembly cycle time.

• Minimal change in physical cabinet gabborites

1.4 Overview

The thesis deals with to the construction of a model of air flow in the cabinets of electric drives ACS580-07 design and development of a new ventilation system, analysis of relevant systems in various design variations. [3]

The thesis primarily focuses on understanding the theory of cooling of electrical components inside electrical drive cabinet, the validation of necessary standards, understanding the model project, model preparation inside CREO and Simence FLOEFD flow simulation equipment. Analysis, model running and its behaviour, and finally, validation of the model compared with the actual result.

Keywords: air flow, simulation, ventilation system, drive, product development.

2. LITERATURE REVIEW

2.1 Standards

This subchapter will explain in more detail why changes to the cabinet ventilation system are required. The main reason is the requirements of the UL 508A standard, but the problem is that it is necessary to consider the various requirements in an integrated manner.

2.1.1 UL 508A

In the USA, UL is accredited by the American National Standards Institute (ANSI) as an audited designator. In 2013, UL was accredited by the Standards Council of Canada (SCC) as a nationally recognized Standards Development Organization (SDO) able to develop National Standards of Canada (NSCs). UL Standards Technical Panels (STPs) serve as the consensus body for both American National Standards (ANS) and National Standards of Canada (NSC).

As you can see, UL standards are a necessary requirement for working in the American and Canadian market. Due to the updating of some standards, the products of the ACS580-07 series had to be checked and re-certified. The new accepted standard will be UL 508A, previously UL 508C, which will no longer be accepted in the future. One of the most important points of the new standard is the location of the ventilation outlet:

A ventilation opening that serves as an air outlet of exhaust air from a forced ventilation system shall not direct air at the area occupied by the equipment operator. The area occupied by the operator shall be 762 mm wide (horizontal) centered on any operator control, display, or disconnect handle over the entire (vertical) height of the enclosure for wall mounted equipment or up to 1828.8 mm above the floor for floor mounted equipment. Exception: When an air outlet from a forced ventilation system is located in the area occupied by an operator a barrier or duct shall be provided to redirect the airflow in a direction 90 degrees or greater away from the operator.

As we know from the previous chapter, the outlet is directly above the control panel. Which directly contradicts the requirement of the UL standard. One variation would be to redirect the airflow over the roof of the cabinet, or redirect the air to the side, as suggested by the standard itself. We will explore these possibilities in more detail in later chapters. [4]

2.1.2 IP standards

Electric and electronic equipment deteriorate or malfunction when water or dust enters the device. The IEC has developed the ingress protection (IP) ratings, which grade the resistance of an enclosure against the intrusion of dust or liquids. The ratings are widely used throughout industry.

IEC 60529 has been developed to rate and grade the resistance of enclosures of electric and electronic devices against the intrusion of dust and liquids. It also rates how easy it is for individuals to access the potentially hazardous parts within the enclosure. In the ACS580-07 series of drivers, three IP standards are used: IP21, IP42 and IP54 [5]

The IP code is composed of two numerals:

The first numeral refers to the protection against solid objects and is rated on a scale from 0 (no protection) to 6 (no ingress of dust).

First number	Size of a solid object	Protected against access with
0_	No protection	No protection
1_	>50mm	Back of hand
2_	>12.5mm	Finger
3_	>2.5mm	Tools, screws
4_	>1mm	Wire
5_	Dust protected	Wire
6_	Dust tight	Wire

Figure 2.1 Protection against solid objects scale

The second numeral rates the enclosure's protection against liquids and uses a scale from 0 (no protection) to 9 (high-pressure hot water from different angles).

Second number	Protected against
_0	No protection
_1	Dripping water
_2	Dripping water tilted 15°
_3	Spraying water tilted 60°
_4	Spraying water from all directions
_5	Water jets
_6	Powerful water jets
_7	Temporary immersion
_8	Continuous immersion

Figure 2.2 Protection against liquids scale

ACS580-07 series of drivers, three IP standards are used: IP21, IP42 and IP54. Standards IP21 and IP42 is less important for the thesis because this standard is easily achieved by installing a barrier net in front of the air inlet and outlet openings. With IP42 standards, it adds an additional dust filter to the ventilation grilles. The IP54 standard most influences the design of the cabinet. With it, it is necessary to use denser gaskets and air filters of a higher class, because of which it is also necessary to change the fan, since the passage of air is much more difficult. It is precisely because of the IP54 standard that it is not possible at the moment to unite air flows in the ventilation system without additional modifications.

2.2 Simulation of air flow

In essence, the entire ventilation and air-conditioning system is designed to create directional air flows in each specific space, while providing a well-defined parameters of the air mixture and the required volume of air exchange. The operation of any ventilation system is based on the principles of natural and forced air circulation. It is most sensible to use both options, because each has its own weaknesses and strengths. One of the basic principles of the ventilation system is the so-called natural traction. The air moves in the room due to the difference in temperature and air pressure. [6]

Natural ventilation is based on the following principles:

- Spent heated air flows always tend upwards

- Cold air masses occupy space closer to the floor

- Cold air masses will always strive to displace warm

For such a ventilation system to function, it will be sufficient to install a channel for incoming air closer to the floor in the cabinet and an outlet for exhaust air under the roof. The principle of ventilation operation implies the creation of a continuous circuit of circulating air, where the flow and exhaust of air masses are balanced. We see implementation of this principle in the operation of the external circuit of the already existing ventilation system.

Forced ventilation is based on the following principles:

- Intake fan pumps air from outside

- Air passes through the filter

- Air passes through the heating or maintenance element (optional)

- Air is fed into the space

- The exhaust fan drains air into the external medium (optional)

This ventilation system is used in the internal ventilation circuit. The ACS580-07 has no exhaust fan, but this option is included in the ACS880 series. As one of the possibilities for improving the ventilation system, one can consider a model with the presence of both types of entrances. In this case, it will be possible to compensate for the difference in temperature flux, but it will require a modification of the construction of the roof of the cabinet.

It should also be borne in mind that this theory works with uniform heating of air. Since the internal environment of the cabinet consists of different elements, each of which has its own shape and a different degree of heating, this leads to uneven movement of air masses inside the cabinet. During the air circulation process, heat sinks and swirls can occur, which can slow down the cooling rate. Behaviour of air flows on the example of server room cooling. There is an air swirl of warm air, which is why the rightmost server does not cool as it should. [7]
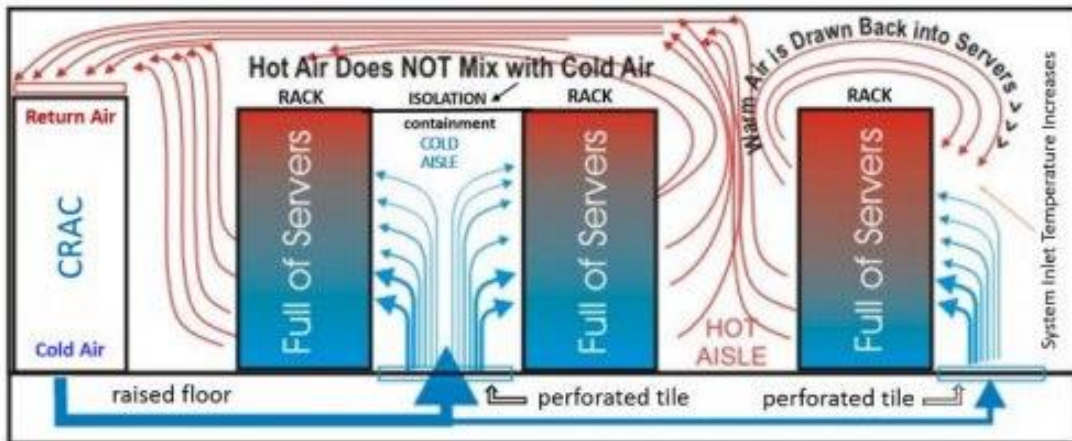
Figure 2.3 Behaviour of air flows on the example of server room cooling. There is an air swirl of warm air, which is why the rightmost server does not cool as it should. [7]

Solidworks flow simulation will be used to simulate air currents. In it, it is possible to simulate the movement of various flows in a closed space, compare their temperature, speed with different options for the structure of the cabinet. Also, this simulation will allow you to check the heating rate of the cabinet during operation. This simulation technique has shown its effectiveness in a range of completely different works: [8] [9]

Virtual Simulation for Detection of Gray Mold with Biosensor Technology in Greenhouse. The essence of the work was to consider ways to spread spores in greenhouses. Thanks to the Solidworks, the author was able to simulate realistic parameters of air movement in greenhouses, on the basis of which he was able to predict the appearance of spores. [10]
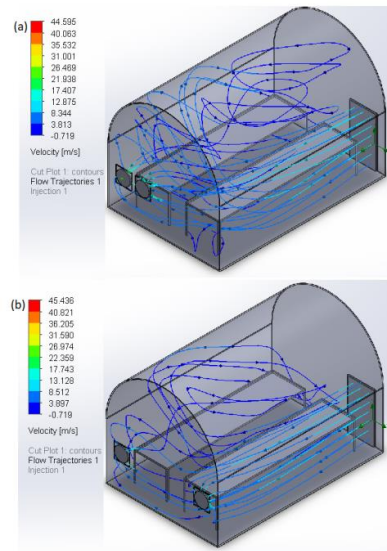
Figure 2.4 Two examples of airflow in a greenhouse when the door and fans are repositioned. [10]

Vehicle Body Design and Analysis Aerodynamic by Flow Simulation - uses a Soldworks to simulate airflow on a car body. A similar function is also well applicable for this thesis. With its help, it is fashionable to consider areas that, for one reason or another, do not receive air flow with a ticking design of the cabinet. [11]

2.2.1 Pipe airflow

To understand the air flow behaviour in the simulation in more detail, we must first consider the flow behaviour in the pipe.

The flow of air or liquid particles passing through a pipe behaves laminarly or turbulently. In laminar flow, the path of the fluid is smooth, and adjacent layers of fluid particles move synchronously. This results in steady flow if the boundary conditions remain constant. In a turbulent fluid system, the flow behaviour is random and turbulent, so the fluid particles become unstable as they move. Flow variables, such as speed, change chaotically and randomly. Numerically, these two groups are dictated depending on the Reynolds number of the fluid. [12]

Reynolds number can be calculated as seen in equation 2.1. Where ρ is the density of the fluid, u is the average flow velocity, L is the length of fluid system and μ is viscosity of the fluid. It is a ratio of inertial forces over viscous forces which indicate the state of the flow system. Then higher Reynolds number is, then the flow behaves more turbulently. [13]

- If the Reynold's number is less than 2000, then the flow will be laminar.
- If the Reynold's number is more than 4000, then the flow will be turbulent.
- If the Reynold's number is between 2000 and 4000, then the flow can be either laminar or the turbulent as well.

$$Re = \frac{\rho u L}{\mu}$$
(2.1)

Where Re is Reynold number, N*s*m^2

ρ is is the density of the fluid, kg/m^3

u is the average flow velocity, m/s

L is the length of fluid system, m

μ is viscosity of the fluid, Pa

The laminar and turbulent behaviour of fluid particles clustered along flow lines in a closed pipe can be seen in figure 2.5. [12]
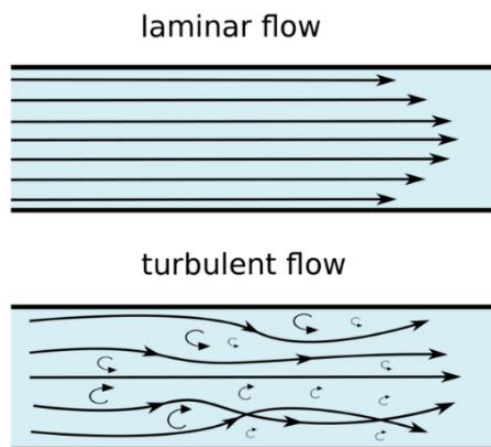

Figure 2.5 Comparison of turbulent and laminar flow with particle streamlines passing through a pipe [14]

In the fluid system with solid wall boundaries enclosing the flow there is boundary conditions at the interface that dictates the nature of the fluid motion. The no-slip boundary condition assumes that the velocity of the fluid layer in contact with the boundary has the same velocity as the boundary itself. The relative movement between the boundary and fluid is zero meaning there is no slip, the fluid is stationary if the solid boundary remains at rest.

Moving away from the boundary to the centreline of the tube the velocity increases to its mean input velocity assuming there are no obstructions. Reynolds number can also vary from a distance from the wall, decreasing the closer the fluid is to the wall. [15]

Our goal is to maintain a more controlled and predictable laminar flow. To do this, you will need to strive for a lower Reynolds number. Density and viscosity cannot be controlled, since in the case of air they will vary slightly depending on temperature. The distance L is also fixed and is equal to the height of the cabinet. Therefore, in the case of air flow simulation, the main parameters will be average flow velocity.

2.2.2 Airflow around a bluff body

As mentioned earlier, the main parameter for flow control will be velocity. But we also need to consider the influence of the components inside the cabinet on the flow behaviour. On their location and shape.

A bluff body is defined as a body that separates oncoming airflow over a large proportion of its surface area due to its shape. This separation creates a wake which is located behind the obstructing body consisting of large areas of disturbed turbulent flow.

In this disturbed flow there is formations of vortices which are structured depending on the Reynold's number. These are regions of revolving fluid which can take form of whirlpools or tornados. They are most created at a moving boundary due to shear caused by the no slip condition, where surface friction slows down the flow near the wall boundary, but they can also be caused by thermal circulation. To measure the vortex strength of these rotating vortices, a parameter termed circulation (Γ) is used. [16] [17]

Bluff bodies can be divided into three different categories depending on their cross-sectional shape: the first(a) is a continuous and finite curvature structures such as a circle or ellipse. The flow of separation point here may oscillate along the shape surface,

due to the smooth-edged face, depending on the flow's Reynolds number; the second(b)is sharp-edged cylindrical structures such as flat plates, squares, and triangles. The flow of separation point is fixed in this category due to the sharp corners with the positioning is independent from the flow's Reynold's number.

The third(c) is a combination of both categories such as a D-shaped cylinder or a square cross-section with rounded corners. [18]

When comparing these three groups of bluff bodies, with different Reynolds numbers, it becomes clear how the level of circulation increases, depending on the body shape. Both measurements were taken with laminar flow, but with different Reynolds numbers, with 200 and 2000. Lower vorticity means a reduction in circulation strength of the vortices which fade out downstream which can be seen in figure 7.
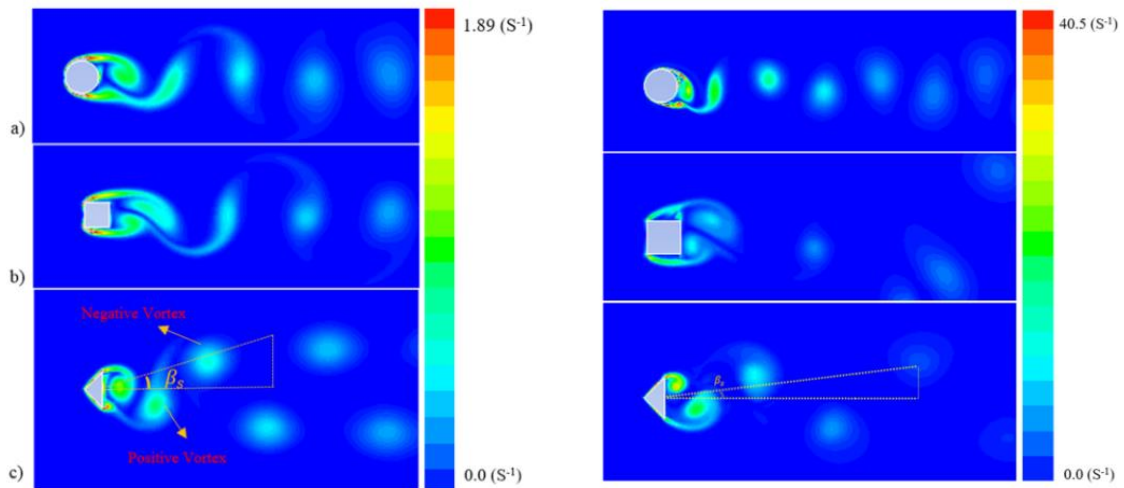
Figure 2.6 Vorticity contours of smooth and sharp-edged cylinders. Left at Re=200, Right at Re=2000 [18]

In a rectangle body the cross-sectional aspect ratio, C/D, where C is the width and D is the diameter, alters the shedding frequency of the downstream flow. A shorter cross-section, meaning a low C/D value, produces a lower vortex shedding frequency compared to a longer cross-section, higher C/D, which produces a greater vortex shedding frequency. However, the vorticity strength is greater for shorter rectangles with around a C/D of 2. This is due to there being less surface distance for the flow to pass meaning more of the kinetic energy is retained producing higher vorticity readings. This can be seen in figure 8 where the cross-section aspect ratios are varied from shorter to longer in length, C/D = 2 to 10.

21
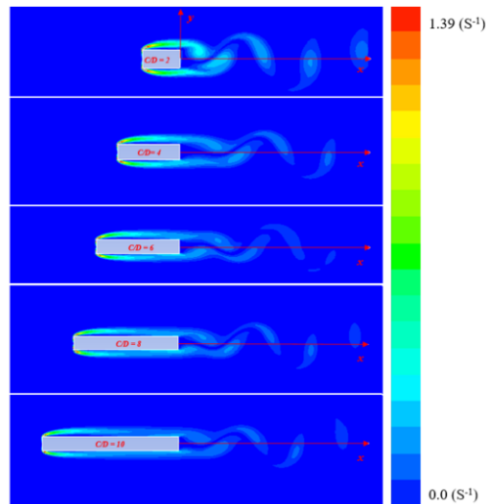
Figure 2.7 Vorticity contours for varying rectangle lengths at Re=200 [18]

Based on these data, we see that the lower the Reynolds numbers, the less turbulent the flow will be. Even when the value is already in a rational range of laminar flow. Also, by changing the shape of the object, trying to use smoother shapes, it is also possible to reduce the turbulence. Using these factors, it possible significantly better control the air flow in cabinet.

2.3 Thermodynamics

To better understand the principle of FLOEFD program operation it is necessary to understand the basic principles by which it works. These are the basic principles of thermodynamics.

2.3.1 Basic Principles of Thermodynamics

Basic Principles of Thermodynamics: A Look at the Fundamental Laws of Nature Thermodynamics, one of the major branches of physics, studies the transfer of energy between different forms and the interaction of heat with other forms of energy. Its principles play an important role in understanding many phenomena in nature, from the motion of planets to chemical reactions in the cells of living organisms. In this article, we will review the basic principles of thermodynamics that underlie this important field of science. [19]

The first law of thermodynamics formulates the principle of conservation of energy for thermal and mechanical systems. It states that the amount of energy in an isolated system remains constant - energy can change from one form to another but cannot be created or destroyed. This is formally expressed by the equation: (Equation 2.2)

$$\Delta U = Q - W \tag{2.2}$$

where ΔU - is the change of internal energy of the system, J

Q is the heat gained or lost by the system, J

W is the work done by or on the system, J

The second law of thermodynamics states that in an isolated system, entropy (a measure of disorder) can only increase or remain constant with time. This means that processes occurring in nature cannot reverse without external influence. The most famous formulation of the second law of thermodynamics states, "Heat cannot spontaneously transfer from a body of lower temperature to a body of higher temperature."

The third law of thermodynamics states that when the absolute zero temperature (0 K) is reached, the entropy of the system also reaches a minimum value. The formulation of this law is important in understanding the properties of crystalline materials at low temperatures. [19]

2.3.2 Main methods of heat transfer

Conduction: This process of heat transfer occurs in solids and stationary liquids. In conduction, heat energy is transferred from molecule to molecule within a substance due to their thermal motion. That is, molecules in a region of higher temperature transfer energy to molecules at a lower temperature. Examples of conduction include heating a metal spoon when it is held in a hot liquid, or heat transfer through the wall of a pot on the cooker.

Convection: This heat transfer mechanism is characteristic of liquids and gases and is based on the movement of masses with an uneven temperature distribution. Under the influence of the difference in density between hot and cold medium, circulation takes place: the hot medium rises and the cold medium sinks. This process is called convection. Examples include heating the air in a room where hot air rises and cold air falls, creating air circulation.

Radiation: This type of heat transfer occurs through electromagnetic waves emitted by a higher temperature body in the form of infrared radiation. Radiant heat can be transmitted through a vacuum, making it particularly important in space technology. Examples of radiant heat are the sun's rays that heat the Earth, or the infrared radiation from a warm body that you can feel when you stand near it.

These modes of heat transfer often combine with each other in natural and technical processes, creating a variety of heat transfer conditions and affecting many aspects of our daily lives. [19]

2.3.3 Convection

Convection will be the primary mode of body transfer in the cabinet. It can be used to check the output of the simulation. How much per cent the heating of key elements will be reduced.

The formula describing the convection process depends on the particular situation or phenomenon we are considering. However, for simple cases of convection in gases, such as heating a room, a formula is often used to calculate the heat flux. This formula is called Newton's formula for cooling or heating.(Equation 2.3) [19] [20]

$$Q = hA\Delta T \qquad\qquad (2.3)$$

where Q - is heat flux, W

    A – is surface area, m^2

    ΔT - is difference in temperature between the body and the environment, °C

    h - is the convective heat transfer coefficient W/(m^2*°C)

The basic equation describing the process of cooling or heating a body through convection can be written as follows: (Equation 2.4)

$$Q = m * c * \Delta T \tag{2.4}$$

where Q is he heat output expressed, J or W

m is body mass, kg

c is specific heat capacity of the body material, J/(kg*°C)

ΔT is the change in temperature of the body, °C

Based on this equation, to find out how much the body temperature will change, you need to know the heat output Q, mass m and specific heat capacity c of the body material. If you have data on the heat transfer Q by convection, you can use this equation to estimate the change in body temperature. Thanks to these formulas, it will be possible to calculate the approximate cooling efficiency of some components of the simulation and compare it with the program data. [19]

3. OVERVIEW OF ACS580 CABINET DESIGN

As was mentioned in previous chapter, ABB is one of the largest manufacturers of electric drives. The two main series are ACS880 and ACS580 drives. In short, their characteristics can be described as:

ACS880 - Industrial drive with wide range of wall-mounted drives, drive modules and cabinet-built drives. Designed to provide customers across industries and applications with unprecedented levels of compatibility and flexibility. Highly customized drives. [21]

ACS580 - General purpose drive. Wall-mounted, drive modules and cabinet-built including all the essential components for typical light industry applications. [2]

In other words, the differences between these two families in the approach to application. The ACS880 is more flexible and has more variations than the ACS580, is also more expensive and better suited for more specific applications. At the same time, the ACS580 is cheaper and better suited for more general applications due to its availability.

Considering both families in terms of general mechanical and electrical design, they are similar in some respects and have common components, but at the same time they have fundamentally different elements.

3.1 ACS580 classification

ABB had family of general general-purpose drive ACS580. It includes many different drives designed for different tasks and purposes. One of the main sub-series is the 07 series - which means a fully engineered cabinet solution. For customers, this solution is very easy to install and can cover a wide range of applications. Also exist series 01 and 04. 01 – it is a separate module which can be installed on a wall. 04 – it can be installed in a cabinet. The difference between these two series is that the first one can be installed separately in the external environment, while the fourth one requires an additional protective casing, and the first one is more versatile than the fourth one with the same characteristics. [2]

07 series cabinets - divided into several sub-series, depending on the maximal available output and frame size of cabinet.

3.2 Electrical drive ACS580

As mentioned earlier, the design of the new cabinet will be similar to the R6 cabinets. All components are installed in a cabinet measuring 2000mm x 600mm x 400mm, the cabinet frame is assembled from universal profiles. Below is a standard layout with connection from bottom, in brackets will be indicated an additional option according to which this element will be installed.

The following elements are of particular importance for this work: cabinet door fan, auxiliary voltage transformer T21, main switch with AC fuses, main contactor, drive module, drive control unit and du/dt filter. (Figure 3.1) These components generate heat during operation, thereby heating the cabinet. It will be necessary to further check the degree of their influence on the overall heating of the system. It is also important to consider the location of the components, as it can cause air turbulence. [2]

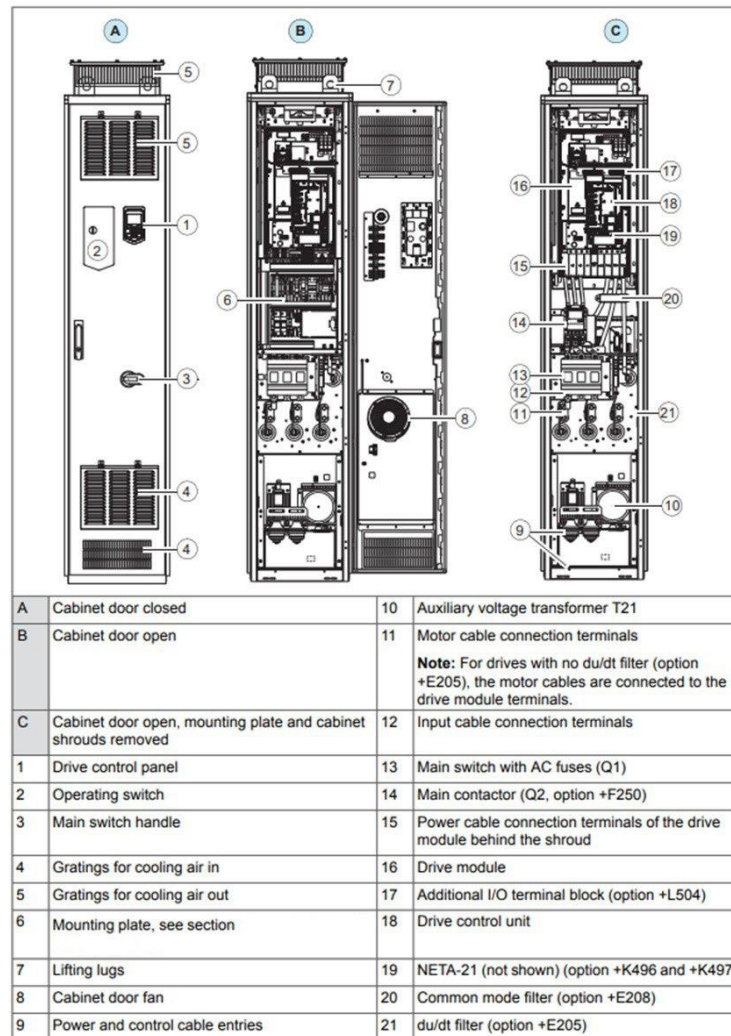| A	Cabinet door closed	10	Auxiliary voltage transformer T21
B	Cabinet door open	11	Motor cable connection terminals
			Note: For drives with no du/dt filter (option +E205), the motor cables are connected to the drive module terminals.
C	Cabinet door open, mounting plate and cabinet shrouds removed	12	Input cable connection terminals
1	Drive control panel	13	Main switch with AC fuses (Q1)
2	Operating switch	14	Main contactor (Q2, option +F250)
3	Main switch handle	15	Power cable connection terminals of the drive module behind the shroud
4	Gratings for cooling air in	16	Drive module
5	Gratings for cooling air out	17	Additional I/O terminal block (option +L504)
6	Mounting plate, see section	18	Drive control unit
7	Lifting lugs	19	NETA-21 (not shown) (option +K496 and +K497)
8	Cabinet door fan	20	Common mode filter (option +E208)
9	Power and control cable entries	21	du/dt filter (option +E205)

Figure 3.1 ACS580 design and components layout

27

Cabinet door fan is important component of ventilation set up. ACS580 drives are fitted with variable speed cooling air fans. The cooling air must be free from corrosive materials and not exceed the maximum ambient temperature of 40 °C for the frames R4 to R9 (50 °C with derating). The speed-controlled fans cool the drive only when needed, which reduces overall noise level and energy consumption.

3.2.1 Components

Cabinet module is in both ventilation circuits of the office at once. It is installed at the top of the dividing wall. It has a built-in fan, which is located in the rear part of the module, which is connected to the external ventilation circuit. It is the key element for the construction of the whole cabinet. The key task is to ensure good cooling of this element.

OS switcher and contactor -These two elements go together, connected to each other by busbars. They are located in the inner circuit of the cabinet, installed directly opposite the door ventilator. There are fuses inside the switch, which get very hot during operation.

DU/DT filter - This element produces the most heat. It is located in the same way as the module on the dividing wall. Some of the elements are located in the internal ventilation circuit. But the hottest parts are discharged into the external ventilation circuit. The coils and radiators of the filter can be used for heat dissipation calculations.

Voltage transformer - is located in the internal ventilation circuit. Its location is very unfortunate, as it is next to the part of the du/dt filter. The air circulation around it is also supposedly impeded.

Fans - As stated earlier, one fan is located inside the module. The second one is located on the door of the cabinet. So, there is one ventilator for each ventilation circuit. The first fan cannot be changed as it is integrated. The second fan can be moved or removed if necessary.

Other electronics components - Other components are various relays, terminals, power supplies and other elements that do not have a high temperature, but their performance can also be taken into account. They are mainly located on the hinged frame, which is installed at the cabinet door, above the contactor.

3.3 ACS580 ventilation system

The ventilation system consists of two circuits, internal and external. The circuits are isolated from each other. As can be seen in the figure, the internal circuit cools all electrical components: the front part of the Du/Dt filter, contactor, fuse, switch, control elements and wiring.

The internal circuit can also be isolated from the external environment if the IP54 standard is applied. Ventilation holes located in the lower and upper part of the cabinet door, at the bottom - the entrance, at the top - the outlet. For air intake, a fan is used, which is installed at the bottom of the cabinet door, the power of the fan also varies depending on the standard of water-resistance. (Figure 3.2)

The external circuit cools the coils and capacitors of the Du/Dt filter and the lats and the drive module. This contour is not drawn from the external environment, as all elements located in it have moisture protection. The air circulation is drained by physical forces and the difference in cold and warm air flow pressure. [2]
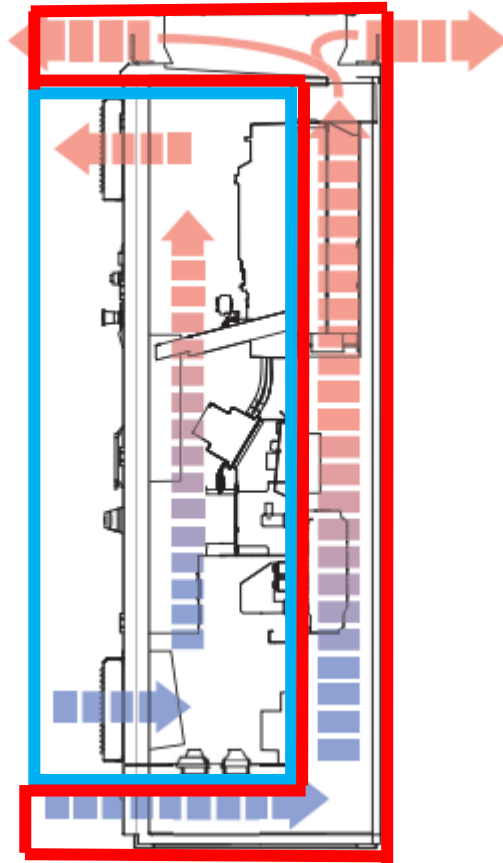
Figure 3.2 Ventilation circuits internal (blue) and external (red)

The main problem of this design ventilation system is that the circuits have different temperatures. We need to simulate the behaviour of the airflow to determine how the cabinet will behave, whether the electronics will overheat. In case of no overheating, there is still a problem with the waterproof cabinet, because the moisture will be able to get from the external circuit to the inner. It is also necessary to test the location of the fan, its functionality and the position of the internal partitions, whether they do not create obstacles in the process of cooling the cabinet.

4. RUNNING THE INITIAL SIMULATION

Simulations will be carried out in the Siemens FLOEFD program. The reason for choosing this program is a software and security limitation. Since the main CAD software in the company is CREO, must use programs compatible with it. CREO is compatible with FLOEFD. [22] [23]

To improve the current ventilation system, you first need to do an initial simulation. The initial simulation is a simulation of the current, original cabinet layout. This simulation will serve as a benchmark for comparison with all future changes.

This chapter will describe the process of creating and setting up the initial simulation. The key inputs will be used for all subsequent simulations. Also, based on the results of the initial simulation, key areas for improving the ventilation system will be selected.

4.1 Rework of cabinet 3D model

For this work, a 3D model was used for internal use in the company. It is also possible to find a publicly available cabinet model and cabinet parts on the ABB official website. (Figure 4.1) The differences in the internal and public models are not significant. The differences can only be in the relevance of the revisions of the various components used in the cabinet. This is since the public version is updated less frequently than the internal one. [24]
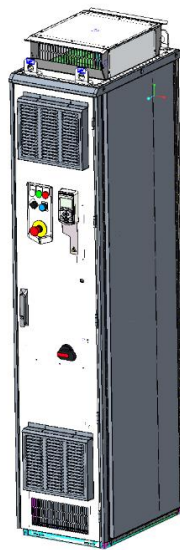

Figure 4.1 3D model of cabinet ACS580-07

For correct simulation, you need to make certain changes to the 3D model. Remove external coating elements, replacing them with a sealed contour structure. This structure will simplify the cabinet geometry and make the simulation generation process faster. Also on the contour you need to mark the inlet and outlet surfaces of the air flow and filters. For better clarity and ease of display, this contour is made transparent. (Figure 4.2)
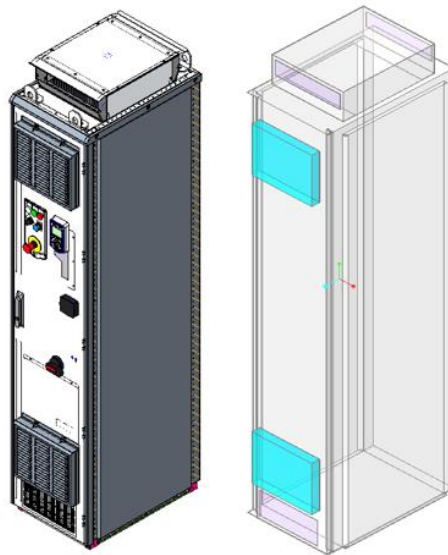

Figure 4.2 On left - cabinet cover panels, On right transparent outline structure

After simplifying the body, it is necessary to check all the components of the model and replace all imported objects with solid structures. Since some elements were imported from other formats, they will need to be corrected. To do this, you will have to make a new solid model using the original drawings. This happens mainly with electronic elements, relays, terminals, DIN rails and others. Some non-essential items can be removed from the model, such as some screws and bolts.

A particularly challenging element was the assembly of the power module. Because this assembly is very detailed and has many subassemblies and parts, a simplified imported version is usually used. This makes it possible to reduce the size of the main cabinet assembly and open 3d model faster. It would be theoretically possible to use the original module assembly in the simulation, but this would significantly lengthen the simulation time. To better understand the differences in model size, a complete module assembly consists of 927 parts and subassemblies, while the entire cabinet contains 1354 parts. This clearly shows that it is not logical to use a complete module assembly, and it is better to make a new solid part.

In the end, 12 parts required rework and another 4 were removed from the final assembly. An environmental zone has also been created around the model; air circulation will be monitored within its boundaries. The zone is set according to the maximum dimensions of the cabinet on each plane. (Figure 4.3)
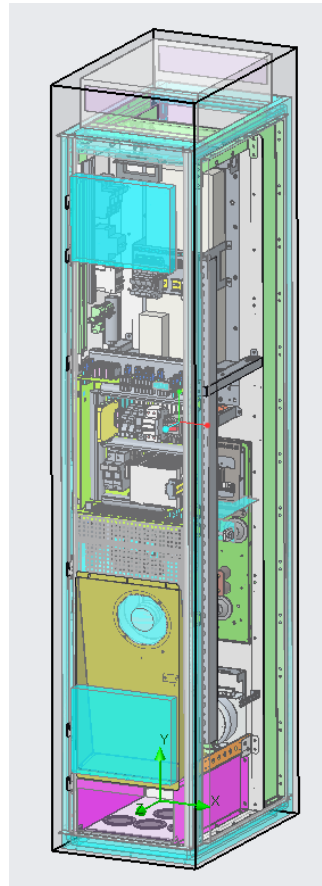
Figure 4.3 The final model with all modifications, ready to start the simulation

4.2 Setting key simulation parameters

After preparing the 3D model of the cabinet, the next step is to set the key parameters of the simulation. The main parameters are general system settings, boundary conditions, porous media, fans and heat source. [24]

4.2.1 General system settings

The general settings are parameters that declare the rules by which further simulation will be carried out. First of all, the physical parameters that will be taken into account were established - fluid flow, conductivity, gravity. These parameters are necessary for the correct operation of the system. Next, the pressure of the environment is established; it will be equal to normal atmospheric pressure at sea level - 101325 pascals. The ambient temperature will be equal to 20 degrees Celsius, that is, the average temperature in a ventilated room. The temperature of the environment will change up to 50 degrees when measuring the stress test for the final version of the solution. The fluid used in the simulation will be air, that is, a mixture of gases equivalent to the usual composition of atmospheric air. The behaviour of the air flow will be characterized by both parameters, laminar and turbulent flow. The humidity indicator will not be considered and will be displayed at an average level, as in a dry environment.

In other words, the key settings are set to bring the environmental parameters closer to the average conditions for using the cabinet in real life. These settings will remain unchanged for all subsequent simulations. The settings can be seen in the appendix at the end of the work.

4.2.2 Boundary conditions

Boundary conditions - this is a setting with which you can set the zones of air flow in and out in the simulated object. With this parameter you can set the method by which air will flow, direction and other parameters. For the simulations in this work, the atmospheric air flow setting will be used, in other words, the air will move naturally. This means that the air will remain static without outside influence, mechanical, atmospheric or otherwise.

For the initial simulation, five air inlet/outlet zones will be set up. One at the bottom of the cabinet, two at the door, and two at the roof. The number and area will vary depending on the conditions of subsequent simulations. (Figure 4.4)
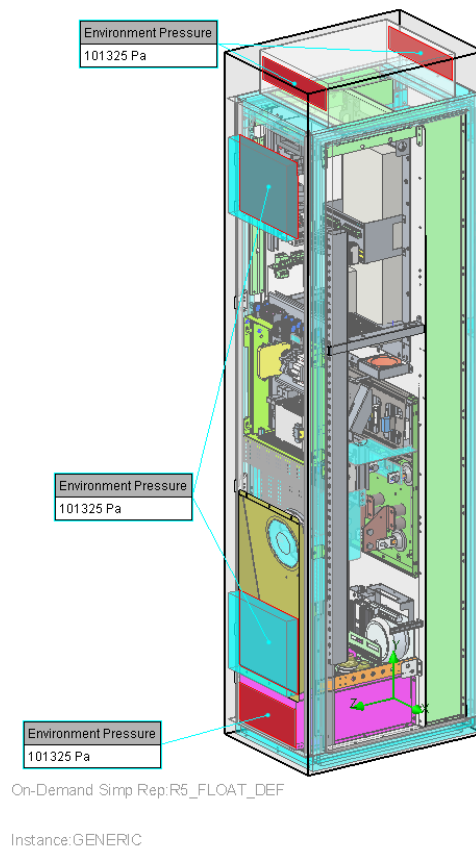
Figure 4.4 Initial simulation boundary conditions.

4.2.3 Porous media

Porous media are an object that can impose additional resistance on an area of the medium, slowing down and limiting the speed of air flow. In other words, these are filters of different structures and characteristics. Using this tool, you can place a filter at any point in the 3D model.

As was said earlier in the previous chapter, filters should only be used in a ventilation circuit whose components are combed to the IP54 standard. For simulation data, filters will be installed only at the inlet and outlet of the air flow from the ventilation openings on the cabinet door. Subsequent simulations will add additional filters located on the roof of the cabinet. To simplify the 3D model, the filter is not displayed graphically and uses a simplified model in the form of a blue rectangle. (Figure 4.5)
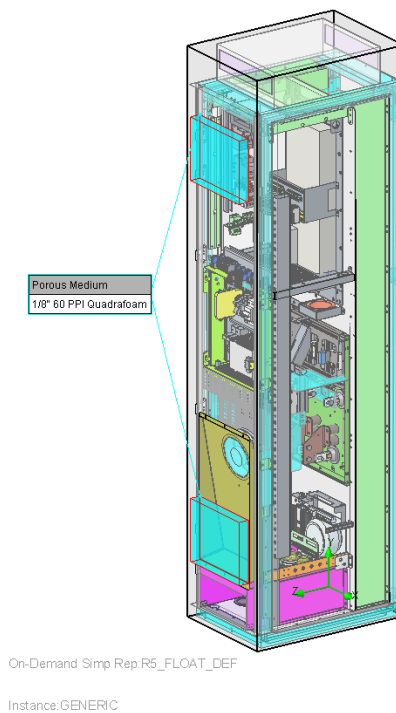
Figure 4.5 Porous media objects

4.2.4 Fans

Fans are the main tool for determining the direction and speed of air flow. In the initial simulation, two fans are used, one located inside the cabinet and one integrated into the module. Their location and number will change in subsequent simulations. (Figure 4.6)
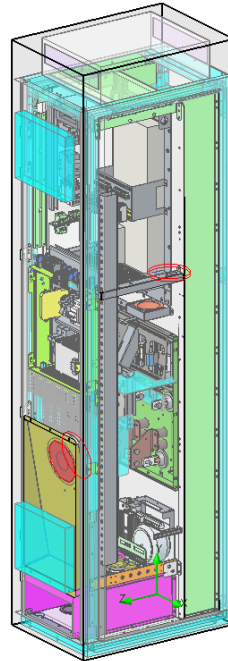
On-Demand Simp Rep:R5_FLOAT_DEF

Instance:GENERIC

Figure 4.6 Location of fans in the cabinet

4.2.5 Heat source

The heat sources for the simulation will be electrical components, which will heat up and emit heat during operation of the cabinet. Their location was described in more detail earlier in item 3.2.1. The simulation will take into account the 10 hottest elements, data on their heating was taken from the company's internal document. The location and their list can be seen in Figure 4.7.

The remaining elements of the cabinet have a temperature less than or equal to the ambient temperature. Therefore, their values are not considered during the simulation.
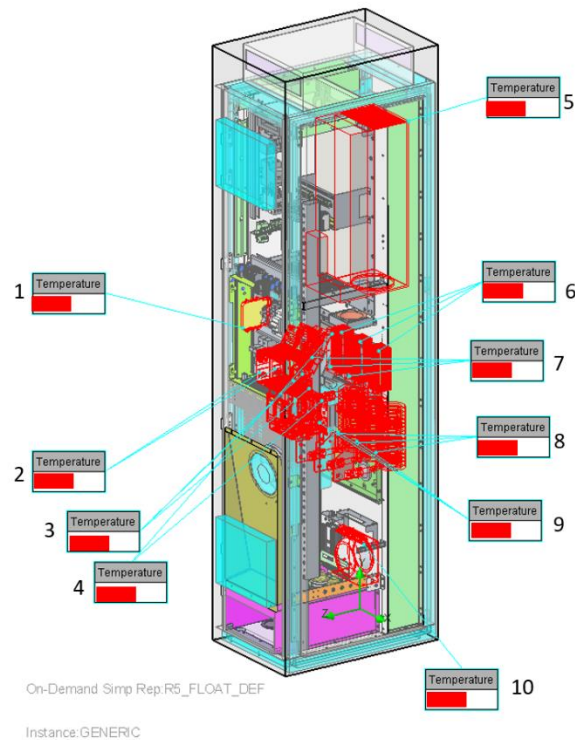
Figure 4.7 Heat sours locations: 1-opperative relay, 2-power electronics blocks, 3- os switcher busbars, 4- os switcher and contactor, 5-module, 6-9 – dudt filter elemens, 10 – voltage transformer

4.3 Initial simulation data analysis

The main two parameters on the basis of which comparisons between different tests will be made will be air flow velocity and temperature. Temperature will be measured in two ways, the overall temperature, and the temperature of the fluid. In our case, the fluid will be air. The difference in temperature indicators will not be so significant, but will still be present, since different variables are used when demonstrating thermal traces. The overall temperature display will show all heat sources, while the fluid temperature display will only display air flow.

The internal elements of the cabinet are not located symmetrically, and at different distances from each other in the horizontal plane. For more accurate measurements, cutting planes will be used. The first and last planes are located at 100mm from the

walls of the cabinet, subsequent planes are in increments of 50mm. Thus, there will be six planes located in the cabinet. (Figure 4.8)
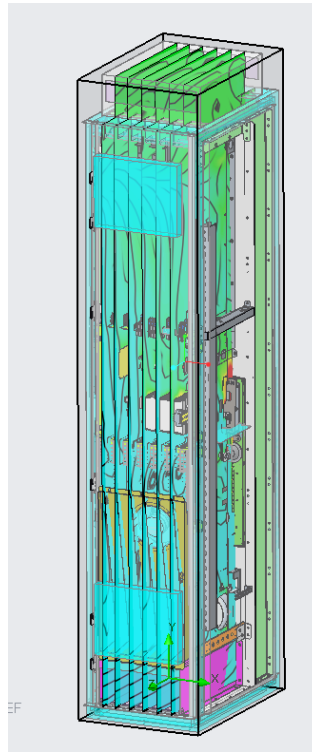
Figure 4.8 Cabinet cutout plates

A few words about the notation system for the upcoming simulation graphs. Temperature and velocity will be graphically displayed in colour spots, from dark blue tones to bright red. The lines will indicate the direction of air flow. Temperature will be measured at several points. The maximum and minimum indicators in the entire cabinet will be measured. The maximum indicator will also be measured in the areas of air inlet and outlet from the cabinet. The speed will look primarily at the visual direction of the flow, and the maximum speed.

Since many figures will be made with this measurement system, only the most important ones will be included in this thesis. Only the first initial test and the final result will be included in full to appendix section. All others will be attached as a separate file.

4.3.1 Overall cabinet temperature

As a result of the simulation, it can be seen that there is high turbulence of air flows in the internal ventilation loop, which causes a problem with the uniform exit of air from the cabinet. In the first and sixth sections there is greater turbulence of air flows than in the others. The reason for this is their location in the cabinet, proximity to the body grids. In the central part of the cabinet the situation is getting better.

Also, noticeable turbulence occurs in the internal circuit at the bottom, the reason for this is a large space and an obstacle on top in the form of a switch. In this case, this plays into the hands and allows you to delay the air flow in order to better cool the section of the cabinet with the switch and contactor. But at the same time, the heat output from the transformer is blocked. (Figure 4.9)

In the external circuit there are also problems with heat removal, because the flow is strongly slowed down after exiting the module; this will be more noticeable later, in subchapter 4.3.4. Also located in the outer circuit is the hottest element of the cabinet, the pipe filter, which emits a lot of heat. This is especially noticeable in sections from the second to the fourth. The flow of cold air tries to go around the air filter more, which slows down its cooling.

In general, it becomes more clear that the external circuit produces more heat than the internal circuit, which may interfere with their integration in the future; this is worth paying special attention to in further simulations.
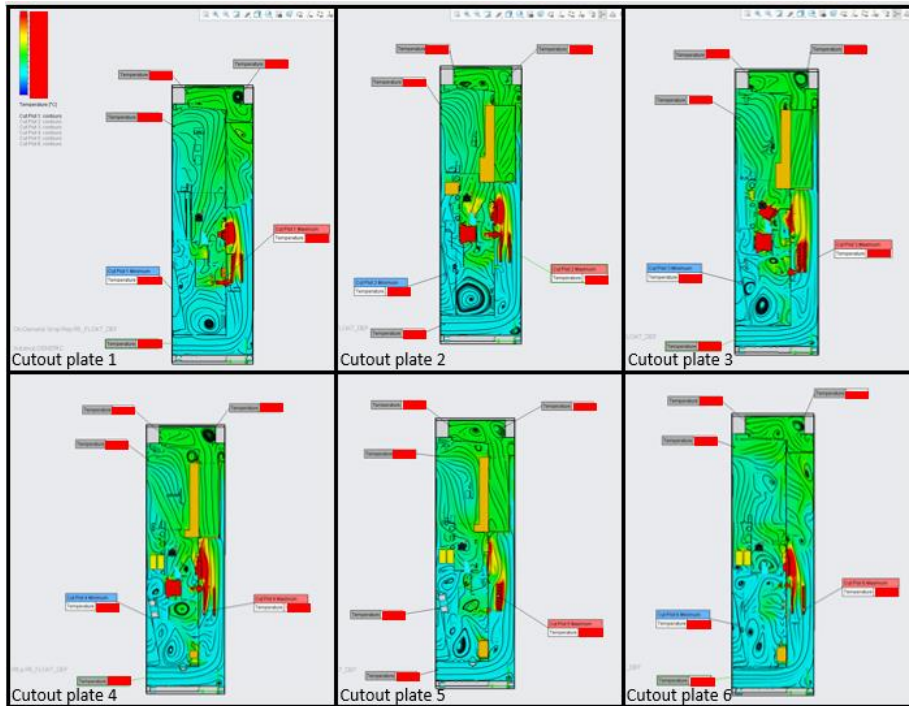
Figure 4.9 Overall cabinet temperature for initial simulation

4.3.2 Fluid temperature

When the temperature of the air flow is considered, the difference between sections becomes more apparent. It can be seen that the hottest section is the second, while the temperature in the fifth is lower. In general, the image does not differ much from the general temperature. For further comparison, this work will consider the results of the air flow temperature, the second and fifth sections. (Figure 4.10)

It is also clear that the cabinet heats up unevenly, and due to the fact that the air is not able to easily escape outside, the cabinet begins to heat up and the output air is much warmer than the input air. In general, the top part of the cabinet is hotter than the bottom. Under ideal conditions, it is good to achieve uniform cooling throughout the entire cabinet.
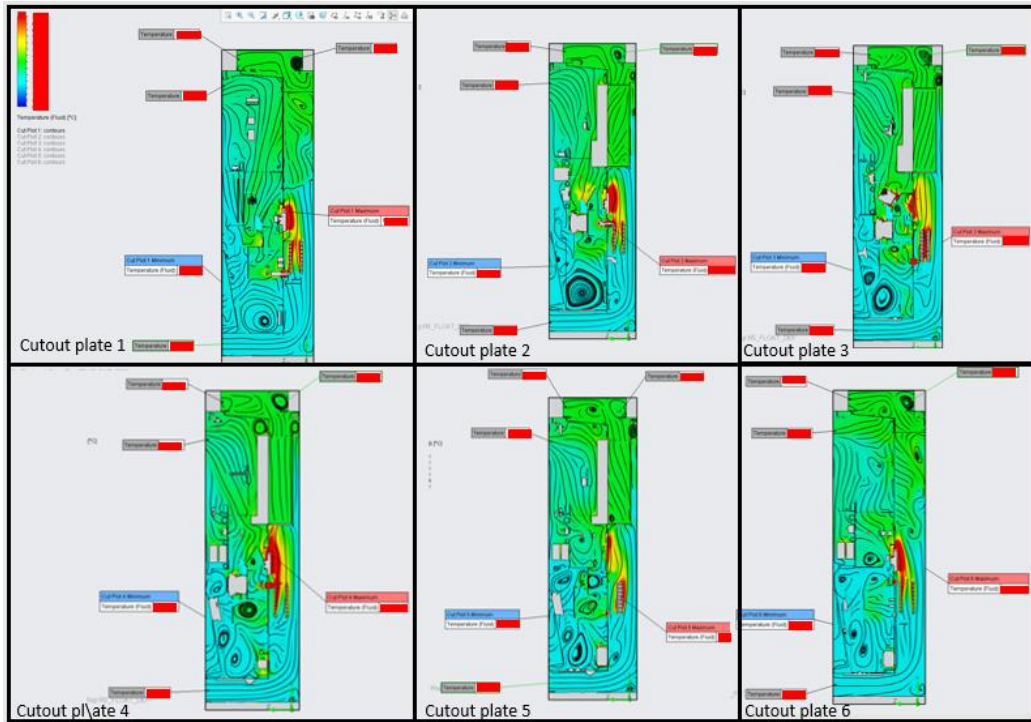
Figure 4.10 Fluid cabinet temperature for initial simulation

4.3.3 Air velocity

The air flow rate best demonstrates the difference between the two cooling circuits. In the outside air moves more laminarly, which makes cooling more efficient. As a result, the temperature of the air flow from the external circuit is slightly higher than the temperature from the internal circuit. The problem areas are the input and output of the flow from the module. With this contour, you can correct the direction of air movement using the geometry of the tunnel, installing streamlined bodies inside.

There is a high turbulence problem in the inner circuit. At the inlet, the flow rate is higher than that of the external circuit, but this advantage is quickly lost due to the air block located at the fan, which closes the busbars at the inlet to the switch. It will be possible to solve this problem by changing the location of the fan or changing the layout of the internal circuit. (Figure 4.11)
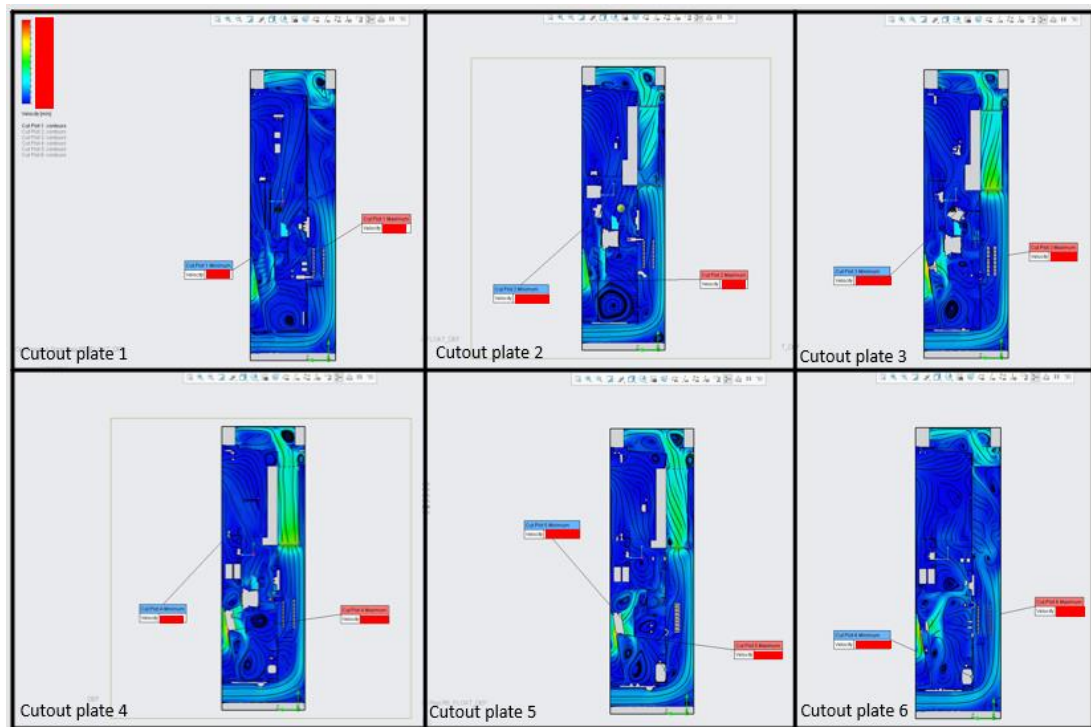
Figure 4.11 Air velocity for initial simulation

4.3.4 Temperature and velocity data

Comparing the numerical indicators, they confirm the conclusions made in the previous subchapters. Complementing this is that section three also requires attention due to its high average temperature of the air flow outlet. The resulting values will be used for comparison with further simulations. The main comparison parameters will be the maximum values of fluid temperature. Another important parameter will be the temperature of the air flow leaving the cabinet. Based on these metrics, subsequent tests will be compared with the original one.

In general, there is a tendency that the way to solve the problem will be in the following things.

• Improve the direction of air flow, make the air flow more stable and redirect it in the right direction.

• Achieve better dust filter cooling.

5. AIRFLOW SIMULATION UNDER VARIOUS CONDITIONS

5.1 Goals and criteriums

The first step is to summarize the goals that need to be achieved in subsequent simulations. The key problem is compliance with the legal UL standard. This means that the flows will in any case have to pass through the roof, so it will be necessary to check whether it is possible to combine them or come up with another way to separate the flow.

Another important part is solving three problems identified as a result of the initial simulation. High turbulence in the internal circuit and improved dust filter cooling in the external circuit.

The last important criterion will be to minimize the costs of improving ventilation. It would be a much better solution if a new ventilation system makes it possible to reduce the final cost of the cabinet.

5.2 Review of simulation results

As mentioned earlier, due to the large number of simulations and the abundance of graphic material, a file with all data obtained during the simulation process is attached to this work. This is done to reduce the final volume of the application section. To compare and demonstrate the results of each simulation, only sections two and five for flow temperature and section three for flow velocity will be used. In the appendix 1 you can find a table with a brief description of each test.

5.2.1 Airflow simulation Test 2

This simulation tests the possibility of combining ventilation circuits. There are no special changes in the design. Only the panel that separated the two ventilation circuits was removed. The ventilation hole at the top of the door is also closed. Now the air will exit exclusively through the roof. Images of the changes can be found in the appendix.

Initially there was concern that air flows from the colder inner circuit could collide with air flows from the outer hotter circuit. Because of this, excessive turbulence may occur and cooling will begin to work worse. As can be seen from the table in Appendix 2, deterioration is indeed awarded. The air flow began to heat up more strongly, the average temperature of the flow outlet increased by 12.3%.(Figure 5.1)

Also, the internal elements of the cabinet began to heat up more, the difference is especially clearly visible in the fifth section, when measuring the flow temperature. (Appendices 16-18) The maximum temperature increased by or 11%. The heat footprint has also become larger.(Figure 5.2)

Figure 5.1 Fluid cabinet temperature for test 2, cutout plates 2 and 5
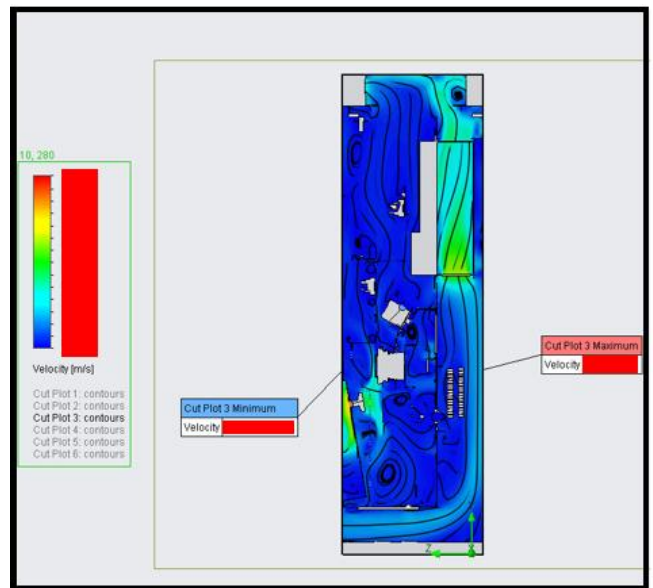
Figure 5.2 Air velocity for test 2, cutout plate 3

Verdict for this test: It is impossible to combine circuits without losing cooling efficiency without more serious changes in design. An air block will form at the outlet, which will become an obstacle to the removal of warm air from the internal circuit. But on the other hand, the deterioration is not critical and you can continue to work.

5.2.2 Airflow simulation Test 3

This test is a logical continuation of the previous one. It is carried out in order to check how much the complete integration of the two circuits will affect the cooling efficiency of the cabinet.

The design has undergone the following changes. The tunnel from the bottom of the office has been removed. The ventilation holes at the bottom have been removed, now air only comes through the door. Just like in the previous test, there is no partition in the upper part of the office, near the roof. (Figure 5.3)

The results show that this text is noticeably worse than the previous one. Looking ahead, this test will be the worst ever. (Appendices 3) The table in the appendix shows that the average outlet temperature increased by 33.3% worse than the original simulation. Overall average temperatures also increased. This result occurs due to a violation of air

circulation; the air flow velocity diagram shows that many vortices occur throughout the cabinet, especially in the lower part. Air cannot flow normally to the module, hence the temperature rise.(Figure 5.4)
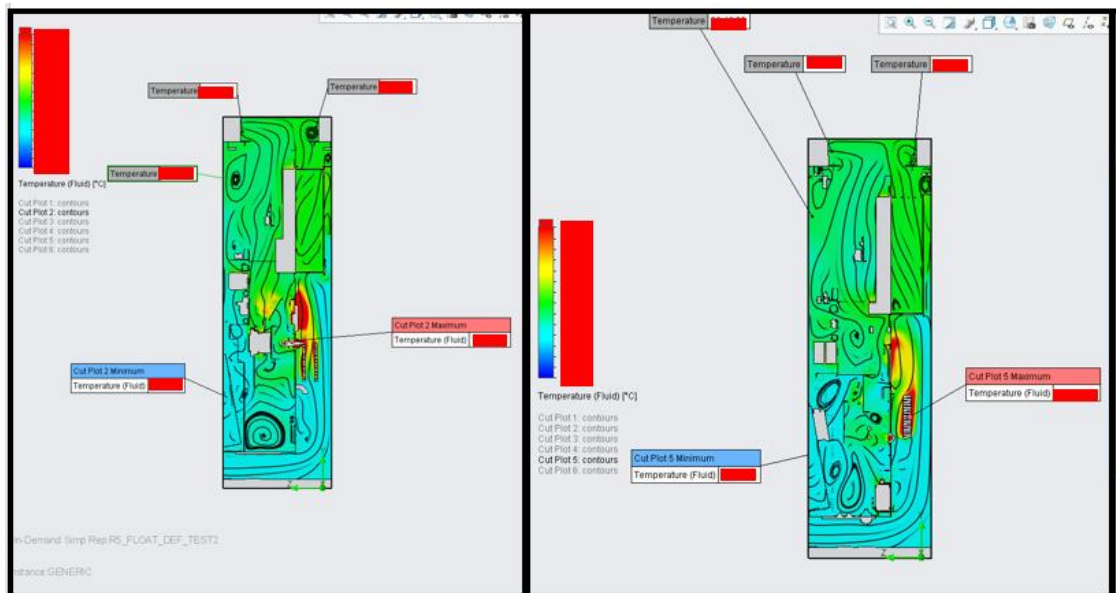

Figure 5.3 Fluid cabinet temperature for test 3, cutout plates 2 and 5
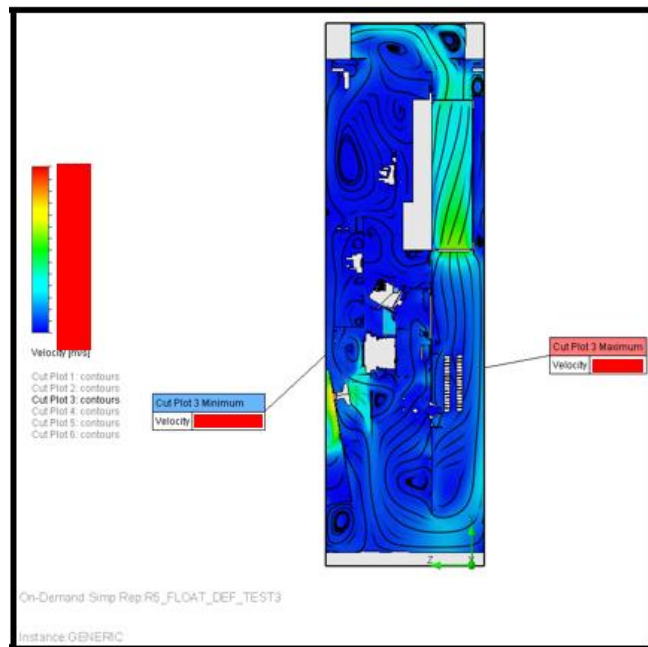
Figure 5.4 Air velocity for test 3, cutout plate 3

Verdict for this test: If there is only one area for air to enter the room, turbulence will occur. It prevents further cooling. Without a uniform flow of air into both circuits, strong heating of the elements and air mass begins to occur, which leads to even greater turbulence, but only when leaving the office. To completely integrate ventilation circuits, it is first necessary to solve the problems of each circuit separately.

5.2.3 Airflow simulation Test 4

In this test, air outing from both ventilation circuits. The difference from the second test is that both circuits are still separated. A plate is installed in the roof of the cabinet to separate air flows.

Since the flows have become separated, they no longer interfere with each other and the air from the internal circuit begins to exit with fewer obstacles and a more even flow. (Appendices 4) This is better than in the second test, but still worse than in the original 7.5%. This difference could be explained by the reduced outlet area.

The external circuit also began to work worse, due to the same reasons. The air outlet area has been halved. But due to the flow rate, this reduction does not cause big problems. The turbulence interferes much more seriously; if it is removed, the speed should increase, and the cooling will become more efficient. The temperature rose by 4.3%.(Figure 5.5)

Figure 5.5 Fluid cabinet temperature for test 4, cutout plates 2 and 5
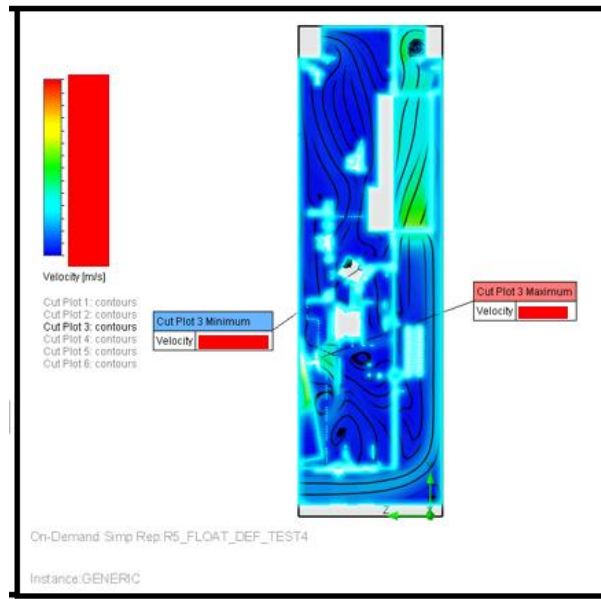
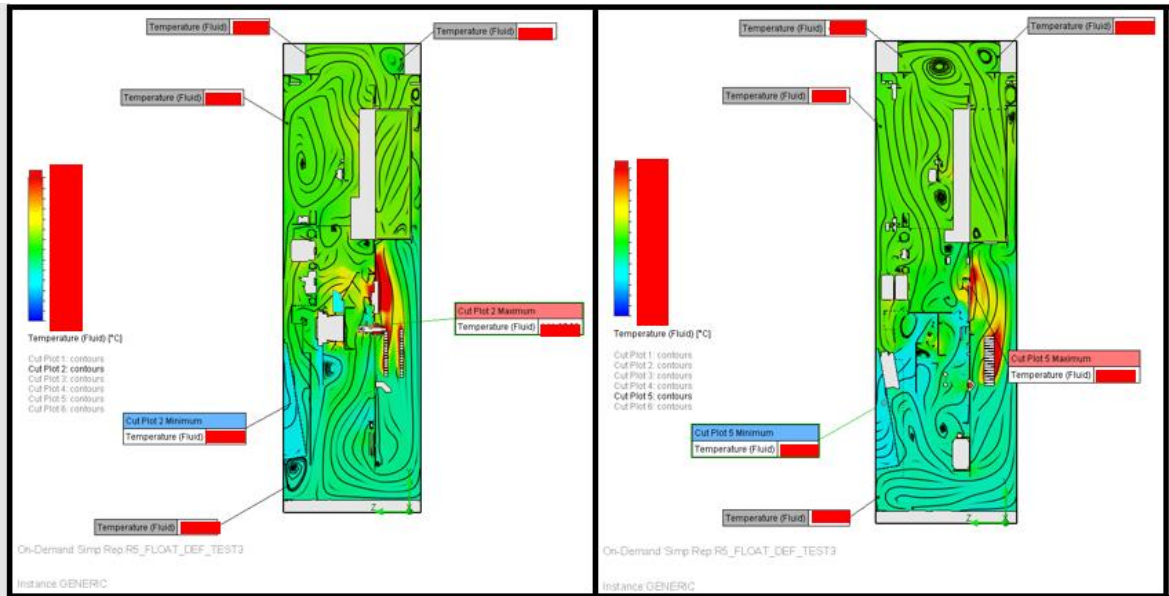*Figure 5.6 Air velocity for test 4, cutout plate 3. (The blue glow of the body is a visual artifact and does not affect the simulation result)*

The temperature indicator in the hottest spot in section 2 in the office decreased by 0.15%, while the same indicator in section 5 increased by 9%. The maximum temperature in the remaining sections also increased. (Appendices 16-18) (Figure 5.6)

Verdict for this test: This looks like a more viable solution, but still have problems. This looks like a more viable solution. The temperature of the air flow itself increased by 5.9%, but the detected problems seem solvable. Subsequent simulations will be based on this model.

5.2.4 Airflow simulation Test 5

This test is primarily to find a solution to improve the operation of ventilation in the external loop. Based on previous tests, it was assumed that some of the air does not enter the module and is retained in the area around it. To test this theory, the position of one air blocker was changed.

As expected, the internal circuit temperature did not change compared to the previous test. Because no changes were made affecting this circuit. (Appendices 5) (Figure 5.7)
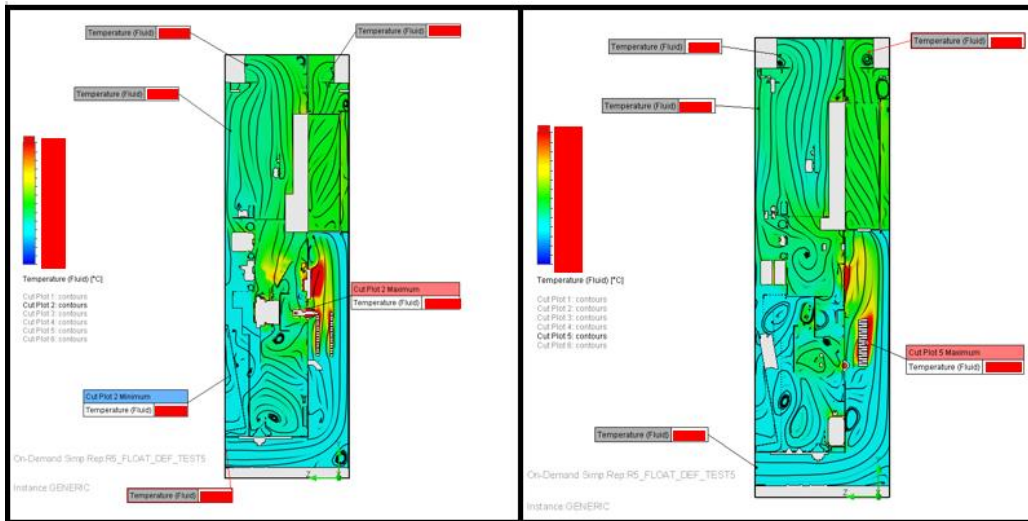
Figure 5.7 Fluid cabinet temperature for test 5, cutout plates 2 and 5

As for the external contour, several changes are noticeable in it. Firstly, the flow temperature decreased by 0.5 degrees or 1% compared to test 4. Secondly, the maximum temperature in each section also decreased. On cutout plate 5, the temperature became only 2% higher than the initial simulation and 7% less than on test 4. The temperature on all other cutout plates is in the range of up to 1%.(Appendices 16-18) (Figure 5.8)
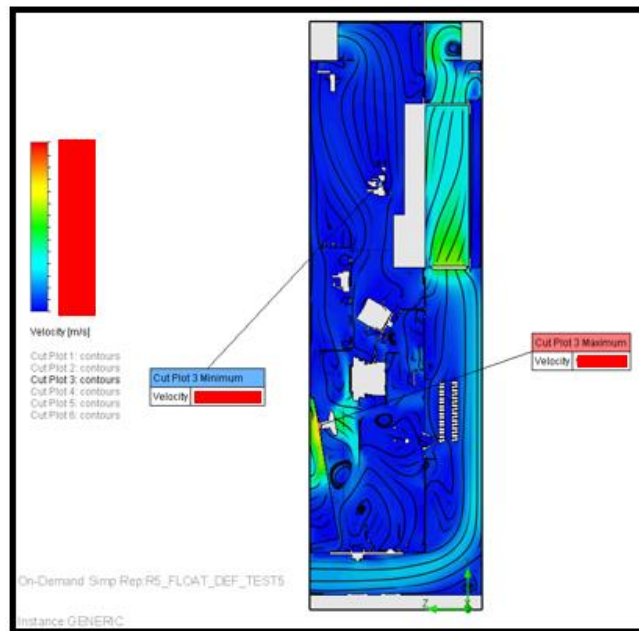
Figure 5.8 Air velocity for test 5, cutout plate 3

Verdict for this test: This small change showed that it could make a difference. Subsequent tests will involve additional air guides.

5.2.5 Airflow simulation Test 6

Test number 6 continues the idea of adding additional air guides to the outer loop. Three elements have been added to improve flow and can be found in the appendix. Again the internal circuit temperature did not change compared to the previous test. Because no changes were made affecting this circuit.

As for the temperature of the external circuit, there is a noticeable slight improvement. The temperature improved by 2.5%. (Appendices 5) But what's even better is that the temperatures at each cutout plate continue to decrease, currently being equal to or 1% better than the original simulation. (Appendices 16-18) (Figure 5.9)

Progress is best seen with flow velocity, the air flow became consistent, and turbulence disappeared when exiting the module. The output flow rate has become twice as fast. (Figure 5.10)

The detail at the bottom of the cabinet added in this test is most likely useless and has little effect on the cabinet. If the situation does not change in subsequent tests, this part will be removed.
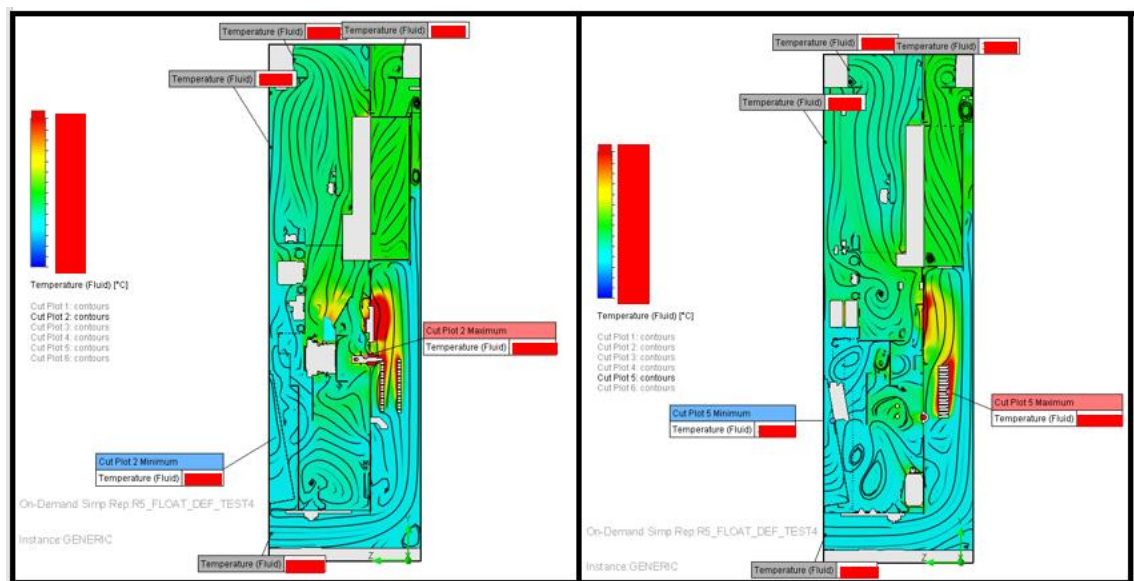

Figure 5.9 Fluid cabinet temperature for test 6, cutout plates 2 and 5
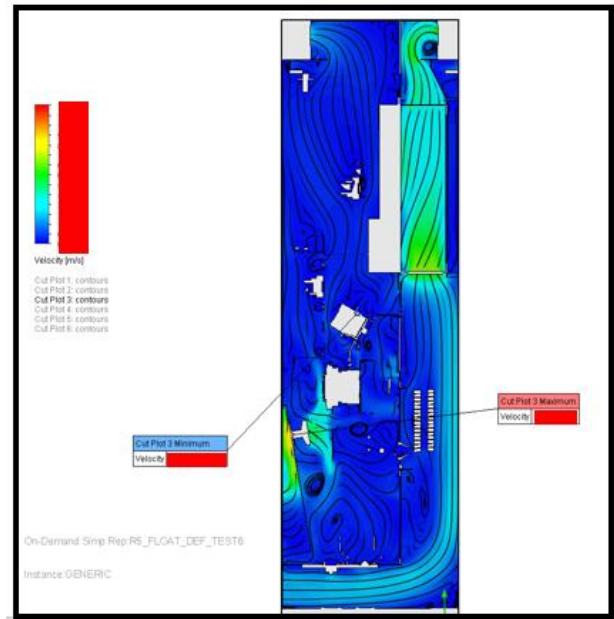
Figure 5.10 Air velocity for test 6, cutout plate 3

Verdict for this test: This solution shows its practicality, it allows you to return the temperature of the cabinet to the original setting, without increasing the outlet openings of the cabinet. In the future, the plastic located at the entrance and exit to the module will always be used.

5.2.6 Airflow simulation Test 7

The seventh test duplicates the second one, keeping the changes made in the sixth test. In this way, another check of the effectiveness of these air units is carried out.

The results of this test are not clear. (Appendices 7) On the one hand, the temperature coming out from the rear of the roof increases by 4% compared to the second test. On the other hand, the temperature leaving the front of the roof decreases by 6%.

The overall temperature of the air flows improved by 4% compared to the second test but was still worse than in the original test by 8%. (Figure 5.11)
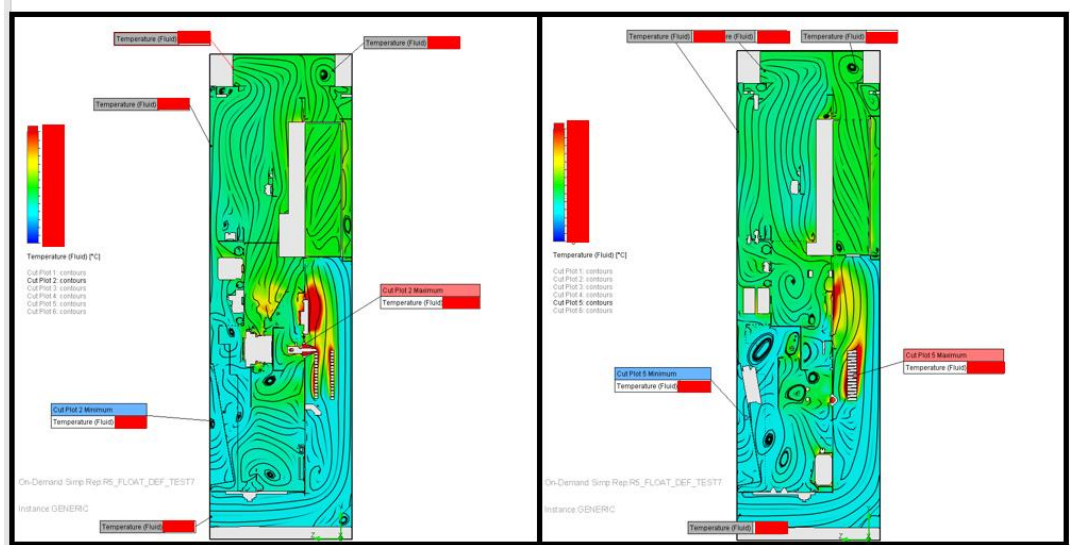
Figure 5.11 Fluid cabinet temperature for test 7, cutout plates 2 and 5

According to the air flow velocity diagram, these changes in temperature are due to the speed of the air flow. The same flow of the internal circuit, when colliding with the roof, splits into two flows going to the front and rear parts of the ventilation in the roof. This division occurs noticeably and more clearly than in the second test, due to the doubling of the speed of the air flow leaving the module. At the front ventilation outlet into the roof, there is a noticeable difference in the behavior of the air. The flow from the outer circuit became more laminar and faster, due to this it began to direct air flows from the inner circuit towards the outlet. The flow going into the rear ventilation hole becomes more turbulent, creating a turbulence that prevents air from leaving the system. (Figure 5.12)
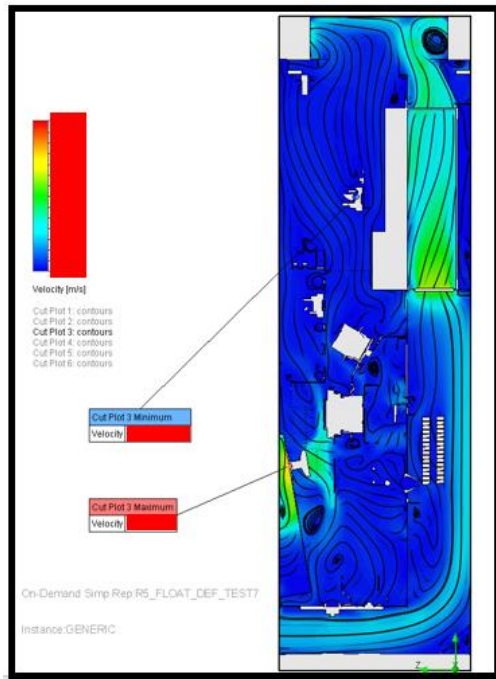
Figure 5.12 Air velocity for test 7, cutout plate 3

Verdict for this test: This simulation confirms the effectiveness of previously made decisions. But it opens up new problems; it will be necessary to solve the problem of sudden braking of the air flow on the roof. As for the maximum values on each cut plate, the data have now remained virtually unchanged compared to the second test. Only one value improved on plate 5, by 5% compared to the second test. (Appendices 16-18)

5.2.7 Airflow simulation Test 8

In this test, an attempt was made to improve the cooling of the filter by redirecting the input flow to the DUDT filter. An air guide was made. More precisely, several guides of different shapes were made, but this test will show the best result. The rest of the cabinet design was used from test number 6.

The overall test result was disappointing. (Appendices 8) The cooling of the cabinet became worse than before, the overall temperature deteriorated by 3% from the results of test 6. The temperature of the hottest spots on each cutout plate also did not change by more than 1%.(Figure 5.13)

The air flow rate also decreased. Redirecting the flow creates turbulence in the external circuit and also reduces the cross-section of the pipe, due to which a smaller volume of air begins to pass per unit of time. (Figure 5.14)

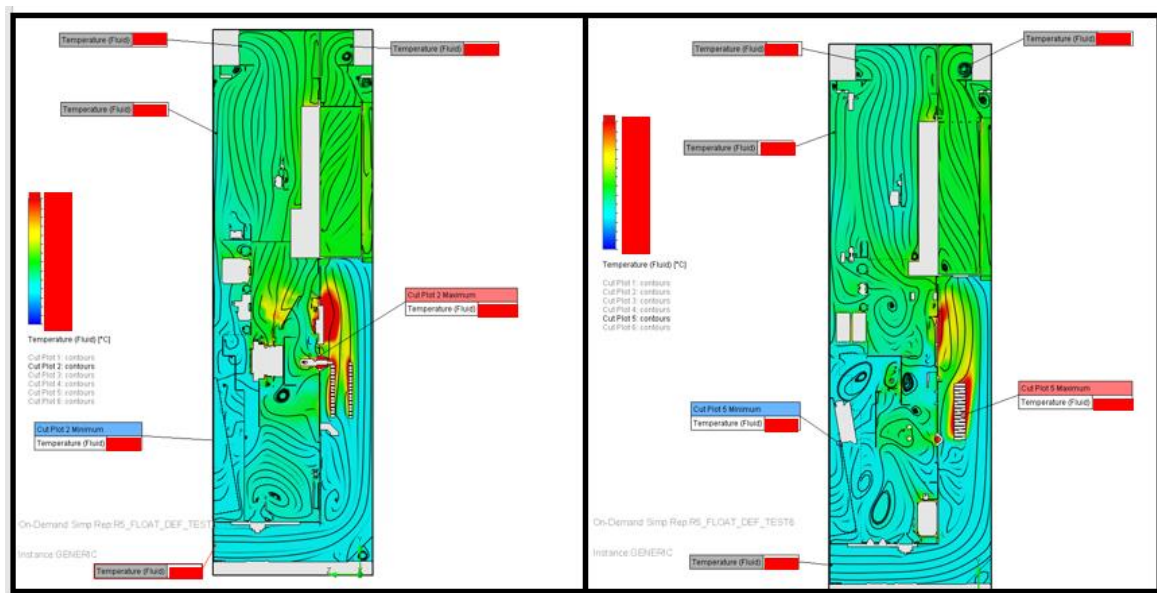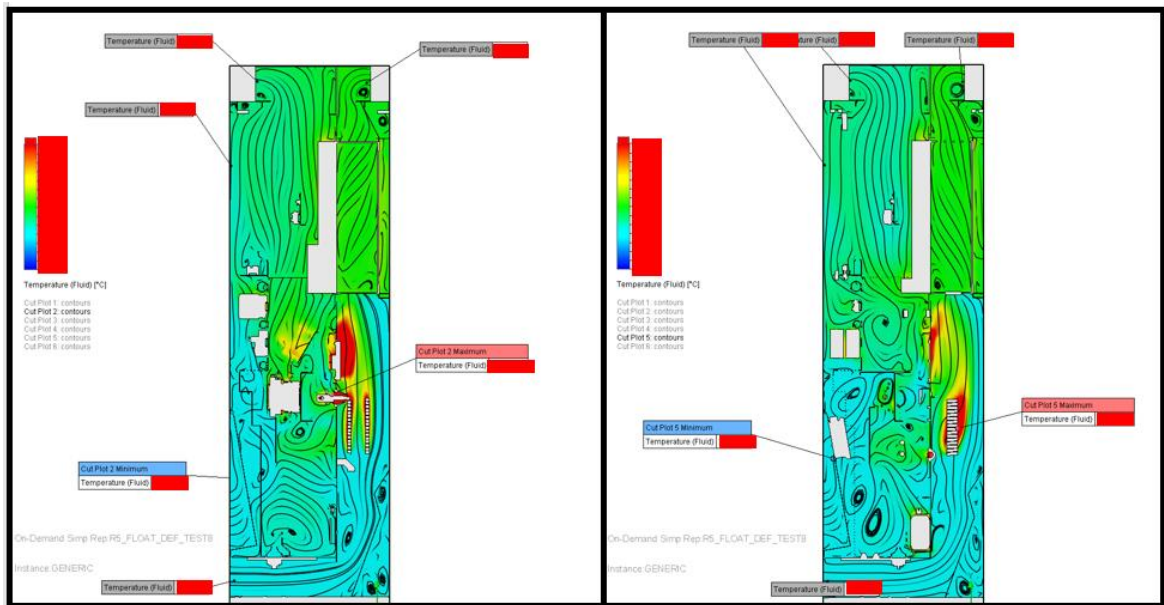

Figure 5.13 Fluid cabinet temperature for test 8, cutout plates 2 and 5
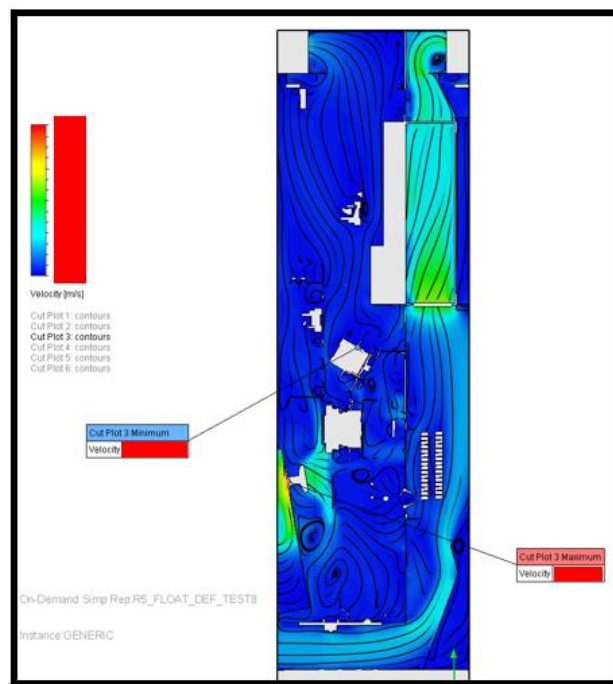
Figure 5.14 Air velocity for test 8, cutout plate 3

Verdict for this test: A potentially good and logical idea turned out to be ineffective in practice. Changing the shape of the guide plate also did not bring any results.

5.2.8 Airflow simulation Test 9

The ninth and subsequent tests will be carried out with a different cabinet roof. Initially, this roof was used in another product - ACS80 and only with the IP54 standard. But it can be compatible with the ACS580 if certain redesigns and changes in the assembly process of the ACS580 cabinets are made. Due to confidentiality, I cannot describe in more detail the details of the change in the assembly process.

The IP54 roof differs from the previously used one in that the area of the ventilation opening in it is 5 times larger. (Appendices 9) Air filters can be installed on it, including those of the IP54 standard, and in case of other standards it is possible to leave the grille without a filter. And the main advantage is that an additional fan can be installed in it.

Test number 9 will use a roof without a fan. Air will be extracted from the front and rear of the roof.
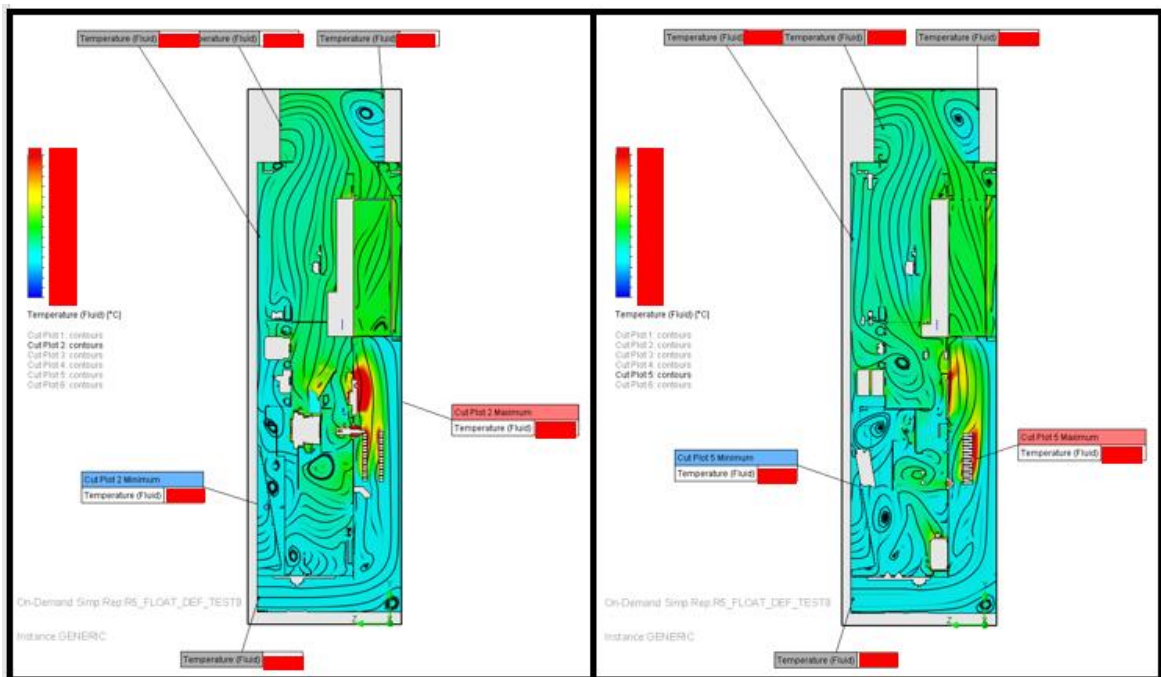
Figure 5.15 Fluid cabinet temperature for test 9, cutout plates 2 and 5

The results of this test are impressive. The output temperature dropped by 7.6% on average compared to the initial test. This is the first positive result in the test. The heat trace of the hottest components has significantly decreased. The lowest of the highest temperatures, as usual on cutout plate 5, decreased by 9.4%. The largest reduction was on plate 3 by 15.6%.(Appendices 16-18) (Figure 5.15)

The airflow also began to circulate more smoothly. The problem with sharp separation and braking of the sweat coming out of the module has disappeared, as the distance between the roof top panel and the module has increased. But another problem has arisen, because now the airflow comes mainly out of the front part of the roof, the air from outside starts to enter the rear ventilation openings. It might be worth closing the back side of the roof for ventilation. (Figure 5.16)
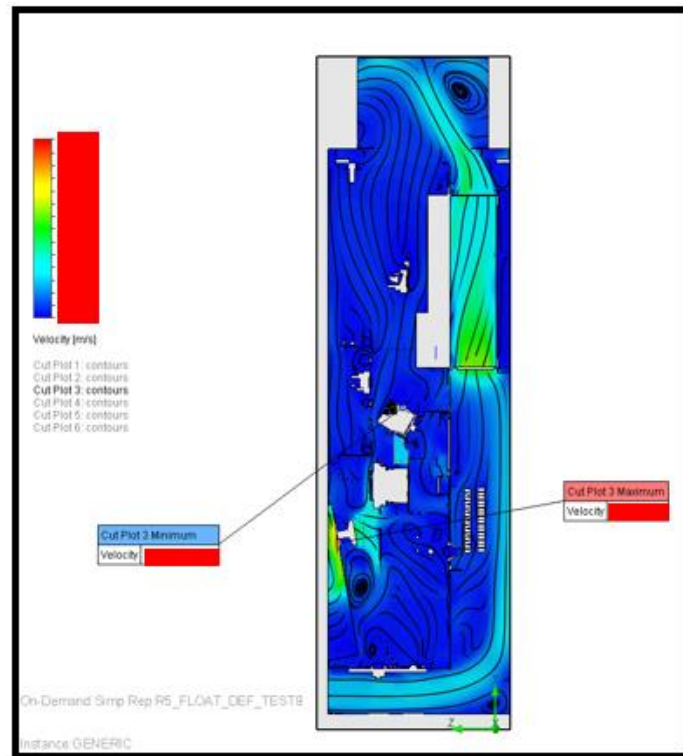
Figure 5.16 Air velocity for test 9, cutout plate 3

Verdict for this test: The results of this test are impressive. The first positive result was obtained in terms of improved ventilation. Increasing the cross-section of the outlet opening significantly speeds up the cooling process and stabilizes the airflow inside the cabinet.

5.2.9 Airflow simulation Test 10

The tenth test differs from the ninth test only in that the rear roof vent has been closed. This reduced the area of the ventilation outlets by half. This reduction of the outlet openings is due to the ingress of outside air at the system outlet.

The results are noticeably worse. The temperature is 1.5% higher than in the initial simulation and 9% worse than it was in the 9th simulation. (Appendices 10) At the same time, the maximum temperature on the cut panels does not change by more than 0.5% from the results of the 9th test. The heat diagram shows that a large amount of air is left at the rear wall of the roof. It has a temperature even higher than the outlet temperature. This is the reason for the temperature increase. The airflow must be redirected or accelerated to remove this turbulence. (Appendices 16-18) (Figure 5.17)
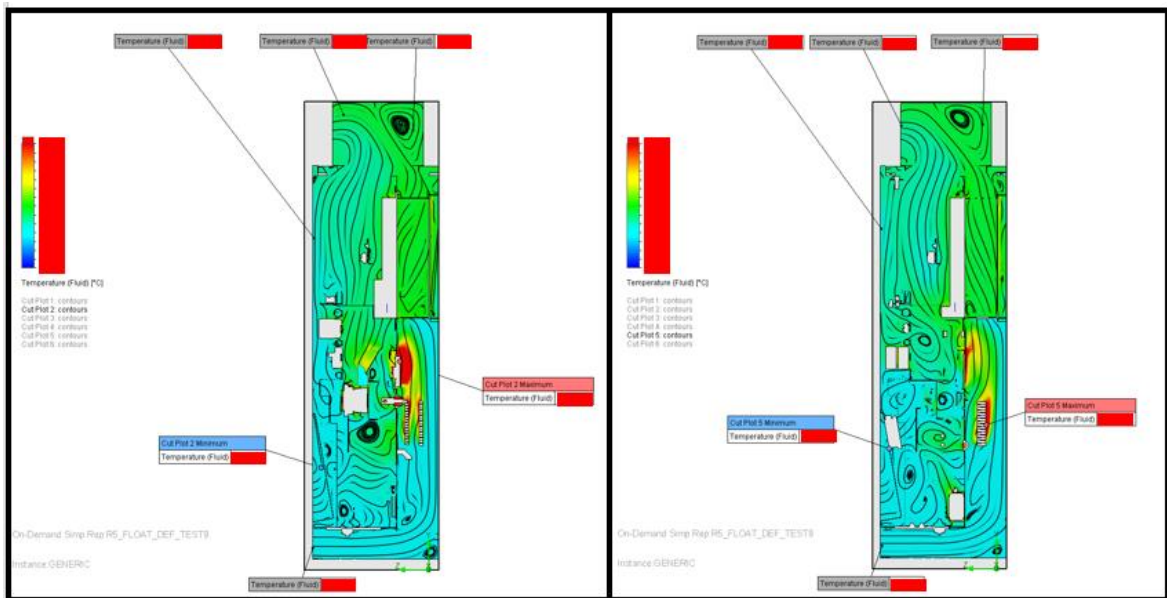
Figure 5.17 Fluid cabinet temperature for test 10, cutout plates 2 and 5

Apart from this swirl in the roof, the airflow remains relatively normal. The velocity diagram does not differ significantly from the previous test.

Verdict for this test: The test showed that theoretically it is possible to do with only one outlet in the roof, but to do this it is necessary to eliminate the vortex that occurs at the rear wall of the roof. It may be possible to install an air guide or to test with a fan first. (Figure 5.18)
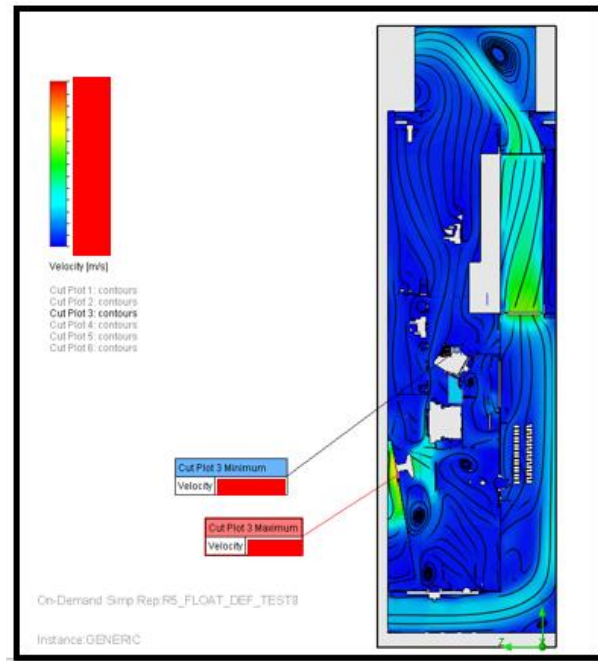
Figure 5.18 Air velocity for test 10, cutout plate 3

5.2.10 Airflow simulation Test 11

In the 11th simulation, an assembly with three fans was tested. To the ventilator in the door and module an additional one was installed in the roof of the cabinet. Also an air guide was added to the rear wall of the roof to reduce the space and try to prevent turbulence as in the previous test.

The results are very good. (Appendices 11) The cabinet became 28% less warm than the initial test. It is also clearly visible in the heat chart that there are far fewer green zones. The turbulence at the rear wall of the roof is still present, but its difference with the cabin temperature has been halved.

The heating zones of the filter have also become lower, with an average difference of 2-3% compared to the ninth cent, but for the first time all six cut plates show a decrease in temperature. (Appendices 16-18) (Figure 5.19)

First, the airflow in the inner circuit accelerated. As a consequence, the number of fumes in the central part of the room started to decrease. The bottom of the internal circuit is still problematic, we need to see if this can be corrected.

Figure 5.19 Fluid cabinet temperature for test 11, cutout plates 2 and 5

First, the airflow in the inner circuit accelerated. As a consequence, the number of fumes in the central part of the room started to decrease. The bottom of the internal circuit is still problematic, we need to see if this can be corrected. (Figure 5.20)
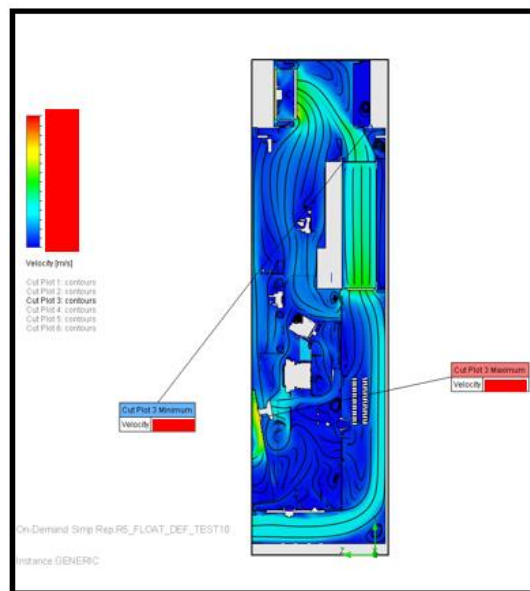
Figure 5.20 Air velocity for test 11, cutout plate

Verdict for this test: The test showed that the additional fan can improve cooling by 28% and significantly increase the air velocity of the intake circuit by 2.5 times. The main disadvantage of this solution is that it makes the cabinet look bigger due to the

use of three fans. It is necessary to check what the result will be with only two fans, without the fan in the door.

5.2.11 Airflow simulation Test 12

The twelfth test uses the same layout as the previous one, except for the complete absence of the fan in the cabinet door. Also, since the fan is no longer used, it allows to replace the standard ACS580 cabinet door with the door from the ACS880 cabinet. There is no fundamental difference between the two doors, except for the size of the ventilating hole at the bottom of the cabinet door. The ACS580 now has two separate vents, one with an overhead fillet and one without. The ACS880 has only one, with an overhead filter. The cross-sectional area of both doors is almost the same, only in the ACS880 it is slightly smaller, by 12%. This substitution cannot be made with a door fan present, as the design of the ACS880 does not provide one. (Appendices 12)

The use of a different door will solve two problems, firstly, the cabinet enclosure will be fully secured to the IP54 standard. Secondly, theoretically reduce the final cost of the cabinet, because when ordering one batch of doors suitable for both cabinets, the final unit price will be less than for two different parts. The verification of this statement will be done in the next subchapter. (Figure 5.21)
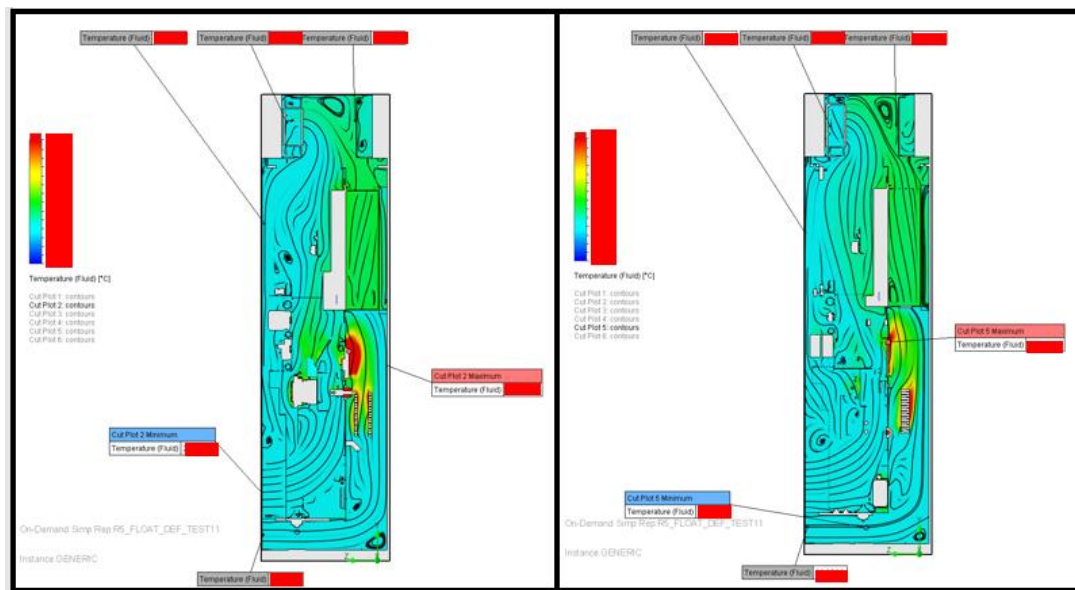
Figure 5.21 Fluid cabinet temperature for test 12, cutout plates 2 and 5

The test results show that the cabinet without the door fan cools better. The temperature dropped by 30.5% compared to the initial test and by 2% compared to the solution with 3 fans.

The air velocity diagram explains the reason for this situation. Without the door fan, the airflow becomes less turbulent at the ventilation inlet. This is due to the fact that there is an axle switch installed immediately after the ventilation opening, together with a plastic wire protection, which is not a streamlined obstacle. On encountering this obstacle, the directional air flow from the door fan starts to split and slow down, almost completely losing its speed. This creates a lot of swirls, which consequently hinder air movement and uniform cooling. (Figure 5.22)
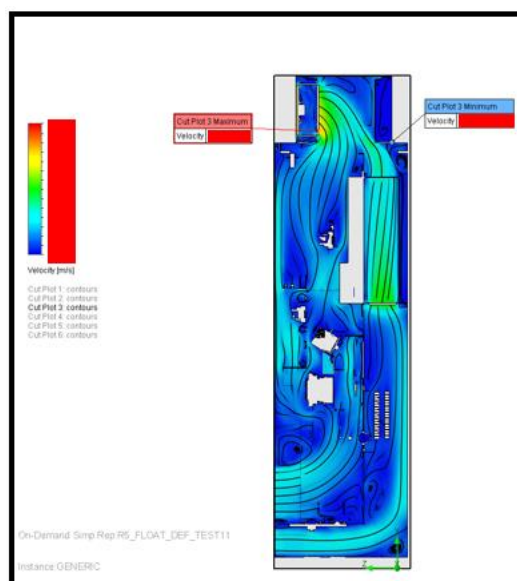
Figure 5.22 Air velocity for test 12, cutout plate

When the air is drawn in through the roof, the air flow is slower, but at the same time it is easier to flow around the elements located at the entrance. This improves the air circulation in the internal circuit.

Cooling of the DUDT filter remains at the same level as in test 11. Since no direct changes were made that would affect the cooling cycle of the external circuit. There is a slight increase in cooling efficiency in the zones that were closest to the internal circuit, but this difference is not great, 1-2% on two series. (Appendices 16-18)

Verdict for this test: The test shows the possibility of using only two fans for cooling. This configuration will be even more efficient and cheaper to produce than the previous

version. The absence of a fan in the door allows not only to use another door, but also leaves more space inside the cabinet. The only thing left to check is the possibility of combining the circuits.

5.2.12 Airflow simulation Test 13

Test thirteen duplicates all the changes from test twelve, but also integrates the ventilation circuits as was done in the third test at the beginning. In theory, the integration of the circuits will allow to further reduce the cost and speed up the production of ACS580 cabinets.

The cooling temperature has increased even more, it has decreased by 33% compared to the original test and now amounts to.(Appendices 13) At the same time, this temperature is only 4% higher than the ambient temperature. This allows us to say that the cabinet is cooled almost completely, for comparison the temperature in the initial simulation is 56% higher than the ambient temperature. (Figure 5.23)
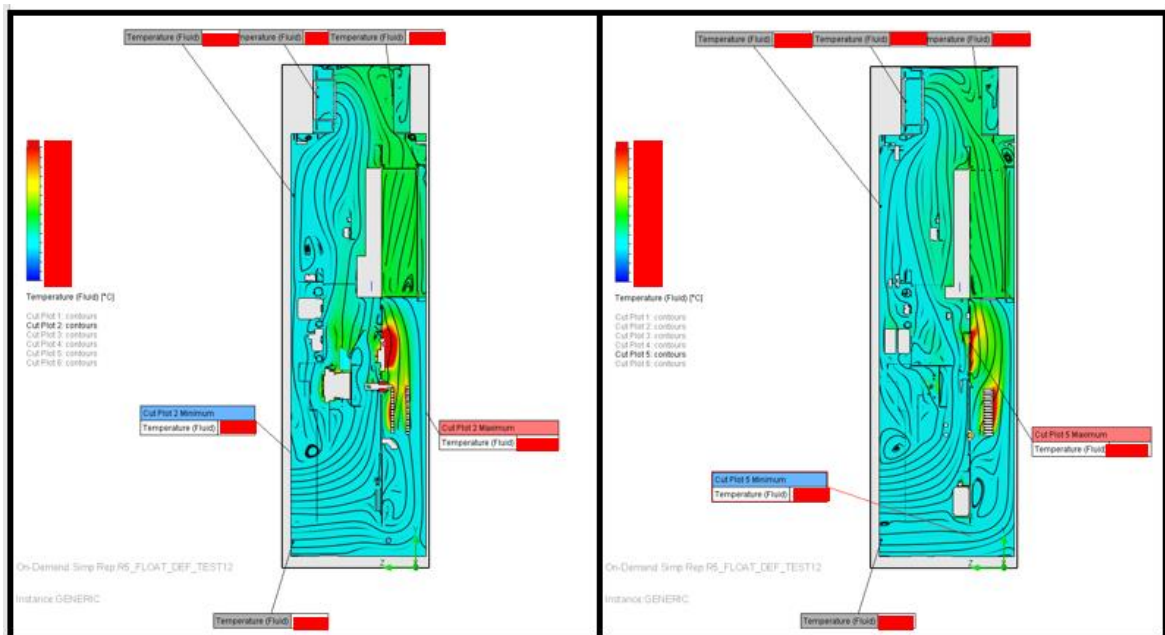
Figure 5.23 Fluid cabinet temperature for test 13, cutout plates 2 and 5
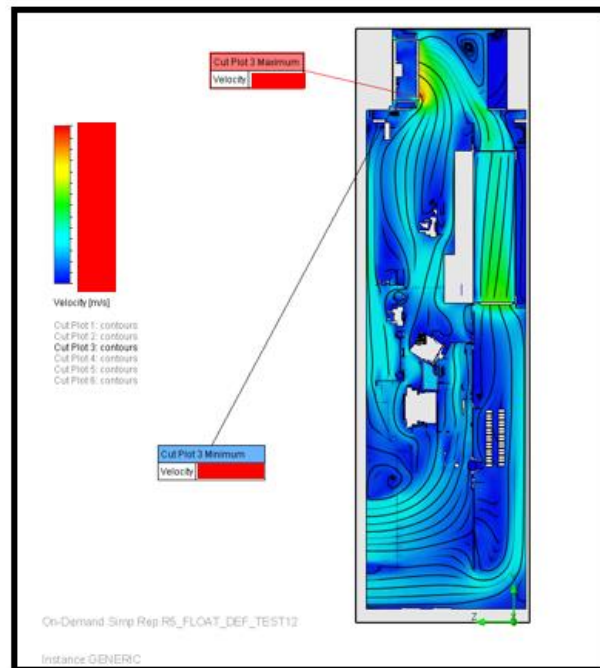
Figure 5.24 Air velocity for test 13, cutout plate 3

The air velocity remained the same, but since by removing the lower separating tunnel and connecting the circuits through the bottom, the air flow at the transformer was improved. This improves the cooling of the whole system. Also due to this, the dudette filter also became less heated. The vortices are still there, but they are much smaller and most of them occur in the corners of the cabinet itself and they have a temperature not exceeding the outlet temperature. (Figure 5.24)

Verdict for this test: This solution can be called the ultimate solution; it brings the output temperature as close as possible to the ambient temperature. It makes the airflow inside the cabinet smoother and reduces the number of vortexes. This assembly will be used in the future as a finite solution. Now it remains to equalize the original model with the final one, at an increased ambient temperature. (Appendices 16-18)

5.2.13 Airflow simulation Test 14

The next two tests will simulate cabinet conditions at elevated ambient temperatures. For the test, the ambient temperature was increased by 2.5 times. This is to test how well the new ventilation system will cope under critical conditions.

First, a test of the original cabinet configuration will be done for the referent. The results show that at such a startup it shows that the cabinet heats up 85% more than at the initial conditions. The difference between the output air and the ambient air is 15.8%. The difference from DUDT fillet heating is 6.67% on cutout plate 5 and 3.42% on cutout plate 2. (Appendices 19) (Figure 5.25)

The air currents are circulated in the same way as in the first test. There is only a drop in speed. (Figure 5.26)

Verdict for this test: The simulation was created as a reference for a subsequent test, and the necessary data were obtained.
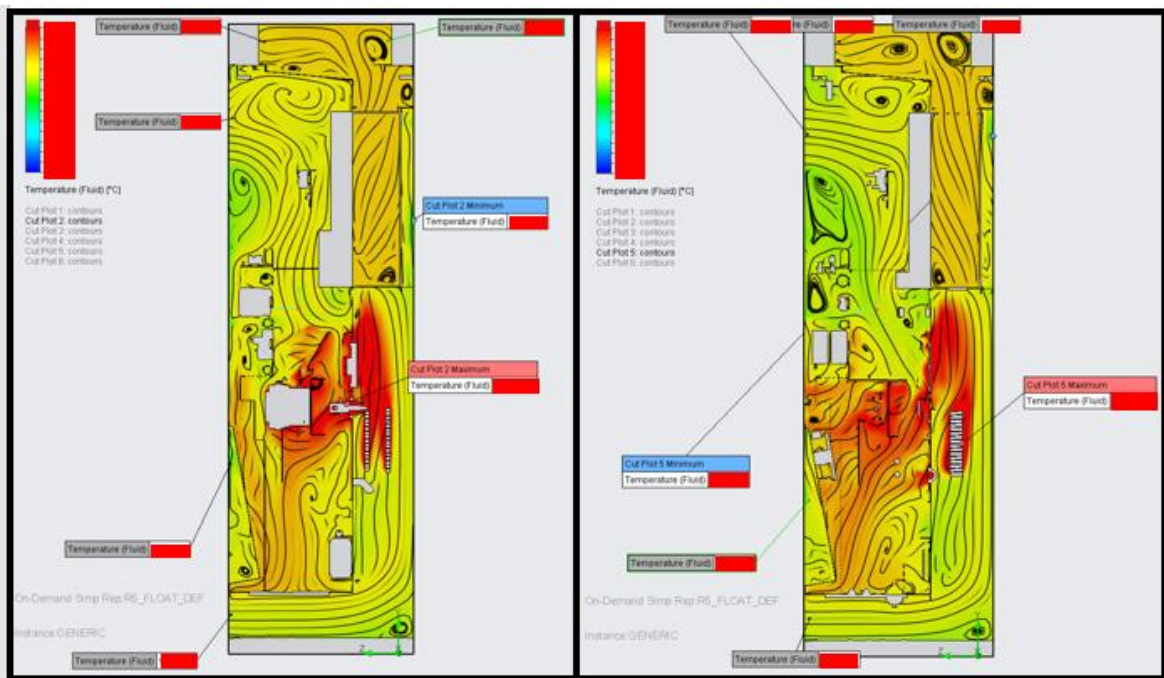
Figure 5.25 Fluid cabinet temperature for test 14, cutout plates 2 and 5
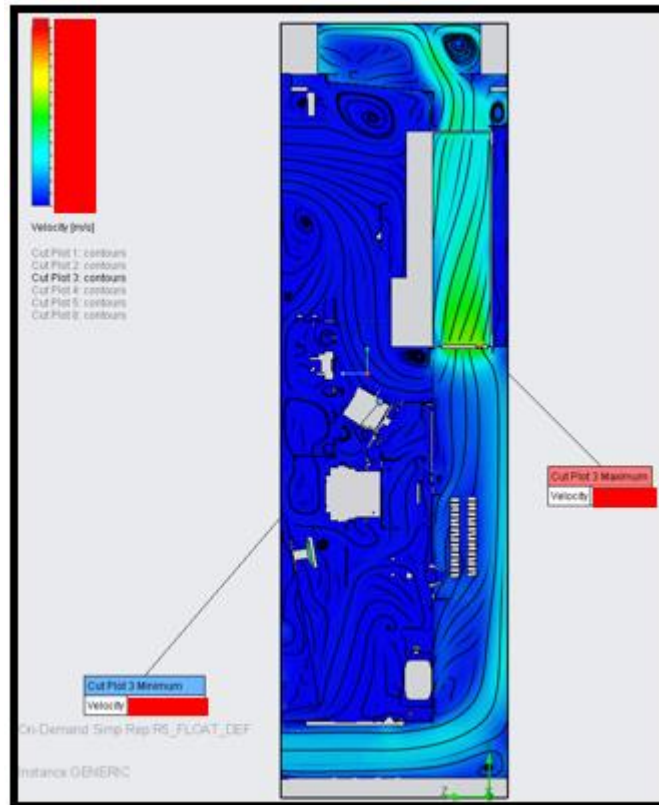
Figure 5.26 Air velocity for test 14, cutout plate 3

5.2.14 Airflow simulation Test 15

This test is also performed at 2.5 times the ambient temperature. The simulation results show that the new ventilation system performs better than the original one. Cooling is 7.6% better than in test 14. (Figure 5.27) The difference between the air leaving the room and the temperature of the air entering the room is 0.82%. This result best demonstrates the efficiency of the new ventilation system. The airflow circulates in the same way as in test 13. The flow velocity also decreased as in test 14. (Appendices 20) (Figure 5.28)

Verdict for this test: This test clearly demonstrates the superiority of a new ventilation system over an old one under crisis operating conditions.
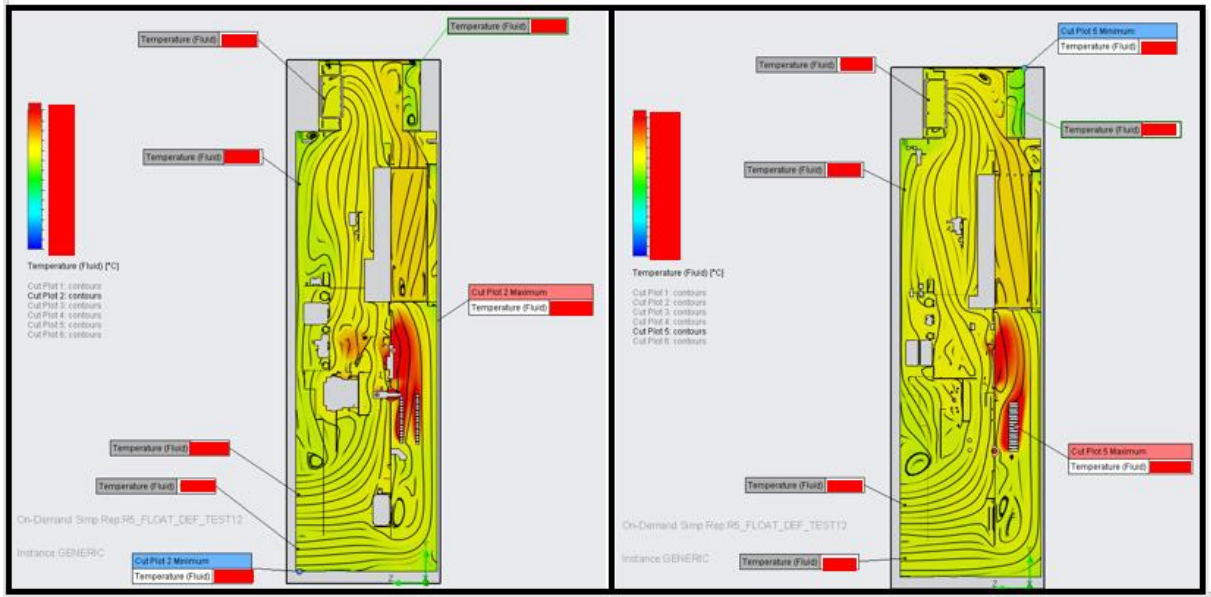
Figure 5.27 Fluid cabinet temperature for test 15, cutout plates 2 and 5
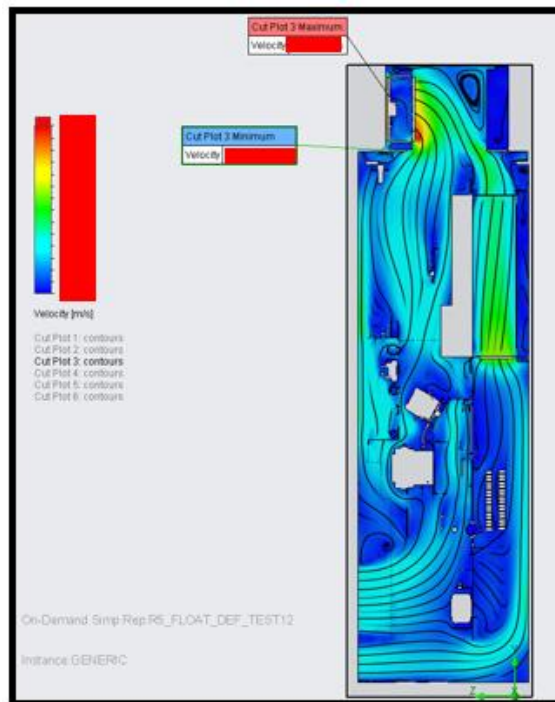
Figure 5.28 Air velocity for test 15, cutout plate 3

5.3 Cost analysis

In the cost analysis, due to confidentiality policy restrictions, I cannot disclose prices or the specific components that will be replaced. As a measure of equivalence, the percentage ratio of the cost of a particular modification to the original simulation will be given.

Cost analysis is one of the most important stages of the work. The key condition was not only to increase the efficiency of the ventilation, but also to prevent the cost of the whole office from increasing, ideally to reduce the cost.

The price of a cabinet is made up of two important components, the price of the components and the cost of assembly. The price of components includes the cost of materials, plus the cost of manufacturing them. The assembly cost includes the man hours that will be spent on the work of assembling the cabinet.

Table 5.1 Price comparisonек tabel

Price comparison table	Total cost ($)	Comparison with test 1 (%)
Test 1		0,00
Test 2		0,54
Test 3		1,98
Test 4		0,99
Test 5		0,99
Test 6		-0,37
Test 7		0,49
Test 8		-1,60
Test 9		0,60
Test 10		1,51
Test 11		2,43
Test 12		7,82
Test 13		9,25

After comparing the production costs of the cabinets, we can see that test 13 is the cheapest cabinet in terms of production costs. The main advantage in price is not due to the cost of components, but due to the simplification of cabinet assembly, which saves manpower.

6. FINAL RESULT

6.1 Comparison of simulation results

To confirm the efficiency of the improved ventilation system, you can see how the heating of the elements will change. For the test, components consisting of homogeneous material were taken. To analyses how changes in the temperature of the air flow in the ventilation system affect the heating of the components, the theoretical calculations from subchapter 2.3 are used.

We can see that the amount of cooling in the original system is rather small, due to the high temperature of the elements and their small area. But for this test we are not interested in the percentage value of the original component temperature, but in comparing the results.

Table 6.1 calculations for test1

Test1	Body1	Body2	Body3	Body4	Body5
mass (kg)	0,84	1,98	0,08	0,08	0,07
surface area (m2)	0,17	0,23	0,0058	0,0058	0,0054
temperature (°C)					
temperature diference (°C)					
heat capacity (J/(kg*°C))	380	881	380	380	380
heat transfer coefficient (W/(m2*°C))	10	10	10	10	10
heat flux (W)					
temprature losses (°C)					
differences from initial temperature (%)	0,28	0,10	0,12	0,12	0,13

Table 6.2 calculations for test13

Test13	Body1	Body2	Body3	Body4	Body5
mass (kg)	0,84	1,98	0,08	0,08	0,07
surface area (m2)	0,17	0,23	0,0058	0,0058	0,0054
temperature (°C)					
temperature diference (°C)					
heat capacity (J/(kg*°C))	380	881	380	380	380
heat transfer coefficient (W/(m2*°C))	10	10	10	10	10
heat flux (W)					
temprature losses (°C)					
temperature from initial temprateur (%)	0,41	0,11	0,15	0,15	0,16
Comparison with test1 (%)	44,44	17,39	30,77	30,77	30,77

Percentage comparisons show that on average, components started cooling 30% more efficiently. This corresponds to an overall improvement in the performance of the ventilation system.

6.2 Achieved goals review

Before starting the work, the following objectives were put forward. Described in subchapter 1.3. Now we can summaries the results

One of the objectives was to reduce the cost of the room by 5% and to increase the efficiency of the cooling system. This objective has been fully met. The cooling efficiency of the cabinet was improved by 33%. The estimated cost has been reduced by 9.25%.

These results are impressive and allow us to consider further steps to introduce the new system into production.

The next goal was to reduce the assembly time of the cabinet. This parameter was not directly disclosed during work. But it directly comes out of the change in the cost of the cabinet. The assembly process is shortened, which reduces the total cost of the product. This is achieved by simplifying the assembly and mounting of the door without a fan. More space inside, which makes the assembly process easier and faster. As well as reducing the total number of components in the cabinet.

The last point was to allow minimal changes in the cabinet dimensions. This point was partially fulfilled. Due to the change of the roof of the cabinet, the total height of the cabinet has changed at 171 mm. This difference in the overall height of the cabinet is not important. The minimum distance from the upper edge of the frame to the ceiling of the room should be at least 400 mm, according to the ACS580-07 cabinet manual. Therefore, this point can also be considered fulfilled. [2]

In the end, the author believes that he has fully coped with the aims and objectives of the paper and has given a comprehensive description of the work carried out.

6.3 Further application of thesis

As previously stated, this thesis was designed to investigate theoretical changes in the ventilation system of the ACS580-07 cabinet. As a result of the work, new options for the ventilation system configuration were found. Some of them significantly increase the ventilation efficiency and reduce the total cost of the cabinet. Further steps could be to test the prototype in real-world conditions.

Because of the high cost of real-life testing, it was necessary to obtain evidence of its feasibility before conducting it. The present thesis fulfils this. The final decision to start testing, should be made by the global manager.

In order to make a decision, it is also possible to further investigate how the modified ventilation system affects the life cycle of the ACS580-07 drive. Its reliability and efficiency under stress conditions. The logistics and assembly processes can also be examined in more detail. Finally consider the introduction of the new ventilation system on related products.

SUMMARY

This thesis was published at the initiative of the author, and the topic was chosen jointly with ABB AS. The thesis was compiled at ABB and all key data used in it was provided by ABB databases. The thesis is based on the idea of improving air cooling systems for electric drives of the ACS580-07 series.

Electric drives play an important role in a large number of industrial applications, electric vehicles, elevators, pumps and robotics. An electric drive is a system, where an electric motor or generator is controlled using a power-electronic converter. A properly selected drive can extend the life of the motor, increase its efficiency, and reduce energy consumption. To ensure efficient operation of the electric motor, the electric driver itself must work efficiently. When the actuator is running, a lot of heat is released and must be dissipated.

The objective of this research is to update the cooling system of the ACS580-07 series cabinets. The thesis primarily focuses on understanding the theory of cooling electrical components inside electrical drive cabinet, the validation of necessary standards, understanding the model project, model preparation inside CREO and Siemens FLOEFD flow simulation equipment. Analysis, model running and its behaviour, and finally, validation of the model compared with the actual result.

During the research was created a simulation of airflow in the electric drive cabinet. The simulation displayed realistic air circulation in the original configuration. After obtaining and analysing the raw data from the first simulation, a number of tests were carried out. During the tests, various design parameters of the ACS580-07 cabinet were changed. A total of 15 tests were carried out, and the results of these tests led to a more optimal cooling system.

The result of this thesis is a new cooling system, which can cool the cabinet 33% better and reduces the production cost of ACS580-07 electric drive by 9%. The new cooling system has a large potential for introduction into production.

KOKKUVÕTE

Lõputöö avaldati autori algatusel ning teema valiti välja koos ABB AS-iga. Lõputöö koostati ABB-s ning kõik selles kasutatud põhiandmed olid esitatud ABB andmebaasides. Töö põhineb ideel täiustada ACS580-07 seeria elektriajamite õhkjahutussüsteeme.

Elektriajamid mängivad olulist rolli paljudes tööstuslikes rakendustes, elektrisõidukites, liftides, pumpades ja robootikas. Elektriajam on süsteem, kus elektrimootorit või -generaatorit juhitakse elektroonilise muunduri abil. Õigesti valitud ajam võib pikendada mootori eluiga, suurendada selle tõhusust ja vähendada energiatarbimist. Elektrimootori tõhusa toimimise tagamiseks peab elektriajam ise tõhusalt töötama. Kui elektriajam töötab, eraldub palju soojust ja seda tuleb hajutada.

Käesoleva lõputöö eesmärk on ajakohastada ACS580-07 kapi jahutussüsteemi. Lõputöö keskendub peamiselt elektriliste komponentide jahutamise teooria mõistmisele elektriajami kapis, vajalike standardite valimisele, mudelprojekti mõistmisele, mudeli ettevalmistamisele CREO ja Siemens FLOEFD voolu simulatsiooni keskkonna sees. Mudeli analüüs, mudeli toimimine ja käitumine ning lõpuks mudeli valimine võrreldes tegeliku tulemusega.

Lõputöö käigus loodi elektriajami kapis õhuvoolu simulatsioon. Simulatsioon näitas realistlikku õhuringlust originaalkonfiguratsioonis. Pärast esimese simulatsiooni lähteandmete saamist ja analüüsimist viidi läbi mitu katset. Katsete käigus muudeti ACS580-07 kapi erinevaid konstruktsiooniparameetreid. Kokku viidi läbi 15 katset ja nende tulemuste alusel loodi optimaalsem jahutussüsteem.

Käesoleva töö tulemuseks on uus jahutussüsteem, mis jahutab kappi 33% paremini ja vähendab ACS580-07 elektriajami tootmiskulusid 9%. Uuel jahutussüsteemil on suur tootmisse toomise potentsiaal.

LIST OF REFERENCES

[1] A. AS, ABB general purpose drives ACS580 Catalog, 2016.

[2] A. AS, ACS580-07 Hardware manual, 2016.

[3] A. AS, Galateo project, 2022.

[4] U. AS, UL standart 508A, 2020.

[5] I. company, IP standart manual explanation.

[6] P. Atkins, The Laws of Thermodynamics: A Very Short Introduction, 2022.

[7] D. Zhou, M. Zhang and C. Du, Enhancing rack servers air cooling capability with extra system inlet airflow through air ducts between racks, 2017.

[8] SOLIDWORKS, Dassault Systèmes, 2021.

[9] A. Fulcher, Particle studies in SOLIDWORKS Flow Simulation, Solid, 2016.

[10] N. Juewong and K. Sangpradit, Virtual Simulation for Detection of Gray-Mold with Biosensor Technology in Greenhouse, 2021.

[11] P. T. L. Nguyen and V. D. Do, Vehicle Body Design and Analysis Aerodynamic by Flow Simulation, 2020.

[12] H. K. V. a. W. Malalasekera, "An Introduction to Computational Fluid Dynamics," in *The Finite Volume Method, vol. Second Edition*, 2007, pp. 40-41.

[13] F. D. a. M. N. Unsal, "Laminar-to-Turbulent Transition of Pipe Flows through Slugs and Puffs," Institute of Fluid Mechanics, 2007.

[14] F. U. Rahman, "Laminar and Turbulent Flow," The Constructor, [Online]. Available: https://theconstructor.org/fluid-mechanics/laminar-turbulent-flow/559432/. [Accessed 8 12 2023].

[15] B. E. Rapp, "Fluids," in *Microfluids: Modelling, Mechanics and Mathematics*, 2017, pp. 256-257.

[16] N. R. Council, Twenty-First Symposium on Naval Hydrodynamics, Washington, DC: The National Academies Press (in English), 1997.

[17] M. J. Pattison, "Vortices," 2011. [Online]. Available: https://www.thermopedia.com/content/1248/. [Accessed 8 12 2023].

[18] J. F. D. a. M. M. Alam, "A review of bluff body wakes," in *Ocean Engineering*, 2019, pp. 475-488.

[19] R. Mankin, Statistiline termodünaamika, Tallinn: Tallinna Tehnikaülikool, 1992.

[20] N. A. B. Zahari and Y. B. H. T. N. B. T. Yaakub, "Fin Configuration Affects under Natural Convection," p. 6, 12 2024.

[21] A. AS, ACS880-07 HP/LP Hardware manual.

[22] Siemens, "Simcenter FLOEFD software," [Online]. Available: https://plm.sw.siemens.com/en-US/simcenter/fluids-thermal-simulation/floefd/.

[23] PTC, "What is Creo?," [Online]. Available: https://www.ptc.com/en/products/creo. [Accessed 08 05 2024].

[24] ABB AS, "Internal document. FLOEFD User Manual," 2022.

[25] L. S. Sterling, The Art of Agent-Oriented Modeling, London: The MIT Press, 2009.

APPENDICES

Appendix 1 All test short summary discription

Folder name	Discription	Air inlet	Ventilation conture	Fans locations	Roof shape
Test1	Initial test, with standard cabinet layout	In five places	Two separate	Module Door	Standart
Test2	Air outlet through the roof with combined ventilation conture through the roof	In four places	Conected through the roof	Module Door	Standart
Test3	Fully integrated contours	In three places	Fully connected	Module Door	Standart
Test4	Air outlet through the roof with separated ventilation conture in the roof	In four places	Two separate	Module Door	Standart
Test5	Air outlet through the roof with separated ventilation conture in the roof, and changed outer contour	In four places	Two separate	Module Door	Standart
Test6	Air outlet through the roof with separated ventilation conture in the roof, and changed outer contour	In four places	Two separate	Module Door	Standart
Test7	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour	In four places	Conected through the roof	Module Door	Standart
Test8	Air outlet through the roof with separated ventilation conture in the roof, and changed outer contour	In four places	Two separate	Module Door	Standart
Test9	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour	In four places	Conected through the roof	Module Door	Big box
Test10	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour	In three places	Conected through the roof	Module Door	Big box
Test11	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour	In three places	Conected through the roof	Module Door Roof	Big box
Test12	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour	In three places	Conected through the roof	Module Roof	Big box
Test13	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour	In three places	Fully connected	Module Roof	Big box
Test14	Initial test, with standard cabinet layout with high ambient temprature	In five places	Two separate	Module Door	Standart
Test15	Air outlet through the roof with combined ventilation conture through the roof, and changed outer contour with high ambient temprature	In three places	Conected through the roof	Module Roof	Big box

Data simulation table		Test2			
		Temprature Fluid (°C)	Comparison with test 1 data(%)	Velocity (m/s)	Comparison with test 1 data(%)
Cutout plate 1	MinParameter		-0,45		0,00
	MaxParameter		0,00		-5,44
	Enter		2,84		
	Exit from Door		-6,99		
	Exit from roof-front		3,58		
	Exit from roof-back		-3,66		
Cutout 1 average Exit temp.			-7,35		
Cutout plate 2	MinParameter		-0,05		0,00
	MaxParameter		-0,01		-4,68
	Enter		3,37		
	Exit from Door		-39,79		
	Exit from roof-front		2,62		
	Exit from roof-back		-22,93		
Cutout 2 average Exit temp.			-28,44		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		-7,27		-2,67
	Enter		-5,74		
	Exit from Door		-22,90		
	Exit from roof-front		-9,21		
	Exit from roof-back		-2,46		
Cutout 3 average Exit temp.			-26,03		
Cutout plate 4	MinParameter		-0,05		0,00
	MaxParameter		-0,11		-3,54
	Enter		3,00		
	Exit from Door		-11,36		
	Exit from roof-front		8,26		
	Exit from roof-back		-2,52		
Cutout 4 average Exit temp.			-6,69		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		-11,03		-3,67
	Enter		-0,15		
	Exit from Door		-9,07		
	Exit from roof-front		7,74		
	Exit from roof-back		-3,17		
Cutout 5 average Exit temp.			-6,65		
Cutout plate 6	MinParameter		0,00		0,00
	MaxParameter		-0,07		-2,32
	Enter		0,00		
	Exit from Door		23,09		
	Exit from roof-front		3,14		
	Exit from roof-back		-5,14		
Cutout 6 average Exit temp.			-4,46		
Test average Exit temp.			-12,39		

Data simulation table		Test3			
		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		0,10		
	MaxParameter		0,07		0,81
	Enter		-29,05		
	Exit from Door		-32,44		
	Exit from roof-front		-19,59		
	Exit from roof-back		-7,97		
Cutout 1 average Exit temp.			-22,25		
Cutout plate 2	MinParameter		-0,05		0,00
	MaxParameter		-0,13		0,84
	Enter		-34,36		
	Exit from Door		-80,80		
	Exit from roof-front		-19,71		
	Exit from roof-back		-32,97		
Cutout 2 average Exit temp.			-48,27		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		-0,17		1,30
	Enter		-38,70		
	Exit from Door		-94,63		
	Exit from roof-front		-50,43		
	Exit from roof-back		-16,84		
Cutout 3 average Exit temp.			-57,60		
Cutout plate 4	MinParameter		-0,05		0,00
	MaxParameter		0,10		0,23
	Enter		-31,59		
	Exit from Door		-43,68		
	Exit from roof-front		-19,44		
	Exit from roof-back		-19,09		
Cutout 4 average Exit temp.			-31,09		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		4,49		0,58
	Enter		-41,75		
	Exit from Door		-40,50		
	Exit from roof-front		-19,42		
	Exit from roof-back		-17,45		
Cutout 5 average Exit temp.			-29,37		
Cutout plate 6	MinParameter		-0,05		0,00
	MaxParameter		0,01		0,51
	Enter		-41,36		
	Exit from Door		-25,20		
	Exit from roof-front		-19,14		
	Exit from roof-back		-10,27		
Cutout 6 average Exit temp.			-18,81		
Test average Exit temp.			-33,31		

Data simulation table		Test4			
		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		-0,20		0,00
	MaxParameter		0,00		-2,06
	Enter		0,77		
	Exit from Door		19,52		
	Exit from roof-front		18,79		
	Exit from roof-back		-4,03		
Cutout 1 average Exit temp.			0,75		
Cutout plate 2	MinParameter		-0,05		0,00
	MaxParameter		0,13		-1,83
	Enter		3,51		
	Exit from Door		-11,95		
	Exit from roof-front		16,54		
	Exit from roof-back		-23,60		
Cutout 2 average Exit temp.			-19,76		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		-5,37		-0,90
	Enter		0,00		
	Exit from Door		-26,18		
	Exit from roof-front		-5,77		
	Exit from roof-back		-1,22		
Cutout 3 average Exit temp.			-23,37		
Cutout plate 4	MinParameter		-0,05		0,00
	MaxParameter		-0,13		-1,41
	Enter		3,00		
	Exit from Door		15,93		
	Exit from roof-front		15,16		
	Exit from roof-back		-1,36		
Cutout 4 average Exit temp.			-2,21		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		-8,95		-1,38
	Enter		0,00		
	Exit from Door		11,95		
	Exit from roof-front		17,02		
	Exit from roof-back		-2,26		
Cutout 5 average Exit temp.			-1,02		
Cutout plate 6	MinParameter		0,00		0,00
	MaxParameter		-0,07		-0,76
	Enter		0,00		
	Exit from Door		12,78		
	Exit from roof-front		18,73		
	Exit from roof-back		-4,59		
Cutout 6 average Exit temp.			4,03		
Test average Exit temp.			-5,97		

Data simulation table		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
		Test5			
Cutout plate 1	MinParameter		-0,20		0,00
	MaxParameter		0,00		-3,17
	Enter		-0,67		
	Exit from Door		17,68		
	Exit from roof-front		15,49		
	Exit from roof-back		-2,47		
Cutout 1 average Exit temp.			-0,22		
Cutout plate 2	MinParameter		0,00		0,00
	MaxParameter		0,21		-2,75
	Enter		-0,77		
	Exit from Door		-23,78		
	Exit from roof-front		16,43		
	Exit from roof-back		-21,17		
Cutout 2 average Exit temp.			-18,55		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		-1,07		-1,39
	Enter		-4,44		
	Exit from Door		-40,89		
	Exit from roof-front		-5,98		
	Exit from roof-back		0,68		
Cutout 3 average Exit temp.			-22,23		
Cutout plate 4	MinParameter		0,00		0,00
	MaxParameter		-0,13		-2,10
	Enter		-1,31		
	Exit from Door		-5,25		
	Exit from roof-front		17,61		
	Exit from roof-back		0,88		
Cutout 4 average Exit temp.			0,37		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		-1,94		-2,20
	Enter		-4,44		
	Exit from Door		-3,59		
	Exit from roof-front		17,93		
	Exit from roof-back		0,00		
Cutout 5 average Exit temp.			0,70		
Cutout plate 6	MinParameter		0,00		
	MaxParameter		-0,04		-1,23
	Enter		0,00		
	Exit from Door		7,25		
	Exit from roof-front		17,87		
	Exit from roof-back		-2,77		
Cutout 6 average Exit temp.			4,50		
Test average Exit temp.			-4,96		

Data simulation table		Test6			
		Temprature Fluid (C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		-0,30		0,00
	MaxParameter		0,00		-2,90
	Enter		0,05		
	Exit from Door		15,90		
	Exit from roof-front		16,70		
	Exit from roof-back		0,94		
Cutout 1 average Exit temp.			2,23		
Cutout plate 2	MinParameter		0,00		0,00
	MaxParameter		0,99		-2,60
	Enter		3,51		
	Exit from Door		-18,67		
	Exit from roof-front		16,10		
	Exit from roof-back		-17,40		
Cutout 2 average Exit temp.			-16,76		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		0,49		-1,24
	Enter		0,00		
	Exit from Door		-24,14		
	Exit from roof-front		-5,77		
	Exit from roof-back		5,06		
Cutout 3 average Exit temp.			-19,24		
Cutout plate 4	MinParameter		0,00		0,00
	MaxParameter		0,99		-1,96
	Enter		3,00		
	Exit from Door		5,19		
	Exit from roof-front		16,70		
	Exit from roof-back		6,66		
Cutout 4 average Exit temp.			3,00		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		0,06		-2,10
	Enter		0,00		
	Exit from Door		-3,32		
	Exit from roof-front		18,32		
	Exit from roof-back		6,93		
Cutout 5 average Exit temp.			4,65		
Cutout plate 6	MinParameter		0,00		0,00
	MaxParameter		-0,04		-1,22
	Enter		0,00		
	Exit from Door		22,85		
	Exit from roof-front		17,63		
	Exit from roof-back		-1,46		
Cutout 6 average Exit temp.			5,04		
Test average Exit temp.			-2,59		

Data simulation table		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		-0,45		0,00
	MaxParameter		0,00		-6,27
	Enter		3,56		
	Exit from Door		18,68		
	Exit from roof-front		4,29		
	Exit from roof-back		-0,62		
Cutout 1 average Exit temp.			-5,35		
Cutout plate 2	MinParameter		0,00		0,00
	MaxParameter		0,46		-5,79
	Enter		3,51		
	Exit from Door		-18,11		
	Exit from roof-front		7,47		
	Exit from roof-back		-19,45		
Cutout 2 average Exit temp.			-23,45		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		-2,84		-3,23
	Enter		0,00		
	Exit from Door		-29,83		
	Exit from roof-front		-8,72		
	Exit from roof-back		-0,90		
Cutout 3 average Exit temp.			-24,75		
Cutout plate 4	MinParameter		0,00		0,00
	MaxParameter		-0,13		-4,30
	Enter		3,00		
	Exit from Door		16,00		
	Exit from roof-front		13,20		
	Exit from roof-back		-1,67		
Cutout 4 average Exit temp.			-3,47		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		-5,72		-4,46
	Enter		0,00		
	Exit from Door		17,26		
	Exit from roof-front		12,45		
	Exit from roof-back		-1,13		
Cutout 5 average Exit temp.			-2,94		
Cutout plate 6	MinParameter		0,00		0,00
	MaxParameter		-2,26		-3,12
	Enter		0,00		
	Exit from Door		14,28		
	Exit from roof-front		5,26		
	Exit from roof-back		-1,97		
Cutout 6 average Exit temp.			4,61		
Test average Exit temp.			-8,24		

Data simulation table		Test8			
		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		0,30		
	MaxParameter		0,01		-2,85
	Enter		3,56		
	Exit from Door		17,93		
	Exit from roof-front		17,20		
	Exit from roof-back		-7,12		
Cutout 1 average Exit temp.			-1,75		
Cutout plate 2	MinParameter		0,00		
	MaxParameter		-0,09		-2,47
	Enter		3,51		
	Exit from Door		-10,60		
	Exit from roof-front		16,16		
	Exit from roof-back		-25,66		
Cutout 2 average Exit temp.			-21,11		
Cutout plate 3	MinParameter		0,00		
	MaxParameter		0,16		-1,18
	Enter		0,00		
	Exit from Door		-17,25		
	Exit from roof-front		-5,49		
	Exit from roof-back		-0,23		
Cutout 3 average Exit temp.			-22,57		
Cutout plate 4	MinParameter		-0,05		
	MaxParameter		-0,04		-1,90
	Enter		3,00		
	Exit from Door		13,51		
	Exit from roof-front		17,61		
	Exit from roof-back		-2,07		
Cutout 4 average Exit temp.			-1,23		
Cutout plate 5	MinParameter		-0,05		
	MaxParameter		-0,30		-1,89
	Enter		0,00		
	Exit from Door		14,88		
	Exit from roof-front		17,93		
	Exit from roof-back		-1,44		
Cutout 5 average Exit temp.			-0,08		
Cutout plate 6	MinParameter		0,00		
	MaxParameter		0,19		-1,04
	Enter		0,10		
	Exit from Door		23,36		
	Exit from roof-front		18,29		
	Exit from roof-back		-8,25		
Cutout 6 average Exit temp.			1,94		
Test average Exit temp.			-6,54		

Data simulation table		Temprature Fluid (C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		0,10		
	MaxParameter		0,01		-0,61
	Enter		2,60		
	Exit from Door		22,66		
	Exit from roof-front		13,43		
	Exit from roof-back		19,63		
Cutout 1 average Exit temp.			10,33		
Cutout plate 2	MinParameter		-0,05		
	MaxParameter		4,32		-1,35
	Enter		3,51		
	Exit from Door		-8,46		
	Exit from roof-front		16,40		
	Exit from roof-back		2,19		
Cutout 2 average Exit temp.			-6,16		
Cutout plate 3	MinParameter		-0,05		
	MaxParameter		15,62		0,13
	Enter		0,00		
	Exit from Door		-5,69		
	Exit from roof-front		-1,36		
	Exit from roof-back		19,02		
Cutout 3 average Exit temp.			-7,67		
Cutout plate 4	MinParameter		-0,05		
	MaxParameter		-0,10		-3,82
	Enter		3,00		
	Exit from Door		18,39		
	Exit from roof-front		23,44		
	Exit from roof-back		21,59		
Cutout 4 average Exit temp.			14,85		
Cutout plate 5	MinParameter		-0,05		
	MaxParameter		9,43		-1,28
	Enter		0,00		
	Exit from Door		18,60		
	Exit from roof-front		21,07		
	Exit from roof-back		22,17		
Cutout 5 average Exit temp.			14,39		
Cutout plate 6	MinParameter		0,00		
	MaxParameter		-0,04		1,40
	Enter		0,00		
	Exit from Door		28,62		
	Exit from roof-front		17,24		
	Exit from roof-back		18,38		
Cutout 6 average Exit temp.			14,92		
Test average Exit temp.			7,64		

85

Data simulation table		Test10			
		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		0,05		0,00
	MaxParameter		0,01		-0,75
	Enter		2,50		
	Exit from Door		24,83		
	Exit from roof-front		8,72		
	Exit from roof-back		2,55		
Cutout 1 average Exit temp.			0,52		
Cutout plate 2	MinParameter		-0,05		0,00
	MaxParameter		4,32		-1,46
	Enter		3,51		
	Exit from Door		-7,85		
	Exit from roof-front		7,75		
	Exit from roof-back		-15,44		
Cutout 2 average Exit temp.			-19,75		
Cutout plate 3	MinParameter		0,00		0,00
	MaxParameter		14,89		0,05
	Enter		0,00		
	Exit from Door		-14,89		
	Exit from roof-front		-8,31		
	Exit from roof-back		2,80		
Cutout 3 average Exit temp.			-16,05		
Cutout plate 4	MinParameter		-0,05		0,00
	MaxParameter		-0,10		-3,90
	Enter		3,00		
	Exit from Door		15,25		
	Exit from roof-front		13,97		
	Exit from roof-back		2,55		
Cutout 4 average Exit temp.			4,23		
Cutout plate 5	MinParameter		-0,05		0,00
	MaxParameter		8,99		-1,35
	Enter		0,00		
	Exit from Door		18,33		
	Exit from roof-front		16,47		
	Exit from roof-back		2,74		
Cutout 5 average Exit temp.			7,58		
Cutout plate 6	MinParameter		0,00		0,00
	MaxParameter		-0,05		1,42
	Enter		-0,05		
	Exit from Door		28,50		
	Exit from roof-front		13,00		
	Exit from roof-back		2,17		
Cutout 6 average Exit temp.			8,35		
Test average Exit temp.			-1,55		

Data simulation table		Test11			
		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		0,25		0,00
	MaxParameter		2,98		38,48
	Enter		3,56		
	Exit from Door		32,73		
	Exit from roof-front		35,86		
	Exit from roof-back		16,28		
Cutout 1 average Exit temp.			30,09		
Cutout plate 2	MinParameter		0,10		0,00
	MaxParameter		5,03		41,96
	Enter		3,51		
	Exit from Door		8,42		
	Exit from roof-front		38,96		
	Exit from roof-back		0,37		
Cutout 2 average Exit temp.			20,77		
Cutout plate 3	MinParameter		0,20		0,00
	MaxParameter		18,85		21,49
	Enter		0,00		
	Exit from Door		1,48		
	Exit from roof-front		23,04		
	Exit from roof-back		15,91		
Cutout 3 average Exit temp.			17,54		
Cutout plate 4	MinParameter		0,20		0,00
	MaxParameter		1,36		22,52
	Enter		3,00		
	Exit from Door		27,91		
	Exit from roof-front		38,49		
	Exit from roof-back		15,52		
Cutout 4 average Exit temp.			31,52		
Cutout plate 5	MinParameter		0,20		0,00
	MaxParameter		13,28		25,03
	Enter		0,00		
	Exit from Door		28,37		
	Exit from roof-front		38,26		
	Exit from roof-back		15,89		
Cutout 5 average Exit temp.			31,69		
Cutout plate 6	MinParameter		0,10		0,00
	MaxParameter		1,42		21,02
	Enter		0,10		
	Exit from Door		33,25		
	Exit from roof-front		36,88		
	Exit from roof-back		15,81		
Cutout 6 average Exit temp.			33,50		
Test average Exit temp.			28,06		

Data simulation table			Test12			
			Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1		MinParameter		0,10		0,00
		MaxParameter		2,98		6,57
		Enter		3,56		
		Exit from Door		34,06		
		Exit from roof-front		39,96		
		Exit from roof-back		16,82		
Cutout 1 average Exit temp.				34,56		
Cutout plate 2		MinParameter		-0,10		0,00
		MaxParameter		5,03		56,52
		Enter		3,51		
		Exit from Door		10,08		
		Exit from roof-front		41,30		
		Exit from roof-back		-3,88		
Cutout 2 average Exit temp.				23,81		
Cutout plate 3		MinParameter		-0,10		0,00
		MaxParameter		19,05		21,98
		Enter		0,00		
		Exit from Door		3,15		
		Exit from roof-front		23,91		
		Exit from roof-back		12,18		
Cutout 3 average Exit temp.				18,47		
Cutout plate 4		MinParameter		-0,15		0,00
		MaxParameter		-0,07		8,65
		Enter		3,00		
		Exit from Door		27,12		
		Exit from roof-front		37,00		
		Exit from roof-back		11,27		
Cutout 4 average Exit temp.				29,86		
Cutout plate 5		MinParameter		-0,15		0,00
		MaxParameter		15,46		6,91
		Enter		0,00		
		Exit from Door		26,29		
		Exit from roof-front		40,83		
		Exit from roof-back		10,97		
Cutout 5 average Exit temp.				34,52		
Cutout plate 6		MinParameter		-0,10		0,00
		MaxParameter		1,56		6,75
		Enter		0,10		
		Exit from Door		32,80		
		Exit from roof-front		41,70		
		Exit from roof-back		10,42		
Cutout 6 average Exit temp.				38,58		
Test average Exit temp.				30,58		

Data simulation table		Test13			
		Temprature Fluid (°C)	Comparison with test 1 data (%)	Velocity (m/s)	Comparison with test 1 data (%)
Cutout plate 1	MinParameter		0,10		0,00
	MaxParameter		4,36		2,09
	Enter		3,56		
	Exit from Door		34,54		
	Exit from roof-front		44,69		
	Exit from roof-back		9,44		
Cutout 1 average Exit temp.			39,72		
Cutout plate 2	MinParameter		-0,10		0,00
	MaxParameter		5,41		57,20
	Enter		3,51		
	Exit from Door		10,91		
	Exit from roof-front		42,27		
	Exit from roof-back		-7,75		
Cutout 2 average Exit temp.			25,06		
Cutout plate 3	MinParameter		-0,10		0,00
	MaxParameter		19,80		28,00
	Enter		0,00		
	Exit from Door		3,70		
	Exit from roof-front		25,20		
	Exit from roof-back		8,99		
Cutout 3 average Exit temp.			19,85		
Cutout plate 4	MinParameter		-0,15		0,00
	MaxParameter		0,59		12,12
	Enter		3,00		
	Exit from Door		27,70		
	Exit from roof-front		40,86		
	Exit from roof-back		8,98		
Cutout 4 average Exit temp.			34,16		
Cutout plate 5	MinParameter		-0,15		0,00
	MaxParameter		15,46		9,41
	Enter		0,00		
	Exit from Door		23,10		
	Exit from roof-front		41,85		
	Exit from roof-back		9,59		
Cutout 5 average Exit temp.			35,65		
Cutout plate 6	MinParameter		-0,10		0,00
	MaxParameter		3,10		12,64
	Enter		0,10		
	Exit from Door		28,47		
	Exit from roof-front		43,02		
	Exit from roof-back		10,39		
Cutout 6 average Exit temp.			39,97		
Test average Exit temp.			33,08		

Average outlet temperature decrease
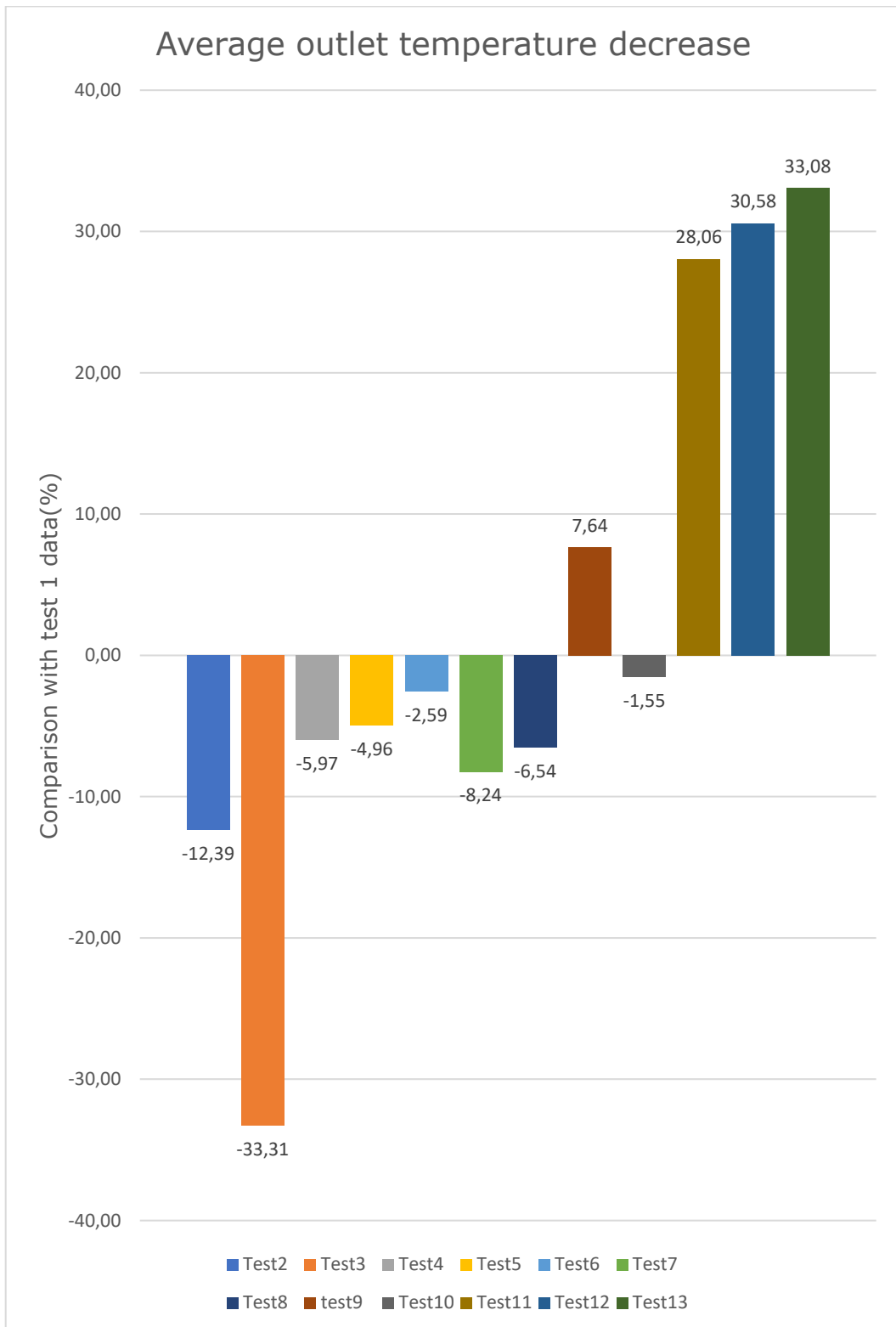
Appendix 15 Test 1 MaxParameter temp. comparison on each cutout plate

Percentage of temperature MaxParameter on each cutout plate for Test 1

Comparison with cutout plate 2 data(%)

- Cutout plate 1: 95,68
- Cutout plate 2: 100,00
- Cutout plate 3: 89,08
- Cutout plate 4: 95,56
- Cutout plate 5: 82,83
- Cutout plate 6: 95,62

■ Cutout plate 1 ■ Cutout plate 2 ■ Cutout plate 3 ■ Cutout plate 4 ■ Cutout plate 5 ■ Cutout plate 6
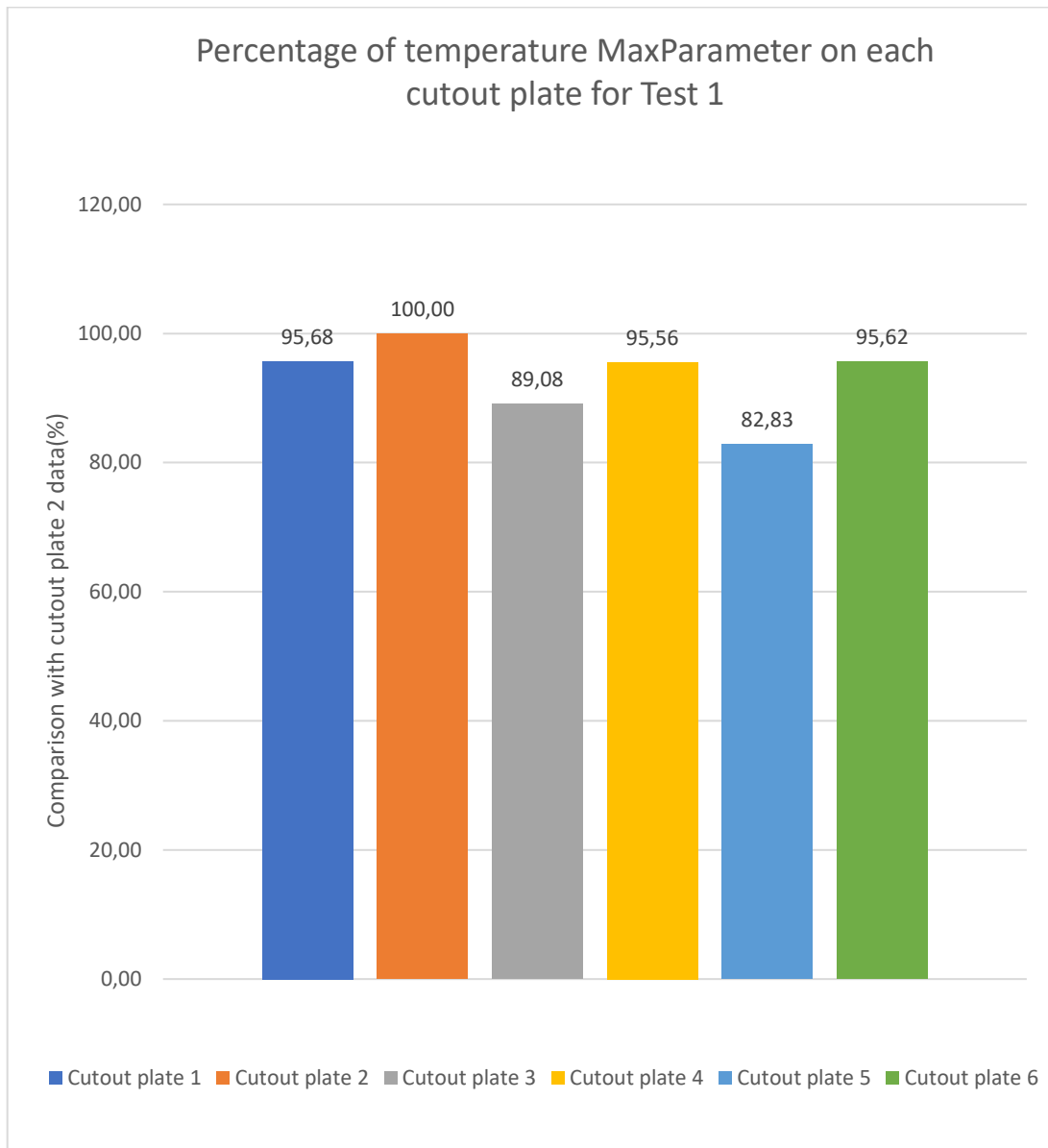
Appendix 16 MaxParameter temperature decrease on cutout plate 1 and 2
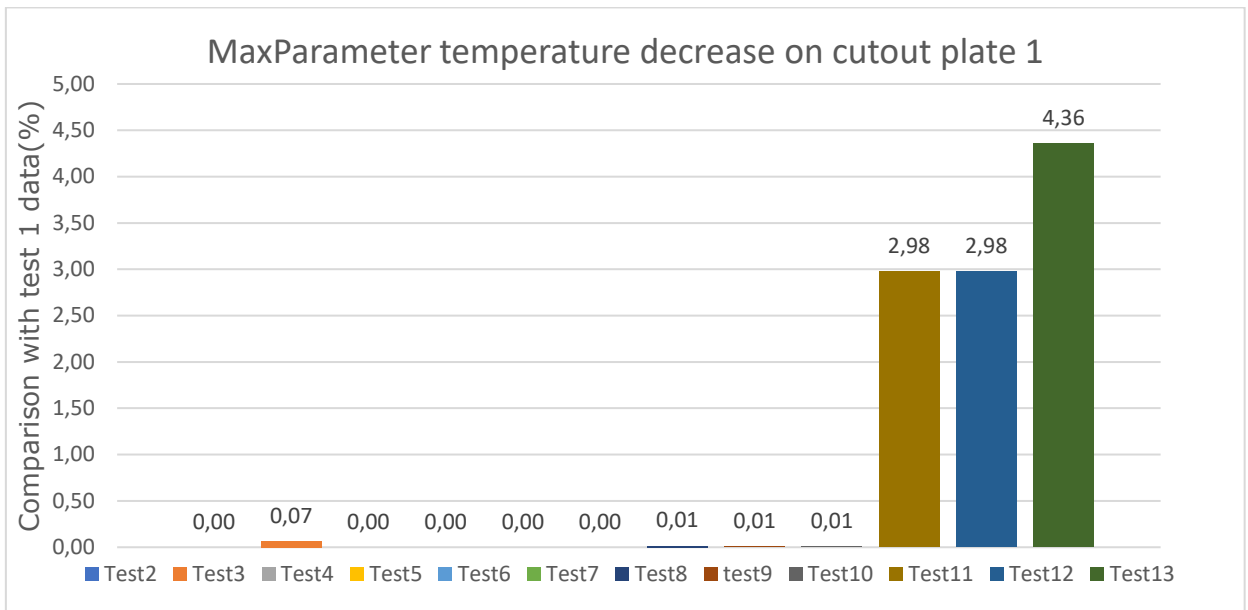

Figure A.1 MaxParameter temperature decrease on cutout plate 1

Figure A.2 MaxParameter temperature decrease on cutout plate 2

Appendix 17 MaxParameter temperature decrease on cutout plate 3 and 4

Figure A.3 MaxParameter temperature decrease on cutout plate 3

Figure A.4 MaxParameter temperature decrease on cutout plate 4

Appendix 18 MaxParameter temperature decrease on cutout plate 5 and 6

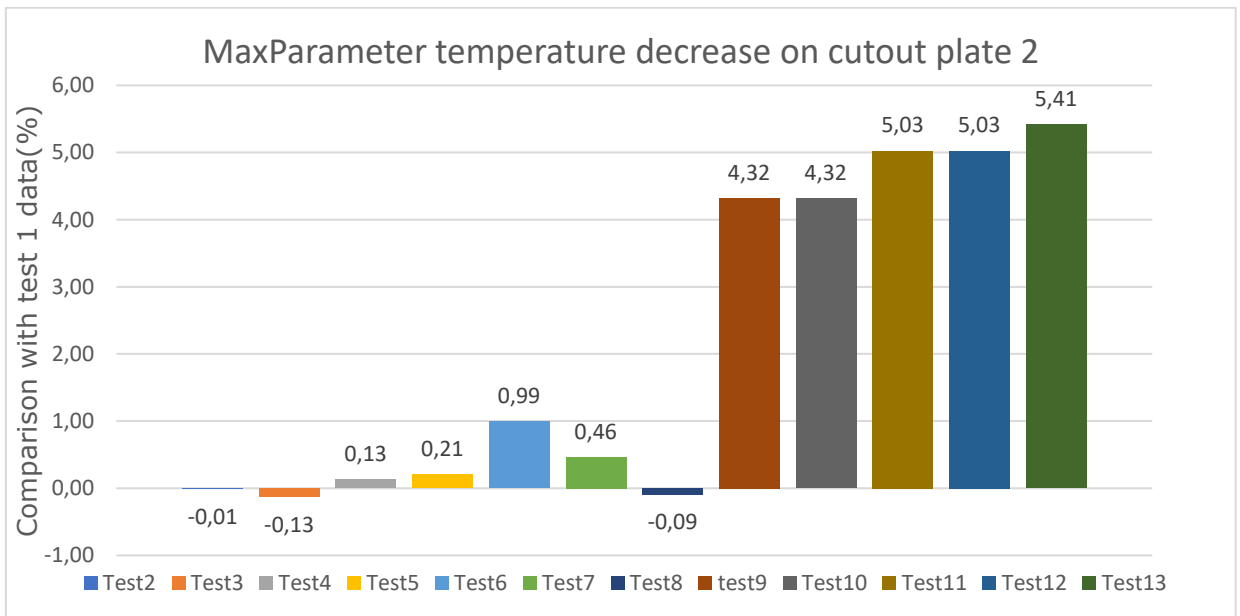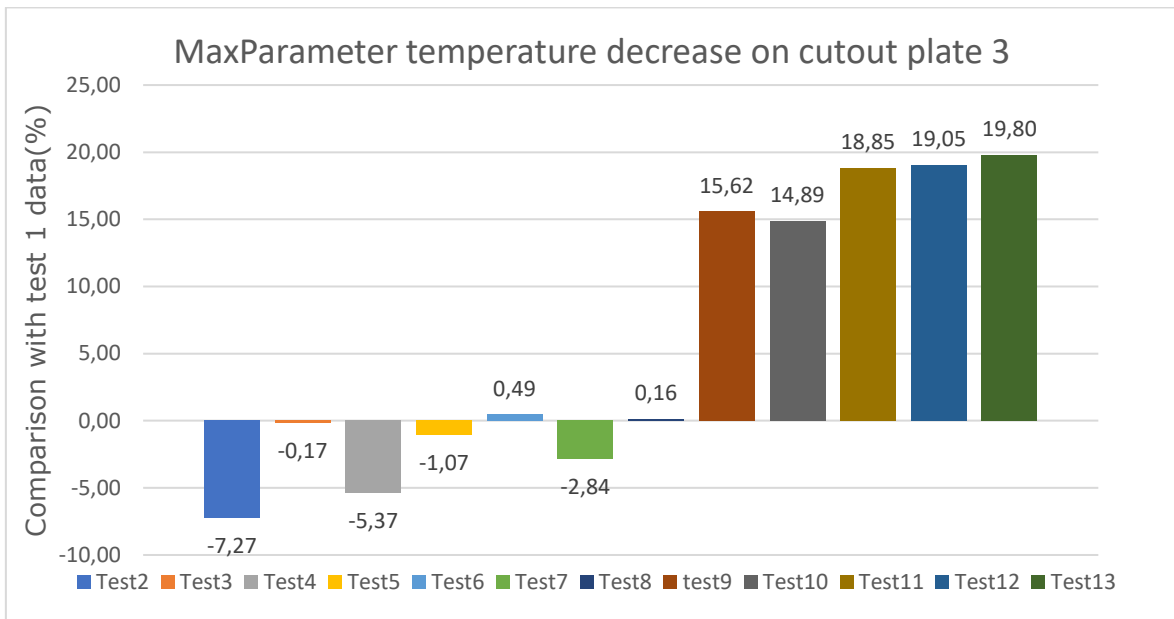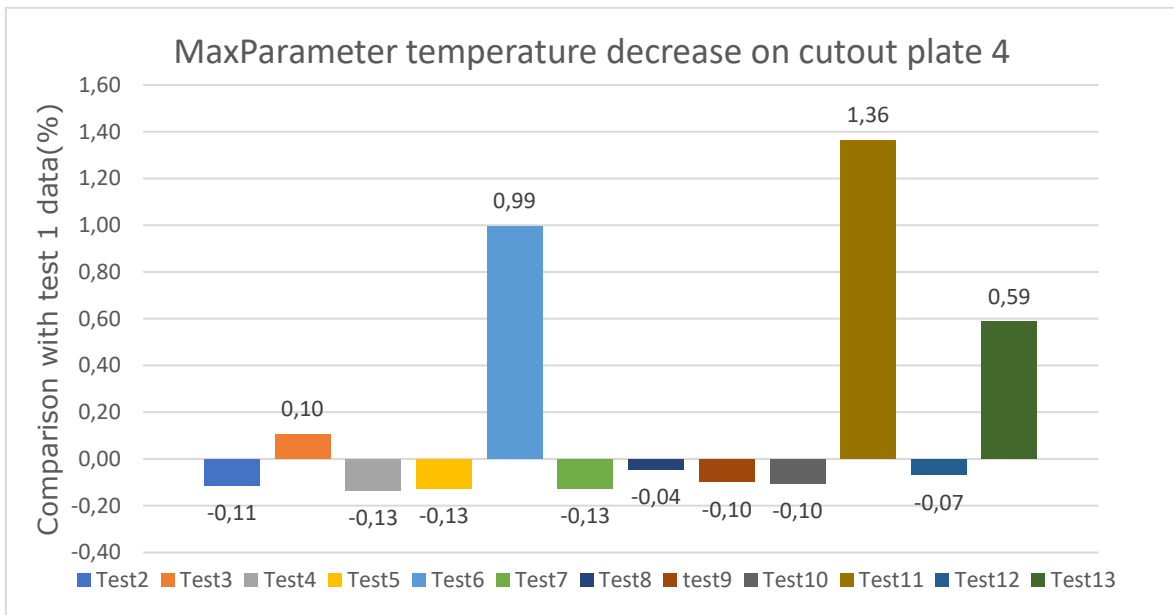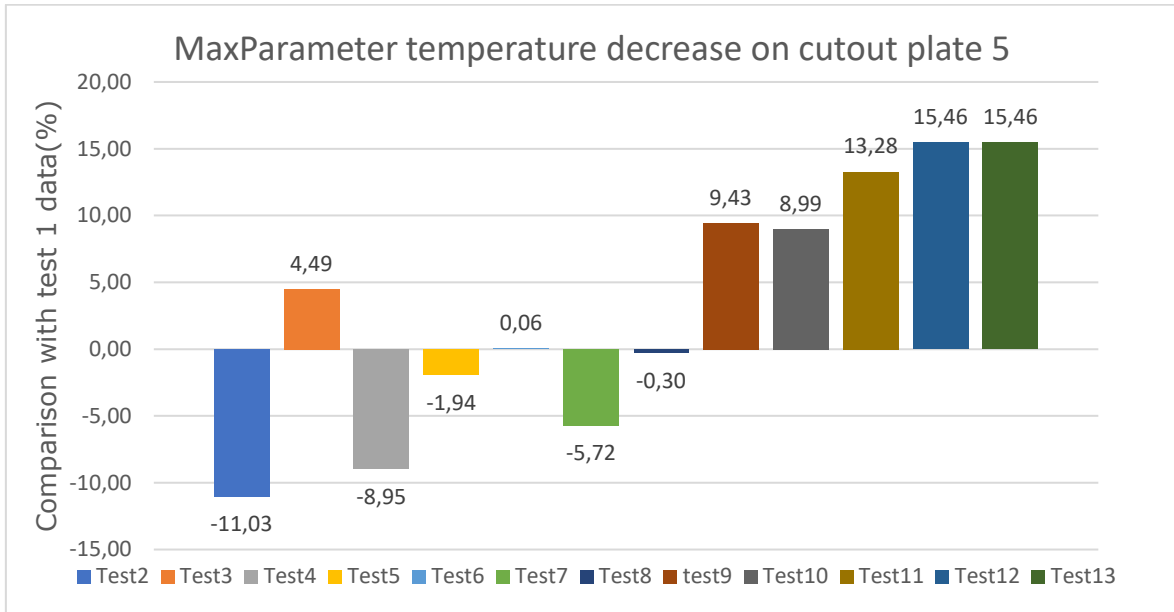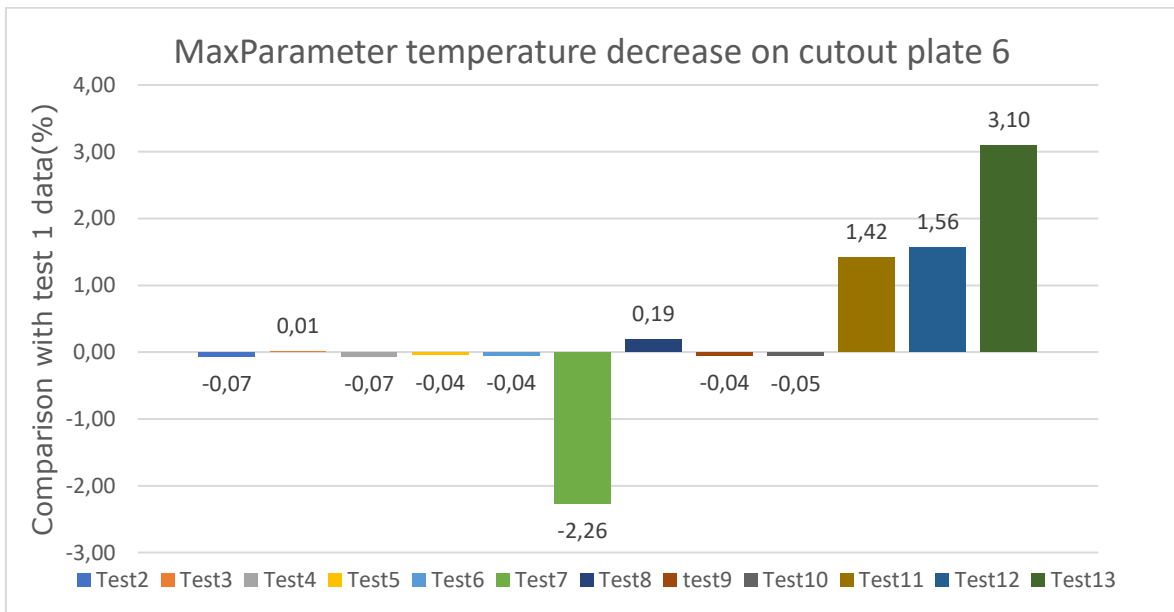*Figure A.5 MaxParameter temperature decrease on cutout plate 5*

Figure A.6 MaxParameter temperature decrease on cutout plate 6

Data simulation table		Temprature Fluid (°C)	Comparison with test 1 data(%)	Velocity (m/s)	Comparison with test 1 data(%)
Cutout plate 1	MinParameter		-89,59		0,00
	MaxParameter		-0,30		-31,33
	Enter		-143,24		
	Exit from Door		-69,18		
	Exit from roof-front		-62,08		
	Exit from roof-back		-61,77		
Cutout 1 average Exit temp.			-76,64		
Cutout plate 2	MinParameter		-100,55		0,00
	MaxParameter		-3,42		-27,56
	Enter		-140,62		
	Exit from Door		-123,95		
	Exit from roof-front		-62,26		
	Exit from roof-back		-98,35		
Cutout 2 average Exit temp.			-110,61		
Cutout plate 3	MinParameter		-92,71		0,00
	MaxParameter		-5,53		-23,12
	Enter		-149,38		
	Exit from Door		-131,27		
	Exit from roof-front		-104,07		
	Exit from roof-back		-66,52		
Cutout 3 average Exit temp.			-118,66		
Cutout plate 4	MinParameter		-89,16		0,00
	MaxParameter		-2,61		-23,90
	Enter		-141,90		
	Exit from Door		-70,59		
	Exit from roof-front		-61,87		
	Exit from roof-back		-66,83		
Cutout 4 average Exit temp.			-80,21		
Cutout plate 5	MinParameter		-95,40		0,00
	MaxParameter		-6,67		-6,18
	Enter		-149,38		
	Exit from Door		-67,90		
	Exit from roof-front		-61,54		
	Exit from roof-back		-66,35		
Cutout 5 average Exit temp.			-78,75		
Cutout plate 6	MinParameter		-92,91		0,00
	MaxParameter		0,00		0,00
	Enter		-149,13		
	Exit from Door		-50,33		
	Exit from roof-front		-59,57		
	Exit from roof-back		-64,70		
Cutout 6 average Exit temp.			-56,42		
Test average Exit temp.			-84,97		

Data simulation table		Test15			
		Temprature Fluid (°C)	Comparison with test 14 data(%)	Velocity (m/s)	Comparison with test 14 data(%)
Cutout plate 1	MinParameter		-6,86		0,00
	MaxParameter		0,30		37,69
	Enter		1,38		
	Exit from Door		-11,54		
	Exit from roof-front		14,28		
	Exit from roof-back		-0,04		
Cutout 1 average Exit temp.			8,39		
Cutout plate 2	MinParameter		3,01		0,00
	MaxParameter		7,48		31,59
	Enter		0,00		
	Exit from Door		5,08		
	Exit from roof-front		14,05		
	Exit from roof-back		2,63		
Cutout 2 average Exit temp.			8,18		
Cutout plate 3	MinParameter		2,59		0,00
	MaxParameter		10,71		26,60
	Enter		0,00		
	Exit from Door		2,32		
	Exit from roof-front		14,14		
	Exit from roof-back		3,48		
Cutout 3 average Exit temp.			7,35		
Cutout plate 4	MinParameter		0,95		0,00
	MaxParameter		2,41		26,77
	Enter		0,20		
	Exit from Door		1,76		
	Exit from roof-front		13,90		
	Exit from roof-back		3,24		
Cutout 4 average Exit temp.			7,17		
Cutout plate 5	MinParameter		3,43		0,00
	MaxParameter		0,19		2,68
	Enter		0,00		
	Exit from Door		1,06		
	Exit from roof-front		14,07		
	Exit from roof-back		3,20		
Cutout 5 average Exit temp.			7,31		
Cutout plate 6	MinParameter		-0,67		0,00
	MaxParameter		-0,05		-2,32
	Enter		0,00		
	Exit from Door		1,48		
	Exit from roof-front		13,55		
	Exit from roof-back		1,68		
Cutout 6 average Exit temp.			7,09		
Test average Exit temp.			7,59		