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APPLIED NUMERICAL ANALYSIS ON THE DEVELOPMENT AND OPTIMIZATION OF AN AIR CONDITIONING DEVICE

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Abstract. *In this work an air conditioning device was built with easy to find materials and variables such as the velocity and temperature of the out coming air were measured. After that, the model was tested using the Ansys' softwares with the purpose of visualizing the efficiency of the device as well as to implement some optimization in order to increase the quality of a possible selling product. The model was drawn using ANSYS DesignModeler and then the mesh corresponding was constructed with ANSYS Mesh, in order to input the data into the ANSYS Fluent software. Inside fluent both the boundary conditions and the materials used were specified and the simulation was initialized. After the result processing it was possible to compare the simulation with the measured data as well as to implement some optimization such as an increase on the number of pipes inside the device and the exchange of its material. The analysis described above was able to prove the reliability of the method used, whereas the results obtained with the software were approximately the same as the experimental ones. The optimization implemented also demonstrated an increase on the quality of the out coming parameters.*

Keywords: *Fluid Mechanics, Air Conditioning, Numerical Simulation, Optimization*

1. INTRODUCTION

Heat exchange is been a matter for men for a long time as the effects of warmth disturbs human comfort and can cause damage on any moving machinery. With this in mind Willis Haviland Carrier developed the first air treatment device in 1902 (Carrier, 2013). The application of Carrier's invention was industrial at first, but the increasing demand for a device that would bring comfort to the heat that bothered people around the world it started to be widely commercialized around the 60's (Condicionado, 2010).

As the use of this product started to increase in what seemed a non-stoppable rate because of its cost effectiveness and the recent climate changes, the demand for electric energy in order to run also rose so research started on devices that would consume less electric energy and cause the least damage to the environment (Alves, 2016).

Nowadays the computational fluid dynamics is going through a massive expansion such as in courses offered by universities as in the release of newer and newer softwares that can solve a large variety of fluid flow problems (Ferziger and Peric, 2012). It is notable that this increase in the popularity of this kind of study is caused by its reliability as well as its broadly reach scope. People all around the world can model and test about any type of problem without constructing a physical model that is often very expensive and the information about the findings can be shared as wanted easily. With Computational Fluid Dynamics' (CFD) expansion, the optimization field made a great step forward as the tests for the possible implementations on a hypothetical product could be simulated and analysed without a series of time and money consuming in local trials.

In order to both come up with a simplified air conditioning device that would require less energy to run and prove that the computational fluid dynamics simulation is affective on analysing fluid problems a model was built and simulate as shown on Fig. 1.

So that the device could function, first water and ice were mixed into the bottom plastic bin so that when the water pump started the water would be transported to the top bin and by gravity would fall through the pipes located inside the assembled box. At the same time with the fan on the air stream would go through the entrance and flow between the pipes being released on the other side of the box.

2. PROCEDURES

2.1 Model Assembly

For the construction of the experimental model the materials listed on Tab. 1 were utilized. The choice of materials was made in a way of reducing cost at most and also to prevent environmental damage as can be seen on Fig. 2.

The experimental device was built in accordance to the following steps:

Figure 1. Function Diagram of the built model.
 Source: Author's Record.

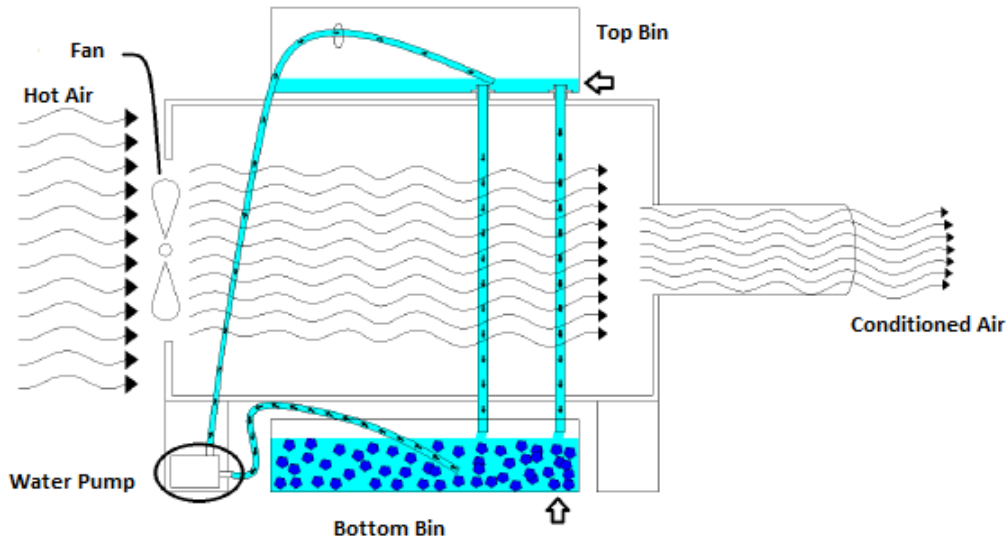
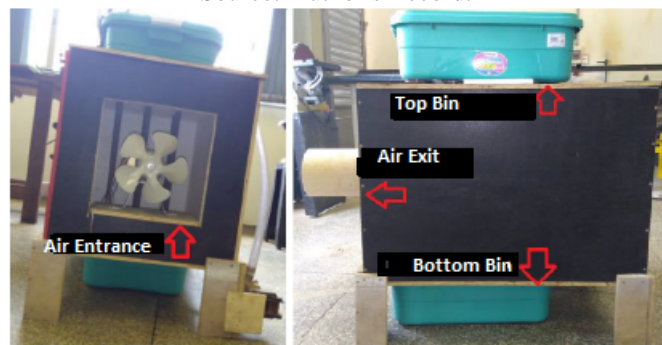


Table 1. List of materials.
 Source: Author's Record.

Item	Quantity	Unit	Materials
1	1	un.	MDF Plate 2750x1803 mm 10 mm
2	5	un.	Styrofoam Plate 1000x500 mm 15 mm
3	3600	mm	25 mm Weldable PVC Pipe
4	300	mm	150 mm PVC Pipe
5	2	un.	28 L Plastic Bin
6	1	un.	Silicon Sticker
7	2000	mm	1 in Garden Hose
8	44	un.	Wood Screw
9	1	un.	127V Water Pump
10	1	un.	1 Tube of White Glue
11	1	un.	127V Fan
12	2	un.	Metal clamp
13	200	mm	Cotton String

Figure 2. Model Built.
 Source: Author's Record.



Step 1: The MDF and Styrofoam plates were sectioned so that two pieces of each material would have 800x250 mm ,800x520 mm and 500x500 mm. These measures correspond respectively to the right side, left side, top, bottom, rear and front side of the device.

Step 2: The Styrofoam plates were glued to the MDF plates of same dimensions with simple white glue.

Step 3: With the plates ready a box of 500x520x800 mm was put together with screws.

Step 4: The front side of the box was punctured in a way that a 150 mm PVC pipe would be fixed on it. This pipe represents the air exit and has the aim of avoiding the interference of surrounding air on the measurements.

Step 5: The 25 mm weldable PVC pipe was sectioned into six 600 mm parts and put through the assembled box with a gap of 50 mm on the top and bottom halves. The fixation was done with silicon stickers.

Step 6: On the rear side of the box a 300x300 mm square was cut through representing the air entrance. The this part off a fan holder was fixed.

Step 7: Two plastic bins were fixed respectively on the top and bottom pipes that remained out of the box so they could store the water used in the system.

Step 8: The garden hoses were fixed with metal clamps on the income and outcome pipes of the water pump.

Step 9: In order to make the measurements more precise a cotton string was attached to the 150 mm. The string was marked with 14 dots with intervals of 10 mm between each.

2.2 Experimental Analysis

The analysis were performed at the Engineering Laboratory of the Federal University of Grande Dourados where the device studied was fired and measurements of velocity and temperature were taken for the out coming air. The outside temperature of the PVC pipes were also measured.

The data was obtained with an anemometer from Instrutherm, the device used was a TAFR-180, insofar the temperature was measured with an infra-red thermometer from Icel named TD-965.

The anemometer's sensor was introduced into the out coming fixed pipe where values of temperature and velocity were taken for each of the 14 marks on the cotton string. The inside pipes' temperatures were taken by pointing the indicative laser to its direction.

The procedures described were considered because of its high precision and low cost.

2.3 Numerical Analysis

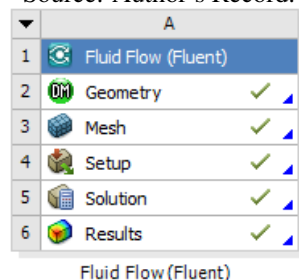
For the numerical analysis *Ansys 19 R1 Student Version* was utilized. A series of steps must be followed inside the software so that the calculations could be performed. The choice of this software was based on how respected it is on the industry and academic community as well as on its robustness. The student version was picked because it is a free working platform.

The already described device was drawn into the *DesignModeler* feature. In order to decrease the number of elements in the simulation, a circle was drawn around the pipes as shown on 4 so the boundary layer would be present when the mesh is composed. The geometry could also be imported from non-ansys softwares.

The mesh was generated on *Mesh*, the calculations were the calculations were performed by *Fluent* and the final processing was done on the 'CFD' post window all of which are Ansys' softwares as shown on Fig. 3.

Figure 3. Steps of Numerical Analysis.

Source: Author's Record.



The solution method used in ANSYS Fluent was Finite Volume and the turbulence model was Realizable k-Épsilon because this is the most common used regimen for turbulent flow conditions.

The boundary conditions could be setted with the experimental data already acquainted. For the incoming velocity of air a brief calculation was performed as shown on Eq. (1).

$$V_{in} = \frac{V_{out} * A_{out}}{A_{in}}, \quad V_{in} = \frac{3.75 * (\pi * 0.0715^2)}{0.3 * 0.3}, \quad V_{in} = 0.694m/s \quad (1)$$

Where:

V_{in} = incoming air velocity.

V_{out} = out coming air velocity.

A_{in} = incoming air port area.

A_{out} = out coming air port area.

The incoming air's temperature was considered as room temperature which was 294,1K on the day that it was measured. The incoming water temperature was setted as 273K as it was represented by a iced-water mixture.

The velocity of the cold water was measured by a simple procedure where the hose was linked to a alternative bowl and the time that it took to fill it up was measured. With the defined area of the bowl it was possible to calculate de velocity of the water which was 0.2 m/s.

As the problem involves forced convection the radiation effects were despised. The mesh generated contained 350,950 elements hexa-structured. The simulation performed 300 iterations and the convergence criteria used can be observed on Tab. 2.

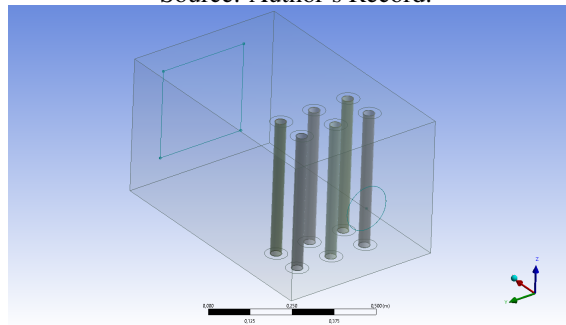
Table 2. Convergence Criteria.
 Source: Author's Record.

Criteria	Residue R
Velocity	1.00E-03
Energy	1.00E-07
Turbulence Kinetic Energy (k)	1.00E-03
Turbulent Kinetic Energy Dissipation Rate	1.00E-03

As of the optimization suggested the same calculations were performed firstly with the double of the number of pipes and then exchanging its material from PVC to Copper which is a better heat conductor. Lastly both of the previous changes were implemented at the same time and the parameters were observed.

As a final result the calculations were performed on the model shown on Fig 4.

Figure 4. Initial Simulated Model.
 Source: Author's Record.



3. RESULTS AND DISCUSSION

3.1 Experimental Results

Firstly the room temperature (T_{amb}) was measured with the anemometer which delivered a value of $T_{amb} = 294.1K$. In order to acquire the outside temperature of each pipe the infra-red thermometer's laser was pointed at the top part and then at the bottom part of the six existing pipes, so the results obtained are the average values of these two measurements as shown on Tab. 3.

Table 3. Average Outside Temperature of PVC Pipes.
 Source: Author's Record.

Pipe	Measured Temperature (K)	Average (K)
1	285.15	
2	284.15	
3	285.20	
4	285.85	285.07
5	284.70	
6	285.40	

For the out coming velocity and temperature of the air the anemometer was used and values were obtained for the 14 markings on the already described string. The values of T_{out} and V_{out} attained were processed and the average calculated as can be seen on Tab. 4 and Tab. 5.

Table 4. Velocity of Out Coming Air.
Source: Author's Record.

Variable	Marking	Value (m/s)	Average (m/s)
V_{out}	1	3.1	3.75
	2	3.4	
	3	3.7	
	4	3.6	
	5	3.6	
	6	3.8	
	7	4.0	
	8	4.0	
	9	4.0	
	10	4.0	
	11	4.0	
	12	3.9	
	13	3.8	
	14	3.6	

Table 5. Temperature of Out Coming Air.
Source: Author's Record.

Variable	Marking	Value (K)	Average (K)
T_{out}	1	292.90	292.55
	2	292.90	
	3	292.70	
	4	292.70	
	5	292.50	
	6	292.50	
	7	292.10	
	8	292.10	
	9	292.10	
	10	292.30	
	11	292.50	
	12	292.60	
	13	292.90	
	14	292.90	

3.2 Numerical Results

In order to validate the chosen procedure the results obtained with the simulation were compared to the experimental values acquired. All the data presented on this section was taken from the CFD Post software.

The temperature field was obtained and the average temperature of each pipe was calculated as shown on Tab. 6.

The average velocity and temperature of the out coming air are displayed on Fig.5 and Fig.6 respectively.

3.3 Discussion

There are minor discrepancies on the values obtained which may be due to measurement errors present on the experimental analysis as well as to the limited number of elements used on the simulation because of the academic version limit. Despite that, according to the results displayed the simulation method used describes with a high level of reliability what occurs on the real life model.

Table 6. Average Outside Temperature of PVC Pipes.
 Source: Author's Record.

Pipe	Measured Temperature (K)	Average (K)
1	275.47	
2	275.90	
3	275.64	
4	275.98	275.71
5	275.40	
6	275.88	

Figure 5. Average Out Coming Velocity of Air.
 Source: Author's Record.

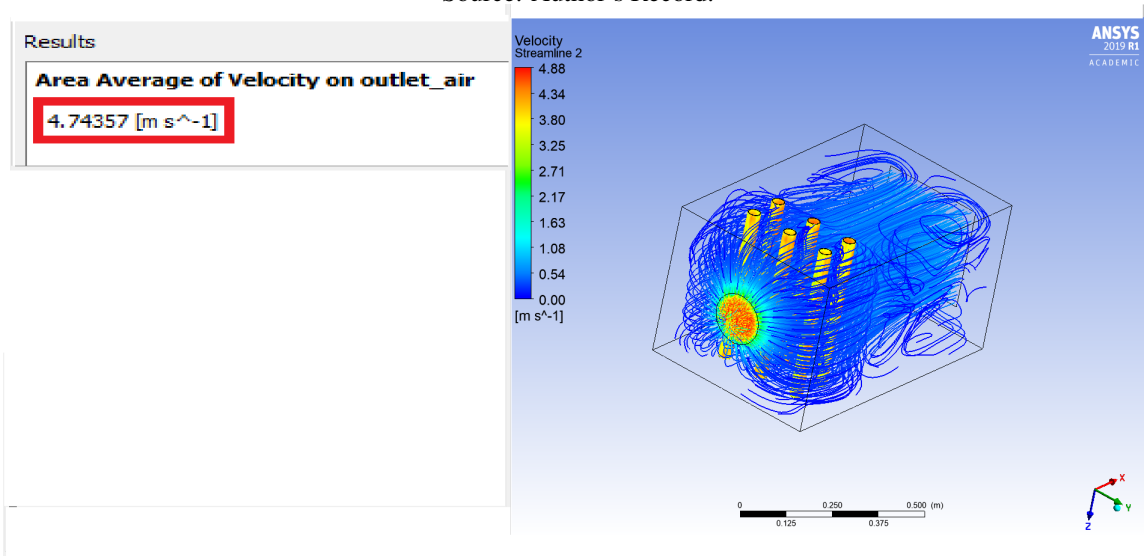
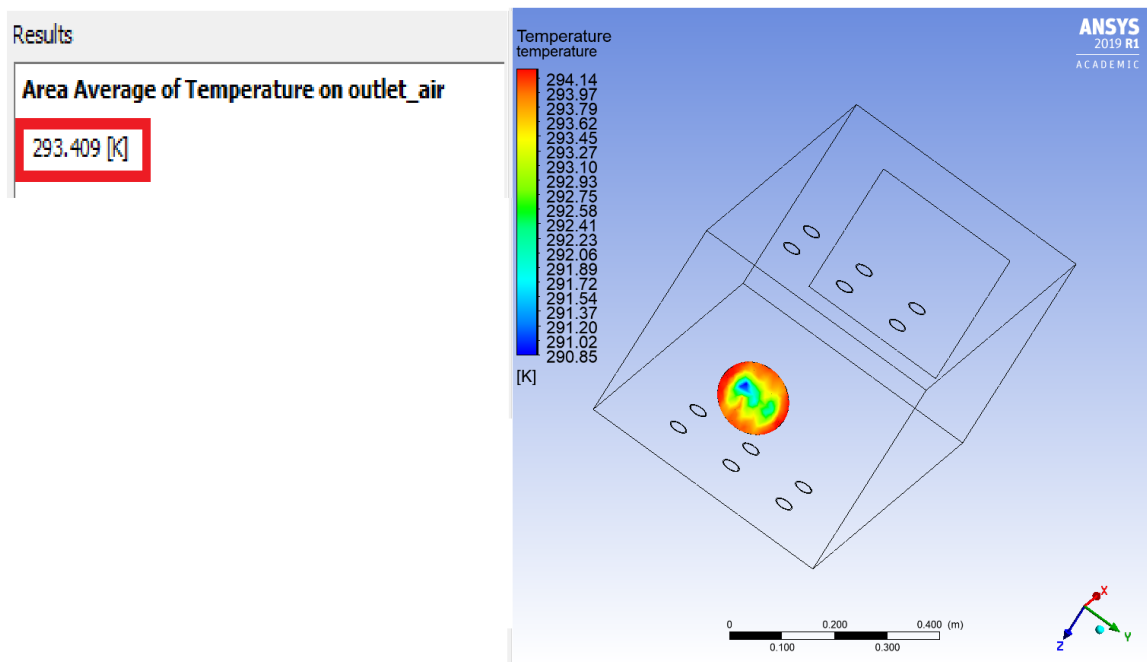


Figure 6. Average Out Coming Temperature of Air.
 Source: Author's Record.



4. OPTIMIZATION

4.1 Area Optimization

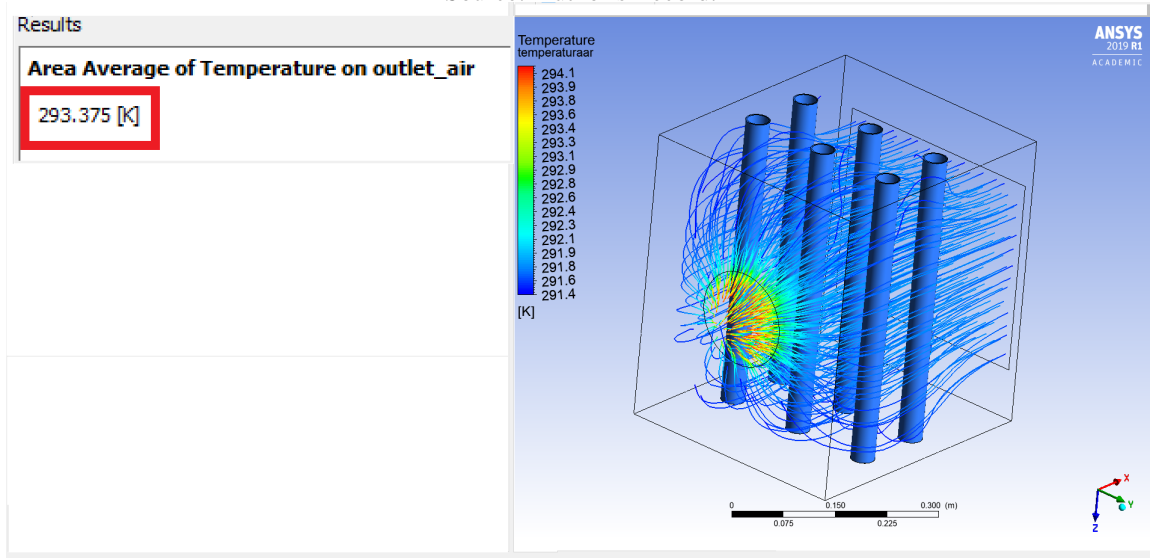
The numerical simulation performed yielded some visual problems on the project developed which opened a gap to a area optimization. As shown on Fig.5 there are some recirculation areas on the inside of the box, this phenomenon causes

an energy waste that can be converted to performance if eliminated.

With that in mind, the device was redesigned and the out coming temperature was acquired as shown on Fig.7.

Figure 7. Out Coming Air Temperature for Optimized Model (Area).

Source: Author's Record.



The image above show the absence of recirculation areas and the calculated value obtained decreased in comparison to the previous simulation which validate the procedure performed. In addition to the device's efficiency, this area optimization reduces the amount of material needed for its construction which is both environmental and costly effective.

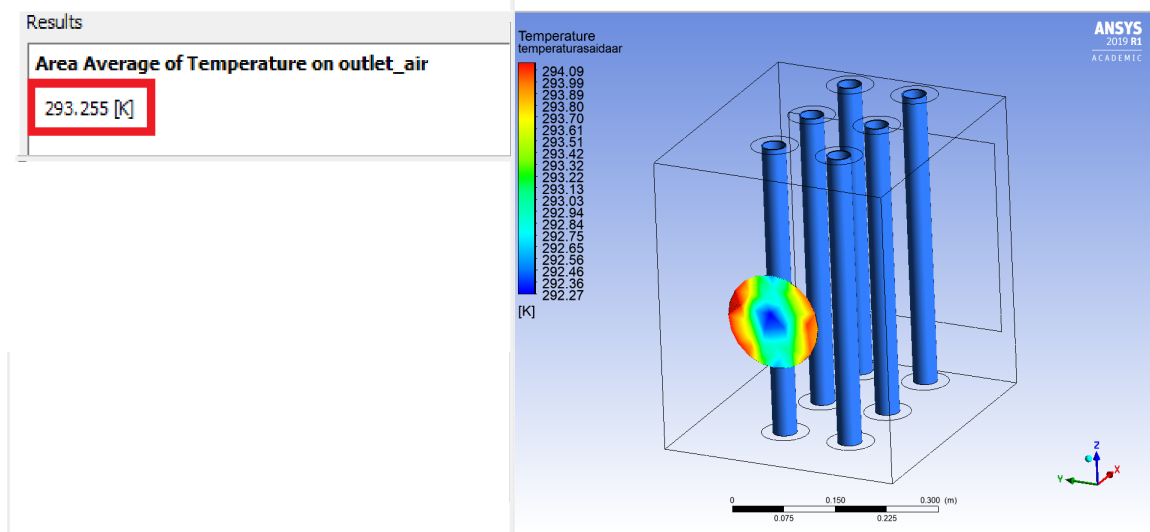
4.2 Pipe optimization

Taking into account that the last optimization met the project's expectations it was kept and another modification was added. The orientation of the pipes was inverted such as that the contact area between the in coming air and the cold pipes would be increased. With this increase in area it is expected that the heat flux reaches a greater value and as a consequence the out coming air ended up colder.

The optimization described and the new air average temperature are shown on Fig.8.

Figure 8. Out Coming Air Temperature for Optimized Model (Pipe).

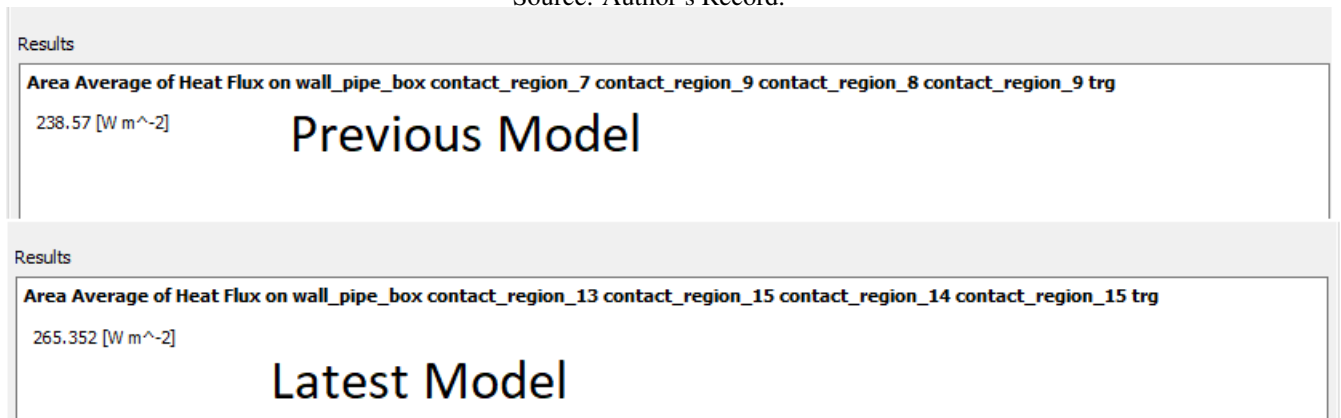
Source: Author's Record.



In relation to the out coming air temperature there was a decrease of 0.12 K. Considering that this modification didn't require any increase on the cost of the product it can be said that it is practicable and improves the device's efficiency.

The heat flux reached a greater value in comparison to the models studied previously as can be seen on Fig.9.

Figure 9. Comparison between heat flux values .
Source: Author's Record.



The optimization proposed met all the expectations in order to increase the project's efficiency.

5. CONCLUSION

The analysis performed testified the success of the method used such that both the experimental and the numerical analysis delivered numbers that could be studied. The numerical analysis was satisfactory proving that the student version of *Ansys* is effective on performing a variety of simulations.

Even though the optimizations performed presented a positive result, the changes on temperature of the out coming air were not significant, for future works it is intended to develop and justify a set of additional optimizations to the original model related to material choice and dimension of the pipes used so that the efficiency of the product is improved and its cost decreased. The number of tubes can also be modified, the challenge is to adequate these modifications and the reliability of the results with the reduced number of elements delivered by the version of the software used.

6. REFERENCES

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7. INFORMATION RESPONSIBILITY

The authors are only responsible for the information included in this work.