Design of Ventilation and Separation System for Wood Dust Sawdust in an Industry using Computational Fluid Dynamics

Eduvigis Oporto
Undergraduate Student
Facultad de Ingeniería
Universidad Nacional de Asunción
Asunción, Paraguay
eduvigisoporto@fiuna.edu.py

Gustavo Martínez
Director of the Department of Mechanical and Electromechanical Engineering
Facultad de Ingeniería
Universidad Nacional de Asunción
Asunción, Paraguay
gmartinez@fiuna.edu.py

Jorge Kurita
Research Professor
Facultad de Ingeniería
Universidad Nacional de Asunción
Asunción, Paraguay
jkurita@fiuna.edu.py

Abstract

The ventilation of machines from industrial processes allows to control among others, heat and toxicity of the environments. Dirty or bad environment is also detrimental to productivity.
Trafopar S.A., is the first Paraguayan factory dedicated to the manufacture and commercialization of Distribution Transformers. The main use of wood in the construction of transformers is as separating pieces between windings, sections or between these and the core.

The proposed system combines local exhaust ventilation and impulse ventilation. The impulsion ventilation system will be through an axial fan and will be in charge of guaranteeing the renewal of the air that will be sucked from the workshop by the localized extraction ventilation system. A localized extraction system with ducts and aerial installation is proposed, with a cyclone as a particle separator, it will be located between the outlet of the main duct section and the fan.

Using CFD it was possible to validate the functionality of the proposed system. The simulation was carried out in two stages, the first consisted of representing the conditions of the carpentry sector before the implementation of the extraction system, and the second stage consisted of modeling the proposed system.
The results of the CFD showed a discrepancy maximum the 12.59% between the values obtained by the CFD and the calculations performed analytically. As the value obtained is less than 15% the analytically obtained results were taken as valid, thus guaranteeing the correct functioning of the system.

Keywords
CFD, Ventilation, Localized Extraction, Wood Dust, Separation

1. Introduction

The main use of wood in the construction of transformers is as separating pieces between windings, sections or between these and the core, where this wood is used only as a separator and not as an insulating medium in the elaboration of the transformer coils.

The type of wood mainly used by the company is Guatambú wood. Currently, the company acquires 2500 kg of Guatambú wood monthly, of which only 40% is transformed into a final product, leaving the remaining 60% as waste, which would be equivalent to approximately 1.8 m^3 of wood dust and sawdust to be extracted, separated and collected. The carpentry sector has 4 machines, these are: a saw, a flattener, a thickness and a sander.

Any work with wood implies or requires an extraction system, this is due to the fact that exposure to wood dust present in the environment of a carpentry, according to local government regulation (Decree Number 5649), belongs to the list of occupational diseases. The ventilation of machines or industrial processes allows to control the heat, the toxicity of the environments or their potential explosiveness, guaranteeing in many cases the health of the operators who are in said work environments (Escoda S., 2000). Not to mention under the COVID-19 context, proper ventilation is important to control airborne diseases in enclosed environment (Kurita et. al, 2020). This implies that a badly acclimated or dirty work environment is also detrimental to productivity, the fundamental reason for carrying out this work.

Ventilation systems used in industries are mainly classified into two types: 1) Extraction by dilution and, 2) Local extraction. The extraction by dilution consists of supplying large volumes of air in a workplace, with the purpose of diluting or displacing pollutants in the air, in order to guarantee thermal comfort. Localized extraction consists of capturing the pollutant in its place of origin before it can enter the work environment.

The use of computational modeling and design software such as SolidWorks, allows to validate by simulation all calculations carried out in an analytical way for the sizing of the proposed system, in order to guarantee its correct operation before purchasing any component of the system.

1.1 General Objective

Design an adequate and viable extraction, separation and collection system for wood dust and sawdust, in order to achieve a comfortable work environment for the carpentry of the company Trafopar S.A.

Specific objectives:

- Dimension the components and equipment of the extraction system, separation, collection of wood dust and sawdust, produced within the company's carpentry.
- Determine the layout of each component of the wood dust and sawdust extraction system.
- Carry out calculations for the dimensioning of the system components and carry out a comparative analysis based on the results of the simulation with the SolidWorks software.

2. Literature Review

2.1. Mechanical Ventilation

Ventilation is the process of supplying or removing air from a space for the purpose of controlling pollution levels in the air, humidity or temperature within the enclosure (ANSI, ASHRAE 62.1, 2013). In plants and/or industrial spaces two general types of ventilation systems are used: The drive systems, which are used to drive air usually tempered to a working room; and the extraction systems, which are used to remove pollutants generated by an operation, in order to maintain a healthy working environment.

2.2. Systems of Ventilation by Impulsion

Drive systems are used for two purposes:

1. To create a comfortable environment in the plant.
2. To replace the air extracted from the plant (replacement systems)

2.3 Exhaust Ventilation System

2.3.1 General Exhaust Ventilation

General extraction systems can be used for the control of the thermal environment and/or for the elimination of pollutants generated in an area, by sweeping a given space with large amounts of air. When used for thermal control, the air must be tempered and recirculated. When used for the control of contaminants (dilution system), they must be mixed with sufficient air to reduce the concentration to safe levels (Valenciana, 1992).

2.3.2 Ventilation Systems by Local Extraction

They are based on the principle of capturing the contaminant at, or very close to its origin. It is more efficient and, by using smaller flows, does not contribute to spreading the pollutant. This system consists of up to four types of basic elements:

- The hood or catchment system
- The set of pipes with their accessories (elbows, entrances, joints).
- The air scrubber.
- The fan (including its engine and power transmission system).

2.4 The Hood or Catchment System

The hood or collection system aims to prevent the contaminant from spreading through the rest of the room, creating an air flow that effectively captures the contaminant and transports it to it.

2.4.1 Hood Design

We must keep in mind that the first condition that a bell must meet is not to interfere with the production process; if the presence of the bell (like that of any other preventive element) generates production difficulties, it must be quickly modified (Castejón, 2008). The steps to realize the design of a bell are:

- Determine the location with respect to the process.
- Determine shape and size.
- Determine the suction flow

2.5 Conduits and Accessories

2.5.1 Minimum Speed in the Conduit.

The velocity inside the conduit is determined by the type of material being transported in the conduit. For particle handling systems it is necessary to establish a minimum design speed in order to prevent deposition and clogging of the conduit. (Table 1)

Table 1: Recommended speeds for different wood particles

Material	Recommended speed ranges (m/s)
Wood dust	7,62 – 10,8
Dry sawdust, light weight	10,8 – 15,24
Wet sawdust, heavy sawdust	15,24 – 20,33
Dry, light chip	10,8 – 15,24
Green wood cuttings	17,78 – 22,87
Shredded wood	17,78 – 22,87
Emery powder	15,24 – 20,33

Source**:** (Serrano, 2006)

2.5.2 Conduit Section

$Q = V \cdot A$

Where:
Q = Air flow rate (m^3/s)
V = Air flow velocity (m/s)
A = Suction tube section area (m^2)

From the equation presented above with the recommended flow and velocity values the duct section is determined.

2.5.3 Dynamic Pressure Method for Design

It is based on the fact that all load losses, due to friction in ducts and form resistance due to detachments in fittings, are a function of dynamic pressure, and can be calculated by multiplying the dynamic pressure by a factor.

2.6 The Air Purifier

Air scrubbers are equipment that remove contaminants from an air or gas stream. For particulate pollutants, purification equipment is divided into two basic groups: Air Filter: They are designed to treat air with low dust concentrations; and Dust collectors: They are generally designed to treat air with higher dust concentrations.

2.7 Ventilator

To move air through a ventilation system, or localized extraction, energy is needed to overcome system load losses. This energy can be provided in the form of natural convection or flotation. However, most systems require a machine, such as a fan or ejector, to maintain air movement.

2.7.1 Industrial Fans

Fans are usually classified according to the type of flow, pressure drops and efficiency, these can be centrifugal or axial, according to the direction of air flow through the impeller.

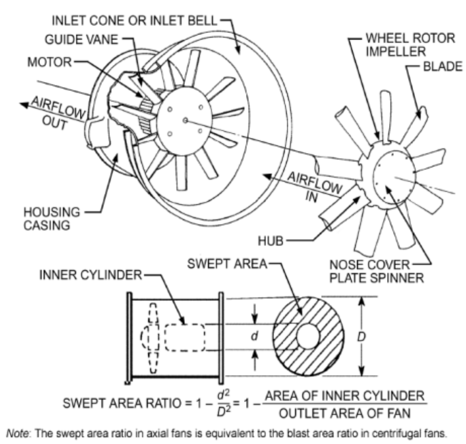


Figure 1: Components of an axial fan
Source: (ASHRAE Handbook, 2016)

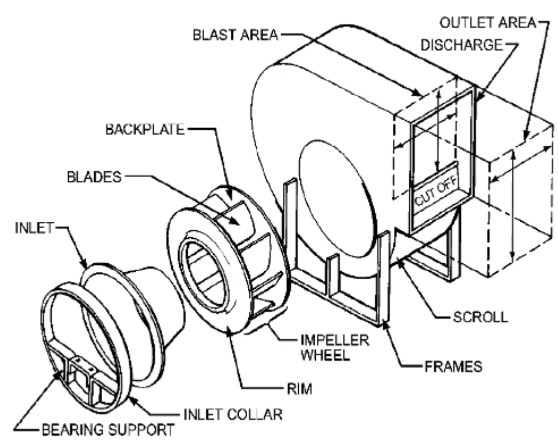


Figure 2: Components of a centrifugal fan
Source: (ASHRAE Handbook, 2016)

2.7.2 Fan Selection

The selection of a fan consists in choosing one that satisfies the flow and pressure requirements with which the air must circulate, for the temperature of the operation and the altitude of the installation.

2.8 Renovation and Recirculation of Air

If the amount of air introduced into an enclosure is less than the amount of air extracted, the pressure in the room will be lower than the atmospheric (negative pressure), this results in an uncontrolled intake of air through window frames, doors and walls. To minimize these effects, mechanical air intake systems are needed in sufficient quantity to avoid the creation of negative pressure in the room. This flow rate can be determined based on the number of occupants and the occupied area.

2.9 Current Status

A raw material mainly used by the company is a wood called Guatambú. It is mainly used to manufacture coil molds of different sizes. The upper and lower chocks framework for both transformers of the enveloping core and stacked core type. Work with this wood is carried out in the carpentry area located in house. (Figure 3)


Figure 3: Current distribution of the woodworking sector

Table 2**:** Machines Available in the Carpentry Sector

Floor table saw: It is used to saw the wood longitudinally and transversely, to go from the standard measure provided to the measure indicated on the manufacturing plan. The diameter of the closure is 300 mm and the complete machine occupies a space of 1 m^2.		**Disc Sanders:** It is used for roughing, sanding and polishing processes, with which a completely uniform surface is obtained on the workpiece. The disc has a diameter of 200 mm, the entire machine occupying an area of approximately 0,1 m^2.	
Thicknesser: It is used to give the wood the exact thickness or thickness indicated on the manufacturing plan; It has some feeders that push the wood. The double blade has a total length of 400 mm, and the machine has an occupation area of approximately 0.65 m^2.		**Flatteners:** It is used for the elaboration of flat surfaces, that is to say, that the piece of wood does not have any unevenness along its entire surface. The blade has a total length of 350mm, the space occupied by this machine is approximately 1,1 m^2.	

Currently, the company acquires 2,500 kg of Guatambú wood every month. Only 40% is transformed into a final product, leaving the remaining 60% as waste, which would be equivalent to approximately 1.23 m^3 of wood dust and sawdust. To be extracted, separated, and collected.

2.9.1 Analysis of Results
It was determined to design a localized extraction system combined with an impulsive ventilation system. The ventilation by impulsion will be carried out by means of an axial fan. The localized extraction system will have a centrifugal fan in charge of generating the suction of the particulate material generated by each machine. The means of separation of wood dust and sawdust generated by the different machines shall be a cyclone.

3. Design of the Localized Extraction System
The layout of both main and secondary ducts will be aerial, where one of the machines (The brushcutter) will go to 2m in height, and the others contouring the edges of the enclosure to 1.8m, this due to the reduced space of the sector, and thus ensuring, that the pipes of the system do not interfere in any way with the operation of the machines.

3.1 Design of the Extraction Hoods
With the recommended flow rate for each machine, and recommended suction values for each process, the following bells are selected for each machine:

- Bell flat opening: Planer and circular saw.
- Cabin hood: Brushcutter
- Bell circular section: Sander
- Bell Type Slit: Vacuum Cleaner

3.2 Dimensioning of Conductors
Circular section conduits shall be used.

Table 3: Section, flow rate and speed of each system section

Section	Pipeline	Speed (m/s)	Diameter (mm)	Commercial Section (m^2)	Final Flow(m^3/s)
Flat machine	A-B2	18	150	0,0177	0,3186
Saw	B-B2	18	125	0,0123	0,2214
Brushcutter	C-C2	18	250	0,0491	0,8838
Sander	D-B2	18	125	0,0123	0,2214
Secondary	B2-C2-E2	15.51	250	0,0491	0,7614
Vacuum cleaner	E-E2	15.59	100	0,00785	0,1224
Main	E2-M1	18	250	0,0491	0,8838
Fan	M2-Vent	7.03	400	0,1257	0,8838

3.3 Determination of System Load Loss

$$PD = \frac{V^2 . \rho_{aire}}{2 . g} * 1{,}019$$

Where:

$PD =$ Dynamic pressure (mm H_2O)

V= Speed of each section (m/s)

$\rho_{air} = 1{,}12$ (kg/m^3)

g = gravitational acceleration (9,81 m/s^2)

With the equation described above, the dynamic pressure in each section of the system is determined, to then determine the loss of load in each section and component of the system. (Table 4)

Table 4**:** Loss of load when working the final sections of the system

Working machine	Loss	Unit	Flow	Unit
Flattener + Saw + Sander + Vacuum Cleaner	85,292	mm H_2O	0,88	m^3/s
Brushcutter	75,544	mm H_2O	0,88	m^3/s

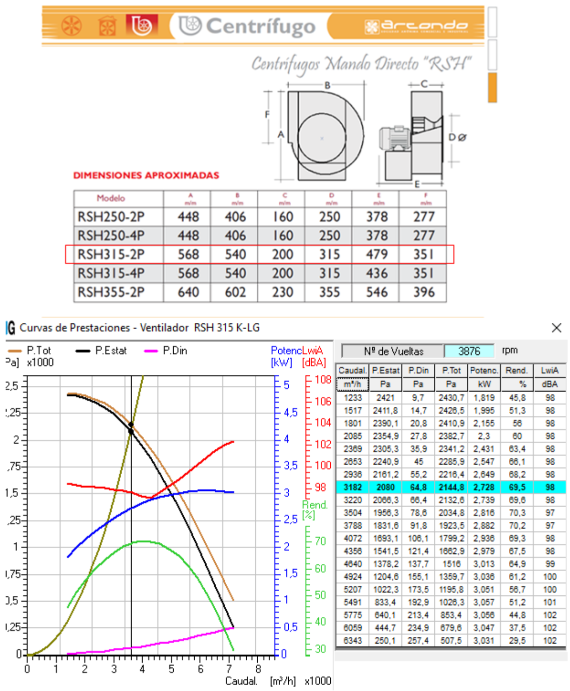
3.4 Dimensioning of the cyclone
The cyclone chosen is of the high efficiency Stairmand type. The pressure drop in the cyclone is calculated by the equation developed by Shepherd and Lapple.

$$\Delta P = 118{,}37 \ mm \ H2O$$

3.5 Filter selection
It shall be located at the outlet of the centrifugal fan, thus ensuring the quality of the air expelled into the environment. The bag type filter F8/MERV14 was selected.

3.6 Fan selection

$$PP_{total} = 211{,}814\ mm\ H2O$$
$$Q_{total} = 0.8838\ m^3/s$$



Modelo	A m/m	B m/m	C m/m	D m/m	E m/m	F m/m
RSH250-2P	448	406	160	250	378	277
RSH250-4P	448	406	160	250	378	277
RSH315-2P	568	540	200	315	479	351
RSH315-4P	568	540	200	315	436	351
RSH355-2P	640	602	230	355	546	396

Caudal. m³/h	P.Estat Pa	P.Din Pa	P.Tot Pa	Potenc. kW	Rend. %	LwiA dBA
1233	2421	9,7	2430,7	1,819	45,8	98
1517	2411,8	14,7	2426,5	1,995	51,3	98
1801	2390,1	20,8	2410,9	2,155	56	98
2085	2354,9	27,8	2382,7	2,3	60	98
2369	2305,3	35,9	2341,2	2,431	63,4	98
2653	2240,9	45	2285,9	2,547	66,1	98
2936	2161,2	55,2	2216,4	2,649	68,2	98
3182	2080	64,8	2144,8	2,728	69,5	98
3220	2066,3	66,4	2132,6	2,739	69,6	98
3504	1956,3	78,6	2034,8	2,816	70,3	97
3788	1831,6	91,8	1923,5	2,882	70,2	97
4072	1693,1	106,1	1799,2	2,936	69,3	98
4356	1541,5	121,4	1662,9	2,979	67,5	98
4640	1378,2	137,7	1516	3,013	64,9	99
4924	1204,6	155,1	1359,7	3,036	61,2	100
5207	1022,3	173,5	1195,8	3,051	56,7	100
5491	833,4	192,9	1026,3	3,057	51,2	101
5775	640,1	213,4	853,4	3,056	44,8	102
6059	444,7	234,9	679,6	3,047	37,5	102
6343	250,1	257,4	507,5	3,031	29,5	102

Figure 4: Behaviour curve and technical characteristics of the selected fan
Source: (Arcondor, s.f.)

3.7 Air Renewal and Recirculation, Fan Selection

$$PP_{total} = 5{,}3\ mm\ H2O$$
$$Q_{total} = 0{,}913\ m^3/s$$

Axial

CARACTERÍSTICAS TÉCNICAS — Axial Tubular

Modelo	Diámetro m/m	Velocidad RPM	Corriente nominal en 380 V (A)	Consumo HP	Potencia HP	Caudal Maximo (m3/h)	Nivel sonoro dB(A)
T3-3/6-2P	300	2780	0.90	0.42	0.50	4108	80
T3-6/6-2P	300	2780	1.31	0.71	0.75	4837	83
T3-3/6-4P	300	1400	0.82	0.06	0.33	2155	66
T3-6/6-4P	300	1400	0.82	0.10	0.33	2533	70
T4-3/6-2P	400	2800	2.53	1.26	1.50	9079	86
T4-6/6-2P	400	2850	3.27	1.96	2	10621	89
T4-3/6-4P	400	1400	0.82	0.16	0.33	4590	71
T4-6/6-4P	400	1400	0.82	0.25	0.33	5310	75
T5-3/6-2P	500	2840	4.85	2.73	3	16526	90
T5-6/6-2P	500	2890	8.11	4.47	5.5	19458	94
T5-3/6-4P	500	1390	1.09	0.32	0.5	8080	75

Figura 5: Technical characteristics of axial mural fans
Source: (Arcondor, s.f.)

3.8 Proposed Ventilation System

- **Localized Extraction System:** The sizing of the components of the localized extraction system was by the dynamic pressure method, for which a total flow of 3182 m^3/h was used and a velocity inside the duct of 18 m/s, resulting in a pressure drop of 2080 Pa, which led to the selection of a 5.5 HP centrifugal fan. For the layout of both the main and secondary ducts, an aerial installation was chosen, where one of the machines (the brush cutter) will go 2m high, and the others will contour the edges of the enclosure, this due to the reduced space in the sector and thus ensuring that the pipes of the system do not interfere in any way with the operation of the machines; all this taking into account that woods with maximum dimensions of 1750x500x30 mm are handled. Regarding the height of the other ducts of the extraction system, it is estimated to be 1.8 m since the regulation is projected to be manual. Because the ducts of the extraction system will be attached to the wall, the chosen height does not generate any type of distortion of the lighting that already exists in the carpentry. The chosen separator is a high-efficiency streaming type cyclone.

- **Drive System:** For the drive, an axial fan is selected, of the tubular axial type, capable of meeting the requirements of the system, which is a flow rate of 3285 m3 / h and a pressure drop equal to 52 Pa, which is equivalent to 5, 3 mm H_2O.
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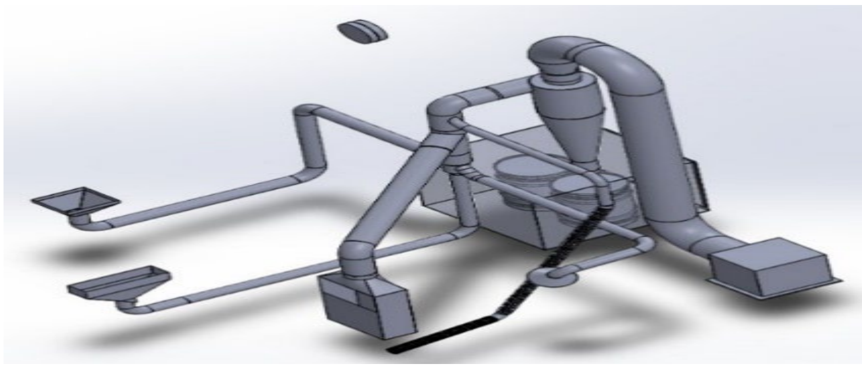


Figure 4**:** CAD Model proposed ventilation system

4. Model and Mesh Configurations

4.1 Materials and Methods

1. SolidWorks
2. CFD Analysis

- **CAD the initial situation:** To build a 3D model of the carpentry, the dimensions were measured on site. As can be appreciated from Figures 1 and 3, the model is very similar to the carpentry, some minor exceptions. (Figure 5)

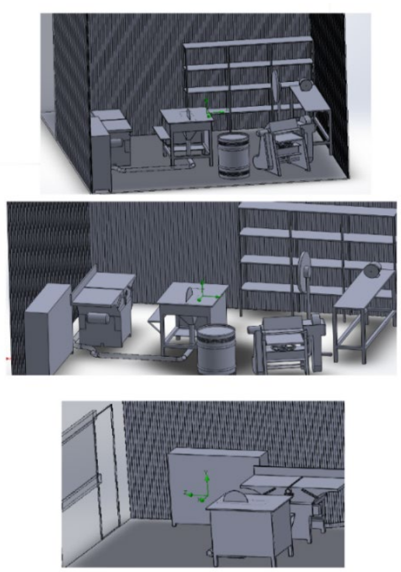


Figure 5: CAD Model of the analyzed carpentry

To determine the boundary conditions to be used in the model made, the mass flow was measured experimentally at the outlet of the brushing and brush cutting machine, timing the operation of each machine, and weighing the collected sawdust. For ceiling and floor fans, a volumetric flow of 2000 FCM is considered, and for the door, which was open, it is considered atmospheric pressure (1 atm).

Table 5: Boundary Conditions

Equipment	Fluid or Particle	Volume Flowrate (ft^3/min)	Mass Flowrate (kg/h)	Velocity m/s	Pressure (atm)
Flattener	Wood	-	1,4087	2,8	-
Thicknesses	Wood	-	155,55	3,5	-
Ceiling fan	Air	2000	-	-	1 atm
Standing fan	Air	2000	-	-	1 atm
Door	Air	-	-		1 atm

For the selection of the meshing conditions used, the volumetric flow rate that would pass through the access door of the sector was calculated under the conditions described in Table 5. With the results obtained from the simulations carried out with increasing meshing pressures, it was possible to perform a sensitivity analysis to find the meshing precision that achieves time and guarantees valid results. This can be seen in Table 6 and Figure 6.

Table 6**:** Results of the Different Global Mesh Configurations.

Mesh Setting Level	Fluid Cells	ft3/min	Number of Iteration
2	5.529	1996,30	40
3	24.935	1996,32	61
4	55.071	1996,26	78
5	149.555	1996,52	109
6	354.528	1996,61	103

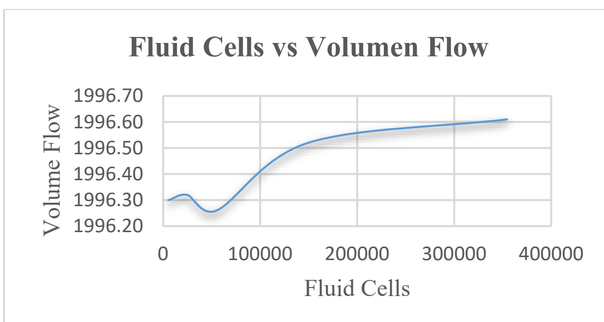


Figure 6: Variation of the volumetric flow rate of air that passes through the modeling door as a function of the number of cells according to the global mesh setting.

In Figure 7 and Figure 8 it is possible to observe the behavior of the particles that are expelled by the planer and the brush cutter respectively when they are each in operation, independently of course, together with their respective simulation with the parameters described. in Table 5, visually validating in this way, that the modeling carried out, with the respective simulation represents the behavior of the wood dust and sawdust after the start-up of said machines.

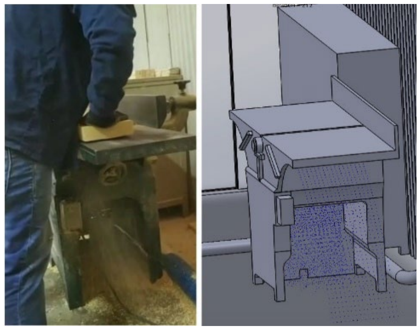


Figure 7: Behavior of the particles ejected by the flattener

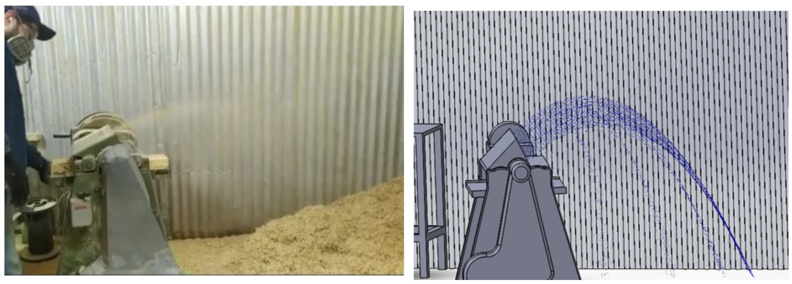


Figure 8**:** Behavior of the particles ejected by the thicknesser

- **CAD Proposed Ventilation System:** In order to simulate the friction losses that the localized extraction system has, it is necessary to carry out the previous modeling of the extraction system, from the extraction hood to the entrance to the fan, this can be seen in Figure 9.

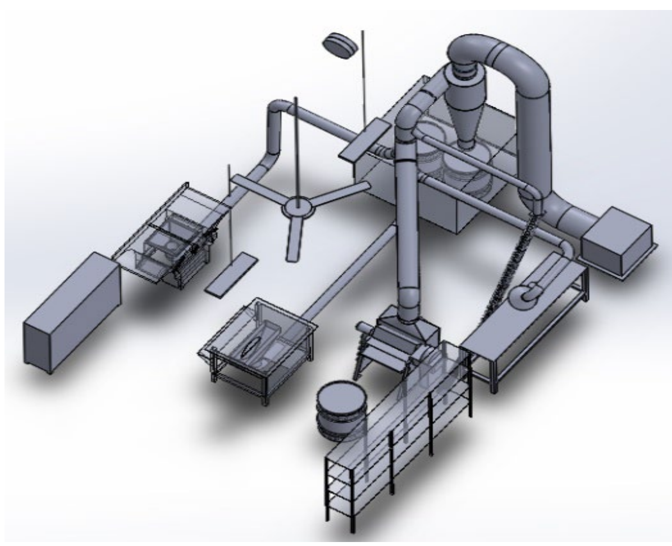


Figure 9: Isometric View of the proposed system designed

5. Results and Discussion
The boundary conditions (inputs and outputs) to be used in each machine can be seen in Figure 10, Figure 11 and Figure 12. Remembering that the meshing of both boundary conditions is performed in Global mesh 5.

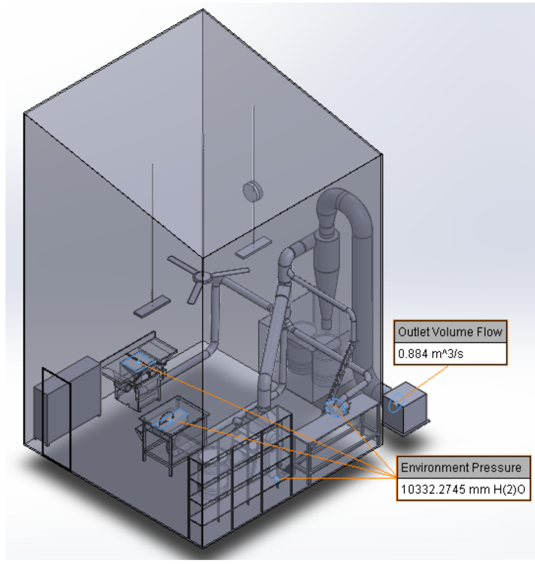


Figure 10: Boundary conditions for first simulation

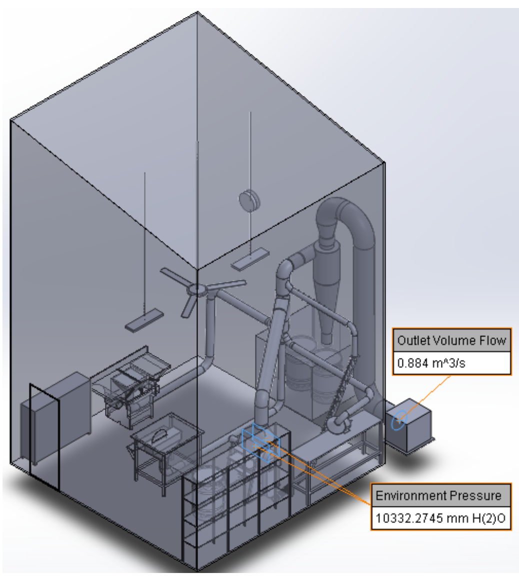


Figure 11: Boundary conditions for second simulation, extraction of the thicknesser

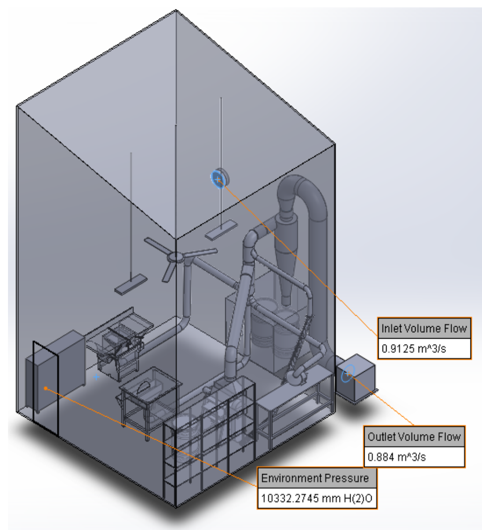
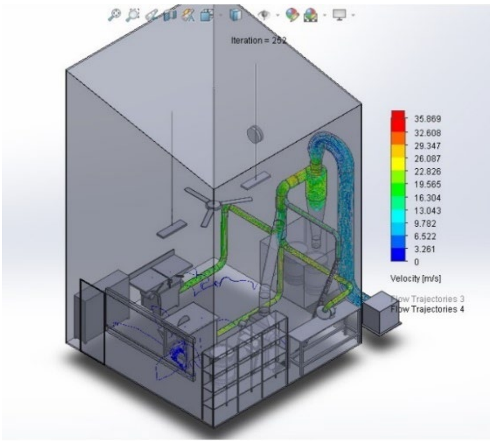


Figure 12: Boundary conditions for simulation of the complete system

5.1 CFD of the Proposed System

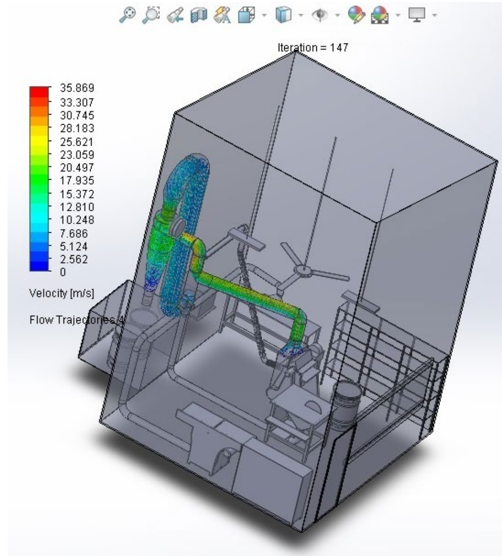
In Figure 13, Figure 14 and Figure 15 it is possible to appreciate the behavior of the air inside the duct, under the general conditions that were described in Figure 10, Figure 11 and Figure 12 respectively, in addition to the table with the values obtained after the CFD.

With the Surface goals tool, the flow rate in each hood was determined, and the pressure generated by the centrifugal fan, and with the equation goals tool, the pressure drop of the modeled system was determined.



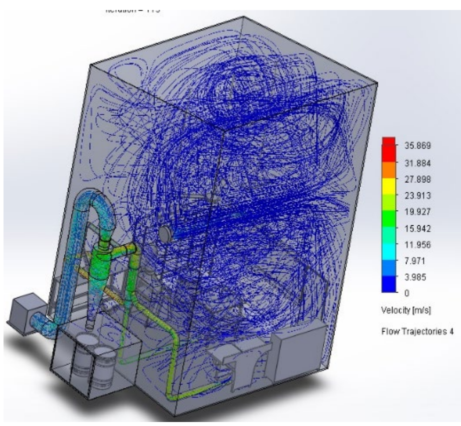
Name	Current Value
Equation Goal 1	184.885 mm H(2)O
SG Av Static Pressure 1Ventilador	10147.6 mm H(2)O
SG Av Static Pressure 2 Cepilladora	10332.4 mm H(2)O
SG Volume Flow Aspiradora	0.0504283 m^3/s
SG Volume Flow Cepilladora	0.321766 m^3/s
SG Volume Flow Lijadora	0.249266 m^3/s
SG Volume Flow SC	0.246839 m^3/s
SG Volume Flow Ventilador	-0.884001 m^3/s

Figure 13: Flow values calculated at the inlet of each hood after simulating and calculating the fan pressure drop.



Name	Current Value
Equation Goal 1	163.568 mm H(2)O
SG Av Static Pressure 1Ventilador	10168.6 mm H(2)O
SG Av Static Pressure Desb	10332.2 mm H(2)O
SG Volume Flow Ventilador	-0.883987 m^3/s

Figure 14: Flow values calculated at the inlet of each hood after simulating and calculating the fan pressure drop.



Name	Current Value
Equation Goal 3	225.891 mm H(2)O
SG Av Static Pressure 1Ventilador	10106.6 mm H(2)O
SG Av Static Pressure 2	10332.4 mm H(2)O
SG Volume Flow Ventilador	-0.884003 m^3/s

Figure 15: Flow values calculated at the inlet of each hood after simulating and calculating the fan pressure drop.

TheTtable 7 and 8 shows the comparison together with the percentage of discrepancy obtained between the analytically determined values and those obtained through the simulation, both of the flow rate for each request, together with the total head loss after the simulation of the complete system.

Table 7: Percentage discrepancy of the theoretical and computational flow

Section	Theoretical Flowrate m3/s	Computational Flowrate m3/s	Difference %
Flattener	0.3186	0.321766	0.99%

Circular Saw	0.2214	0.246839	11.49%
Sander	0.2214	0.249266	12.59%
Shredder	0.8838	0.870586	1.5%

Table 8: Percentage discrepancy of the theoretical and computational flow

Section	Theoretical Pressure Drop mm H_2O	Computational Pressure Drop Mm H_2O	Difference %
Flattener - Blower	201	225.891	12.4%

Source: Authors' own creation

6. Conclusion

A combined extraction system combined with a delivery system was chosen. The impulsion system will be through an axial fan and will be in charge of guaranteeing the renewal of the air that will be sucked from the sector by the localized extraction system. A localized extraction system is proposed with circular section ducts and aerial installation, with a high efficiency cyclone of the Stairmand type as a particle separator, it will be located between the outlet of the main duct section and the fan. In order to save the fan blades of the localized extraction system, a G2/MERV 4 type filter will be used in it.

The sizing of the components of the localized extraction system was by the dynamic pressure method, for which a total flow of 3182 m^3/h and a velocity inside the duct of 18 m/s were used, resulting in a pressure drop of 2080 Pa, which led to the selection of a 5.5 HP centrifugal fan. With the flow requirement of the localized extraction system, the minimum renewal flow of the sector will be limited, values that, once added together, indicate the total air flow that the impulsion system must be capable of injecting. The impulsion system is capable of injecting a flow rate of 3,285 m3/h with a pressure drop of 52 Pa, by means of a 0.25 HP tubular type axial fan.

The simulation resulted in a discrepancy of 6.7% between the values obtained by the simulation and the calculations carried out analytically with respect to the total pressure drop of the extraction system; and a discrepancy of 12.59% referred to the flow inside the duct. Due to the fact that both lower values are the maximum established as allowed (15%), the results obtained analytically are taken as valid, thus guaranteeing the correct functioning of the system.

References

ANSI,ASHRAE *Ventilation for Acceptable Indoor Air Quality. Sociedad Estadounidense de Ingenieros de Calefacción, Refrigeración y Aire Acondicionado.* s.l.: Inc .: Atlanta, GA . 62.1, 2013. *STANDARD ASHRAE 62.1-2013.*

Arcondo, Catalogo de ventilador axial tipo mural. En: s.l.: s.. 2021.

Arcondor, s.f. Catalogo Ventiladores Centrífugos RSH. En: s.l.:s.n.

Ashrae Handbook, *Fundamentals.* 1791 Tullie Circle, N.E., Atlanta, SI Edition. 2013.

ASHRAE Handbook, *HVAC Systems and Equipmente.* s.l.:s.n. 2016.

Avelino Pérez, P., *Transformadores de distribución: Teoría, cálculo, construcción y pruebas.* s.l.:Reverté. 2008.

Barrezueta Zevallos, C. D. & Moncada Romero, B. A., *Diseño del sistema de ventilación de la sección de soldadura en el edificio PROTMEC.* s.l.:Tesis de Licenciatura. Espol. 2016.

Castejón, E., *Extracción Localizada.* s.l.: Universitat Oberta de Catalunya. 2008.

Chapman, S. J., *Máquinas Electricas.* Quinta ed. s.l.:MC GRAW HILL. 2012.

Echeverri, C. A. L., Diseño óptimo de ciclones. *Revista Ingenierías Universidad de Medellín,* 5(9), pp. 123-139. 2006.

Escoda, S., 2000. *Manual de Ventilación.* Barcelona: S&P.

Escoda, S., 2000. MANUAL DE VENTILACIÓN. *S&P,* p. 7.

Instituto Nacional de Tecnología, Normalización y Metrología, 2016. *Norma Paraguaya NP 55 004 16.* s.l.:s.n.

Instituto Nacional de Tecnología,Normalización y Metrología, 2016. *Norma Paraguaya NP 49 018 16.* s.l.:s.n.

Londoño, Carlos Alberto Echeverri, *Ventilación Industrial 2da Edición.* s.l.:Ediciones de la U. 2021.

Kurita, J., Limousin, M., Ferreira, N., & Ozuna, J. CFD Analysis on Air Ventilation at a Manufacturing Plant as a Tool for Designing Machine Layout, a Case Study. In 5th North American International Conference on Industrial Engineering and Operations Management, Detroit, Michigan, USA. (2020, August).

Marquez Quizhpi, A. A. & Ulloa Montero, J. P., *Diseño de un sistema de extracción de polvo y viruta de madera para la carpintería de la Fundación Saleciana "PACES",* s.l.: Tesis de Licenciatura. 2018.

Sapag Chain, N. & Sapag Chain, R., *Preparación y evaluación de proyectos.* 5ta ed. s.l.:s.n. 2008.

Serrano, R., Recomendaciones para el mejoramiento de los sistemas de extracción neumática de madera. *Revista Forestal Mesoamericana Kurú,* pp. 61-69. 2006.

Valenciana, G., *Ventilación Industrial. Manual de Recomendaciones practicas para la prevención de riesgos profesionales.* s.l.:s.n. 1992.

WageIndicator Foundation, *Tusalario.org.* [En línea] 2021. Available at: https://tusalario.org/paraguay/salario/salario-minimo-1

World Health Organization, *Hazard prevention and control in the work environment: Airborne dust..* Geneva: s.n. 1999.

Biography

Eduvigis Oporto Electromechanical engineer graduated in November 2021 from the Faculty of Engineering of the National University of Asunción, currently a member of the student section of ASME Paraguay. She has extensive experience in plant managing during her tenure at Trafopar S. A.

Gustavo Martinez director of the Mechanical and Electromechanical Engineering Department.

Kurita In 2004 Dr. Kurita was granted the Fulbright scholarship to attend a graduate program on Mechanical Engineering at Michigan Technological University. From 2011 Dr. Kurita worked as a development engineer II in the competitive automotive industry, Filtran LLC, located in Des Plaines, Illinois. Dr. Kurita worked in the CAE group, contributing to developing simulation techniques to help build state-of-the-art filtration systems. Dr. Kurita participated in developing OEM filters; some of them obtained awards from Jatco and GM. From 2016 Dr. Kurita is back to his alma mater as a research professor in Universidad Nacional de Asuncion. Later the same year, he is appointed to lead the research department of the School of Engineering. In 2017 he was appointed to be the Mechanical Engineering Department head at Universidad Nacional de Asuncion. In August of the same year, Dr. Kurita is awarded the “Distinguished Citizen by the City Council of Asunción” for his contributions to education in Paraguay’s space sector. And in December of the same year, he was mentioned as “Outstanding Protagonist of 2017” by the newspaper Ultima Hora.