CONTROL TEMPERATURE OF THE AIR CONDITIONING SYSTEM OF A VESSEL FROM EXERGOECONOMIC ANALYSIS

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Table of contents

INVESTIGATION AREA

Investigation line:

- Energy efficiency and rational use of energy.

INTRODUCTION

CARACTERÍSTICAS PRINCIPALES

ESLORA TOTAL	93.00 m
ESLORA ENTRE PERPENDICULARES	82.60 m
MANGA MOLDEADA	14.07 m
PUNTAL	7.00 m
CALADO DE DISEÑO	4.10 m
DESPLAZAMIENTO A PLENA CARGA	2550 t
VELOCIDAD DE CRUCERO	20.00 nudos
POTENCIA MÁXIMA	2*4800 kW
ALCANCE A 12 NUDOS (VELOCIDAD DE PATRULLA)	10000 Nm
AUTONOMÍA	40 días @ 64 20 días @ 100
TRIPULACIÓN MÁXIMA	64+36 personas

APLICATION INDUSTRY

- Naval and/or maritime

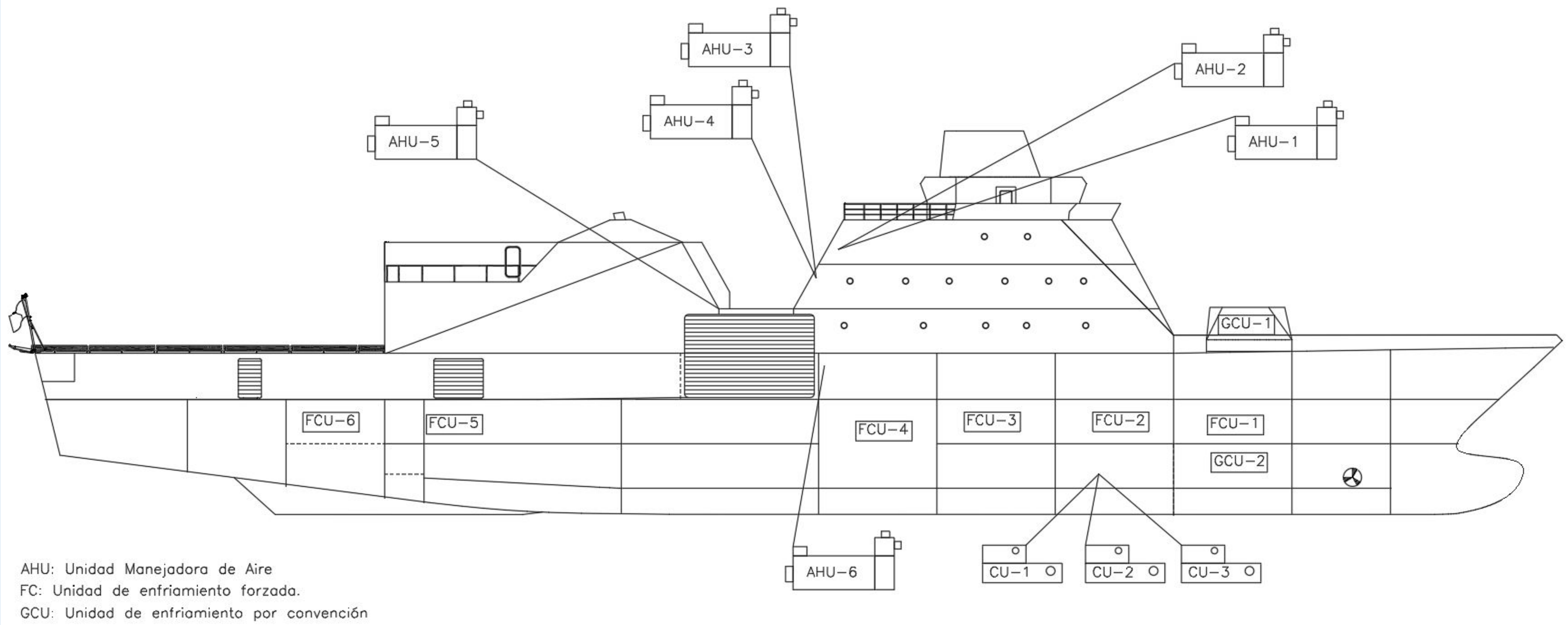
PURPOSE

- Efficient use of energy
- Thermoeconomic saings

INTRODUCTION

System´s equipments

Source: image taken in the following link (https://frizonia.com/equipos/)



Source: Own elaboration (COTECMAR)

STATEMENT OF THE PROJECT

- **Scientific Problem:** ¿What temperature control does present better performance and consumption indicators for the air conditioning system in the OPV second generation ship?

- **Object of study:** Ship Offshore Patrol Vessel (OPV).

- **HYPOTHESIS:** With a better dimensioning of the air conditioning system in the OPV ship from the calculations of thermal load for the real operating conditions at different control temperatures, a better rational use of energy can be obtained with better exergetic and exergoeconomic indicators.

State-of-the-art

- Sakulpipatsin & others: they applied a method of exergetic analysis in an office building with an HVAC system in the Netherlands, reaching a global exergetic efficiency of 17.15 and 6.81% for the cases of heating and cooling, the analysis also indicates that the emission and control system of thermal energy and the energy conversion system are the main causes of inefficiencies.
- Carlos Rodríguez Jaraba & others: Comparative study of the thermal load calculation method for air conditioning systems on ships. The use of the Ashrae methodology shows a 15.65% reduction in the real capacity required for the study location with respect to the value obtained by the Sname's methodology, without considering the differences in the U factor in the calculations. This shows that the use of the practices recommended by Sname for the design of air conditioning systems in ships can generate oversized equipment.
- Fajardo & others:

(i) as the thickness of the insulation increased, the irreversibilities decreased,

(ii) increases in exergy destroyed increased the costs of generating the cooling load.

(iii) thermal load and insulation investment costs per unit area and unit cooling load were lower for polyurethane.

He found that for ASHRAE recommended temperatures of 22 to 24°C, the highest exergetic efficiencies and lowest exergy destructions are obtained.

OBJECTIVES

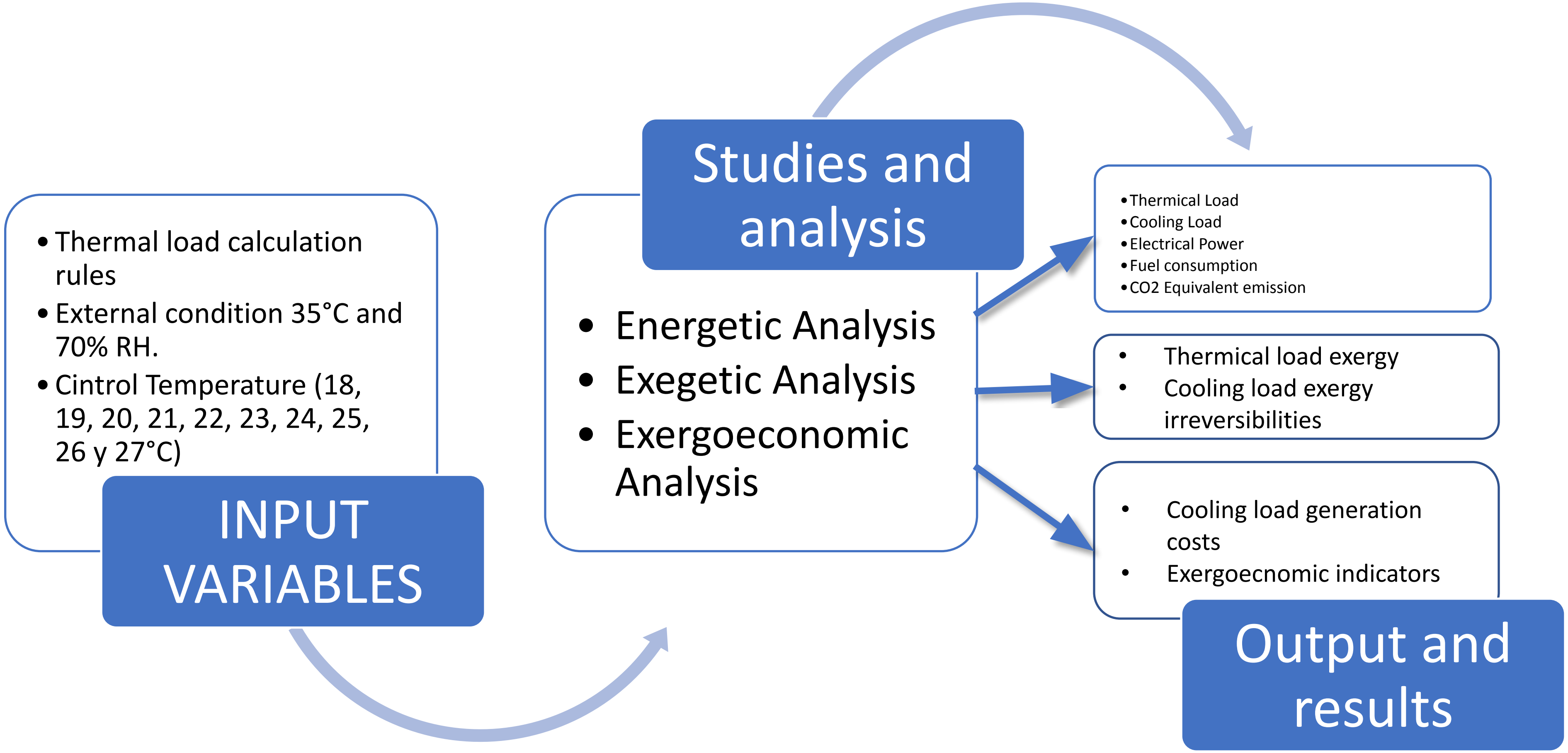
GENERAL OBJECTIVE

Study the behavior of exergetic and exergo-economic indicators of the air conditioning system in an OPV ship depending on the environmental and comfort conditions.

SPECIFIC OBJECTIVES

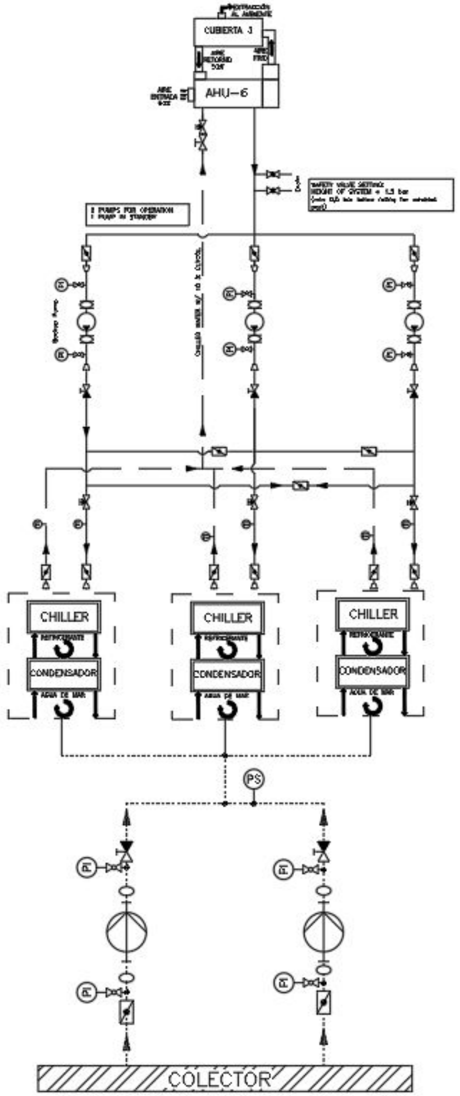
- Determine the capacities of the air conditioning system that allow a better rational use of energy in the OPV ship.
- Calculate energy, exergetic and exergoeconomic indicators for the air conditioning system in the OPV ship based on comfort conditions.

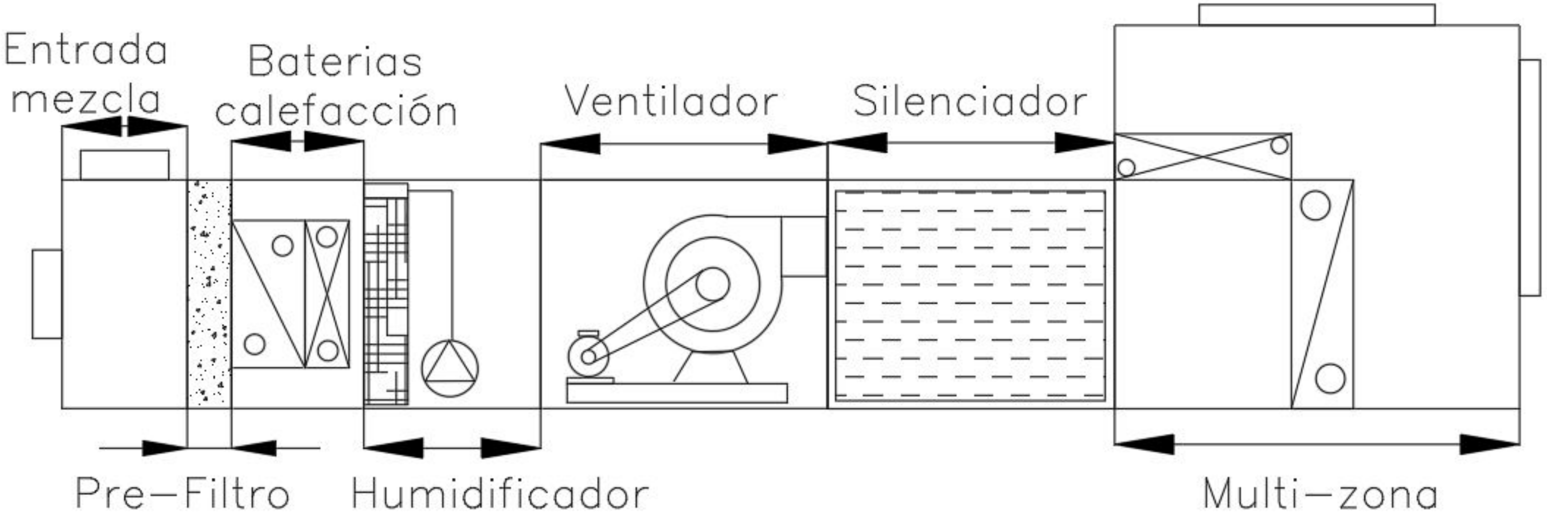
INVESTIGATION METHODOLOGY



INVESTIGATION METHODOLOGY

SYSTEM TYPICAL CONFIGURATION





INVESTIGATION METHODOLOGY

EXERGETIC ANALYSIS

- Where $\dot{X}_F$ is the exergy of the cooling and electrical load of the cooling equipment in each location, $\dot{X}_P$ the sum of the exergies of the contributors of the thermal load and $\dot{X}_D$ the destroyed exergy. in this work, air-conditioned spaces were taken as thermodynamic systems.

$$\dot{X}_F = \dot{X}_P + \dot{X}_D \ \ (kW)$$

- The exergetic efficiency (ε) which is the ratio between the exergy of the products and the exergy supplied, that is, to compare the exergy of the thermal load with the exergy of the cooling load.

$$\varepsilon = \frac{\dot{x}_P}{\dot{x}_F} \times 100 \ (\%)$$

INVESTIGATION METHODOLOGY

Exergies of thermal load contributions

Description	Ecuations
Fuel load	
Product load	
Cooling load	
Electrical power of fan coil	
Transfer through walls, ceilings and floors	
People, minor equipment, power equipment and lights	
Radiation	

INVESTIGATION METHODOLOGY

EXERGOECONOMIC ANALYSIS

- The balance of costs as expressed in the following equation, where *CP,k* represents the total rate of costs associated with the satisfaction of the thermal load, *CF,k* the total rate of costs associated with the generation of the cooling load, *Zk* the total rate of total non-exegetical costs, that is, the investment costs of equipment, and the rate of operation and maintenance costs:

$$\dot{C}_{P,k} = \dot{C}_{F,k} + \dot{Z}_k \ (\$/h)$$

Description	Ecuations
Total rate of costs associated with the satisfaction of the thermal load for each configuration	
Total cost rate associated with cooling load generation for each configuration	
Total non-exergetic costs	

INVESTIGATION METHODOLOGY

The exergy costs destroyed from the following equation and considering that the product costs were fixed.

$$\dot{C}_D = c_{F,k}\dot{X}_{D,k}$$

The exergoeconomic factor is the reason for the contribution of non-exergetic costs to the increase in total cost. For the case studied, it compares the capital costs in investment and operation and maintenance with the costs of irreversibilities.

$$f_k = \frac{\dot{Z}_k}{\dot{Z}_k + c_{D,k}}$$

The cost of cooling load generation per unit volume and heat load exergy

$$\frac{Costo\ Carga\ de\ enfriamiento}{Volumen \times Exergía\ Carga\ termica\ total} = \frac{\dot{C}_F}{(\dot{X}_{P,tot})(V)}\ \left(\frac{\$}{GJm^3}\right)$$

INVESTIGATION METHODOLOGY

- Energetics indicators: the values of thermal load, cooling load, electrical power consumption, fuel consumption, equivalent CO2 emissions.

- Exergetic indicator: thermal load and irreversibilities, exergetic flow of cooling load, exergetic flow of thermal load, exergetic flow of irreversibilities, exergetic efficiency.

- Exergoeconomic indicators: cooling load exergy flow costs, exergoeconomic factor and cooling load generation cost indicator per volume unit.

RESULTS ANALYSYS

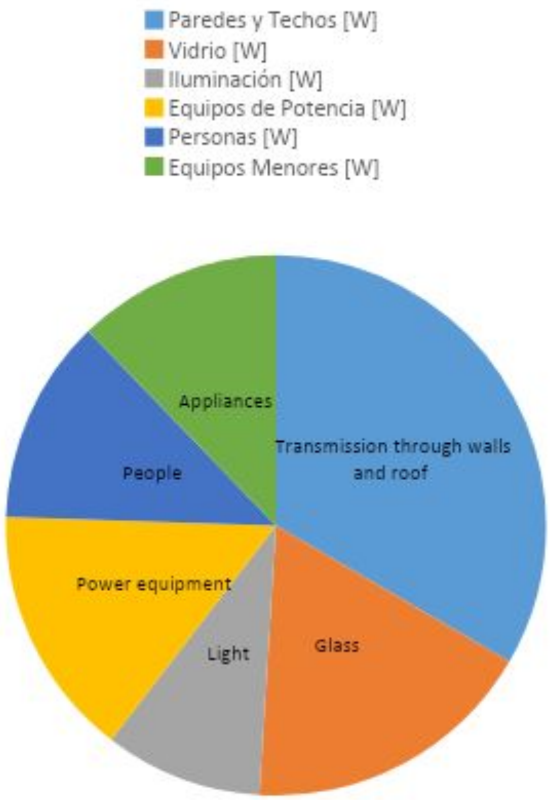


Figure- Thermal load with ISO on the vessel for the control temperature of 18°C

The Figure shows the percentages of each of the types of thermal load for the vessel at the control temperature of 18°C, for the thermal load reached in the vessel it has a value of 112941.40 W.

RESULTS ANALYSIS

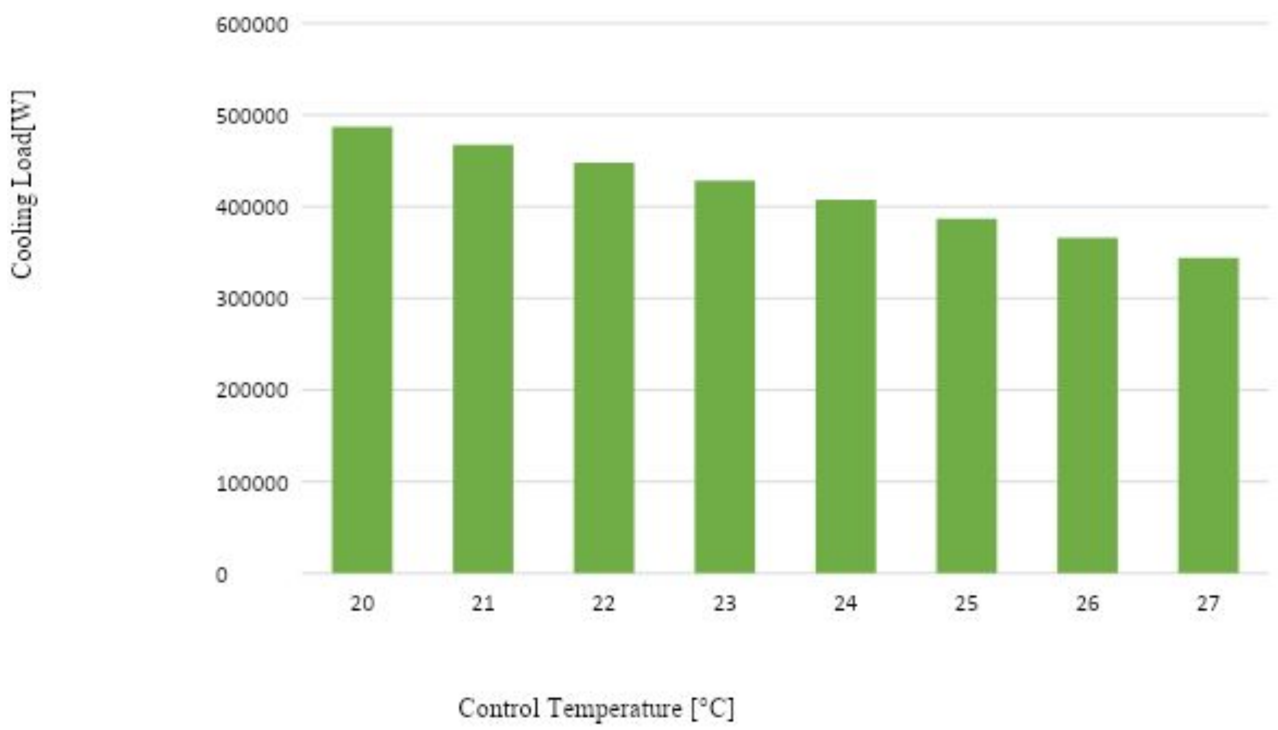


Figure - ISO heat load for different control temperatures

- The total thermal load for the different control temperatures, where it is observed that for each degree centigrade that the control temperature decreases, the total thermal load increases 1783.39 W, of which 85% are due to transmission through walls, ceilings and floors, and only 15% is due to glass transmission.

RESULTS ANALYSYS

Parameter values for energy analysis:

Variables	Valores
	5,57 (W/W)
Fuel oil Cost # 4	1.23 USD
%C in mass in the fuel oil # 4	84,2 %
Molecular weight CO_2	44 kg/kmol
Molecular weight C	12 kg/kmol

RESULTS ANALYSIS

Electric power consumption, specific fuel consumption, fuel consumption, CO2 equivalent emissions and cooling cost (ISO)

Energetic consumption/Control Temperature					
18°C	336.20	0.2828	95.07	293.50	30.64
19°C	331.15	0.2829	93.68	289.21	30.19
20°C	326.12	0.2830	92.31	284.98	29.75
21°C	321.10	0.2832	90.95	280.79	29.31
22°C	316.10	0.2835	89.62	276.68	28.89
23°C	311.10	0.2838	88.30	272.62	28.46
24°C	306.11	0.2842	87.00	268.60	28.04
25°C	301.14	0.2847	85.72	264.66	27.63
26°C	296.17	0.2852	84.46	260.77	27.23
27°C	291.23	0.2858	83.22	256.94	26.83

Reducing the control temperature by one degree centigrade increases electrical power consumption by 1.58%, fuel consumption, CO2 equivalent emissions and cooling cost decrease by 1.47%.

RESULTS ANALYSYS

Exergoeconomic analysis of different control temperatures

Control temperature									
18°C	21.354	306.87	30.658	33.76	52.012	273.12	27.285	48.639	0.439
19°C	21.354	296.36	30.210	33.48	51.564	262.88	26.797	48.151	0.443
20°C	21.354	280.75	29.768	33.20	51.122	247.55	26.247	47.601	0.449
21°C	21.354	266.88	29.331	32.93	50.685	233.96	25.712	47.066	0.454
22°C	21.354	253.23	28.901	32.65	50.255	220.58	25.175	46.529	0.459
23°C	21.354	236.00	28.476	32.37	49.830	203.63	24.570	45.924	0.465
24°C	21.354	222.00	28.057	32.09	49.411	189.91	24.001	45.355	0.471
25°C	21.354	207.46	27.645	31.82	48.999	175.64	23.406	44.760	0.477
26°C	21.354	197.66	27.238	31.54	48.593	166.13	22.892	44.246	0.483
27°C	21.354	180.49	26.839	31.26	48.193	149.23	22.190	43.544	0.490

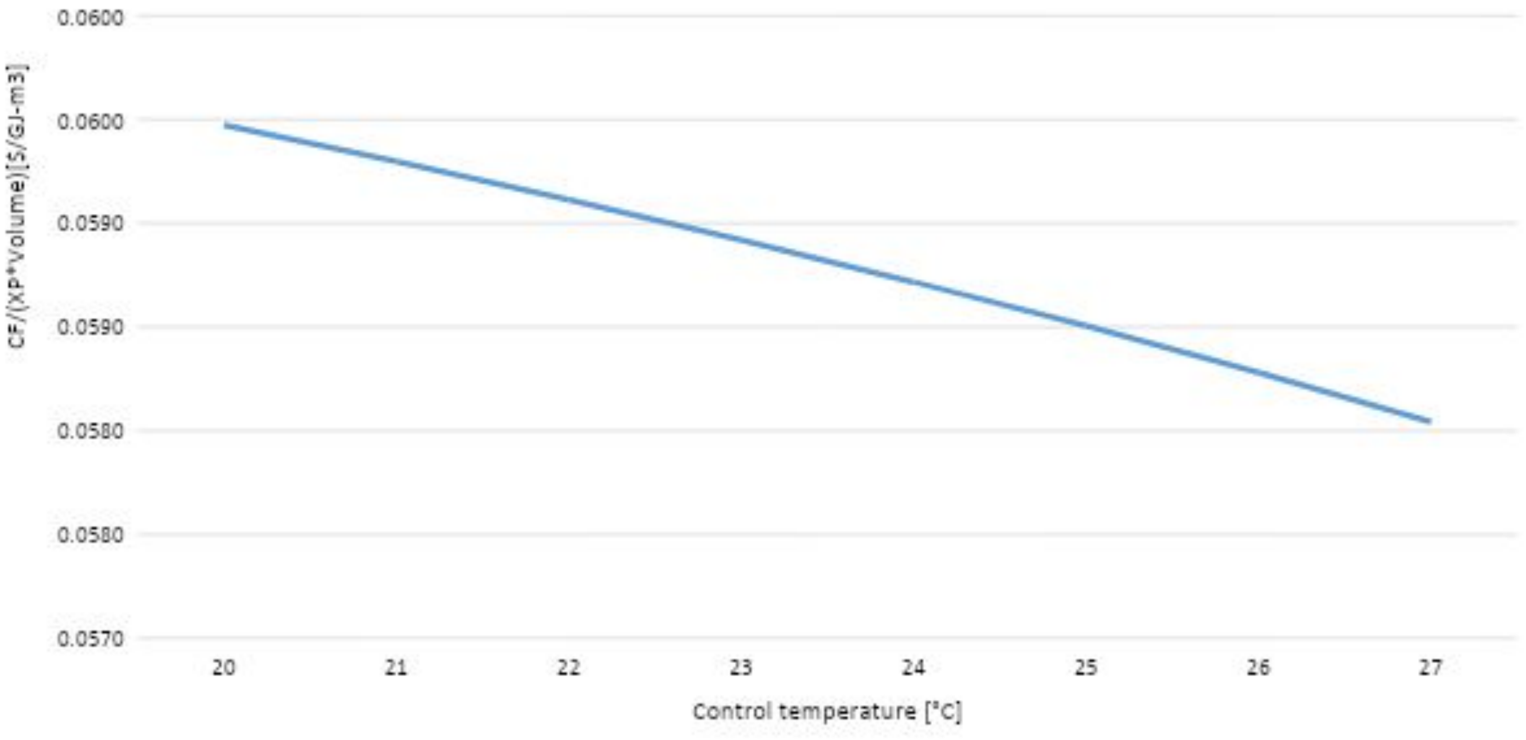
RESULTS ANALYSIS

Parameter values for the exergetic balance

Description	Ecuations
	Control Temperature
	35 °C
	40°C , Wall temperature
	33 °C People 40 °C Minor equipments 40° C Lights
Sun	6 000 K [67]

RESULTS ANALYSYS

Cooling Load Generation Cost Per Unit Volume And Heat Load Exergy For The Different Control Temperatures:



Capital costs represent between 45 to 49% of the total costs, which presents an average decrease of 1.0% for each degree centigrade that the control temperature increases, <u>as it requires less cooling capacity.</u>

CONCLUSIONS

- For the vessel, the major contributors of thermal load were the transfer of heat through walls and ceilings, and glass, which represent 33 and 18%, respectively. Which by an increase of one degree centigrade in the control temperature the thermal load is reduced by 2.4 and 1.1%, respectively.
- Exergy destruction decreases when selecting a higher comfort temperature. For every degree Celsius that the comfort temperature is increased, exergy destruction is reduced by 4.16%.
- Increases in exergy destruction increase the value of the indicator of cooling load generation costs per volume and unit of thermal load exergy. For the control temperature of 20 ° C the average generation cost is $ 0.0595 / GJ-m3 while for 27 ° C it is $ 0.0580 / GJ-m3.
- To improve the efficiency of the system, the highest possible control temperature should be selected, maintaining the standards of thermal comfort for the occupants. Likewise, systems must be designed based on the selected control temperature to reduce possible oversizing of the air conditioning system.

THANK YOU