ANALYSIS AND DESIGN OF AN AIR HANDLING UNIT USING THERMOPSYCHRO SOFTWARE

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Summary: *This work presents a software for the study of air conditioning processes, from the basic processes, sensible heating and cooling, humidification, dehumidification, evaporative cooling, mixing of humid air currents, cooling towers, etc.; as well as air handling units for summer and winter. The software allows an exhaustive study of all thermodynamic variables involved in the design, including enthalpy, entropy and exergy in each state, and losses due to irreversibilities in each process. It is supported by the psychrometric diagram, allowing its visualization for all the cases to be analyzed. Finally, it is worth highlighting the pedagogical use of these tools that improve the learning experience by providing students with a greater mastery of the aspects of psychrometry, facilitating calculations that would otherwise be tedious and repetitive, motivating them to focus more on the design aspects and the analysis of the meaning of the different parameters for technological application purposes.*

Key words: THERMOPsychro, air-conditioning, air handling unit, exergy, energy.

1. INTRODUCTION

When a thermodynamic analysis is carried out in an energy facility, two main objectives are sought, (i) the calculation of the degree of thermodynamic perfection of the processes involved in the facility and (ii) obtaining the actions to be taken to reduce the fuel consumption or the electrical energy consumption supplied to the facility, in short, to increase its efficiency. For this, it is necessary to apply the corresponding thermodynamic analyses, energy balances (based on the First Law) and exergy balances (based on the Second Law), [1, 2]. It is known that the first analysis has an important limitation, since it is not able to differentiate between the quality of the different energy flows existing in a thermal installation. This quality (called exergy), which is the capacity to perform useful work and the possibility of performing an analysis of the changes in energy quality, which leaves a possible way to improve the facilities in order to save fuel or electrical energy, is undertaken in the second analysis [3]. Therefore, in order to optimize an existing air conditioning system or to choose between different air conditioning design alternatives, it is appropriate to use the exergy analysis of them. Thus, different objectives can be achieved by means of this tool, such as the identification of devices with lower exergy efficiency, the determination of the origins of irreversibilities or the reduction of exergy losses through the introduction of improvements in the devices. A more advanced study would allow evaluating the sensitivity of the different efficiencies to variations in operating conditions and/or design parameters. [4] performed a wet air exergy analysis to explore the potential energy savings available for various conditions and locations in an evaporative cooling process. [5] performed an exergy analysis to evaluate the performance of the three most common air conditioning schemes: all-air, dual-duct and fan-coil systems.

In this work to obtain the numerical results (thermodynamic variables at the main points of an air- conditioning system and design parameters of the installation) and graphics the ThermoPsychro software is used, which provides a complete thermodynamic study, supported by the psychometric diagram and allows a final report of the results exportable to a pdf file. The software used is able to provide all this information for an engineer designing or analyzing humid air treatment systems. From the results obtained it is possible to achieve an improvement of the cycle efficiency, detection of irreversibilities in each process and to have a complete analysis of psychrometric systems in general. The software is very versatile, since it allows a wide combination of input data, in addition to the possibility of working in design mode by introducing the sensible and latent loads of the room to be air-conditioned.

2. SOFTWARE THERMOPSYCHRO

THERMOPsychro (www.thermosuite.com) is a software for the design of air conditioning systems, altering the properties of the air (mainly humidity and temperature) to achieve favorable conditions, typically with the objective of distributing conditioned air in an occupied space to improve comfort. The software provides a detailed numerical and graphical solution of the thermodynamic states, as well as the main variables for thermal design, allowing the user to choose the input variables, based on knowledge of them, making the software a very versatile tool. THERMOPsychro provides the energy and exergy diagrams, presenting the losses due to irreversibilities in each equipment of the installation, which is key for the improvement and optimization of the air handling units. The information provided by these diagrams is very valuable, providing the efficiencies of each process, sensible and latent heats, amount of exergy destroyed in each process of the system, exchanger efficiencies, etc.

It is a tool for both educational and industrial use, facilitating the student to acquire knowledge in a dynamic way which improves the learning experience and helps the engineer or technician of a company to design and/or improve this type of installations.

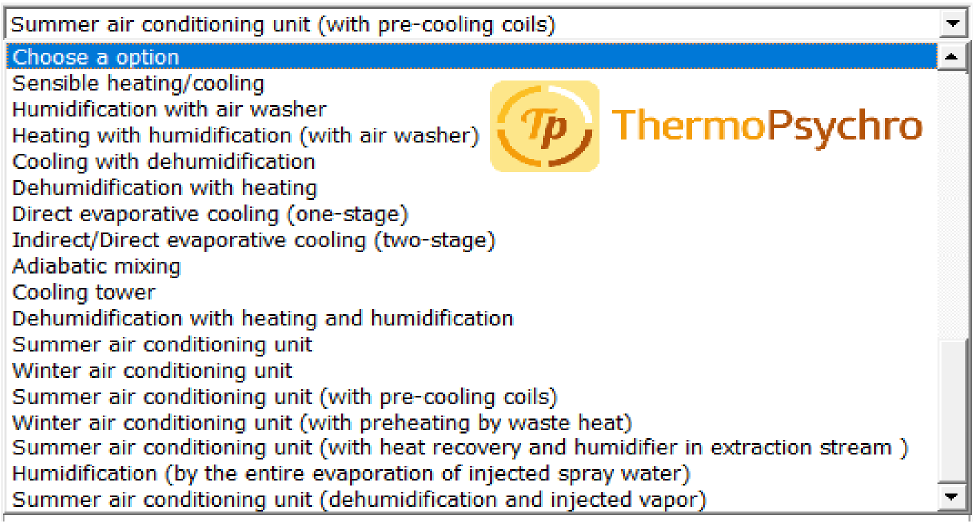


Figure 1. Psychrometric units.

Figure 1 shows the processes that can be solved, comprising basic processes and air conditioning processes. The software also has the possibility of analyzing air conditioning processes using desiccant materials.

3. CASE SOLVED

We solve the case of an Air Handling Unit (see Fig. 2) for summer, located at sea level with an atmospheric pressure of P_0=101325 Pa. The comfort conditions in the space to be air conditioned are T_3=22 ºC and ϕ_3=60 % RH, being the recirculated flow rate 0.5 kg/s. The refrigerant is at T_w= 14 ºC, while fresh air (1 kg/s) enters the cooling unit at T_1=29 ºC and ϕ_1=44 % RH. A by-pass factor of 15 % is considered. Dead state conditions have been defined for a temperature of T_o=4 ºC, a pressure of P_o=101325 Pa and a relative humidity of ϕ_o=70 %.

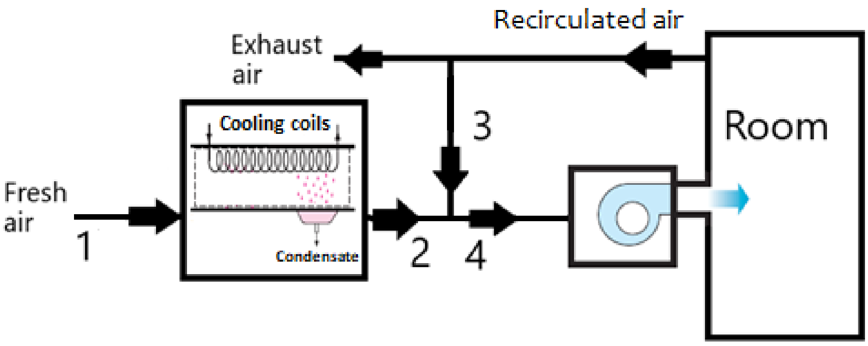


Figure 2. Air Handling Unit.

Any air conditioning system will consist of a set of basic processes available in THERMOPsychro. In summer air conditioning, the temperature and relative humidity are usually quite high, so the air is conditioned by lowering its temperature and humidity. To achieve the above, the cycle shown in Fig. 2 is presented, where a dehumidification process is carried out until a suitable humidity value is achieved, so that the air temperature is slightly increased without the need to incorporate a heating coil unit, since an adiabatic mixture of recirculated air (3) and air (2) will be sufficient to have an adequate impulsion and achieve a state of comfort in the room to be air-conditioned.

3.1. Calculation of the exergy of humid air in kJ/kg of dry air, [1]:

Thermal exergy: $$Ex_{,th} = C_{p,a} + \omega\, C_{p,v})\, T_o\, [T/T_o - 1 - \ln(T/T_o)] \quad (1)$$

Mechanical exergy: $$Ex_{,me} = (1 + \omega')\, R_a\, T_o \ln(P/P_o) \quad (2)$$

Chemical exergy: $$Ex_{,ch} = R_a\, T_o\, [(1 + \omega') \ln((1 + \omega_o')/(1 + \omega')) + \omega' \ln(\omega'/\omega_o')] \quad (3)$$

Total exergy: $$Ex_{,t} = Ex_{,th} + Ex_{,me} + Ex_{,ch} \quad (4)$$

3.2. Calculation of the water exergy in kJ/kg water, [1]:

Total exergy: $$Ex_{,w} = h_f(T) - h_g(T_o) - T_o\, s_f(T) + T_o\, s_f(T_o) + [P - P_{sat}(T)]\, v_f(T) - R_v\, T_o \ln \phi_o \quad (5)$$

3.3. Calculation of the exergy of a heat flux, [1]:

Total exergy: $$Ex_{,Q} = (1 - T_o/T_f)\, Q \quad (6)$$

4. RESULTS AND DISCUSSION

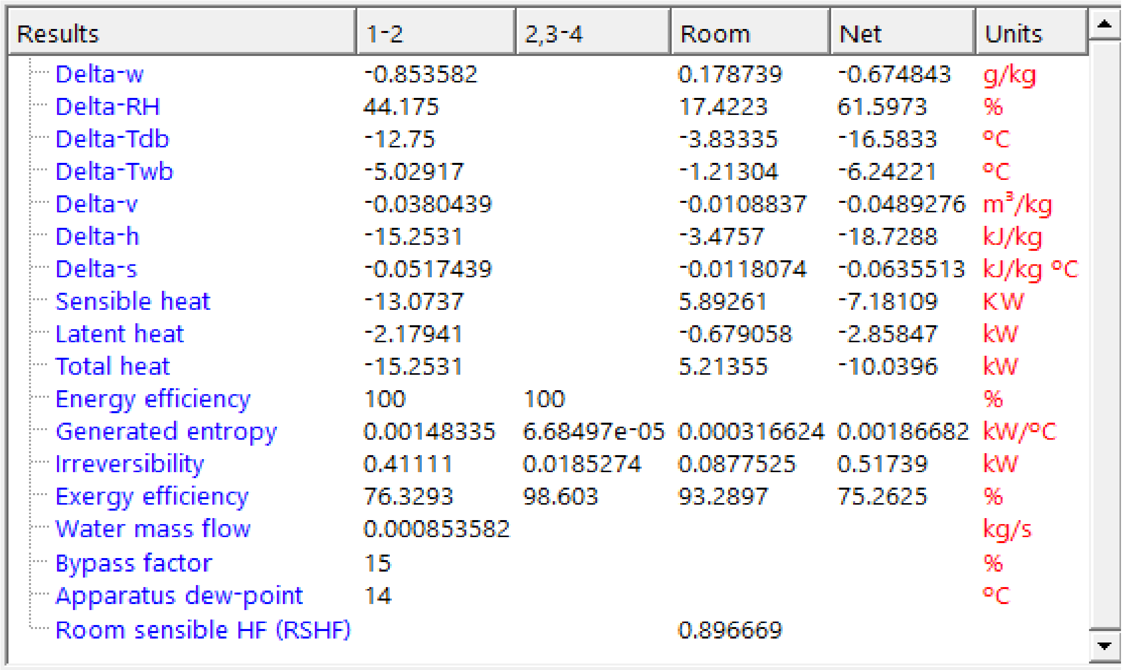
Fig. 3 shows the thermodynamic properties of each state, while Fig. 4 shows the variations of these, as well as other important performances of each element (sensible heat, latent heat, irreversibility, efficiencies, etc.) that make up the installation, zone to be air-conditioned and the global one. The psychrometric diagram (Fig. 5) is an industry standard tool used to visualize the interrelationships between dry air, humidity and energy in the different states of a facility. It facilitates the work of the person responsible for the design or maintenance of any aspect of air conditioning. The properties of moist air and water are based on ASHRAE-RP1485 from ASHRAE, Hermann et al [6].

Fig. 6 shows the energy diagram. Four main groups of thermal energy flows interacting with the outside are identified; the outdoor air load, the active cooling input (cooling coils), the thermal load in the zone to be air conditioned (room), and the energy loss due to air exchange with the ambient environment (exhaust). The energy possessed by the condensed water is negligible. From the energy point of view, the objective is the optimal design of the air conditioning unit, improving its efficiency, minimizing cooling by reducing the external air load, the room load, and the energy wasted during the air conditioning process (mostly renewal air).

In Fig. 7, it can be seen that the major contributors to exergy destruction are, with 49.21 %, the air expelled to the environment, and with 37.82 % of the total exergy destroyed in the dehumidification process, mainly due to the significant temperature difference between the refrigerant and air streams and the condensation process itself. Included here are losses due to internal irreversibilities (13.24 %) and losses due to sensible (21.07 %) and latent heat transfers (3.51 %). The exergy loss accompanying the condensed water is obtained from Eq. 5 and is 5.78 %. Due to the small maximum temperature difference in the mixer (supply and return air) of adiabatic currents (6.22 ºC), the exergy destruction in the mixer is only of 0.86 %. The analysis incorporates the exergy analysis in the room, differentiating between the internal irreversibility (4.06 %) and the exergy destruction by latent heat loss (2.26 %). The exergy inputs to the overall system analyzed are the exergy of state 1 (external conditions) with 80.37 %, and the sensible heat provided in the room (19.63 %).

Variable	State 1	State 2	State 3	State 4	Units
Pressure	101325	101325	101325	101325	Pa
Dry bulb temperature	29	16.25	22	18.1667	ºC
Relative humidity	44	88.175	60	77.4223	%
Humidity at saturation	25.618	11.5526	16.6698	13.0742	g/kg air
Specific humidity	11.0178	10.1642	9.89577	10.0745	g/kg air
Degree of saturation	0.43008	0.879817	0.593636	0.770566	
Dew temperature	15.5197	14.2895	13.8835	14.155	ºC
Wet bulb temperature	20.0612	15.032	16.872	15.6589	ºC
Density	1.14824	1.20069	1.17765	1.19294	kg/m^3
Specific volume	0.870897	0.832853	0.849151	0.838267	m^3/kg
Saturation pressure	4008.48	1847.79	2644.89	2086.14	Pa
Vapor pressure	1763.73	1629.29	1586.93	1615.14	Pa
Enthalpy	57.312	42.0589	47.2725	43.7968	kJ/kg air
Entropy	0.204195	0.152451	0.170229	0.158421	kJ/kg air ºC
Air pressure	99561.3	99695.7	99738.1	99709.9	Pa
Total exergy	1.73679	0.79449	1.06354	0.87182	kJ/kg air
Thermal exergy	1.09292	0.269644	0.574294	0.358972	kJ/kg air
Mechanical exergy	0	0	0	0	kJ/kg air
Chemical exergy	0.643871	0.524846	0.489243	0.512849	kJ/kg air
Dry air mass flow	1	1	0.5	1.5	kg air/s
Volume flow	0.870897	0.832853	0.424576	1.2574	m^3/s

Figure 3. Thermodynamic variables.



Results	1-2	2,3-4	Room	Net	Units
Delta-w	-0.853582		0.178739	-0.674843	g/kg
Delta-RH	44.175		17.4223	61.5973	%
Delta-Tdb	-12.75		-3.83335	-16.5833	°C
Delta-Twb	-5.02917		-1.21304	-6.24221	°C
Delta-v	-0.0380439		-0.0108837	-0.0489276	m³/kg
Delta-h	-15.2531		-3.4757	-18.7288	kJ/kg
Delta-s	-0.0517439		-0.0118074	-0.0635513	kJ/kg °C
Sensible heat	-13.0737		5.89261	-7.18109	KW
Latent heat	-2.17941		-0.679058	-2.85847	kW
Total heat	-15.2531		5.21355	-10.0396	kW
Energy efficiency	100	100			%
Generated entropy	0.00148335	6.68497e-05	0.000316624	0.00186682	kW/°C
Irreversibility	0.41111	0.0185274	0.0877525	0.51739	kW
Exergy efficiency	76.3293	98.603	93.2897	75.2625	%
Water mass flow	0.000853582				kg/s
Bypass factor	15				%
Apparatus dew-point	14				°C
Room sensible HF (RSHF)			0.896669		

Figure 4. Results obtained.

Both from an energetic and an exergetic point of view, the cooling and dehumidification unit is the critical element to optimize in this case study. In more complex installations (with more elements), the exergetic analysis can be more valuable to evaluate the destruction in all these elements, and to be able to act accordingly in each one of them, or in those where it is more advantageous to act. The software has different air handling units, for summer and winter, for study and analysis.

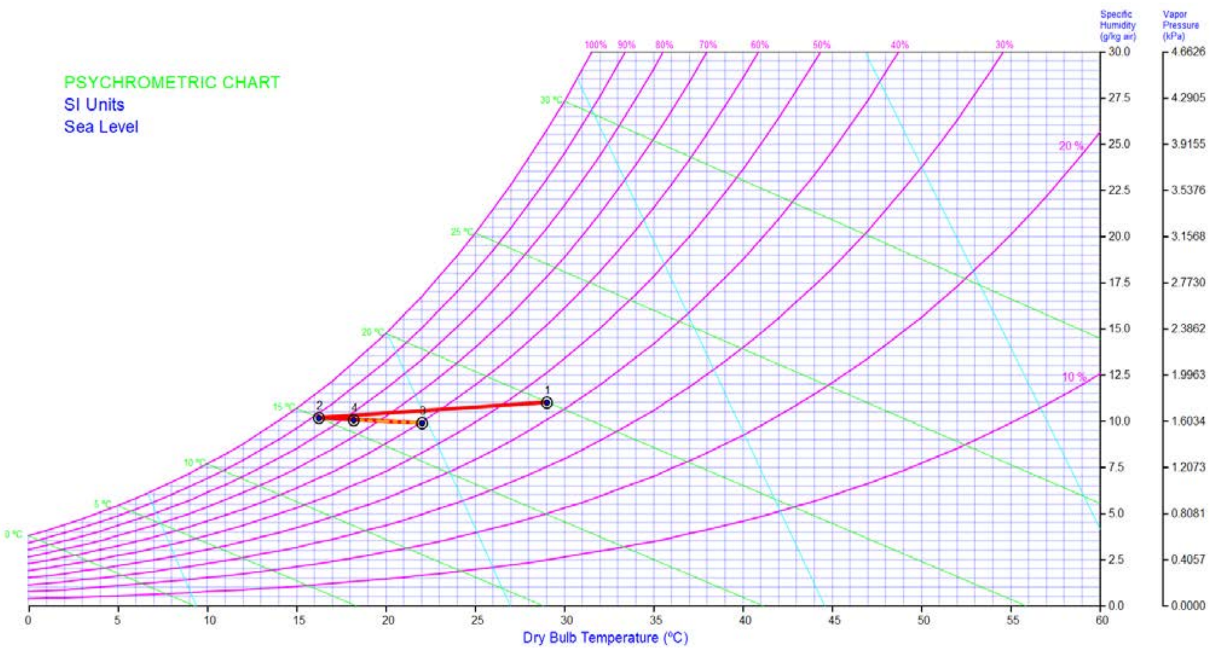


Figure 5. Psychrometric diagram of the process.

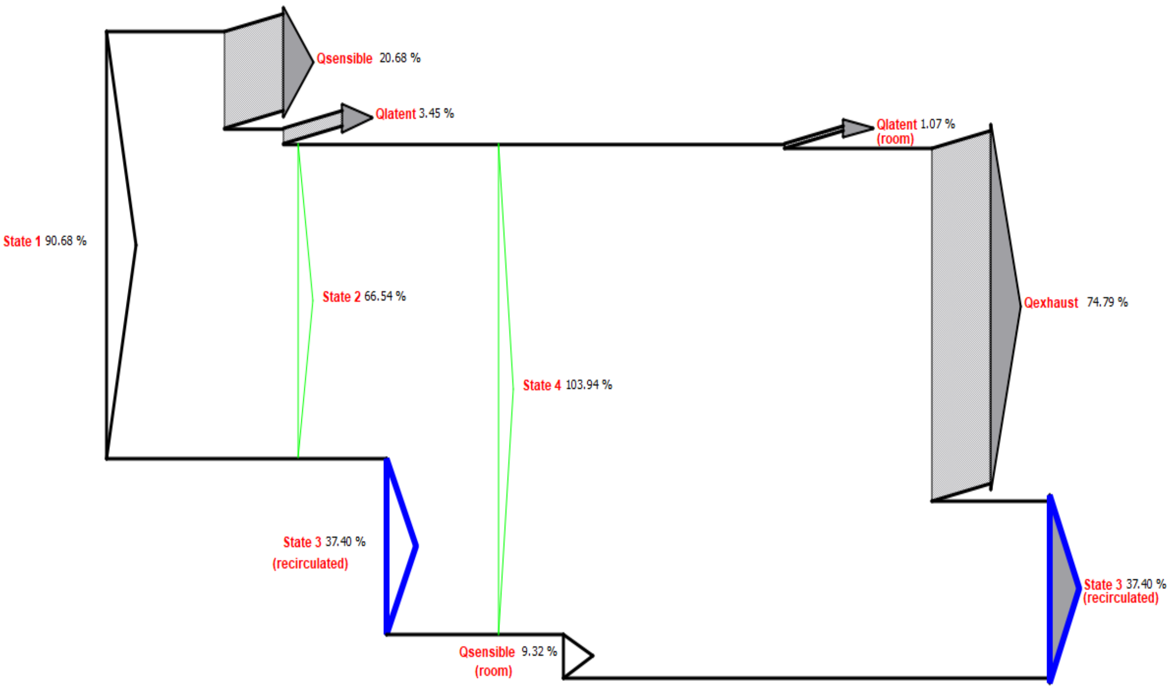


Figure 6. Energy diagram.

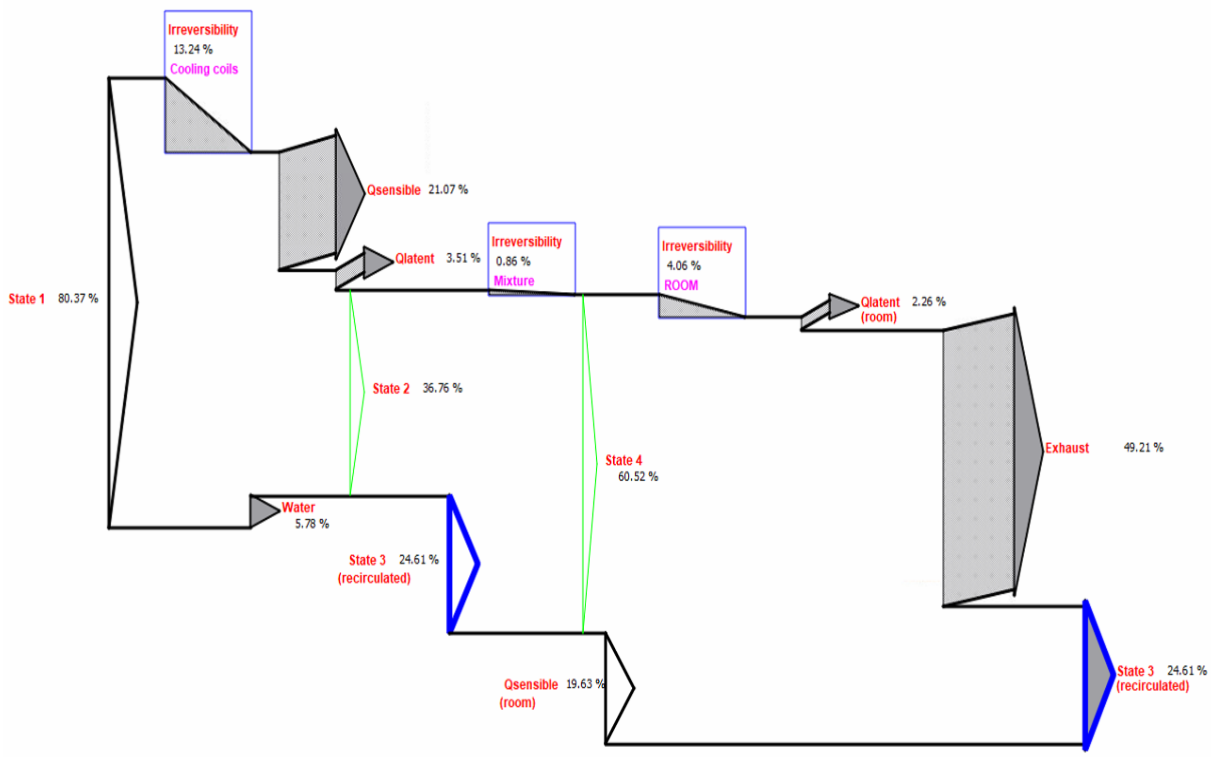


Figure 7. Grassmann's exergy diagram.

5. CONCLUSIONS

The performance of an exergy analysis of the refrigeration and air conditioning systems offers the possibility of detecting the origin of the irreversibilities of the system and is the beginning of the optimization of the system. This analysis complements the study carried out by means of an energy analysis of the air conditioning unit. Using the THERMOPsychro software, it can be quickly and effectively determined which devices contribute most to the destruction of exergy, in order to analyze whether they can be subject to improvement when operating and design constraints allow it. The software presented in this paper allows the thermodynamic analysis of basic processes as well as air conditioning units in a fast, accurate and relatively easy to use manner.

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