SIZING AN AIR-BASED CHILLER TO AIR CONDITIONED A COLLEGE BUILDING (UNISUL)

DIMENSIONANDO UM REFRIGERADOR DE AR PARA UM EDIFÍCIO DA FACULDADE (UNISUL)

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Abstract:
In this paper, the usage of an air-based water-cooled chiller is studied to air condition a college building. The chilled water flows to an air handling unit located outside and an active chilled beam located inside each room. A short explanation on each component is made, including a comparison between systems. The study is based on norms established to properly scale an air conditioning system. The result showed that this chiller system will have a high energy cost if operated on its max capacity every day for 230 days in a year, but it's counter balanced as it will provide a high air condition standard, including enough air change and humidity, adequate temperature and provide temperature control to each room.
Keywords: Air cooled chiller, Air conditioning, Active chilled beam, Air Handling Units

Resumo:
Neste artigo, o uso de um chiller refrigerado a água a ar é estudado para condicionar o ar de um prédio de faculdade. A água resfriada flui para uma unidade de tratamento de ar localizada do lado de fora e um feixe resfriado ativo localizado dentro de cada sala. É feita uma breve explicação sobre cada componente, incluindo uma comparação entre os sistemas. O estudo é baseado em normas estabelecidas para dimensionar adequadamente um sistema de ar condicionado. O resultado mostrou que este sistema de chiller terá um alto custo de energia se operado em sua capacidade máxima todos os dias por 230 dias em um ano, mas é contrabalançado, pois irá fornecer um alto padrão de ar condicionado, incluindo mudança de ar e umidade suficiente, adequadas temperatura e fornecer controle de temperatura para cada quarto.
Palavras-chave: Refrigerador a ar, Ar condicionado, Feixe de resfriamento ativo, Unidades de Tratamento de ar

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1. INTRODUÇÃO

This paper is based on the Brazilian Technical Standards, NBR 16401-3 [1] determines a correct air change and flow rate for types of rooms, such as classrooms and storages, NBR 5858 [2] is used to calculate the amount of BTU/h the building will require and NBR 15848 [4] gives a base on proper installation, equipment maintenance and air quality. The regulatory standard NR 17 [3] is used to ensure what are the ideal air conditions, such as temperature and humidity.

Air conditioning became increasingly popular in the last decades, it went from luxury to a standard obligation in buildings, so it's clear that air conditioning needs to be taken into account when planning a building. Air conditioning also implies the necessity for better air conditions in certain areas, also called air change rate, something that became really important lately with the covid-19 pandemic. With this increase in use, different models and types of air conditioning were developed, this paper studies specifically the use of chillers for air conditioning.

A chiller system has multiples variables, so this paper will take account on all those, such as the type of chiller (water or air based), the refrigerant fluid, pipe isolation, the use of an air handling unit (AHU) or a fan coil unit (FCU), recommended air changes and other variables. The target building is a college named UniSul, located in Itajaí, Brazil, right now this college has no structures to actually implement a working chiller air conditioning system, so this paper will study an ideological structure, taking account of all of the current building dimensions, rooms and heat loads.

Furthermore, this paper will show a comparison between air conditioning systems in order to establish which type of systems is more adequate for this ideological scenario. Other than water-based water-cooled chillers and water-based air-cooled chillers, right now it's common to use splits for air conditioning too, so those will also be taken into account during the comparison later in this paper.

As explained by Roberto Lamberts [14] in his class about Desempenho Térmico de Edificações, thermal comfort is an ideal temperature where the person doesn't feel either hot or cold, allowing for a proper performance. In a college building, where students are constantly using their minds and body, the need for ideal thermal comfort is essential.

The air condition will be highly ventilated, with enough air change and flow rate, ideal temperature of 24 ºC. In a well-designed chilled beam system, humidity and condensation is not a problem as explained by Daniel Kailey [13], so all characteristics of an ideal climate for a good

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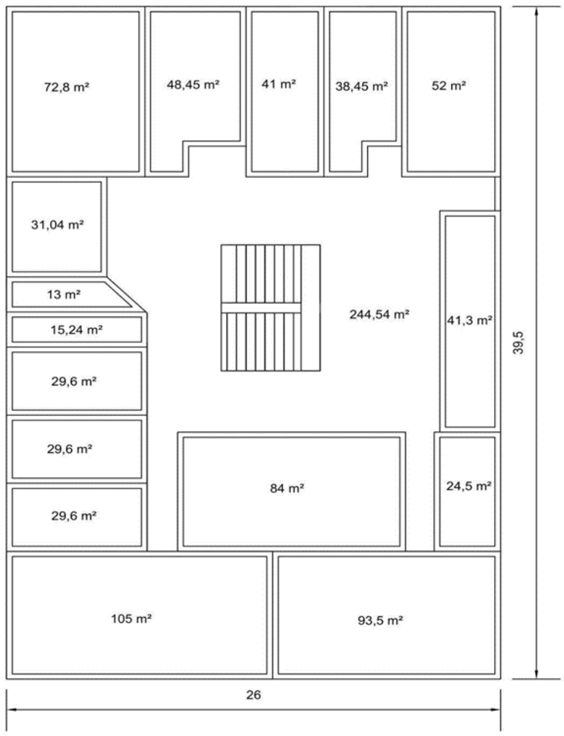
thermal comfort are reached, as established on NR 17[3], and to complement, this paper also follows ASHRAE 55 [15] for ideal climate conditions.

2. MATERIAL AND METHODS

For case studies like the one approached in this paper, it is first needed the building's blueprint. It was needed to make approximate measures using a manual measure tape to get a rough size of the whole building rooms. The college consists of three floors and a stairway in the middle connecting all floors, since floors aren't divided by a solid floor, the air conditioning in the hall and stairs will need to overcome a huge area. All rooms were measured, including bathrooms and store rooms; chiller systems allow for better inner space air conditioning without the need to increase its power consumption, different from splitter systems.

Figure 1 - UniSul's Blueprints, the leftmost is the ground floor, in the middle is the second floor and the rightmost is the third floor. Every room have wall height of 3,8 m except for the bathrooms, those have 2,5 m



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To dimension a chiller for air conditioning, it is needed to calculate how much BTU/h this given chiller system will need to supply to the FCU or AHU. These calculations follow instructions established on the NBR 5858 [2], where it takes account of all building area, number of persons, window area and electronics; those data can be found on table 1. Taking into account any window has some type of sunlight protection, isn't well sealed and the number of people inside the building fluctuates, it is then estimated a total of 148 RT.

Table 1 - The sum and data from the whole building, divided on each floor, giving its values in both BTU/h and RT.

	Total area (m²)	Number of persons	Total window area (m²)	Eletrical equipments (W)	
	Ground Floor	Ground Floor	Ground Floor	Ground Floor	
	948,5	45	33	3697	
	Second Floor	Second Floor	Second Floor	Second Floor	
	988,52	40	30	1977,04	
	Third Floor	Third Floor	Third Floor	Third Floor	
	993,38	40	38	1986,76	
Sum	2930,4	125	101	7660,8	Total
Equivalent BTU	1611720	40000	101000	30643,2	1783363,20
Equivalent RT	134,31	3,33	8,42	2,55	148,61

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Chillers come in various sizes and types, the measure unity for a chiller capacity is usually given in RT, which means 12.000 BTU/h. Air cooled chillers range from 15 to 300 RT, making them the right choice for small buildings, meanwhile water-cooled chillers usually have 200 RT or more, those are used in big and tall buildings. Air cooled chillers are typically easier to install and are relatively cheaper than a water-cooled chiller. Tosi Industry offers a line of modular chillers called TIAM, those consists of units of 15 TR each, in order to get the minimum of 148 TR needed and an extra one for safety measures, the air conditioning system will require two sets of 6 modular air cooled chiller of 15 TR each, each set consists of 1 chiller with a fix velocity compressor and 5 chillers with a variable velocity compressor, the main difference between those lies on the energy efficiency, this system will wield a total of 180 TR. This chiller system can operate using around 83% of its power, this gives space for at least one chiller to be kept turned off while it is in maintenance. Tosi modular chillers come with specific pumps and the refrigerant liquid is HFC R410A. The chilled water that will be pumped to the building without the need to mix any other component such as glycol, reason is that the water will be pumped at 8º C, temperature which the water doesn't need any antifreeze propriety.

Now with the condenser part of the system established, the evaporator needs also to be dimensioned, there's three common ways, firstly the air handling units, those are equipment that will receive the cold water from the chiller, a fan will pass air through the chilled coil and this air is distributed to the building area, they come with multiples features, like humidifiers, heat and cooling, air change et al, but its complexity is balanced by its high prices and energy consumption. Another studied alternative are the Fan Coil Units and Active Chilled Beam Unit, both works with the same principle, cold water is piped to and a fan forces air through it. Fan Coil Units have no way to make air changes, so they are cheaper and easier to install, while Active Chilled Beam Units do have a way to make air change, active chilled beam requires a primary air supply. This primary air passes through nozzles, which induce air from the space up through the cooling coil. For the main area, including stairs, main hall, storage rooms and bathrooms, an AHU will be chosen to make good air change and better environmental conditions, those will use some return air to save energy since those places are a big parcel of the whole building area, meanwhile the classes rooms will be refrigerated using Chilled Beams to make sure each class has enough air change and adequate temperature of 24º C as determined in the NR 17 [3].

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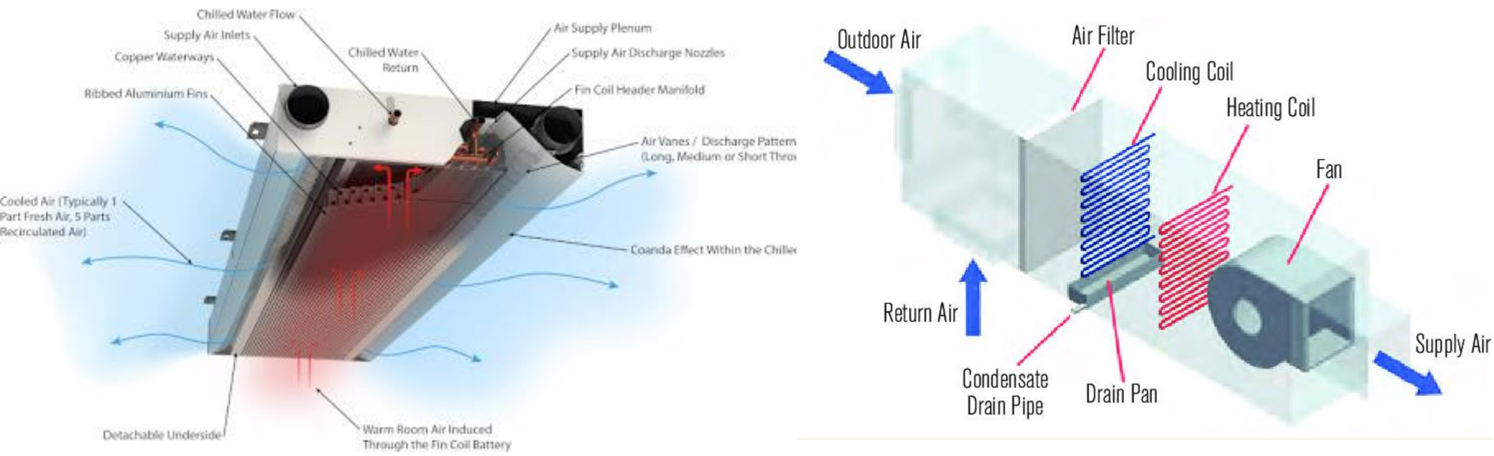
Figure 2 - Chilled beam and its componentes.



Font by: 05/06/2021 http://www.chilled-beams.co.uk/chilled-beam-technology/active-chilled-bea(A). Air Handling Unit and its components, font by: https://www.researchgate.net/figure/Schematic-of-a-typical-draw-through-commercial-air-handling-unit-AHU_fig1_312059897. 05/06/2021 (B)

In order to correctly scale an AHU, it's needed to properly know the air flow needed, this parameter will make sure an enough air volume per hour will be sent to the air diffusers, this calculus is based on the multiplication of the total volume and the air change established on NBR 16401-3 [1]. This calculation is based on the sum of the total hall, corridors, bathrooms and staircase volume. A total of 47.200 m³/h of air is needed, the equipment chosen is the AHU 45H series, from Tangra, it has, among other properties, an air flow of 48.000 m³/h, also comes with heat reuse from the return air, air filter and mixing section. Active chilled beams need to be scale based on the area they are in, it means a chilled beam for each room, this will ensure each class has control over the temperature, table 2 shows the calculations based on NBR 16401-3 [1].

Table 2 - All rooms, their types, max number of people per room usually and the other data comes from NBR 16401-3, at the end is the effective flow, this value is used to scale the chilled beam. The right-most column is the Active Chilled Beam model chosen.

Area m²	Type	Flow per person L/s * people	Flow per area L/s*m²	Max. Nº of people	Effective Flow L/s	Chilled Beam Trox
67,5	Classroom	5	0,6	25	165,5	3000U (Two)
49,5	Classroom	5	0,6	25	154,7	3000U (Two)
73,5	Laboratory	5	0,6	20	144,1	3000U (Two)
56	Classroom	5	0,6	25	158,6	3000U (Two)
56	Storage	2,5	0,3	15	54,3	2100G
116	Veterinary Medicine	5	0,9	20	204,4	2400U (Three)
68	Classroom	5	0,6	25	165,8	3000U (Two)
52	Classroom	5	0,6	25	156,2	3000U (Two)
52	Classroom	5	0,6	25	156,2	3000U (Two)
110	Classroom	5	0,6	25	191	2400U (Three)
70	Storage	2,5	0,3	15	58,5	2100G
48,1	Classroom	5	0,6	25	153,86	3000U (Two)
114,7	Veterinary Medicine	5	0,9	20	203,23	2400U (Three)
73,5	Storage	2,5	0,3	15	59,55	2100G
35	Classroom	5	0,6	25	146	3000U (Two)
49	Classroom	5	0,6	25	154,4	3000U (Two)
105	Classroom	5	0,6	25	188	2400U (Three)
93,5	Classroom	5	0,6	25	181,1	2400U (Three)
72,8	Classroom	5	0,6	25	168,68	2400U (Three)
48,45	Classroom	5	0,6	25	154,07	3000U (Two)
41	Classroom	5	0,6	25	149,6	3000U (Two)
38,45	Classroom	5	0,6	25	148,07	3000U (Two)
52	Classroom	5	0,6	25	156,2	3000U (Two)
31,04	Classroom	5	0,6	25	143,624	3000U (Two)
29,6	Odontology	5	0,9	20	126,64	2400U (Two)
29,6	Biomedicine	5	0,9	20	126,64	2400U (Two)
29,6	Classroom	5	0,6	25	142,76	3000U (Two)
41,3	Storage	2,5	0,3	15	49,89	2100G
24,5	Classroom	5	0,6	25	139,7	3000U (Two)
105	Theater	2,5	0,3	60	181,5	2400U (Three)
93,5	Classroom	5	0,6	25	181,1	2400U (Three)
84	Classroom	5	0,6	25	175,4	2400U (Three)

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An important part of all chillers systems is the pipe insulation, this will ensure that heat isn't lost during the water/air travel through the building, while preventing water condensation from forming that would damage the pipe. Armacell offers a vast series of products, ranging from water pipe insulation, flexile air duct insulation and diffusers for the air outlet. The main water pipe will have 130 mm in diameter to make space for the whole flow rate that comes out of the chiller, for this pipe will be chosen the Armaflex M110. For the piping in the branch selector output/input pipe the diameter chosen is 54 mm and used Armaflex M054.

The AHU will require some air duct to conduct the air to the whole second floor roof, to ensure a good weather resistance and temperature isolation, Armaflex duct ALU sheet series ADU-19MM/E-L will be used this include the pipe to conduct the air to the chilled beams.

One branch controller will be used in each floor to distribute the chilled water without the need to use enormous pipes, this will make sure a good aesthetics is kept inside the building, it also provides an easier way to branch the water pipe to all chilled beams.

3. RESULTS AND DISCUSSIONS

A plant with the representation of all components is made, see figure 3. The AHU for all the main area is kept on the building roof, along with the air chilled beam, water pump and air pump, which is the standard for chillers systems. The chiller branches initially to the AHU and to all three branch controllers, which then branches the water pipe line to all chilled beams in the floor.

Figure 3 – Schematics of the hypothetical piping. (1) is the Branch selector and (2) are all Chilled Beams. Light blue line is the pipe line where flows the water around 8 ºC and dark blue line is the pipe line for the return water, around 14 ºC. Red line shows the air supply line. Representation of the first floor.

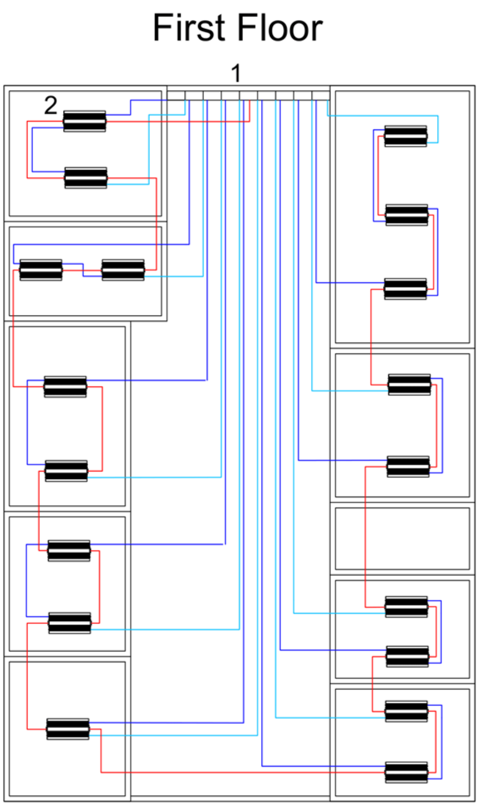

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Figure 4 – Representation of the second floor, same schematic as the Figure 3 and 5.

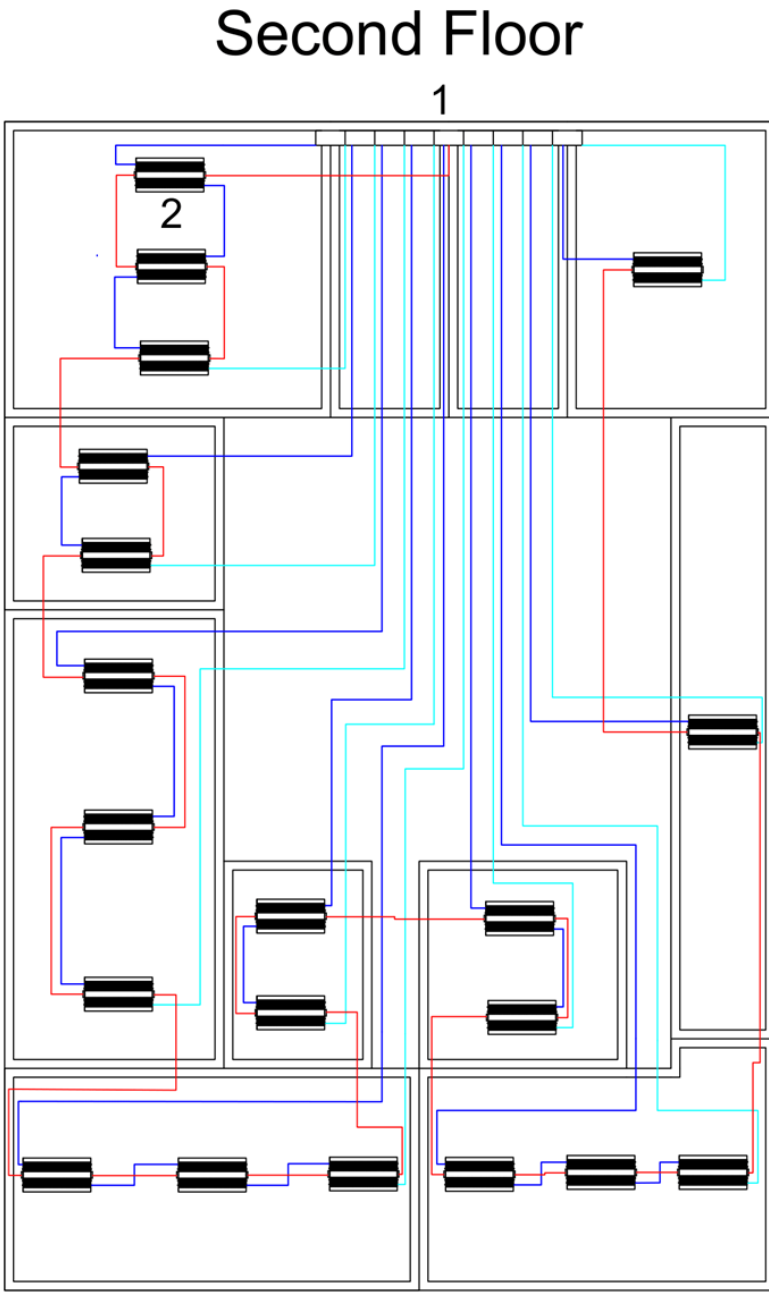

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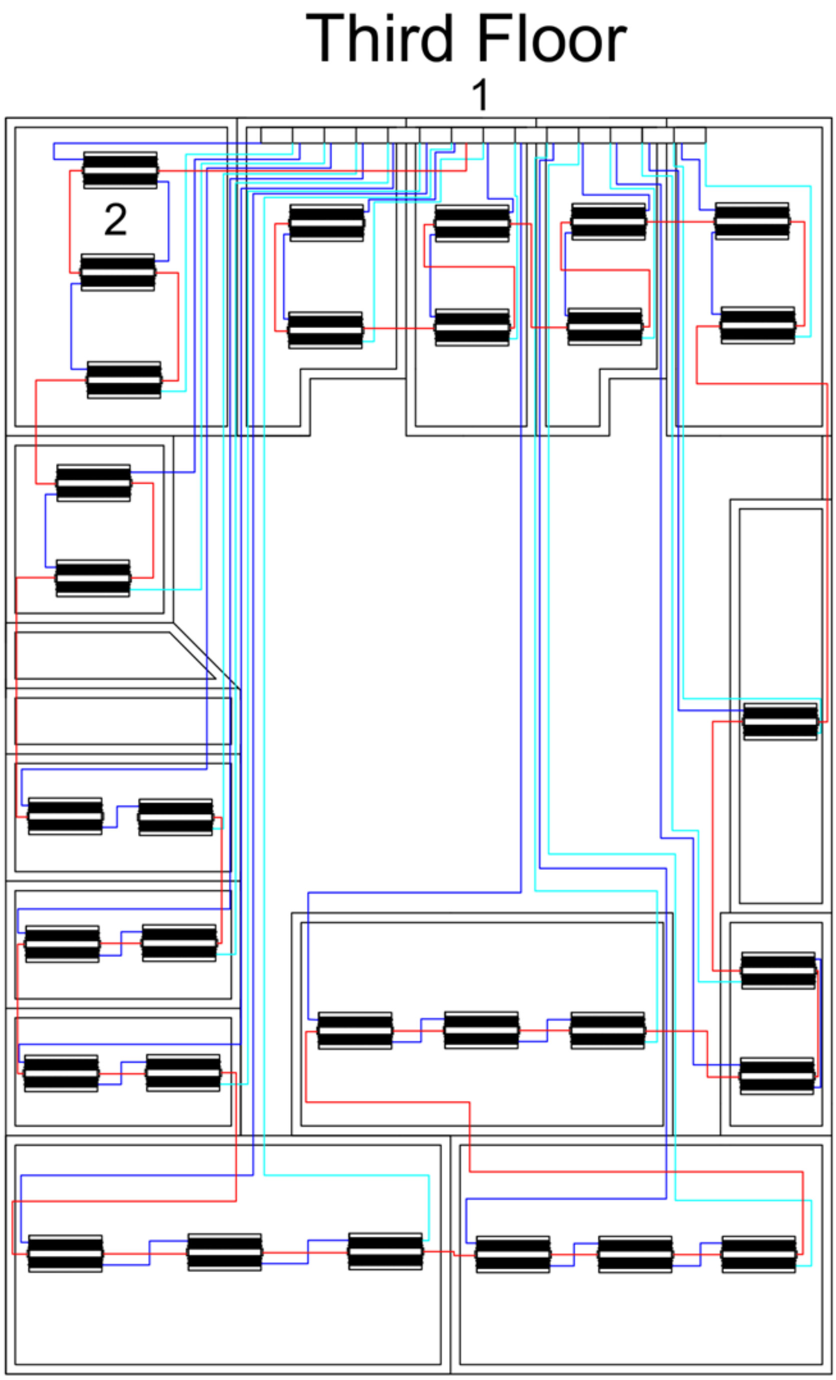
Figure 5 – Representation of the third floor, same schematic as the Figure 3 and 4.



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The AHU outlet is only on the roof, there's no need to pump this air deep into the building since the main hall, staircase and bathrooms have no physical border, the air can easily flow through all this area, the only thing pumped to the building inners are the chilled water and the renovation air.

Unisul classes happens during the night from 7 pm to 11 pm, a total of 4 hours that the chiller will be kept active, but some students arrive an hour earlier and the chiller needs some time to actually refrigerate the whole building to the correct temperature of 24º C, so the total usage is around 6 hours daily. Classes only happen from Monday to Friday, a total of 230 days in a year. Tosi air chillers have a high energy efficiency of 5 E.E.R. The total watts consumption based on energy efficiency is needed to calculate yearly energy consumption of this 180 RT chiller.

$$Electricity = BTU/EER$$
$$Electricity = 2.160.000/5$$
$$Electricity = 430.000\ kW$$

$$Consumption = \frac{Electricity \times Daily\ hours \times Days \times Year}{1000}$$
$$Consumption = \frac{430.000 \times 6 \times 230 \times 1}{1000}$$
$$Consumption = \frac{430.000 \times 6 \times 230 \times 1}{1000}$$
$$Consumption = 596.160\ kW/h$$

$$Cost = Consumption \times kW/h\ \ price$$
$$Cost = 596.160 \times 0{,}505$$
$$Cost = 301.060\ R\$\ /\ year$$

A total of 432 kW is consumed by the chiller alone during its usage. In a year, a total of 596.160 kW/h is used. The average price of 1 kW/h is R$ 0,505, summing to R$ 301.060 yearly. Active Chilled beam doesn’t consume electricity directly, the only energy consumption is based on the fan that will provide air to those components. It will be presumed the usage of 3 air supply systems, one for each floor. A supply system consists of just ventilators to provide external air to the air pipe line. Each supply system cost R$ 5.320, summing to R$ 15.960 yearly.

The AHU will be the one who least consume energy as it is more efficient in its energy usage and with the return air temperature reuse, a total of R$ 12.230 yearly, it is clear that the AHU could be kept active for longer times using just some of the modular chiller active, this would provide a good air circulation for staff while classes aren’t happening.

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Summing all consumption, the cost of this system will wield a total of R$ 329.250 yearly, or R$ 1.431,52 daily, a high price to pay to make sure the whole college has a high standard air condition, including ideal temperature and air change rate.

4. FINAL CONSIDERATIONS

Chiller systems for air conditioning are increasing in popularity due to multiple factors, like modularity, easy installation and high efficiency, but they come with high energy consumption and maintenance cost. Its costs are proportional to the amount of RT needed to refrigerate the building, some actions can be taken to reduce this amount, such as blackouts in windows, better thermal isolation in windows and walls, higher efficiency chilled beams and chillers.

It seems that AHU consumes less energy than the Chilled Beam for the amount of area it can cover, in the future, a better study in the use of only AHU to refrigerate the whole building is needed. Some classrooms have multiple chilled beams, this is to provide ideal air flow rate, this number can be reduced if the main AHU can provide extra air change.

The energy usage reflects only a small parcel of the days in a year as it would require all chillers and chilled beams to be active, which doesn't happen in most of the days, especially during winter and autumn. A deeper study is required to properly know how many students simultaneously are on the same day in each room, that would allow to reduce the number of chilled beams. Table 2 shows how reducing the number of active chillers would reduce the energy consumption.

Table 3 - The difference in price by reducing 2 modules of 15 TR until it reaches the minimum of 60 TR.

Total RT	Equivalent (BTU/h)	Electricity (W)	Consumption (W/h)	Cost (R$)	% of area of the building	Daily consumption (R$)
180	2160000	432000	596160	301060,8	100%	1308,96
150	1800000	360000	496800	250884	83%	1090,8
120	1440000	288000	397440	200707,2	66%	872,64
90	1080000	216000	298080	150530,4	50%	654,48
60	720000	144000	198720	100353,6	33%	436,32

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As seen in table 3, by reducing the amount of chiller modules active simultaneously, the area that the chiller will be able to cover is also reduced, this is shown in the "percentage of area of the building". For instance, if on said day only half the classes are occupied, only 6 modular chillers of 15 TR would be required to properly condition this area.

The air supply for each floor could also be swapped for smaller AHU, only enough to provide enough air flow rate. AHU would provide some extra characteristics to the air that will be forced through the chilled beams, allowing a control over humidity and the reuse of some of the conditioned air to reduce energy consumption. Furthermore, swapping some of the active chilled beams for passive chilled beams is another study point. A deeper search is needed to prove if those scenarios could be more effective.

This conclusion can aid in the selection of methods for future studies related to correct sizing of a chiller system for medium and small buildings.

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