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Use of water generated by air conditioners for non-potable purposes

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ABSTRACT
This study aims to evaluate the [redacted]
building located in the city of [redacted]
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KEYWORDS: Air condi[redacted]

1 INTRODUCTIO[redacted]

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on the production [redacted]
Fontes, Jar[redacted]
(2015); Cu[redacted]
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2 OBJECTIVES

in this context, this work aims to identify the potential for using the condensate water produced by air conditioners and its possible use in a building, having as a case study a hospital building in Recife, since part of the building consumption does not require the use of potable water.

3 METODOLOGY

3.1. The edification

The hospital under study belongs to a private healthcare network. The building where it is installed was inaugurated in 2011, and has a constructed area of 22,000 m², distributed over 15 floors, where 204 beds, 10 operating rooms, 258 parking spaces in the garage building, and a gree n area of 516.55 m².

3.2. Air conditioning equipment

The building's air conditioning system is composed of indirect expansion equipment, powered by the chilled water system, and direct expansion equipment powered by refrigerant gas. One refrigeration ton (1 TR) corresponds to 12,000 BTU/h, which is the British Thermal Unit per hour, the most commercially used unit. The number of air conditioning equipment in the building is 339 with varying thermal capacities. The sum of the thermal capacity of the equipment served by the chilled water system is 763.54 TR, and of the equipment that uses refrigerant gas is 161.71 TR, for a total thermal load value of 925.25 TR in the building, which corresponds in British thermal units to 11,103,000 BTUs.

3.3. Measurement of the condensate water

The water volume of the condensate was estimated in three different ways. The first through the use of a graduated beaker where equations were applied to estimate the total volume of water.

A specific methodology was adopted, where three measurements were performed, each with an interval of three minutes, in one equipment of each thermal capacity, then the average was calculated to obtain the volume produced by this equipment. The volume was multiplied by the operating time of the equipment to find the daily volume of water produced by the condensate. The calculation was performed from equations 1 and 2

$$QDIA = \frac{QCP \times TF}{TM} \qquad \text{Equation (1)}$$

QDIA= Amount of water produced during a day;
QCP= Amount of condensate water produced during a period;
TF= Running time of the equipment;
TM= measurement time.

$$QMÊS = \underline{QDIA \times DM} \qquad \text{Equation (2)}$$

QMÊS= Amount of water produced during the month;
QDIA= Amount of water produced during a day;
DM= Number of operating days in the month.

The second, by means of a pluviometer with an Arduino Datalogger, installed at the outlet of the drainage of the equipment (fan Coil) of 5 TR of the 1st pavement, 15 TR of the 4th pavement and 15 TR of the 5th pavement of the South technical floor.

The periods that the raincouge passed in each equipment was from 19/02 to 26/04 of 2019 in the fan Coil of 5 TR, from 27/04 to 20/05 of 2019 in the fan Coil of 15 TR of 4' Pavimento and 16/09 to 12/10 of 2019 in the fan Coil of 15 TR on the technical floor

The third measurement methodology was through hydrometers installed in the general drainage networks of the North and South technical floors through which the condensate water passes. The latter verified the amount of condensate water that the building collected for non-potable use.

3.4. Estimate of the non-potable demand

Four non-potable building demands were estimated for possible consumption points of condensate water. Water for washing floors and wiping with the MOP is one of them. In the building, these services are performed by an outsourced company that has a pre-established cleaning schedule approved by the hospital management.

For floor washing, the water consumption rate to calculate the water demand of the environments was according to the rate presented by (TOMAZ, 2010) of 2 L/m2. Based on this rate, equation 3 was adopted to estimate the volume of water consumed for this type of use.

DMONTH (washing) = <u>AREA x TC x DM</u> Equation (3)

DMONTH= Water demand for floor washing during the month;
AREA= Environment area;
TC= Consumption rate;
DM= Number of times the room is washed in the month.

Cleaning with MOP is carried out in two ways, with cart or bucket. The cart has a bucket with a maximum capacity of 20 liters that is used in the ICU's and the second with a bucket of maximum capacity of 28 liters that is used for cleaning in other areas.

Using the maximum capacity of the bucket is not recommended so that it does not overflow during the operation, a volume that corresponding to about 65% of its maximum volume. Being adopted for calculation basis in this work the values of 13 and 18 liters, respectively.

Equation 4 was used to estimate the volume of water used for the wiping process in the building environments. It is worth noting that according to ANVISA (2010), the rinsing water is no longer considered clean after the first rinsing of the MOP.

DMONTH (mopping)= <u>VB x QB x DM</u> Equation (4)

DMONTH = Water demand for floor cleaning with MOP during the month;
VB = Volume of water in bucket;
QB = Amount of buckets per environment
DM = Number of times the environment is cleaned in the month.

For garden irrigation the common rate is 2 L/m2 x day (TOMAZ, 2010). The garden areas were obtained from the building's architectural design data. The frequency of irrigation is 2 times a day. The garden consists of grassy plants and small shrubs. The equation used was similar to that for floor washing.

DMONTH (jardim) = <u>ÁREA x TC x DM</u> Equation (5)

DMONTH = Water demand for garden irrigation during the month;
AREA= Garden area;
TC= Consumption rate;
DM= Number of days the garden is watered in a month

In the cooling tower, according to Alpina (2019) water losses are small and do not exceed, as a rule, 2% of the circulating water flow, assuming thermal differentials and normal climatic conditions. The losses add up from evaporation, the dragging of very fine droplets by the fans, and also from deconcentration purging. Drag and deconcentration purge must be considered together, because both do not contribute to the increase of hardness of circulating water

In the study, the volume of water losses from the cooling tower was measured through the hydrometer installed to measure the volume of water purged by the towers. The volume of water lost by dragging and evaporation were not considered. The readings were performed weekly to record the variation of the volume of purged water, volume which is replaced by the system compensation box.

4 RESULTS

4.1. Forecast through the graduated beaker

The potential estimate of the condensate water generation with the aid of the graduated beaker was subdivided into four groups, which are: apparatus of the technical floor north (PT North), technical floor south (PT South), other hydronic appliances (supplied by ice water) and appliances using refrigerant gas as cooling fluid.

The operation time of the air conditioning equipment located in the PT (fan coils) and of the hydronic equipment inside the building is 24 hours (1440 minutes), for the refrigerant gas equipment, it was estimated an average operation time of 16 working hours (960 minutes), because they are located in environments with fixed working hours, such as the administrative sectors of the hospital.

Equations (1) and (2) were used to estimate the daily and monthly condensate water production. Table 1 shows the water volume of the total condensate produced by the system. The equipment whose lines are highlighted were measured with the beaker, the other volumes were established by a rule of three to estimate the volume produced in relation to the thermal capacity of the equipment, as there was difficulty in accessing these equipment.

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Table 1 - General condensed water production

	Equipments	Quant.	Capacity (TR)	Average volume measured (L in 3 minutes)	Operating time (minutes)	Total daily volume (L)	Total daily volume (m³)	Total month volume (m³)
PT north	Fan coil	1	40	6,9	1440	3312,00	3,31	86,11
	Fan coil	2	25	6,48	1440	6220,80	6,22	161,74
	Fan coil	1	20	3,45	1440	1656,00	1,66	43,06
	Fan coil	1	15	0,42	1440	201,60	0,20	5,24
	Fan coil	2	12	2,27	1440	2185,54	2,19	56,82
PT south	Fan coil	1	25	6,48	1440	3110,40	3,11	80,87
	Fan coil	2	15	0,42	1440	403,20	0,40	10,48
	Fan coil	3	8	0,1733	1440	249,55	0,25	6,49
	Fan coil	10	5	0,1683	1440	807,84	0,81	21,00
Hydronic equipment (indoor environments)	Fan coil	1	15	0,42	1440	201,60	0,20	5,24
	Hi wall	2	0,625	0,021	960	13,464	0,01	0,35
	Hi wall	3	0,75	0,0583	960	55,968	0,06	1,46
	Cassete	8	1,17	0,039	960	100,818	0,10	2,62
	Cassete	103	1,5	0,0433	960	1427,17	1,43	37,11
	Cassete	10	1,67	0,056	960	179,88	0,18	4,68
	Hi wall	1	1,83	0,062	960	19,71	0,02	0,51
	Hi wall	29	2	0,067	960	624,73	0,62	16,24
	Hi wall	3	2,5	0,1133	960	108,77	0,11	2,83
	Hi wall	4	3	0,101	960	129,25	0,13	3,36
	Hi wall	2	3	0,101	960	64,63	0,06	1,68
	Hi wall	41	3,13	0,105	960	1382,27	1,38	35,94
	Hi wall	1	3,5	0,118	960	37,70	0,04	0,98
	Hi wall	4	4	0,135	960	172,34	0,17	4,48
	Hi wall	4	4,58	0,154	960	197,33	0,20	5,13
Refrigerant gas equipment (indoor environments)	Split (VRF)	11	0,65	0,0219	960	77,01	0,08	2,00
	Split (VRF)	6	0,75	0,0583	960	111,94	0,11	2,91
	Split (VRF)	2	0,83	0,0279	960	17,880	0,02	0,46
	Split (VRF)	19	1	0,0337	960	204,65	0,20	5,32
	Split (VRF)	9	1,05	0,0353	960	101,79	0,10	2,65
	Split (VRF)	14	1,5	0,0433	960	193,98	0,19	5,04
	Split (VRF)	6	1,65	0,0555	960	106,63	0,11	2,77
	Split (VRF)	2	1,83	0,0617	960	39,49	0,04	1,03
	Split (VRF)	7	2	0,0673	960	150,80	0,15	3,92
	Split (VRF)	6	2,08	0,0700	960	134,42	0,13	3,50
	Split (VRF)	2	2,5	0,1133	960	72,51	0,07	1,89
	Split (VRF)	9	3	0,101	960	290,82	0,29	7,56
	Split (VRF)	3	3,3	0,111	960	106,63	0,11	2,77
	Split (VRF)	3	4	0,1346	960	129,25	0,13	3,36
	Split (VRF)	1	5	0,1683	960	53,86	0,05	1,40
				Overall total volume of condensed water		24654,24	24,65	641,01

1 Source: Authors, 2021

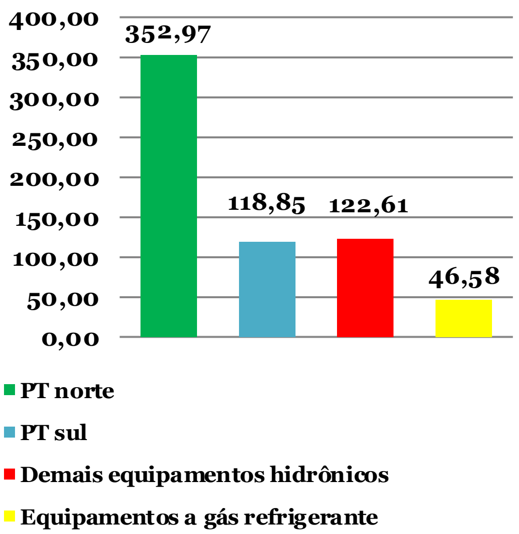
It is possible to observe that there is a variation of water production between the fan coils of 12 and 15 TR that can be considered unusual, because the equipment of lower thermal capacity produced a volume of approximately 5.4 times higher than that of greater capacity. The reasons for this variation were not studied, being considered as a particular case of this system.

In the south PT the most expressive result was observed between the water production in the fan Coils of 15 and 25 TR, where it was calculated deductively by the simple rule of three , the volume produced by the equipment of 25 TR based on the volume measured in 15 TR, would be a value of 0.7 liters in 3 minutes of measurement, but the volume of water was 9.25 times higher.

Indirect expansion systems have the possibility of using various equipment location arrangements (fan Coils), air distribution duct networks (outdoor air, inflation and return air) as pre-established by the designer. This difference between arrangements can influence the production of condensed water, since there is the possibility of mixing air with different temperatures and humidities (exterior with inflation, exterior with return and among others).

The volumes corresponding to the proposed subdivision for the system are presented in graph 1 according to and methodology of the beaker. The first period used as a calculation basis for estimating monthly production was between 06/05/2019 to 03/06/2019, for 26 days.

Graph 1 - Water consumption indicators as m³/m²/year.



Source: Authors, 2021

When observing the relationship between the condensate water production and the thermal capacity of the equipment in the subdivision presented, the north PT has a total of 149 TR, south PT has 129 TR, the other hydronic equipment has 450,54 TR and refrigerant gas equipment have 161.70 TR.

The thermal capacity of the equipment in the northe PT is approximately 15.5% higher than that of the south PT, however the condensed water production estimated by the equation was higher than 296.98%. The hydronic equipment has a greater capacity of than the sum of all remaining thermal capacity of the building equipment, however it is 287.88% lower estimate of water production of the north PT.

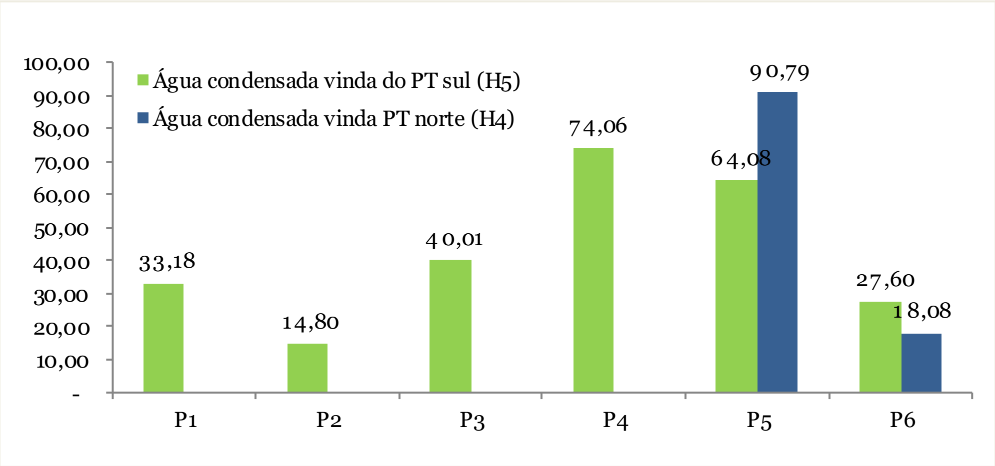
4.2. Forecast through the hydrometer

A The building has a water treatment system that captures several sources in order to reuse this resource. The system has a total of 6 hydrometers (H) installed, being distributed: H1 - water from the local utility, H2 - treated water coming from the building system, H3 - tower purge water, H4 - PT North condensate water, H5 - PT Sout and H6 condensate water - Treatment system disposal.

The data collection occurred in the hydrometers H4 and H5, which are installed in the general drainage of the equipment of the PT north and PT south respectively. The total water production of condensate was analyzed from May to October 2019 (six months), subdivided into 6 periods (P), where: P1 - (06/05 to 03/06); P2 - (03/06 to 03/07); P3 - (03/07 to 30/07); P4 - (30 to 30/08); P30/09 (30/09).

H4 was installed on 08/20/19 after the release from the administration responsible for the building maintenance. The volume of water generated by the appliances present in the south and north PT are shown in graph 2.

Graph 2 - Volume of condensed water (m³) recorded in the period (P)



Source: Authors, 2021

There is a significant variation between the volumes recorded by the hydrometer between periods, where in P2 and P4 for the south PT, there is a difference in volume of water collected of 59.26 m³, and the smallest difference was recorded in the period P4 and P5 with 9.98 m³. In the period P5 that covers predominantly the month of September, the building used a volume of 154.87 m³ of condensed water for non-potable purposes, and in the P6 referring to October a volume of 45.68 m³.

As the water treatment system works autonomously, it was not possible to clearly understand why the volumes captured by the system show the observed volume variations. Because the treatment system is supplied from other sources, it is believed that it will only start pumping from the condensate water reservoirs when necessary.

The volumes recorded by the hydrometers can be considered partial, as they only cover the water collected in PT North and PT South. In addition, when the treatment automation system demands, otherwise condensate water will be discharged. The other hydronic and refrigerant process equipment scattered throughout the building does not have its drainage connected to the system, and the condensate water is also directed to disposal.

4.3. Rain gauge with arduin

Before analyzing the behavior of condensate water production in the equipment of 5 and 15 TR located in the southern PT, a verification test was performed to observe the relationship between the volume of water generated in a period of time in relation to the volume recorded by the Arduin connected to the pluviometer, taking into account the temperature and relative humidity of the air at the time of each verification. The test was performed in a 12,000 BTU air conditioning equipment installed in an administrative room with an area of 19.50 m², with 2 fixed workstations. The openings of doors for the transit of people were not considered. The data collected was for 2 days and is shown in table 9.

It was sought to find the relationship between the volume produced measured through the beaker (ml) and the volume recorded by the Arduín connected to the pluviometer (mm),thus finding the equivalent contribution area that will belater used to find the volumes in ml for the other values in recorded by Arduíno. (mm).

$$V(ml) = \frac{Lpluv}{Área\ \emptyset} \qquad \text{Equation (6)}$$

V (ml)= Volume of water produced over a period measured with the beaker;
Lpluv= Reading of the volume in the rain gauge over a period in millimetres (mm);
Area Ø= Contribution area of the rain gauge in square meters (m²)

After applying equation 6, and finding the areas of contribution for each period in relation to the volumes recorded, the average between the areas was removed, which will be used to calculate the volumes of water from the condensate produced by the equipment of 5 and 15 TR

Tabela 2 - Alternatives for reducing water consumption in hospitals

	Interval (hour)	Volume recorded by the beaker (ml)	Rain gauge register (mm)	Contribution area (m²)
1° day	10:00 - 11:00	1180	Falha	-
	11:00 - 12:00	1400	77,75	0,0555
09/09/2019	12:00 - 13:00	1150	59,50	0,0517
	13:00 - 14:00	1195	61,5	0,0515
2° day	10:00 - 11:10	1500	94,5	0,0630
	11:10 - 12:00	1625	63,00	-
10/09/2019	12:00 - 13:10	1640	84,00	0,0512
	13:10 - 14:00	1250	62,00	0,0496
Average				**0,0538**

Source: Authors, 2021

To analyze the behavior of condensate water production in the air conditioning equipment where the rain gauge was installed with arduin, the data presented followed the criteria of being used only the data that contained the complete daily record of the volume, being discarded the days that presented some failure in the reading or storage of the information.

The first installation occurred in the 5 TR fan Coil, between the period of 19/02 to 26/04 of 2019, corresponding to 67 days of measurement. Of these, only 14 days showed complete daily data. The second installation on the 15 TR equipment on the 4th floor of the south PT was between the period from 04/27 to

05/20 2019, which give 24 days of measurement. The arduino from this period stopped taking readings and was removed for maintenance.

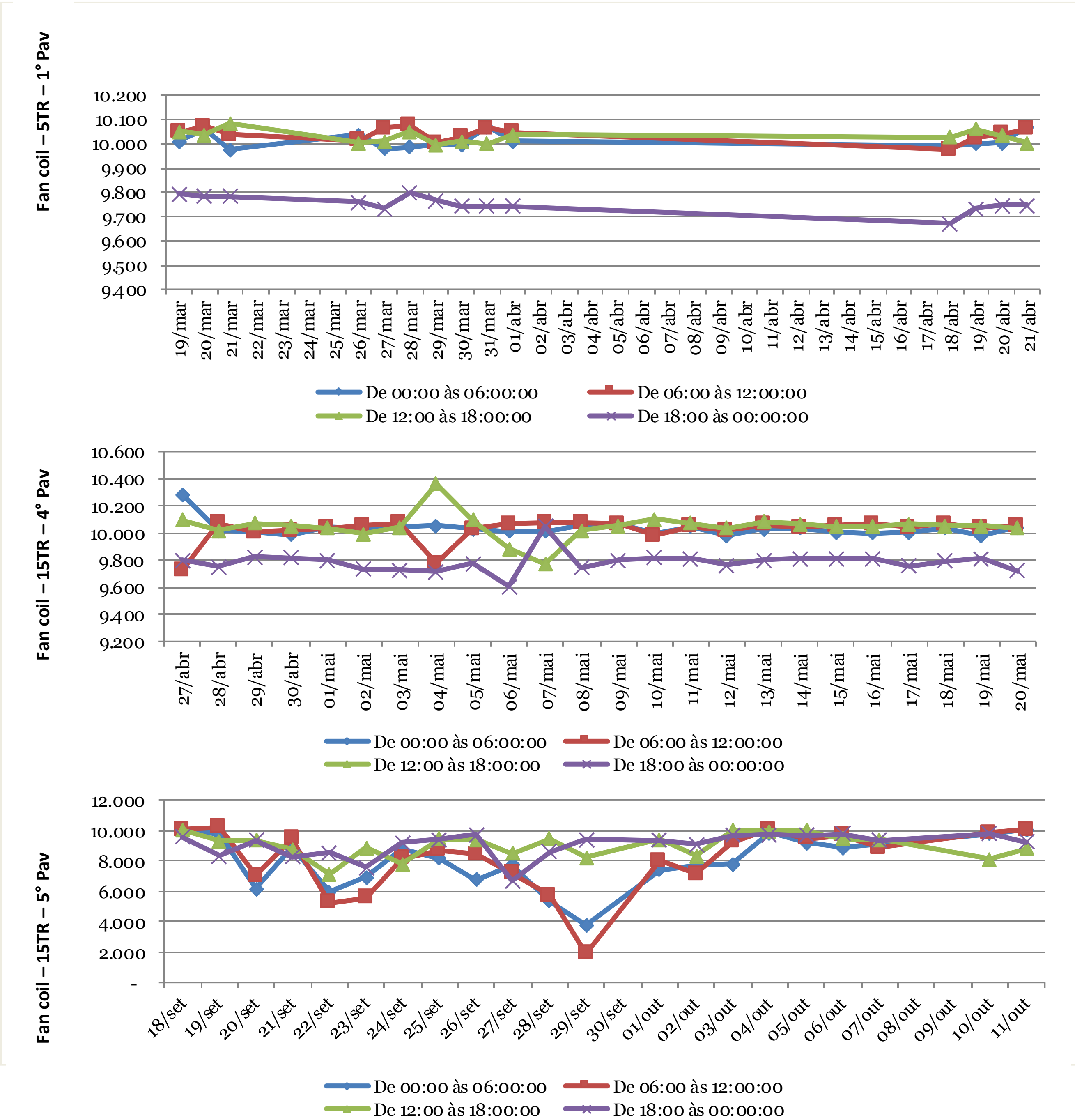
Failures were observed at the time the data were being collected. The collection took place between the period of one to two weeks. In a few days, some data were not recorded, and in others, there were gaps between the records, which came to be hours. Days with failures were excluded for calculation purposes.

The possible factors that contributed to the occurrence of failures were the falls and/ or power oscillation, where the Datalogger turned off for an uncertain period and did not return to operation normally after the event, another possible failure is linked to the operation of the motion sensor installed in the rain cauge that would not be in full operation. For this last factor presented, it was taken the action of replacing the sensor.

With the rain gauge maintenance performed, the third installation occurred on the 15 TR fan coil located on the 5th floor of the south PT during the period from 9/16 to 10/12 2019, which corresponds to 27 days, of which only 21 days were complete. It is possible to observe that the behavior of the condensed water production in the 5 TR Equipment in the south PT does not have a large variation in production compared to the others, being 356 mL.

In the 15 TR fan coil on the 4th floor in the south PT it was also observed the maximum variation of the condensate water production reached 646 mL. In the third 15 TR equipment located on the 5th floor of the south PT, the maximum variation is already more pronounced, reaching 7,519 mL on one of the days. This variation shows the instability of the condensed water production, even for equipments that present the same technical operational parameters as the 15 TR fan coils. Graph 3 presents the times and days of condensed water collection.

Grapf 3 – General condesed water production



Source: Authors, 2021

4.4. Profile of non-potable building demands

For floor washing, the periodicity of this type of action was raised through the data provided by the company contracted by the hospital hygiene. Even if there is a schedule for carrying out the activities (preventive maintenance), depending on the level of hygiene that each environment requires, washing may occur at a higher frequency than scheduled, as in rainy days, where the flow of cleaning is greater because people transit wet can carry some kind of contamination of the streets. The volume of monthly demand for this point of consumption was 147.45 m.

In the case of floor cleaning with MOP, environments such as bathrooms, dressing rooms, kitchen, cafeteria, operating rooms and garage are not included in the schedule, because for these areas only the washes are scheduled

It is worth noting that the values found took into account the periodicities and number of cleanings of environments per bucket (18 liters) as informed by the maintenance company responsible for cleaning the hospital. The volume for monthly demand for mopping is approximately 181,74 m³.

The building has a garden in its main entrance that has a small variety of shrubs and its predominance are grassy plants. Watering is performed twice a day. The volume for monthly demand for garden watering was 61.98 m³.

The cooling tower water demand of the air conditioning system is determined by the volume of water that is purged. Through a hydrometer installed in the purge branch of the towers, it was possible to follow the volume of water discharged. The volume discarded according to each period was: P1 = 189,82 m³; P2 = 319,37 m³; P3 = 278,67 m³; P4 = 165,13 m³; P5 = 80.62 m³ e P6 = 300,73 m³.

The greatest variation presented between the periods was 238.75 m³ between the period P2 and P5. The amount of water purged daily is determined through the analysis of the water, and aims to reduce the concentration of contaminants in the water circulating the system. In the building it is controlled manually, where if the concentration of contaminants is high the operator can increase the opening of the purge valve or close at a lower concentration.

4.5. Potential of use of condensate

When an equipment is individually studied, the volume found can be considered insufficient to actually be used in building activities, but when the potential of all the equipment of a building is observed, water volumes become very satisfactory.

In graph 5 it is possible to observe that the volume that the building captured water from the condensate of the equipment in the period P5, would meet 100% the demand for floor washing, or garden irrigation and replacement of the cooling tower together. And partially mopping up more than 86% of the demand for this use. In the following period, the amount of water captured by the system was less expressive. In turn, the demand for cooling tower replacement based on its purge regime, grew by more than 375%. It is possible to observe that the amount of water captured would meet 73.69% of the garden's demand.

5. CONCLUSION

This study analyzed the potential of condensate water production of air conditioners for non-potable use within a building of hospital typology in the city of Recife, whose methodology can be replicated for other building typologies, locations in Brazil and the world.

The equations used in the first method showed that in 26 days the estimated volume as water production generated by the condensate of all equipment would be 641,01 m³. In the second method (rain sauge with arduin), water was collected from part of the equipment, which is located on technical floors on the outside of the building (PT south and north). The highest volume was captured among the 6 periods observed was 154,87 m³.

Some periods observed had a low condensate water collection through the building. This was due to the fact that the system used for water treatment had more than one source of supply for reuse (rain, autoclave, purge from cooling towers, and condensate from air conditioners), in addition to having automation, so that, when the volume of water was above the demand, the system did not trigger the pumping of condensate water, or even turn it off, discarding it into the collecting net.

Through the third method, the behavior of the condensate water production in three pieces of equipment was observed and shown to be different. Even the equipments that have equal operational parameters presented a variation in the condensate production in relation to the register time that reached approximately 650 ml (from 12:00 to 18:00 and from 18:00 to 00:00), and in another 7500 ml (from 06:00 to 12:00 and from 18:00 to 00:00). This highlights the importance of future investigations based on other parameters not addressed that will analyze the possible causes of the variation of condensed water in the equipment. Among the volumes raised for non-potable demand for building, three have little variation in their monthly volume estimates (Garden watering, Floor washing and Mopping), it is worth noting that these were determined by the proposed equations. The purging of the cooling towers, another demand raised, showed significant variations of up to 238.75 m³ of water between the observed periods, emphasizing that this volume is real, measured through a hydrometer installed in the purging system.

If the building carried out the total collection of condensed water based on the first equation, it would supply about 92.6% of the total demand of these four non-potable points of use, taking into account the scenario of greater non-potable demand between the studied periods that was 691,92 m³. It should be noted that the building has already used a volume of 154.87 m³ of condensed water in non-potable demands, a volume that is quite significant when linked to savings due to the non-use of potable water provided by the local concessionaire for this resource.

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