Impact of greywater reuse on domestic wastewater flow rate in a multi-storey building in Brazil

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ABSTRACT:The main objective of this study was to verify the impact of the greywater reuse system to flush toilets in wastewater flow rates of a multifamily residential building. The monitoring of blackwater and dark greywater was carried out installing a Parshall flume measurement system, and the flow rates of light greywater were measured with the installation of hydrometers. The monitoring was performed by daily readings of all the meters in the building starting 8 am, and also the survey of the four 24h production profiles. 64% of the wastewater produced corresponds to the total light greywater production. 22% correspond to the dark greywater and 14% to blackwater. The intervals of higher per capita production observed were: from 10 am to 12 pm for dark greywater and from 6am to 8am for blackwater. The time range of higher total wastewater production was from 10am to 12pm, when it was produced 85.09 ℓ/per.2h on average. The per capita production indicator of light greywater obtained was 152.02 ℓ/per.day, the indicator of dark greywater was 52.64 ℓ/per.day, and the indicator of blackwater production was 33.46 ℓ/per.day. The average per capita production of $WW_{Network}$ was 215.62 ℓ/per.day. The reduction impact in $WW_{Network}$ due to the reuse was 9.45% in the monitored building in this work.

Keywords: *Wastewater; Greywater reuse; Blackwater; Ecosan; Multi-storey building*

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1. INTRODUCTION

The problem of dealing with the increase of human waste has gradually grown in the world and has become a dilemma. In terms of sanitation in Brazil, the proper destination of human waste aims to control and prevent the diseases related to it (Funasa, 2006). But it became clear internationally that the sanitation systems should not only collect the human waste with hygiene and safety and dispose properly, but also offer an option to reuse the nutrients in agriculture (Niemczynowicz, 2001). The organic solid waste and domestic wastewaters are a potential source of nutrients, energy and water (Van Voorthuizen et al, 2005). The separation of these solid and liquid wastes at the source and the decentralized treatment can lead to an efficient use of the existing nutrient and at least 25% of reduction in the final consumption of potable water (Zeeman et al, 2007).

The conclusions of scientists and politicians, including the governments of several European countries, to make the nutrients in the wastewater available to recycling in agriculture, are that sanitary systems should be altered to allow the decentralization, perhaps to the level of a one single-family residence or a group of single-family habitations (Niemczynowicz, 2001). Therefore, the decentralized, sustainable or ecological sanitation (Ecosan) focuses on the segregated collection of the wastewater of different qualities, directing them to appropriate treatments (near the site where they were generated), intending to maximize the opportunities of reuse and recovery of nutrients, water and energy (Masi, 2009).

Although the main focus of Ecosan is the reuse of urine and excreta, as well as saving the potable water used to transport human excreta (Paulo et al., 2007), the reuse of greywater is an attractive alternative to conventional sanitation systems, because the water reuse in residential buildings is very interesting, considering that the water consumption in densely urbanized areas, at this scale, is up to 50% of total consumption (Gonçalves & Jordão, 2006). In addition, water reuse is a key part of reducing the pressure on water resources lowering the demand for potable water for purposes that do not require water's high quality (Chrispim & Nolasco, 2016).

According to Paulo et al. (2007), the separation of blackwater (from the toilets) from greywater (all effluent generated in a residence except the parcel from the toilets), reusing the second, would be a great step towards the implementation of the ecologic sanitation, since this practice would significantly reduce the volume of wastewater generated.

Therefore, the characterization of these various types of wastewater in residential scale is extremely important to the success of reuse projects, because the more information is obtained from the effluent, more appropriate the decision regarding the treatment that meets the stablished quantity and quality demands to the desired objective (Nour et al., 2006). Given the above, this research aimed to verify the impact of the greywater reuse system in wastewater flow rates of a multifamily building, through the characterization of the segregated wastewater production.

2. MATERIALS AND METHOD

2.1 Research contextualization

The research was developed in a multifamily residential building with greywater reuse system used to toilet flushing, located on an upscale neighborhood in the city of Vitória, Espírito Santo. The building has a Greywater Treatment Plant (GWTP) and also some water conservation measures such as individual

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hydrometers and equipment that promote water savings such as toilets with attached water reservoirs and faucet sink aerators.

The building also has two sources of water supply: a potable source, provided by the water utility company, and an alternative source, not potable, the recycled water. These sources are routed by independent systems: the cold potable water distribution subsystem and the recycled water distribution subsystem. The building also has a hot potable water distribution subsystem, as it has a collective and centralized water heating by solar panels located on the top of the building.

According to the building's hydrosanitary project, all the toilets in the pilotis floor and the standard floor should be supplied with reuse water. In the project, only the toilet in the doorman's bathroom was supposed to be supplied with potable water. However, in the monitoring, three toilets in the pilotis pavement and a few toilets in the maid's bathrooms of the standard pavements were being supplied with potable water through the hygienic hand shower feeding point, not using recycled water. It was not possible to quantify the number of toilets with this connection error because it was not possible to access every apartment. This connection error happened because the GWTP was not finished when the residents started to move in, so the water supply of the toilets was connected to the hygienic hand shower feeding point temporarily, with potable water, to make sure the toilets worked properly. In a few apartments it was forgotten to exchange this connection.

The wastewater collection system is segregated at the source. The wastewater from the shower, sinks, tanks and washing machines (WM) are collected by a special lateralpipe of light greywater (GW_{light}) and conducted by gravity to the GWTP. The wastewater from the kitchen sinks and dishwasher machine (DM), called dark greywater (GW_{dark}), area collected by a lateral pipe of dark greywater and send to a grease trap and to a final inspection chamber of the building, from where it goes to the public sewer network. The wastewater from the toilets (blackwater) is collected in a lateral pipe of blackwater, directed to the last inspection chamber of the building and then to the public sewer network.

2.2 Greywater Treatment Plant (GWTP)

The GWTP is located on the underground and occupies a total area 12 m^2, including the circulation area. It is composed by 6 modules with individual dimensions of 1.0x1.0x2.2 m (LxWxH), 2 pumps to recirculate the sludge, air compressor and a filtering system.

In this treatment plant the wastewater goes through an inlet chamber (Fig. 1), which retains the solids in the gross greywater and controls the inlet flow rate of the GWTP, directing the surplus to the public sewer network. The box inlet contains two regulation tulip-typeweirs of 100 mm of diameter (Fig. 2). The water which goes through the first tulip-type weiris directed to the GWTP, and the water which goes to the other tulip-type weir is directed to the public sewage system. The flow rate control is done by the adjustment of the height of the weirs.

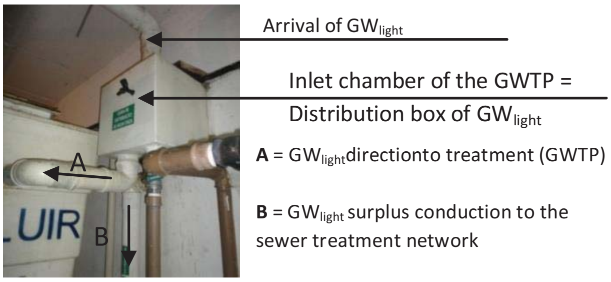


Figure 1. Greywater distribution box

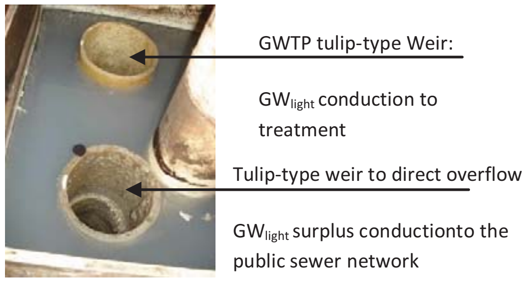
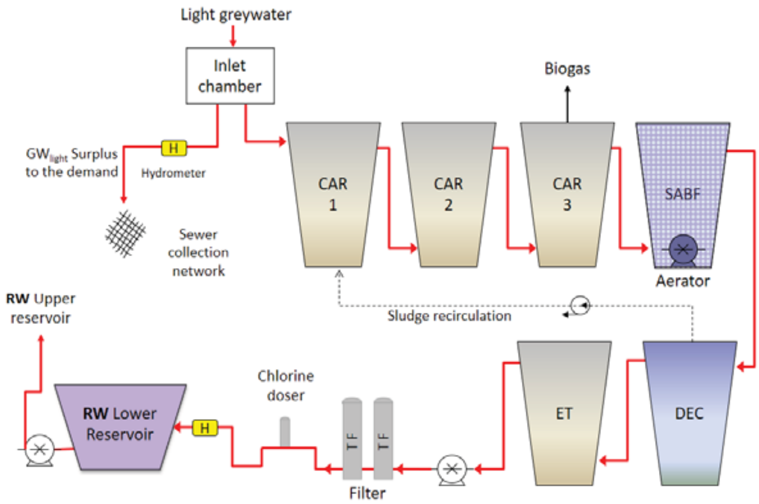


Figure 2. Tulip-type weirs of the inlet chamber

After that, the wastewater is conducted, in the following order, to the three compartments of the Compartmented Anaerobic Reactor (CAR), Submerged Aerobic Biological Filter (SABF), Secondary Decanter (SD), Equalization Tank, Tertiary Filter and chlorine disinfection, as the flowchart in Figure 3. Once the process finishes, the treated water, called recycled water, is stored in a lower reservoir, from where it is pumped to an upper reservoir, from which it will feed the toilets of the apartments. The reservoirs of recycled water and potable water are independent. In case it is needed, a reversion of the reuse system to use potable water was predicted.



Gw_{light} – Light greywater; RW – Recycled water; DEC – Secondary decanter; SABF - Submerged Aerobic Biological Filter; TF – Tertiary Filter; H – Hydrometer; CAR - Compartmented Anaerobic Reactor; ET - Equalization Tank

Figure 3. Flowchart of GWTP process.

2.3 Wastewater flow rate monitoring

To monitor the blackwater and dark greywater flow rates, a Parshall Flume (PF) was installed, equipped with an ultrasonic level sensor and a microprocessor-based converter, which provide an instant indication of the flow rate and the total volume that goes through, according to the detailed bellow (Pereira & Sasaki, 2002):

Parshall Flume (primary instrument) - flow rate measurement instrument compound by an open channel with standard dimensions - the liquid is forced through a narrow throat, and the liquid level upstream of the throat indicates the flow rate to be measured through a standard formula;

Level sensor (secondary instrument) - ultrasonic transducer which emits a sound wave that reaches the surface of the material and is reflected as an echo; the transit time or return time is measured, and the distance to the reflecting object is converted electronically into a distance indicator, which is then converted to level, flow or other desired parameters; and

Converter (secondary instrument) – microprocessor-based device which receives the level sensor signal (measurement of the depth of the water) and converts it to flow rate or volume totalization, depending on the features of the flume.

The Parshall flume (Fig. 4) with neck width of 1", made of fiberglass, has been installed in the last inspection chamber of the system before the connection with the public sewer network. The ultrasonic level sensor (Fig. 4) was installed in an area protected from the weather, in the converging section at 2/3 from the narrow throat of the Parshall flume, in a metallic bracket, leveled and centered on the axis of the throat, as determined by the manufacturer. The converter (Fig. 5) was installed on the service hall located on the building ground floor.

Figure 4. Parshall flume and ultrasonic level sensor

Figure 5. Converter

An admeasurement of the Parshall flume wastewater measurement system installed was performed and the values found were 39% higher than the real values. Thus, it was possible to correct the flow rate registered by the converter to obtain a closer value to the real wastewater flow rate. To monitor light greywater produced beyond demand, it was installed a hydrometer in the pipe that directs the surplus light greywater to the sewer collection network. This pipe is located after the overflow tulip-type weir on the distribution box of the greywater, on the GWTP.

Another hydrometer was installed in the treatment output, because the sum of the records of the two hydrometer would represent the total light greywater production ($GW_{light\ Total}$). The monitoring of the blackwater and dark greywater flow rates was carried out from September 2010 to January 2011. Whilst the light greywater flow rates were monitored between December 2010 and January 2011. The monitoring of the wastewater was carried out through daily reads of the measuring devices in the morning, starting at 8am. Furthermore, four 24h production profiles, in which were registered by hydrometer readings every 2h, also starting 8am. The reading was manual and performed by only one person, so the same reading sequence was executed every day.

2.4Characterization of domestic wastewater flow rates

With the installation of the wastewater measurement equipment it was possible to calculate the blackwater plus the dark greywater production (P_{BW} + GW_{dark}), the production of light greywater demand surplus thrown into the collection network ($P_{GW\ Light\ Network}$), the total production of light greywater ($P_{GW\ Light\ Total}$), the total domestic wastewater production thrown into the collection network ($P_{WW\ Network}$) and the total wastewater production ($P_{WW\ Total}$) of the building.

As the effluent measured in the Parshall flume system (PFS) is BW with GW_{dark}, only the volume of the BW was calculated separately. Considering that the BW are the effluent from the toilets (T), including water, urine, feces and toilet paper and, in the building analyzed, the recycled water (RW) supplies only the toilets, the daily production of BW was calculated based on the RW consumption data, which is the toilet consumption; the daily frequency of toilet use to urinate and defecate per person (obtained from Aguiar 2011); the average volume of excreted feces per person per each act of defecating ; the average volume of urine excreted per person per urination (obtained from Aguiar 2011); and the building population,

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obtained from the doorman's monitoring. Once the BW production is found, the GW_{dark} is calculated by subtracting the BW of the value measured by the PFS.

2.5 Indicator of per capita production of domestic wastewater

The indicator of per capita production of domestic wastewater (ℓ/per.d) is defined as the volume of the production of domestic wastewater produced per person per day. As there is a water segregation system in the building, production indicators per capita of GW_{light}, GW_{dark}, BW, $WW_{Network}$ and WW_{Total} were calculated. The indicator of per capita production of GW_{light} corresponds to the total production of GW_{light} per person per day, including the amount which was reused, that is, the offer of GW_{light} produced per person. The indicator of total domestic wastewater production per capita in the building corresponds to the total amount of domestic wastewater produce per person per day in the building, including the quantity of reused GW_{light}. And the indicator of $WW_{Network}$ corresponds to the total domestic wastewater produced per person per day in the building, except the amount of GW_{light} reused.

2.6 Evaluation of the reuse impact on the domestic wastewater flow rates

The evaluation of the reduction impact of $WW_{Network}$ was performed from the analysis of the per capita indicators of production of $WW_{Network}$ and WW_{Total} of the monitored building, with ten days of monitoring. In the situation without reuse, all the wastewater produced goes straight to the sewage treatment network. Therefore, the impact of the reducing the discharge on the network was calculated as Equation 1 below:

$$RI_W = \frac{PI_{WW\,Total} - PI_{WW\,Network}}{PI_{WW\,Total}} \times 100 \ (\%) \qquad (1)$$

where RI_W = is the impact of reducing the domestic wastewater on the sewage network (%), $PI_{WW\,Total}$= is the indicator of the per capita production of WW_{Total} (ℓ/per.d), e $PI_{WW\,Network}$ = is the indicator of per capita production of $WW_{Network}$ (ℓ/per.d).

3. RESULTS

3.1 Wastewater flow rate history

The production history of blackwater (BW) and the dark greywater (GW_{dark}) in the building was obtained through daily monitoring, from September 1, 2010 to January 23, 2011. As for the light greywater production sent to the network ($GW_{lightNetwork}$) and the domestic wastewater sent to the public sewer network ($WW_{Network}$) were monitored in a few days of December and January, with 11 days of monitoring for light greywater and 10 days of monitoring for domestic wastewater released in public sewage collection system.

3.2 Domestic Wastewater distribution

Figure 6 shows the distribution of total domestic wastewater produced in the building, in which is possible to verify that 64% corresponds to $GW_{light\,Total}$, with an average volume of 9 m^3/day; 22% correspond to GW_{dark} with an average production volume of 3.12 m^3/day; and the smallest parcel, 14% corresponds to BW with an average volume of 1.98 m^3/day. However, a parcel of the GW_{light} (1.86 m^3/day) is reused after the treatment to flush toilets and 7.4 m^3/day are directed to the public sewer network. The Figure 7shows the distribution of the WW sent to the sewage network. On average, 16% (1.98 m^3/day) of the WW of the building sent to the public sewer network correspond to BW, 26% (3.12 m^3/day) are GW_{dark} and 58% (7.14 m^3/day) correspond to $GW_{lightNetwork}$.

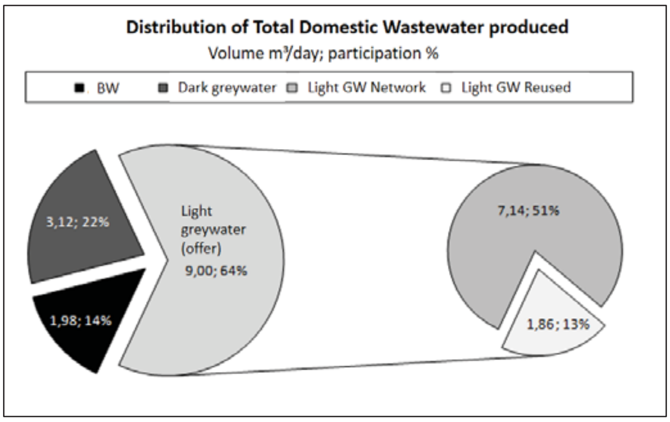

Figure 6. Composition of the WW_{Total} produced.

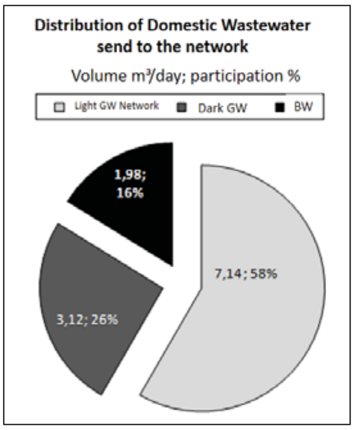

Figure 7. Composition of $WW_{Network}$

3.3 Variation of WW production throughout the day

The profiles of the 24h production per capita of BW, GW_{dark}, $GW_{light Network}$, $GW_{light Total}$, $WW_{Network}$ and WW_{Total} are shown in Figure 8. It is possible to notice that the per capita profile of GW_{dark} showed the highest production peak from 10am to 12am (24 ℓ/per.2h). On the other hand, Penn at al. (2012) reported that the dark greywater sharp peak was approximately at 08am at the morning.

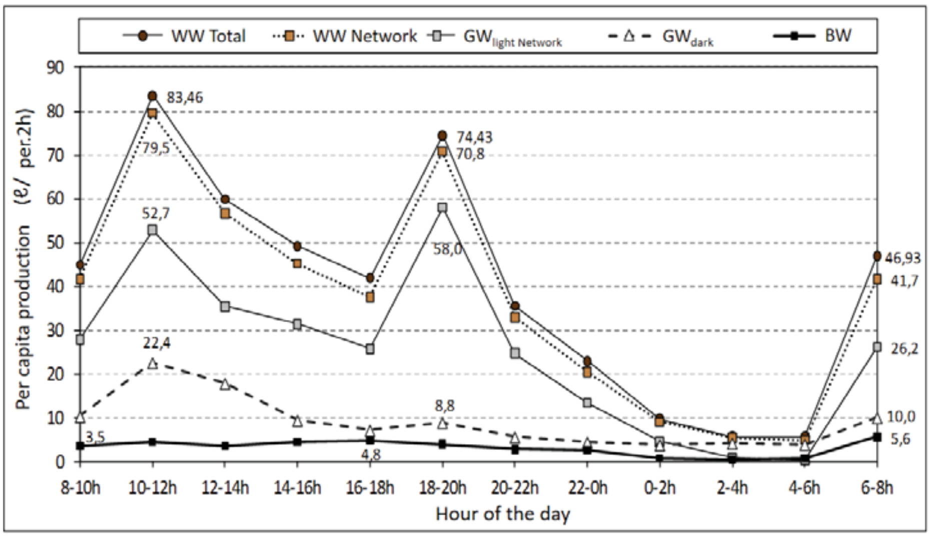

Figure 8. Per capita production profile of domestic wastewater in 24 hours.

The production profile per capita of BW presented a peak from 6am to 8 am (5.6 ℓ/per.2h), similar to the peak of blackwater production (0.9 ℓ/10 min/per or 10.8 ℓ/per.2h) in the study developed by Penn et al. (2012). The time range with the highest $WW_{Network}$ and WW_{Total} was from 10am to 12am, when 81.1 ℓ/per.2h and 85.09 ℓ/per.2h were produced, respectively.

3.4 Indicator of per capita production

The indicators of per capita production of light greywater, dark greywater, blackwater, domestic wastewater sent to the sewer network and the total domestic wastewater, obtained in this research, are

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presented in Table 1 along with indicators found in literature for comparison. According to the results, the average greywater production in this study was 204.66 ℓ per person and day, while the total average wastewater production was approximately 238 L per person and day (86% as greywater and 14% as blackwater), higher comparing to Antonopoulou et al. (2013) estimated in Greek households, 142 ℓ per inhabitant and day (58% as greywater and 42% as blackwater) and Penn at al. (2012) estimated in houses in Israel, 138 ℓ per person and day.

Table 1. Indicators of production per capita of GW_{light}, GWdark, BW, $WW_{Network}$ and WW_{Total} comparing to the literature

Author	Year	Location	Edification type	Wastewater production (L per person and day)				
				IP $_{GWlight}$	IP $_{GWdark}$	IP $_{BW}$	IP $_{WW\ Network}$	$IP_{WW\ Total}$
This resarch	2011	Vitória – ES	Multifamily with reuse	152.02	52.64	33.46	215.62	238.12
Cheung et al.	2009	Florianó-polis– SC	Single-family low-income residence with reuse and RW	91	22	31	-	-
Custódio & Ferreira	2005	Goiânia – GO.	Single-family	-	-	-	138.76	-
Valentina	2009	Vitória – ES	Multifamily with reuse	195	-	-	-	-
Pansonato et al.	2007	Campo Grande - MS	Low-income residence	58,6	17,34	-	-	-
Peters et al.	2006	Florianó-polis– SC	Low-income residence	54.3	-	-	-	90.63
Prathapar et al.	2005	Oman	Residences	105	55			
Palmquist e Hanæus	2005	Sweden	Residences	66		28.5		
Halalsheh et al.	2008	Jordan	Residences on rural areas	14				
Parkinson et al.	2005	Goiânia – GO	Single-family				241	241
Henze & Ledin	2001	Japan	Single-family	120	20	50	200	200
Antonopoulou et al.	2013	Greece	Residences	63.8	18.8	59.4		142
Penn et al	2012	Israel	Residences	73.8	26.6	37.7		138.1

RW: rain water use

It is possible to see in Table 4, that the average per capita production of GW_{light} obtained in this work (152,02 ℓ/per.day) was the second highest among those presented in the literature. The largest was obtained by Valentina (2009) (195 ℓ/per.day) in a standard building like the building monitored in this study. The lower (14 ℓ/per.day) was found by Halalsheh et al. (2005) in households located in rural areas in Jordan, a country facing water scarcity. The production of GW_{light} found in this work was almost three (3) times greater than that obtained by Peters et al. (2006), whose value was 54.3 ℓ/per.day, for low-income residence. This difference is due to the fact that the building analyzed by this work is a high standard type, which justifies the higher consumption of water and, consequently, increased greywater production.

The results obtained in this work for the per capita production of dark greywater (52.64 ℓ/per.day), or effluents from kitchens, was close to that found by Prathapar et al. (2005), which showed that production in Oman, Asia, averaged 55 ℓ/per.day. The mean per capita production of blackwater was 33.46 ℓ/per.day, value close to those reported by Cheung et al. (2009), a low-income residence on the outskirts of Florianópolis - SC (31 ℓ/per.day), by Palmquist & Hanæus (2005), a residence in Sweden (28.5 ℓ/per.day) and by Almeida et al. (1999), in homes in England (31.51 ℓ / per.d), while it is lower comparing to Henze & Ledin (2001) and Antonopoulou et al (2013).

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The average per capita production of domestic wastewater released to the public sewer network (215.62 ℓ/per.day) was lower than the average estimated by Parkinson et al. (2005). And it was higher than the values found by Henze & Ledin (2001) and also by Custodio & Ferreira (2005) in a community of single-family homes in Goiânia-GO. However, the indicator found by Custodio & Ferreira (2005) was considered low by the authors, because they verified in the studya low return coefficient (0.37),that is, only 37% of the potable water that enters the condominium returns to the sewer network. The rest is dissipated mainly on watering gardens, since it is a residential condominium with extensive gardens.

4. EVALUATION OF THE REUSE IMPACT IN WASTEWATER PRODUCTION

The evaluation of the reduction impact in wastewater production released to public sewer network was performed from the analysis of indicators of the total production of domestic wastewater per capita and the amount released to the sewer network, in 10 days of monitoring in the studied building. The indicator of Total production of wastewater would correspond to the indicator of the wastewater sent to the sewer network if the building did not have reuse. Thus, it is possible to calculate the reduction of the wastewater sent to the sewer network due to the reuse. The results are shown in Table 2.

Table 2. Reduction impact of domestic wastewater send to the sewer network

$IP_{WWNetwork}$ (ℓ/per.d)	$IP_{WW\ Total}$ (ℓ/per.d)	RI_{WW} (%)
215.62	238.12	9.45

The impact in reduction of wastewater send to the sewer network, under the reuse conditions this work for the monitored building was 9.45%. Through this result, it fulfilled the objective of this work that was verify the impact of the greywater reuse system in wastewater flow rates of a multifamily building, through the characterization of the segregated wastewater production.

5. CONCLUSION

The daily wastewater production was 238.12 ℓ per person per day, 86% of this amount was characterized as greywater (64% light greywater and 22% dark greywater) and 14% blackwater. Whereas only a parcel of the light greywater is reused (13% of the total wastewater produced in the building).

The average daily volume per capita of GW_{light} (152.02 ℓ) was much higher than the volumes of BW (33.46 ℓ) and GW_{dark} (52.64 ℓ), and there is still a large portion of GW_{light} (51 % of sewage produced) that could be reused for other activities such as pavements washing and garden watering, but is diverted to the sewage collection network.

The wastewater production sharp peak was at the morning (10 am to 12 am), but the light greywater production sharp peak was at the evening (6 pm to 8 pm) and the blackwater production sharp peak was between 6 am to 8 am.

The practice of reuse has led to a reduction of 9.45% of domestic wastewater released to the sewer collection network in 10 days of monitoring. The low value found may be associated with the use intended for greywater after treatment be only for toilet flushing. In addition, this percentage could better if the greywater will use

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