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THE IMPACT OF COVID-19 TO DOMESTIC WATER USAGE AND RAINWATER HARVESTING AT AN OFFICE BUILDING IN JAKARTA

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Abstract

COVID-19 transforms many social fabric and people adopt new lifestyle due to the pandemic. It compels people to regularly wash their hands which lead to increasing water demand. The research on an office building in Central Jakarta, Indonesia, during 2018 - 2020 indicates 31.23 % increase in water demand per capita per day. The pandemic also reduces the effectiveness of the building's rainwater harvesting (RWH) system because people require more water while its RWH remains unchanged. Note that the last sentence cannot be applied universally or in absolute manner due to the variability of annual rainfall and the difference in buildings' characteristics.

Keywords:

COVID-19;
Rainwater harvesting system;
Water conservation;
Water usage;
Work-from-home.

1 Introduction

Water is the fundamental substance for life on Earth. Human is able to last three weeks without food, but can only survive for three days without water. Water can be found in the atmosphere, ocean, rivers, lakes and in the rocks beneath. Of all of the water on Earth, 97 % is saltwater, leaving a mere 3 % as freshwater. However, the 2 % of freshwater is trapped in ice at the poles, so all humankind relies on just 1 % of that water. That 1 % of earth's water that we all rely on, most of it is located underground and really difficult and expensive to get to. So humans have mostly settled close to surface water like rivers and lakes [1, 2].

The increase of water usage all over the world has raised by 1 % for every year since 1980 and is predicted to grow about 20 - 30 % larger until 2050 [3]. Rapid growth of population followed by industrialization, urbanization and water consumption has resulted in water shortage where 20 % of world population experiencing water scarcity [4].

Indonesia is also facing major challenge regarding water security which includes clean water and proper sanitation, sufficiency of freshwater supply, excessive groundwater pumping, damaged watershed and climate change. Despite Indonesia being placed in the world top 10 nation rank with most water supply, there are few fundamental problems in the utilization management. It is primarily due to non-uniform season variation and water supply deviation. Located in the tropical area, the country experience rainy and dry season. During the rainy season, some areas in Indonesia experience major water overflows followed by flood and other destruction in response to the event. In contrast, throughout the dry season water scarcity and drought come arise as a problem around the other areas [5].

Reduction of water consumption and identification of new water resources have been introduced in order to maximize water management. Jakarta resides for 10.77 million of citizen with the average water requirement of 150 liters/person/day. This sums up the total of the city water demand to the amount of 547.5 million m^3. However, the public water supply is only able to provide for 57 % of the needs [6]. For urban areas in general, one of the most common alternative sources is the rainwater [7] Using rainwater to battle water scarcity is very potential to be applied in Indonesia due to its geographical location in tropical area with high rainfall [8].

Many cities across the globe are considering rainwater harvesting (RWH) as a feasible alternative supply for high-rise building. The potential of rainwater harvesting is considerable in urban

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areas since large portion of the cities are covered by roof or impermeable materials. Water gathered from roofs of residential or commercial building is another way to decrease potable and non-potable water demand [9]. Rainwater harvesting is a method or technology to collect rainfall from roofs, ground surface, pavement, or rock beds to be potentially used as alternative water resources [10]. This practice is not only a source to partially meet water demand, but also a way to reduce urban flooding when rainwater is stored by installed tanks [9].

The proofs of RWH's benefit are presented in various researches. Roof water from 20 ha of collection area in Nanyang Technology University (NTU), Singapore has reportedly reduced 12.4 % potable water consumption by supplying toilets for the whole campus [11]. A study has been conducted in a 10-storey commercial building with an equivalent occupancy of 176 and includes 600 m^2 of roof area, 100 m^2 of pavement and 100 m^2 of garden in Australian cities. The water savings were approximately 23 % for all cities [12].

The figures in the previous paragraph are derived from the studies carried out before COVID-19 outbreak. The pandemic changes the world; it transforms the lifestyle of many people especially during the outbreak. One of the biggest lifestyle changes is the increased frequency of hands washing which becomes the utmost importance to combat the virus. The more frequent bathing and regular disinfecting spray are also part of the pandemic life. Naturally, this new habit demands additional domestic water required as confirmed by various studies [13, 14].

Another lifestyle change is the emergence of work-from-home scheme. The contagious nature of coronavirus compels government to limit the amount of persons within buildings including offices. Workers who are prohibited to enter their offices have to work from their house. Consequently, it reduces the quantity of water used at office buildings, but the hands washing habit could counteract the effect.

The objective of this paper is to probe the effect of COVID-19 outbreak in water usage of office buildings. It remains to be seen whether the combination of the reduction of office buildings occupants and hands washing habit would increase or decrease the water use of buildings. Furthermore, the additional aim is to understand the advantage of using rainwater harvesting to public water usage for office building as well as the impact of COVID-19 on its effectiveness.

2 Materials and method

2.1 The office building

The research is carried out in an office building located in Central Jakarta, Indonesia. It is 1238 m^2 and 16 stories building and designated for various corporates which rent the spaces for their offices. The building's construction ended in 2016 and started operational afterward.

The building uses the water supplied by a state-company who provides domestic water and supported by the rainwater harvesting system. The building management pays the water bill regularly every month. The figures from the water bill will be analyzed to investigate the domestic water use pattern. The RWH helps supplying water for building users when rain pours. The roof catches rainfall and the rainwater is distributed through pipe to the water storage with 90 m^3 volume at the bottom of the building. Both roof and water storage tank are made of concrete. Next the captured rainwater undergoes treatment by the sand filter, the carbon filter, and various chemical filters. Afterwards, the treated rainwater is mixed with the water from the water company. The resulting water is pumped upward to be distributed to the tenants.

Unfortunately, the exact building occupants are not recorded in precise manner. The building management informed that tenants gradually came in since 2016 and the figure was consistently full started from 2017. The number of building users in the building is approximately 500 persons when it was fully operational since 2017.

2.2 Precipitation record

The available water from rainfall depends on the precipitation. The data is obtained from Meteorology, Climatology and Geophysics Agency Rainfall Station in Kemayoran, Central Jakarta. The station is situated at 6.16 S 106.84 E and at + 4 m MSL with WMO ID 96745. This station is preferred for it is the closest rainfall station to the researched building. It records daily rainfall and its monthly summary during 2018-2020 is presented in Table 1.

Table 1: Monthly precipitation record 2018 - 2020.

Month	*R* [mm/month]		
	2018	2019	2020
January	215.4	382.2	692.0
February	431.2	270.1	1043.2
March	202	327.3	220.7
April	159.1	194.6	182.8
May	16.5	47.8	50.4
June	12.5	23.1	21.1
July	14.5	0.0	12.1
August	32.8	0.0	101
September	64.8	0.0	3.9
October	159.6	1.0	208.3
November	140.9	50.1	87.3
December	52.3	263.8	134.7

3 Results and discussion

3.1 Domestic water use

The primary data to identify the change in water use before and after the pandemic is the water bill. It is charged every month by the state company which supplies domestic water. The available data is monthly water bill from January 2018 until November 2020 and it is displayed on Fig.Fig. 1.

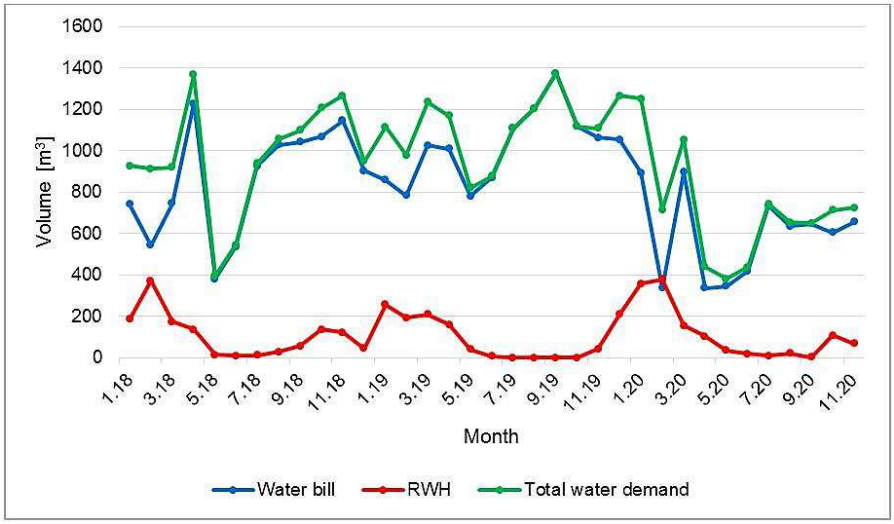


Fig. 1: The water use of the office building during January 2018 – November 2020.

There are three lines in Fig. 1 which helps to explain the behaviour the office building's water usage. The graph in Fig. 1 illustrates the data in Table 2. The blue line presents the monthly water bill from the state company (column 2). The red line presents the sum of the harvested rainwater from the building's roof (column 3). Its calculation is presented in 3.2 Monthly conservation. The green line is the total water used by the office building's users (column 4) which is derived by adding the water bill volume (blue line; column 3) and harvested rainwater (red line; column 4).

Table 2: The water use of the office building during January 2018 – November 2020.

Month	Water bill [m^3]	RWH [m^3]	Total demand [m^3]	Water use rate [m^3/day/person]
Jan-18	742	187	929	69.96
Feb-18	544	371	915	76.13
Mar-18	746	175	921	68.60
Apr-18	1230	138	1368	108.09
May-18	382	14	396	28.50
Jun-18	536	11	547	57.08
Jul-18	928	13	941	69.86
Aug-18	1029	28	1057	76.12
Sep-18	1043	56	1099	84.35
Oct-18	1070	138	1208	86.74
Nov-18	1146	122	1268	93.97
Dec-18	904	45	949	70.19
Jan-19	859	258	1117	81.67
Feb-19	785	194	979	80.15
Mar-19	1027	210	1237	91.33
Apr-19	1011	160	1171	88.69
May-19	782	41	823	60.94
Jun-19	872	7	879	88.69
Jul-19	1110	0	1110	80.13
Aug-19	1207	0	1207	87.14
Sep-19	1374	0	1374	106.18
Oct-19	1118	1	1119	80.77
Nov-19	1065	43	1108	82.71
Dec-19	1056	210	1266	97.68
Jan-20	895	358	1253	91.75
Feb-20	338	379	717	59.50
Mar-20	898	156	1054	81.11
Apr-20	338	103	441	64.41
May-20	347	36	383	69.88
Jun-20	419	18	437	65.20
Jul-20	734	10	744	107.33
Aug-20	635	21	656	99.09
Sep-20	648	3	651	97.51
Oct-20	605	109	714	105.18
Nov-20	658	69	727	112.92
Jan-20	895	358	1253	91.75

The graph of the water bill is fluctuative and there are notable regular patterns.

1) First, Fig. 1 illustrates how the installed RWH helps in alleviating the water demand of the office building. The rainy season in Indonesia is generally from November to March with its peak in January – February. It is apparent from Fig. 1 that the water bill (blue line) drops during this periods especially January – February due to the high amount of rainwater utilized (indicated by the rise of the red line).

2) Second, the water demand is always lower at the middle of the year due to the Eid al-Fitr. The days of Eid al-Fitr were at 14 - 15 June 2018, 3 - 4 June 2019, and 23 - 24 May 2020. It is the biggest national holiday in Indonesia thus the office building's users are absent from work. Thus, the

office building is only occupied by few workers. Moreover, the combination between COVID-19 outbreak and Eid al-Fitr makes it very hard to determine the number of building users.

3) The water consumption during COVID-19 outbreak is lower than pre-pandemic. It is because there are fewer people occupying the office building, a common behaviour across the world [15].

The building management team was interviewed to probe the number and the behaviour pattern of the building users. While the number of users is not exactly measured, the building management explained:

1) There were approximately 500 persons at the building at every working day which is from Monday to Saturday.

2) The figure dropped to about 88 persons at every Sunday.

3) Furthermore, the figure dropped even further during Eid al-Fitr i.e. about 40 persons. It is approximated that 40 persons attend the office building during Eid al-Fitr which is assumed lasts for 7 days. This pattern applies from January 2018 to March 2020.

COVID-19 pandemic started from March 2020 in Indonesia. Since April 2020, the government introduced work from home policy and limited the occupation of the building to 50 %. Therefore, the number of persons working in the office building from April 2020 to November 2020 was (see Table 3 for the comparison summary).

1) There were approximately 250 persons during working days (Monday – Saturday).

2) There were about 44 persons at the building on Sunday (half of pre-pandemic figures on Sunday).

3) Lastly, the number of building occupants is 40 persons during Eid al-Fitr, similar to previous years.

Table 3: The comparison of the number of building users prior to COVID-19 outbreak (January 2018 - March 2020) and during COVID-19 outbreak (April 2020 - November 2020).

Day	Prior to COVID-19 outbreak	During COVID-19 outbreak
Monday - Saturday	500	250
Sunday	88	44
National holiday	40	40

The paragraphs and Table 3 explain the variation of the building's water usage in broad term. Now, the water usage rate (in liters/day/person) will be estimated using the number of building users given by the building management.

The water usage rate is obtained by dividing the total water used (Fig. 1, green line; Table 2, column 5) by the number of days in month and the number of persons in the office building (Table 3, column 2). The results are presented in Table 4 and Fig. 2.

Table 4: The water usage rate of building users in 2018-2020.

Month	The water usage rate [liters/day/person]		
	2018	2019	2020
January	69.96	81.67	91.75
February	76.13	80.15	59.50
March	68.60	91.33	81.11
April	108.09	88.69	64.41
May	28.50	60.94	69.88
June	57.08	88.69	65.20
July	69.86	80.13	107.33
August	76.12	87.14	99.09
September	84.35	106.18	97.51
October	86.74	80.77	105.18
November	93.97	82.71	112.92
December	70.19	97.68	

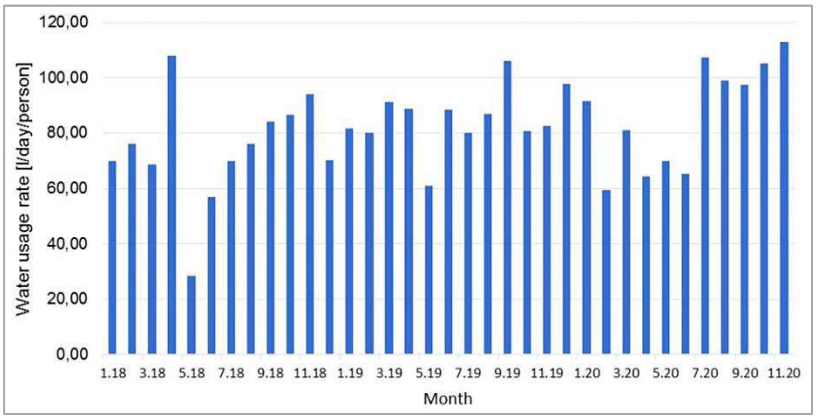


Fig. 2: Monthly-averaged daily water use.

Every building user in an office building normally requires 50 liters/day of cold water and 20 liters/day of hot water which in total is 70 l/day/person [16]. Since most tap waters in Indonesia only provide cold water and people rarely use hot water, the water usage of a building user is set to 70 l/day/person. By averaging the monthly water usage rate before the pandemic stroke (January 2018 - March 2020), each building user needed 79.56 l/day/person, more than what the national standard sets (70 l/day/person).

The estimation of the water usage rate during COVID-19 outbreak starts from April 2020. However, due to Eid al-Fitr at 23 - 24 May 2020, the amount of persons working in the building during April - June 2020 is difficult to estimate. The working environment returned to normal (or new normal when there was 50 % limitation of building users) starting from July 2020. It was assumed there were 250 persons inside the building during working days and 44 persons during Sunday which was half of the pre-pandemic figures see Table 3.

Again, the water usage rate is obtained by dividing the total water used (Fig. 1, green line; Table 2, column 5) by the number of days in month and the number of persons in the office building during the pandemic (Table 3, column 3). The data in Table 4 and Fig. 2 reveal that the water usage rate in July 2020 – November 2020 was considerably higher than pre-pandemic. During these 5 months, the monthly water usage rate is averaged and the result is 104.41 l/day/person. It is 31.23 % higher than pre-pandemic figure.

The increase in the water usage rate is primarily due to washing hands habit during the pandemic. A research in Bangladesh found people wash hand much more frequent, take longer duration, and tend to overuse water during the pandemic [17]. They are common practices and the office building users also reflects such behaviours. Not only regular building users consume more water to clean their hands. Even the temporary guests are obliged to wash hand before they enter the building. These behaviour changes contribute to the 31.23 % of water consumption increase per person.

3.2 Water conservation

Water saving through rainwater harvesting system is calculated from the ratio between the stored rainwater (V_{RWH}) and the total water demand (D). The latter is the sum between stored rainwater (V_{RWH}) and the water supplied by the state-company (V_{SC}). The calculation process is expressed by Equation 1.

$$\%\ Conservation = \frac{V_{RWH}}{D} \times 100\ \% = \frac{V_{RWH}}{V_{RWH} + V_{bill}} \times 100\ \%\ , \quad (1)$$

where:
V_{RWH} - daily volume of available rainwater,
D - daily volume of total water demand,
V_{bill} - daily volume of water supplied by the state company (from the water bill).

Equation (1) is not expressed as V_{RWH}/V_{bill} because building users still use water from the state company for consumption. Furthermore, they also still use the company's water when rain has not started.

Available rainwater supply are obtained by multiplying daily precipitation rate with roof catchment areas and runoff coefficient [18] presented in equation

$$V_{RWH} = R \times A \times C, \tag{2}$$

where:
V_{RWH} - available rainwater supply volume,
C - roof runoff coefficient,
R - rainfall height,
A - roof catchment area.

The runoff coefficient for building roof depends on its imperviousness and the efficiency of the building's plumbing system. Since building's roof is made of concrete surface and plumbing leakage is common in, the roof runoff coefficient is determined as 0.7 by combining figures from several references [19-21].

The researched building uses water tank with 90 m^3 capacity to store rainwater. If the amount of collected rainwater surpasses tank capacity, the excess water will be directly discharged to the city drainage system. Afterwards, the stored rainwater is treated and used. Water surplus could occur when the rainwater volume is greater than the building water demand. When it occurs, it is up to the building management either to conserve the rainwater or to release it to the city drainage system in order to prepare for the next day's rainfall.

The comparison between the conserved rainwater and the building's water demand is presented in Figs. 5 – 7. The rainwater supply (blue line) cannot exceed 90 m^3 since it is the maximum capacity of the water tank. The water demand is assumed uniform daily except during holidays (every Sunday and Eid al-Fitr) when there were only few people remains.

By visually judging Figs. 5 – 7, they indicate the rainwater supply was inadequate to fully substitute water supply from the water company most of the time even during rainy seasons. There were days when the rainwater supply is more than the building requires, but those days are few. Even some of the excess water must be discharged due to the tank's capacity.

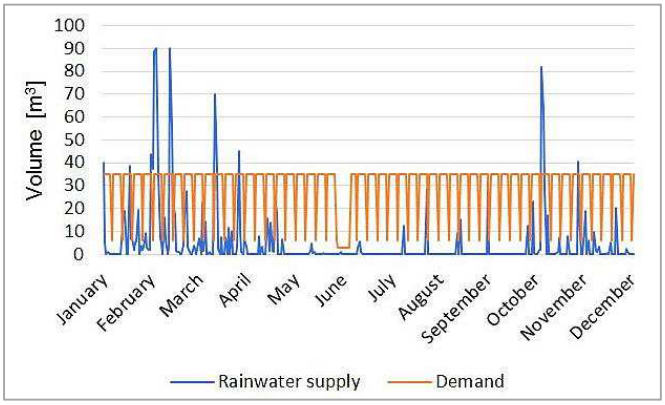


Fig. 5: The daily comparison between rainwater supply and water demand in 2018.

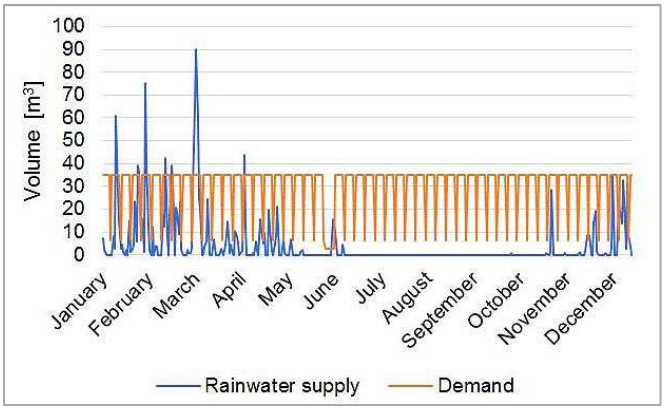


Fig. 6: Daily comparison between rainwater supply and water demand in 2019.

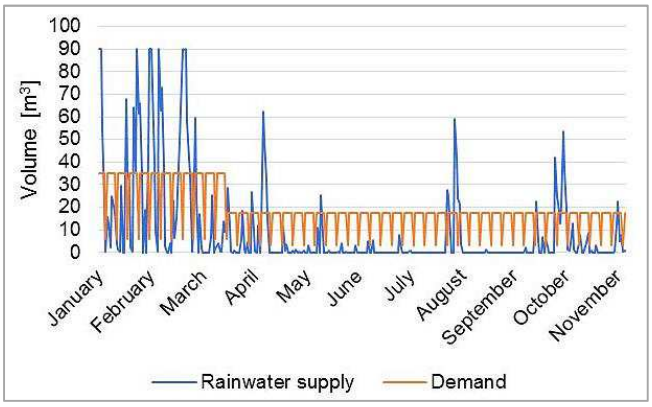


Fig. 7: Daily comparison between rainwater supply and water demand in 2020.

In Figs. 5 - 7 are calculated to obtain the percentage of the RWH's capability to conserve water The computation follows Equation (1) except it applies monthly water bill and monthly stored rainwater (excess rainwater is not taken into account). The results are presented in Table 5, Table 6 and Table 7.

Apparently the RWH still cannot substitute or even reduce water consumption by large margin. The tables suggest the installed RWH typically saves about 10 % water annually and it could only reach 20 % when the precipitation is high, for instance like in 2020, Table 7.

Its most obvious reason is because of the urban setting where tall building in small land area hosts many persons. The small area means small catchment area which limits the volume of captured rainwater. It also means small water storage as well for there is little available space. Another reason is the disparity of precipitation between dry and rainy season in tropical climate. The rainfall is much heavier in rainy season than in dry season - when it barely pours. The rainfall disparity, in combination with the limitation of water tank capacity, means wasted rainwater potential.

Table 5: Monthly cumulative of water conservation by the rainwater harvesting system in 2018.

Month	***V* [m^3]**	***D* [m^3]**	**% Conservation**
January	186.61	928.61	20.10
February	372.95	916.95	40.67
March	175.00	921.00	19.00
April	137.84	1367.84	10.08
May	14.29	396.29	3.61
June	10.83	546.83	1.98
July	12.56	940.56	1.34
August	28.42	1057.42	2.69
September	56.14	1099.14	5.11
October	138.27	1208.27	11.44
November	122.07	1268.07	9.63
December	45.31	949.31	4.77
Annual conservation			11.21

Table 6: Monthly cumulative of water conservation by the rainwater harvesting system in 2019.

Month	*V* [m^3]	*D* [m^3]	% Conservation
January	331.12	1190.12	27.82
February	234.00	1019.00	22.96
March	283.56	1310.56	21.64
April	168.59	1179.59	14.29
May	41.41	823.41	5.03
June	20.01	892.01	2.24
July	0.00	1110.00	0.00
August	0.00	1207.00	0.00
September	0.00	1374.00	0.00
October	0.87	1118.87	0.08
November	43.40	1108.40	3.92
December	228.54	1284.54	17.79
Annual conservation			9.92

Table 7: Monthly cumulative of water conservation by the rainwater harvesting system in 2020.

Month	*V* [m^3]	*D* [m^3]	% Conservation
January	546.47	1441.47	37.91
February	694.33	1032.33	67.26
March	191.20	1089.20	17.55
April	158.37	496.37	31.91
May	43.66	390.66	11.18
June	18.28	437.28	4.18
July	10.48	744.48	1.41
August	87.50	722.50	12.11
September	3.38	651.38	0.52
October	180.46	785.46	22.98
November	75.63	733.63	10.31
Annual conservation			23.58

It is not straightforward to deduce how COVID-19 outbreak affects the effectiveness of the RWH due to the variability of annual precipitation. The year 2020 comprised mostly pandemic period (March - November) and Table 7 indicates the RWH achieves its highest performance compared to the non-pandemic years (2018 and 2019). However, the figures are biased due to heavy rainy season in 2020 and light rainy season in 2018-2019. For perspective, the annual precipitation in Jakarta is generally around 2000 mm/year while the recorded annual precipitation in 2018 - 2020 is 1490 mm/year, 1553 mm/year, and 2750 mm/year respectively. The variability of annual rainfall makes the effectiveness analysis more complicated.

One could take rough approach in order to estimate how the pandemic affects the RWH's effectiveness. Firstly, three scenarios are defined:

1) The scenario 1 is the pre-pandemic when 500 persons attend the building daily with 79.56 liters/person/day water usage rate.

2) The scenario 2 is during the pandemic when 250 persons attend the building daily with 104.41 liter/person/day water usage rate.

3) The scenario 3 is the post-pandemic transition when it is assumed 500 persons attend the building daily with 104.41 liters/person/day water usage rate. It is assumed people will resume their normal activity like pre-pandemic but they still maintain the hand-washing habits until COVID-19 fully subsides.

Then, the annual precipitation of 2000 mm/year is applied to all three scenarios while assuming there is no discharged excess water and the roof runoff coefficient is 0.7. The result is presented in Table 8.

Table 8: The comparison of the RWH effectiveness in various scenarios.

Scenario	Building users	Water usage rate	Annual water demand	Annual stored rainwater	Water conserved
-	persons	[liters/person/day]	[m^3]	[m^3]	[%]
1	500	79.56	14519.70	1732.71	10.66
2	250	104.41	9527.41	1732.71	15.39
3	500	104.41	19054.83	1732.71	8.34

Table 8 indicates RWH generally conserves approximately 10 % at the normal circumstances, not far off from what the calculation in this article, Table 5 and Table 6. It is also the figure obtained from the study by NTU in Singapore which is within tropical climate as well [11]. The figure is different with the studies carried out in Malaysia where RWH could save more than 30 % of water demand [22, 23]. This is because the difference in the buildings' characteristics, although the study cases locations are geographically and climatically close. Our research object is the highly dense office building where the area is small with many occupants inside while the studies in [22, 23] have larger catchment area. It suggests the building's characteristic is as important as climate characteristic in determining RWH's effectiveness.

Table 8 indicates RWH generally conserves around 10 % at the normal circumstances. It increased during the pandemic and it suggests the reduction of building occupants is more significant than the additional water requirement for healthy protocols (50 % persons reduction vs 31.23 % water usage increase per capita). The contribution of RWH is even less in Scenario 3 where the building is full capacity again while its users preserves hand-washing habits.

4 Conclusion

The research indicates there is 31.23 % increase in water usage which is significant yet necessary. The increase in water usage per capita per day is expected during COVID-19 outbreak for people will wash hands more often hence demanding more water.

Analyzing how the pandemic affects RWH is complicated due to the variability and randomness of annual rainfall as well as the difference in building characteristics. Three scenarios are conjectured to estimate COVID-19's effect on RWH. The pandemic increases the water demand while the RWH remains unchanged hence the latter's effectiveness will decrease. It is up to everyone's interpretation if it means RWH must be intensified or other solutions must be formulated in order to meet the increasing water demand.

As long as people still preserve hand-washing habit, the water demand will increase and it is already proven by this research and others. It suggests the work-from-home policy could help alleviating the increasing water demand. It is true whether several studies proved the pandemic also increases water demand even if everybody stays at home [24, 25]. However, theoretically work-from-home policy could spare people from wash their hand when they arrive at their offices and also when they reach their home -when even they must have a bath instead of hand-washing-. These activities stemming from work-from-office policy surely require more water than work-from-home policy when people only require additional water for occasional sanitation and consumption. More researches should be carried out in order to probe the effect of work-from-home policy to water demand.

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