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RESEARCH ARTICLE

WATER FOOTPRINT ASSESSMENT AS A TOOL FOR IMPROVING SUSTAINABILITY IN BUILDINGS: CASE STUDY SOCIAL HOUSING PROJECT IN CAIRO, EGYPT

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ABSTRACT

Background: Water issues related to scarcity, drought and quality are serious problems in many countries worldwide. In the building sector; water efficiency has a vital rule in achieving sustainability. Buildings rating systems are a way to measure the water efficiency in buildings but most of the rating systems consider only the direct water use and neglect the embodied water. **Objectives:** The research aims at evaluating the total water footprint of buildings; in order to analyze the aspects affecting the sustainability of the project and to configure the best strategies which could be used to improve water efficiency. **Methods:** The research adopts the water footprint assessment; which takes into account direct and indirect water use and the blue and grey WFPs; to assess the water footprint of a social housing project in Egypt. To account for the indirect water footprint Athena IE and BEES softwares are used and for direct water LEED V4 water use reduction calculator is used. **Results:** The results showed that the direct WFP/ year for one building was found to be 17 times greater than its embodied WFP and there were disparity between the results of the blue, grey, direct and embodied WFPs. **Conclusion:** The research showed the importance of considering embodied water footprint in addition to direct water footprint. The research concluded the opportunities available for improving the water efficiency in the project.

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INTRODUCTION

Water crisis has magnificent influences on the sustainable development in many fields. In 2030 there will be 40% gap between water demand and water availability. This limited water resource will need to support a population of 9.7 billion in 2050; and by that date; about 3.9 billion of the world's population will live in water-stressed river basins (*WHO-Water safety and quality*, 2018). Also, in 2050, water demands are expected to increase by 400% from manufacturing use, and by 130% from household use (LisaGuppy, 2017). Buildings are a major consumer of water and uses about 25% of global water resources (Dean, 2018). Building rating systems are a way to measure the sustainability in buildings, and all of them consider water efficiency as a main category; the weightage of water efficiency differs from one rating system to another depending on the aims of it and the local requirements; in LEED-USA water efficiency category represents 9.1%, in BREEAM-UK water efficiency represents 6.8% (K.GWaidyasekara, 2013),in GPRS-Egypt water efficiency represents 30% (*Green building rating system- GPRS*, 2018). But most of the rating systems consider only the direct water and neglect the embodied water (K.GWaidyasekara, 2013). In order to make buildings actually water efficient, there must be integration between the direct and the indirect water efficiency. The Reduce, Replace and Reuse approaches should be adopted in the initial stage of designing then in the construction and operation of the building (*Water efficient building design-guide book*, 2018). The water footprint is defined as an indicator of the amount of freshwater used to create a product through all the production stages; it looks not only at the direct water use of a consumer, but also looks at the indirect water use in the product. The water footprint could be identified on different scales like a personal scale, a building scale or a city scale. The water footprint is a volumetric measure, showing freshwater consumption and pollution.

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The water footprint of a product breaks down into three components, first is the blue water footprint which refers to the consumption of blue water resources like surface water; second is the green water footprint which refers to the consumption of green water resources like rainwater; third is the grey water footprint which represents the pollution (Arjen Y. Hoekstra, 2011) .So, the water footprint for buildings could be defined as the amount of direct potable water used for toilets, kitchen, irrigation, or any sort of direct water consumption and the amount of indirect water used in the construction materials and process.

METHODOLOGY

To assess the water footprint of any building through the life phases; life cycle analysis could be used or Water footprint assessment. In this research water footprint assessment is adopted and it refers to the full range of activities; in order to quantify the water footprint of a process to assess the environmental, social and economic sustainability of the water footprint and to formulate a response strategy. A full water footprint assessment consists of four phases; the first is setting goals and scope to identify the purpose of the study; the second is the Water footprint accounting in this phase the inventory boundaries must be clear to identify what to include and what to exclude from the accounts, to consider blue, green or grey water footprint, direct or indirect water footprint, internal or external water use; the third is the water footprint sustainability assessment to consider the environmental, social and economic dimension of sustainability; forth is the water footprint response formulation to identify what can be done to reduce the water footprint within that area (Arjen Y. Hoekstra, 2011).When water footprint assessment is applied on the scale of buildings; it is predicted that this will give clear indications about the direct and indirect water consumption and water pollution; which will help on achieving the water efficiency in the projects especially projects which need to adopt more affordable methods for construction and process like social housing projects.

To assess the embodied water footprint; field study and cadastral survey was carried out to recognize the amount of the used building material and finishing materials. In order to account the amount of water used in the construction process and the emissions to water; Athena impact estimator and BEES softwares were used. Athena IE was used for assembling all the building and finishing materials through the whole life cycle except for the marble and ceramic tiles as those two materials do not exist in Athena IE. The amount of water use from the two softwares will be considered as the blue embodied water footprints and because there was no rainwater recycling used in the construction process; the green water footprint will be neglected. The results of the emissions to water; are used to calculate the grey water footprint. Eq.1 is used to calculate the grey water footprint regarding Nitrogen and phosphorous emissions as the two main sources for water pollution:

$$GWF=L/(c_{max}–c_{nat}) \text{ liters} \quad (1)$$

Where GWF is greywater footprint, L is the load of the pollutant “Nitrogen or phosphorous” from the point source and C_{max} is the maximum acceptable concentration in the water body and C_{nat} is the natural concentration of the substance in the water body (N.A. FRANKE, 2013). For phosphorous the maximum allowable concentration is 0.02 mg/L and natural concentration is 0.01 mg/L (Mesfin M. Mekonnen, 2017). For Nitrogen the maximum concentration is 2.9 mg/L and natural concentration is 0.4 mg/L (Mesfin Mekonnen, 2015). And for the total grey water footprint Eq.2 is used, where $GWF_{Embodied}$is the total embodied grey water footprint. For the total embodied water footprint Eq.3 is used, where $WF_{Embodied}$ refers to the total embodied water footprint.

$$GWF_{Embodied}= GWF_{Embodied\ Phosphorous}+ GWF_{Embodied\ nitrogen} \text{ Liters} \quad (2)$$

$$WF_{Embodied}=WF_{blue,\ embodied} +WF_{grey\ ,embodied} \text{ Liters} \quad (3)$$

For the direct water footprint; data from the water company regarding water consumption in the project was limited to the amount of water consumed for each unit per month with no specific details about the distribution of the consumption, so questionnaire was carried out to configure the direct water consumption. In addition to this; LEED v4 indoor water use reduction calculator was used to account the baseline water consumption and the actually water consumption in the project.

Green water footprint will be neglected as there is no rainwater harvesting systems. Direct grey water footprint for households; is estimated based on the assumption of the Nitrogen and the phosphorous per person in the project. Eq.1 will be also used for calculating the direct grey water footprint related to phosphorous, assuming global Phosphorus production per person is between 1 to 3 g per day t domestic waste (Claudia Maria Gomes, 2017), this paper used the minimum amount of 1 g and Eq.4 will be used to account the direct grey water footprint related to phosphorus.

$$GWF_{Direct\ Phosphorous}=L/(0.02–0.01) \text{Liters/year} \quad (4)$$

The grey water footprint related to nitrogen due to domestic use in Egypt is 28 billion m3/year (Mesfin Mekonnen, 2015), and as the Egyptian population is about 100 million, so the direct GWF related to Nitrogen is about 280 m3/year/person. The total direct grey water footprint will be accounted from Eq.5, taking into account the efficiency of the wastewater treatment plant. The total direct water footprint is accounted by using Eq.6. The full integrated methodology could be illustrated in fig.1.

$$GWF_{Direct}=GWF_{Direct\ Phosphorous} + GWF_{Direct\ nitrogen} \text{ Liters/year} \quad (5)$$

$$WF_{Direct}= BWF_{direct}+ GWF_{direct} \text{ Liters/year} \quad (6)$$

Case study: The case study in this paper is New-Cairo social housing project in Egypt; as this sector is facing many challenges due to water related problems. In Egypt the water situation is critical; Egypt is 96% dependent on water from the Nile and is located in arid and semi-arid climate where rainfall in Egypt is very scarce .Egypt is predicted to be under water scarcity in 2025 due to climatic changes and the inefficient use. The overall country average per capita usage of drinking water is about 300 liters/day (M.Nour, 2013). Egypt suffers from a shortage of 30 billion m^3(CAPMAS, 2016).

About 35% of the reached water in Cairo is lost through leakage (Kumar, 2016). Egypt now is under the poverty water line with 600 m^3/ capita/ year in 2018 (MWRI, 2018), and is predicted to be 350 m^3/capita by 2050; while the water poverty line is 1000 m^3/capita /year. The New-Cairo social housing project is in New-Cairo; which is located east to Cairo and 350m above sea level, this project is similar in design and almost all features of all social housing projects in Egypt. Population in the city is about 3 million (New urban communities authority, 2010), climate is mild with hot humid summers, the average annual temperature is 20.8 °C and about 28 mm of precipitation falls annually (Climate data, 2012). The potable water supply for New Cairo is 1,100,000m^3/day (New urban communities authority, 2010), there are some domestic wastewater treatment plant the largest with a capacity of 250,000m^3/day to treat domestic wastewater (New-Cairo water treatment plant, 2014) and a potable water treatment plant that services new cairo has a capacity of 500,000m3/day (Utilities and urban development, 2016).The deteriorated stormwater system and infrastructure in New-Cairo affects the sustainability of water resources, and the extreme rain events which happen due to climatic changes leads to more load on the infrastructure.

The project consists of two phases; and the study will focus on the second phase which began operation in 2016 and consists of 71 typical buildings and located on an area of about 141,640m^2. Buildings in the project represent about 20% of the total area while open spaces represent 80%., as shown in fig.2. Buildings are gathered in clusters, each building in the project has a ground floor and five typical stories; with a height of 18.8 m and an area of 360 m^2; with typical simple façade designs and flat roofs, as shown in fig.3. Each typical building in the project consists of 24 residential units, as each floor in the building has four typical residential units; each unit has an area of about 90 m^2, each unit has one kitchen and one bathroom. Through the field study of the project; it was found that there were some aspects affecting the water efficiency. It was found that the wide asphalt roads and impervious areas; had a negative effects on the micro climate and increased the heat island effect in addition to increasing the run off. The rainwater infrastructure is also not sufficient and after an event of rain; stormwater merges the spaces. The green open spaces in the project are mostly deteriorated and damaged due to the lake of irrigation and irregular maintenance. There were also repeated problems in the supply pipeline since the beginning of the operation. It was also found that there is leakage in many indoor water pipes and this caused deterioration for the façades finishing materials. In this social housing project water sub metering is not used to measure the water consumption for each residential unit; but each unit had to pay for 30 m^3 / month (water consumption third district, 2019); and this one of the reasons which made residents do not care about the amount of water they consume because whether the consumption is high or low; the same amount must be paid.

Water footprint assessment for the case study: The following will show the water footprint assessment analysis for the social housing project in New-Cairo:

Setting goals and scope: The goal of the assessment is to analyze the direct and indirect water footprints, assess the sustainability related to water aspects and setting solutions for improving water efficiency.

Water footprint accounting: In this phase there will be accounting for the embodied and direct WFPs in one typical building.

Embodied Water footprint accounting: The buildings used reinforced concrete for the columns, beams, roofs and stairs; and clay blocks were used for the walls. For finishing materials mortar and paints were used for the walls, for the floorings ceramic tiles are used for all the interior spaces except for the stairs marble tiles was used; In addition to wooden doors and wood and glass for windows. Athena IE and BEES softwares were used to configure an integrated embodied water footprint. First, Athena IE was used to assemble the concrete foundation, roofs, insulation and concrete tiles for the roofs, columns and beams, walls, doors, windows, stairs and some finishing materials. First step in Athena IE is entering the project data name, area, and height and building life expectancy. Next is adding the assemblies, the first assembly is the columns and beams assembly, the number of columns and beams is added, in addition to the area, bay size and supported span; the average bay size is 4m and span 3m, the number of columns for the building is 48 columns, the number of beams for each floor is 21 beams and for the six floors are 126 beams. The second assembly is floor assembly; there are 6 floors in the building with an area of 360m^2, this is added in the Athena IE as a span of 9m and width of 240m; as the software doesn't accept spans more than 9.75m. The third assembly is the roofs assembly; the roof area is 360m2, this is added to the software also as a span of 9m and width of 40m; then roof extra materials are added to assemble the bitumen insulation, the mortar and concrete tiles, in addition to adding the latex paint used for the interior concrete ceilings. The fourth assembly is for the concrete foundation, in addition to adding foundation extra materials for the bitumen insulation. The fifth assembly is for walls; Clay bricks are used for the exterior and interior walls and concrete are used for the lintels of the doors and windows. For the exterior walls the whole length was 86m and a height of 18.8m, there are 120 wooden windows and 24 aluminum exterior doors; clay bricks were added for exterior wall envelope as well as latex paint. For interior walls the whole length was 140m and height of 18m, with 168 wooden doors; clay bricks, mortar and glazing panels for windows were added as walls extra materials. The final assembly was project extra materials to add the concrete used for the stairs. The life cycle inventory results by life cycle stages results showed that; 1.70E+07 L of water was used, Nitrogen emission to water was 4.30E+08 mg and Phosphorous emissions to water was 1.05E+04 mg.

BEES online version 2.0 was used to account the flooring materials; ceramic and marble tiles. Results for ceramic tiles and marble tiles were 1.98e+7 L and 2.98e+6. So, the total indirect water consumption by the building through the life cycle stages is about 3.97e+7L, which represents the $BWF_{Embodied}$. For grey water footprint; Eq.1 is used to account the phosphorous and nitrogen related water footprints, and it was found that the $GWF_{Embodied\ Phosphorous}$ is 1.05e+6 L and $GWF_{Embodied\ nitrogen}$ is 1.61e+8 L, so by using Eq.2 the $GWF_{Embodied}$ is about 1.62e+8 L. The total embodied water footprint is using Eq.3, and showed that $WF_{Embodied}$ is about 2.01e+8 L.

Direct Water footprint accounting: For the direct water use; the average water consumption per unit is $30m^3$/month (water consumption third district, 2019), assuming an average of 4 persons per unit, so the average water consumption per person is 250 L/day. From the field study it was found that the water devices used in each residential unit are; 1 Bathroom lavatory, 1 toilet, 1 toilet tap and 1 kitchen tap. From the field measurements it was found that the rate flow and rate flush average are close to the baselines used by LEED v4 indoor water use reduction calculator which are lavatory tap 8.3liters/min, Kitchen tap 8.3Liters/min, shower 9.4 Liters/min and single flush toilet 6Liters/flush; so those baselines will be considered; except for the toilet tap; not found in LEED v4 calculator; the flow rate was about 3 L/min. By using the calculator, it was found that the supposed water consumption per person is about 188 L/day; table.1 shows the summary of the baseline water use.

From the field visit and questionnaire it was found that water use is more than that, and is almost like the data approved by the water company, it was found that the average of actual water use from the lavatory faucet is 332 L/day for each residential unit due to the change in the actual time of use from 60 sec to 120 sec per use, and the actual water use from the kitchen faucet is 166 L/day for each residential unit due to the change of number of uses per day. So, the average water consumption per person is 238 L/day and for each residential unit is 952 L/day, as shown in table 2.Because each building has 24 residential units, so the blue water footprint for the whole building is 8.33e+6 L/year/building. For the grey water footprint; the total grey water footprint related to phosphorus was calculated from Eq.6 and it was found that $GWF_{\text{Direct Phosphorous}}$ was about 3.50e+9 L/year/building; and from the average domestic nitrogen production in Egypt it was found that $GWF_{\text{Direct Nitrogen}}$ is about2.68e+7 L/year/building. so from Eq.5 it was found that GWF_{Direct} is about 3.52e+9 L/year. And from Eq.6, the WF_{Direct} is about 3.52e+9 L/year/building.

Water footprint sustainability assessment: From the full water footprint accounting it was noticed that; some accountings were giving indicators about the sustainability aspects related to the water situation, in both direct water footprint and embodied water footprint. According to the embodied WFP results it was found that; for the embodied blue water footprint the most water consuming Phase was the production phase with $15902m^3$ and next the construction phase with $757m^3$ than the beyond building life phase with 356 m^3 and the use phase with 26.2 m3 and finally the end of life phase with 0.379.For the embodied GWF, the production phase was also the first contributor to water pollution then the construction in both nitrogen and phosphorus related WF. The total embodied BWF represents 19.7% of the total embodied WFP while the total embodied GWF represents 80.3%. According to the direct WFP it was found that; the higher consumer of direct water use were the lavatory faucets than the showerheads. The $GWF_{\text{Direct Phosphorous}}$ represents 99% of the total direct grey water footprint while the $GWF_{\text{Direct Nitrogen}}$ represents about 1%; The Direct BWF represents 1% from the total direct WF while the GWF represents about 99% from it. When comparing direct and embodied WF; assuming that total WF for one building represents the sum of the embodied water footprint and the direct water footprint per year for the building; it will be noticed that the direct WF/year represents about 94.7% and the embodied WF represent about 5.3% of the total water footprint. It was also noticed that the embodied BWF represents 82.7% while the direct BWF /year represents 17.3% of the total BWF, this is shown in fig.5-38. On the other hand; the direct GWF represents 83% /year and the embodied GWF represents 5% from the total WF for one building.

Water footprint response formulation: In order to mitigate the water footprint, it is hard to deal with embodied water as the project is already processed; but for the direct water some strategies could be implemented to reduce the amount of water used and the amount of waste water charged to the wastewater system. In case of using grey water recycling system; the amount of grey water available per unit per day is about 636 liters; this represents the waste water from lavatory faucet and showerhead. The grey water could be used in non-potable uses like flushing or irrigation; the amount of water needed for flushing per unit per day is about 120 liters and this could make savings of about 12.6%. In the case of using rainwater harvesting system, with efficiency of 75%; the amount of rainwater harvested from the building’s roof is about 7560 liters/year/building; theoretically this represents 21.6 liters/ day/building and 0.9 liters/day/unit; when using it for flushing this represents only 0.01% savings. When using aerators for showerhead, for lavatory faucet and dual flush, LEED v4 indoor water calculator is used to calculate the savings; the total water use per unit is 630 liters/day/unit, which is 30.6% saving from baseline and 34% savings from the actual water use, as shown in table3.

RESULTS AND DISCUSSION

When evaluating the total water footprint, a number of aspects were restricted to some limitations; which affected the accounting of the water footprint. For example; Athena IE and BEES softwares are based on data related to the United States, but the research tried to choose the most appropriate components to the case study. Another example, when dealing with the direct water footprint; no detailed data about the water consumption in the units were provided; there for LEED V4 water reduction calculator as it is the most common rating system in Egypt and almost worldwide, in addition to questionnaires which were used to found the missing data. It was found that the water footprint accounting was the most challenging phase as it required many data and composite variables; Athena IE and BEES softwares were used in an integrative way for the embodied water footprint accountings; it would be more effective if those two softwares are linked together and shared their data base. When accounting the direct grey water footprints; it was hard to account the nitrogen and the phosphorous so previous researches about grey water footprint in world countries were used to know the average greywater footprints related to nitrogen and phosphorous .The water footprint assessment also showed that water footprint is influenced by social behaviors, by climate and technical ways used in construction and operation. The results showed that the direct water footprint/year for one building was found to be more than 17 times greater than its embodied water footprint; when analyzing the results it was found that the direct water usage in one building for about four years equals to its embodied WFP and the amount of water polluted due to the direct water use per year equals to the same amount of the water polluted due to building 21 buildings of the project. So

Table 1. Default water consumption according to the water devices used

Fixture type	Default (sec)	Baseline Flow rate (liter/min)	Design Flow rate (liter/min)	Default daily uses	Default water use (Liter/day)
(residential) lavatory faucet	60	8.30	8.30	20	166
(residential) toilet faucet	30	8.3	3	20	30
Residential showerhead	480	9.50	9.50	4	304
Residential kitchen faucet	60	8.30	8.30	16	132.8
Toilets		6 (lpf)	6 (lpf)	20 flushes	120
Total default water consumption per unit(4persons) = 752 L/day					

Table 2. Actual water consumption in each residential unit

Fixture type	Actual (sec)	Baseline Flow rate (liter/min)	Design Flow rate (liter/min)	Actual daily uses	Default water use (Liter/day)
(residential) lavatory faucet	120	8.30	8.30	20	332
(residential) toilet faucet	30	8.3	3	20	30
Residential showerhead	480	9.50	9.50	4	304
Residential kitchen faucet	60	8.30	8.30	18	166
Toilets		6 (lpf)	6 (lpf)	20 flushes	120
Total actual water consumption per unit(4persons) = 952 L/day					

Table 3. Water consumption when using aerators and dual flush, (Author, 2019)

Fixture type	Actual (sec)	Baseline Flow rate (liter/min)	Design Flow rate (liter/min)	Actual daily uses	Default water use (Liter/day)
(residential) lavatory faucet	120	8.30	3.8	20	76
(residential) toilet faucet	30	8.3	3	20	30
Residential showerhead	480	9.50	6	4	192
Residential kitchen faucet	60	8.30	8.30	18	166
Toilets		6 (lpf)	6 &3(lpf)	20 flushes	90
Total water consumption per unit(4persons) when using aerators and dual flush= 630 L/day					

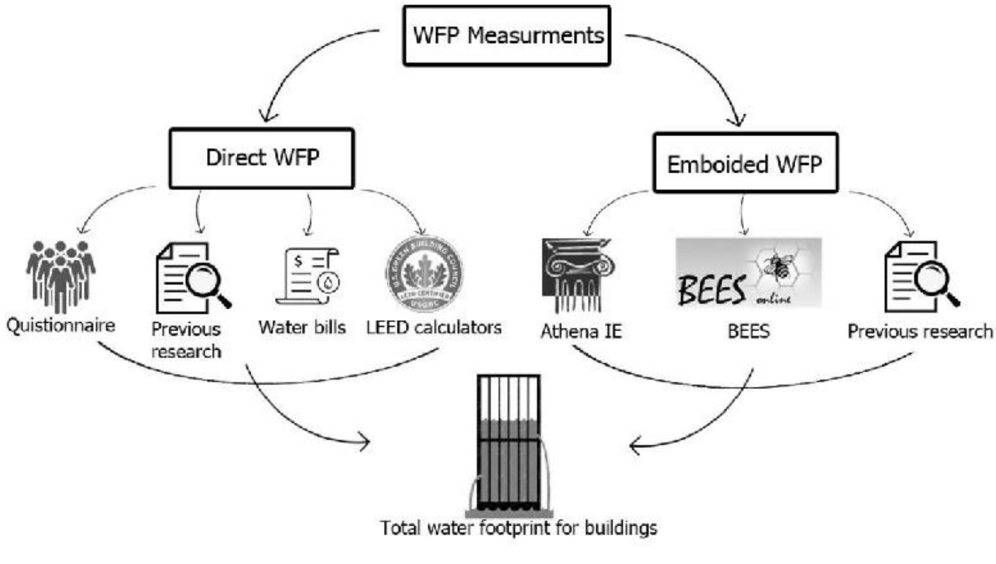

Fig.1 Total water footprint accounting (Author, 2019)

Fig.2: Site plan of New-Cairo social housing project (googleearth, 2019)

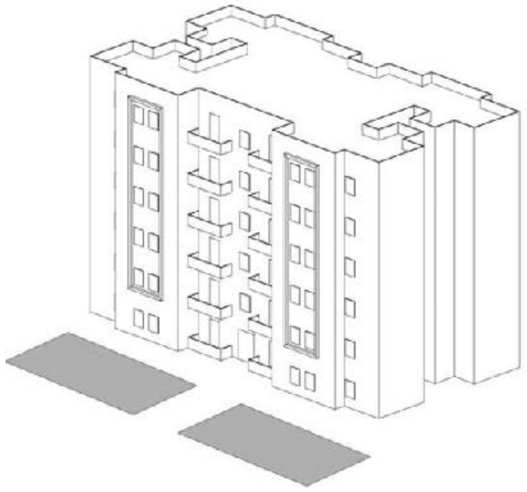

Fig.3. Model of the typical residential building. Source: (Author, 2019)

GWF must be really considered and not only BWF; as it affects the WFP in a great amount. In order to improve water efficiency in the case study; it was hard to deal with the embodied WFP as the project is already under process. To mitigate the direct WFP it is recommended to integrate between using water efficient devices and reusing greywater for flushing in indoors while also using greywater for irrigation. In this case study harvesting rainwater and stormwater would not be very efficient due to the climatic aspects; so it is recommended to improve the quality of the open spaces and adopting green infrastructure solutions to manage rainwater and stormwater like green roofs and bio-swales which will also improves the environmental aspects and reduce heat gain. Water sub-meters is highly recommended even though it don't have direct impact on the water consumption but it affects the people's behaviors. In addition to using water efficient technical strategies, there is a need for raising the residents' awareness about the importance of reducing water use. Also using leakage sensors will save water, time and energy as it reduces the effort needed to detect the leakage.

Conclusion

The integrated methodology used in this research showed a good evaluation for the full water footprint of the case study and this helped in analyzing the aspects of water efficiency in order to recognize which life stage is the most consuming and which type of WFP is mostly affecting the total WFP. Future research topics that are proposed by this paper include; making water footprint assessment for other buildings to compare between the water efficiency of the different strategies used in each project, developing a national database for the construction materials, using different methods to account the WF to check the accuracy of each method, affordable methods to apply greywater recycling and rainwater harvesting and alternative water efficient construction materials. Mitigating water footprint in social housing projects in Egypt needs more concern and regulations. Government departments should consider water conservation prior to undertaking works in any new housing project. Consideration to water conservation should be made during the planning stages of any intended works. And Audits should be made for existing built assets to determine water consumption levels; following completion of an audit, plans should be developed to manage any identified inefficient water use. Launching campaigns for raising awareness; about water efficiency practices among people is of main concern. It is essential for the management to recognize that water conservation as a long term investment and not just for short term financial gains.

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