Indian Journal of Science and Technology, *Vol 9(6), DOI: 10.17485/ijst/2016/v9i6/87671, February 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Studies on Virtual Water Content of Urban Buildings in India

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Abstract

Background/Objectives: Water conservation in buildings seldom considers the water used in building production or in other words the virtual water content of buildings. There is very few reported research in this field, especially in the Indian context, despite the fact that water scarcity is a burning issue requiring urgent attention. The paper attempts to provide a baseline study of virtual water content of urban buildings in India and establish its significance in sustainable design practice. **Methods:** Virtual water content is calculated through case studies of one residential building each from Kolkata and Pune under a common framework. The methodology includes the computation of inherent and induced virtual water, where the former is on account of the materials and the latter is for the actual construction. The inherent water considers five major materials of construction viz. bricks, cement, steel, aluminium and glass, as data pertaining to embodied water coefficients of only these are available on date. The inherent and induced virtual water when added gives the total virtual water content expressed per unit floor area. **Findings:** The virtual water content was calculated at 19.3588 kl/m2 and 16.2707 kl/m2 for Kolkata and Pune respectively. The inherent water component at 61.45% and 82.00% of the virtual water for Kolkata and Pune respectively conformed to earlier findings that the inherent water was comparatively more significant than the induced water component. An important finding of the study was that buildings in warm-humid climate used more water in their on-site processes as compared to their counterparts in moderate climate. The quantum of virtual water translates to water requirement of 1233 families for one whole year on an average. This is a significant amount of water hidden in buildings that goes unnoticed. **Applications/Improvements:** Rapid urbanization and growing water scarcity necessitates serious attention to virtual water content of buildings for a more holistic approach towards water conservation leading to a sustainable future. In this context, the study assumes a novel approach in our understanding of virtual water content of buildings and hopes to inspire further research in this area.

Keywords: Embodied Water Content, Sustainability, Urban Buildings, Virtual Water Content, Water Scarcity

1. Introduction

Water is one of the most precious commodities on earth without which life would not have been possible. With the present day realization of the significance that it holds in our lives there has been conscious efforts to save water. It is needless to mention that the construction industry is very water dependent consuming an enormous amount of fresh water during its entire life cycle. A lot of studies and efforts in conserving this water have been undertaken including policies framed by the Government, actions initiated by state governments and local bodies. However, most of our efforts have been targeting the direct use of water during the operational stage of the building. The indirect use of water which includes the embodied water of the materials of construction along with the water used during construction is still not well explored as a potential area for saving this 'blue gold'. The concept of embodied water of construction, akin to that of embodied energy of construction, is still in its nascent stage. Although some work has been done on embodied water of agricultural products, very little has been achieved in the field of embodied water of construction. If one considers that in a country like India where the construction industry is the

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second largest bread earner, after agriculture, it is quite natural to assume and safely state that the next target for studies in embodied water should be the construction industry.

The present research attempts to take a holistic look at the virtual or embodied water of contemporary urban buildings by analyzing the virtual water of sample urban buildings in the city of Kolkata and Pune and arriving at a better understanding of the subject and establishing its significance. The cities of Kolkata and Pune were chosen primarily because the authors belong to these cities and secondly because both these cities have witnessed tremendous growth in the building sector during the past decade. However the cities present a completely different picture in terms of its climate and water resources. While Kolkata falls in the hot humid zone with abundance of water being part of the Ganga-Brahmaputra delta which are glacier fed perennial rivers, Pune falls midway between warm-humid and hot-dry zone and belongs to a water stressed area which is totally rain dependent. As such apart from the burgeoning growth of the building sector, the two cities present contrasting perspectives when it comes to water.

2. Virtual Water

Professor John Anthony Allan[1] from Kings College, London, was the creator of the virtual water concept which measures how water is embedded in the production and trade of food and consumer products. Hoekstra and Chapagain[2] have defined the virtual water content of a product (a commodity, good or service) as "the volume of fresh water used to produce the product, measured at the place where the product was actually produced". Virtual water is also known as embodied water or embedded water. The concept and study of embodied water akin to embodied energy and the estimation of water footprint, akin to the concept of carbon footprint has been mostly centring on agricultural products and food products.

2.1 Virtual Water of Construction

According to Jacob Tompkins[3], director of Waterwise, a UK NGO focused on decreasing water consumption, "The construction industry is very water dependent, directly via material and processes such as water of concrete, water for dust suppression, water for cutting, water for mortars etc. and, indirectly, with embedded water in all construction products". According to Paul Shaffer[3], associate at the Construction Industry Research and Information Association, CIRIA "Embedded water will become an important factor in construction in the near future and we need to collect evidence to see how much of a problem it will be". With this backdrop and the current issues of sustainability, the concept of embodied water and research in this area assumes great proportions. Let us look at how buildings utilize water. Water is used at every stage in a building that could be stratified as follows:

- Stage 1

Water required for the manufacturing of the materials of construction (cradle to gate / cradle to site). This forms the first part of the embodied or virtual water of construction and can be more specifically termed as the inherent virtual water component.

- Stage 2

Water required during the actual construction process at site (site preparation to pre-occupancy/completion/actual operation). This forms the second part of the embodied or virtual water of construction and can be more specifically termed as the induced virtual water component.

- Stage 3

Water consumed by the building post occupancy or during its operational stage. This can be termed as the operational water.

When all the three stages of water are combined together one can compute the life cycle water. The accepted practice is to compute the life cycle water for a 50 year life cycle. For a better understanding, the same is graphically represented in Figure 1.

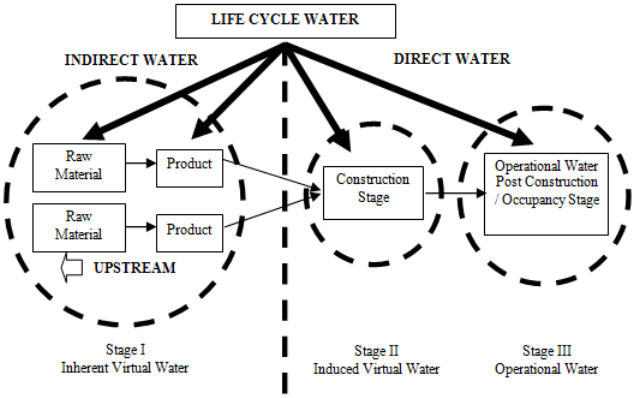


Figure 1. Life cycle water of construction.

It may be noted that water is also required for demolition after the serviceable life of the building. However, this quantity is not included in the life cycle water analysis when a 50 year life cycle is considered. Unfortunately, the present sustainability issues target only the operational water at stage 3. But if one considers the entire life cycle of a building, it is quite apparent that the water utilized in stage 3 is only a part of the water required by the building. If and only if the entire water requirement can be quantified, a more holistic approach towards estimating the life cycle water demand of a building could be arrived at.

2.2 Existing Research on Virtual Water

Very little research has been reported in the field of virtual water of construction. A brief of the important findings of all existing research in this field reported till date is indicated in the subsequent paragraphs.

There are five research publications from Australia. McCormack et al.[4] looked at 17 non-residential case studies and found that the virtual water could be as much as 20.1 kl / m^2 of gross floor area, with steel contributing the highest in terms of materials. The study also indicates that the water use during construction (induced virtual water) is less significant than the virtual water of the materials of construction (inherent virtual water). Crawford and Treloar[5] have also dealt upon the various tools available for calculating the embodied energy of buildings and applied it to quantify embodied (virtual) water of a commercial building with surprising results. The total virtual water worked out to 54.1 kl/m^2 of constructed area with steel contributing to the maximum i.e. 17%. The direct water requirement during construction (induced virtual water) however was much less significant with only 0.7% of the total virtual water. Findings of another study carried out by McCormack et al.[6] estimated that the embodied water of a typical Australian house equals to about 15 years' worth of operational water, which is quite significant. Results of an independent study carried out by Crawford[7] on residential, commercial and industrial type of buildings in Australia reveals further interesting results. Key findings from the project was that the water embodied in replacement materials can represent as much as 50 per cent of the life cycle water requirements for many of the assemblies assessed. Results of another study carried out by Crawford[8] on life cycle water analysis of an Australian residential building and its occupants computed the embodied (virtual) water and operational water as 31.4 kl/m^2 and 31.6 kl/m^2 of constructed floor area respectively, concluding that the embodied (virtual) water was as much as the operational water.

There is one reported publication from the UK. Brathwaite[9] in his paper evaluated the significance of the water embodied within the construction of materials and the construction process of the Kingspan Offsite Lighthouse, UK's first zero carbon home. Summary of his findings indicate the total virtual water at 818 kl/m^2 of constructed floor area with steel contributing the highest i.e. 67% of this. He concluded by stating that the embodied water figure calculated shows that this water is a significant amount and should be addressed by the Government and included in BRE Environmental profiling, if it's not already considered.

In China, Meng et al.[10] considered 6 office buildings in E-town, Beijing and computed the embodied water at 20.83 m^3 per m^2 of floor area.

In India, there are two published data available with regard to embodied water of materials consumed by the construction industry. The Comprehensive Industry Document[11] indicates an average embodied water of 1.00 kl/metric ton of cement produced, and the embodied water of steel as indicated in the Manual on Water Supply and Treatment[12] works out to 200 to 250 kl /metric ton of steel produced.

So far as computation of virtual water specific to the construction process in India is concerned, there are two reported publications. The first by Bardhan[13] studied a group of multi-storied residential apartment buildings in Kolkata and concluded that the virtual water in the materials or in other words the inherent water was to the tune of 25.604 kl/m^2 of floor area and the induced water i.e. the water use during construction was 2 kl/m^2 of floor area. The embodied water for the project worked out to 27.6040 kl/m^2 of floor area. The paper also calculates the embodied water of bricks and indicates it as 0.714 kl/m^3 of brickwork. The second study by Bardhan[14] considered another multi-storied residential building in Kolkata and calculated the embodied water as 26.8102 kl/m^2 of floor area.

3. Methodology for Present Study

To avail of a common platform, one residential building in each of the cities of Kolkata and Pune were studied by

Table 1. Residential case studies in Kolkata and Pune

Project data	Case study in Kolkata	Case study in Pune
Location	Rishra	Pimple Nilakh
Number of floors	3 towers of Ground + 12 Floors	6 towers of Ground + 12 Floors
Number of dwelling units	210 nos	144 nos
Total floor area	20368 m^2	17280 m^2
Project duration	38 months	44 months
Project completion	2014	2013
Type of structure	RCC framed structure with RCC pile foundation	RCC framed structure with RCC pile foundation

computing the water embodied in the major materials of construction (Inherent virtual water) and the water use during construction (Induced virtual water). The inherent and induced water for each project was then summed up to arrive at the total virtual water for each case study. A comparative of the virtual water of both cities was then carried out to arrive at conclusive results. A brief description of the two residential projects that were studied in Kolkata and Pune are indicated in Table 1.

To compute the inherent virtual water, five major materials of construction which are bricks, cement, steel, aluminium and glass were taken. The study had to restrict itself to these five materials due to availability of published data with respect to these only. The assumed quantities of embodied water coefficients for the five materials are indicated in Table 2 along with their source.

The data for each of the case studies was collected on the basis of a questionnaire that was filled up using information as shared by the project teams/sites. The Bill of Quantities, procurement bills and vendors/suppliers payment bills were used as basis for collection of data on quantities of materials of construction. These quantities were then multiplied by the embodied water coefficients of the materials to arrive at the inherent virtual water component.

The data on water use during construction i.e. the induced virtual water component was based on information shared by the project team and/or physical observations carried out on site. The average water use per day was estimated and was then translated to per m^2 of floor area for the entire project duration. Due to inadequate and poor record keeping, data of actual water use for each day could not be estimated, and so an average use per day was taken.

4. Results and Discussions

4.1 Inherent Virtual Water

Inherent virtual water was computed based on the quantities of each of the materials multiplied by the respective embodied water coefficients as given in Table 2 for foundation works and superstructure works separately and translating the same to per m^2 of floor area.

Table 2. Assumed quantities of embodied water coefficients

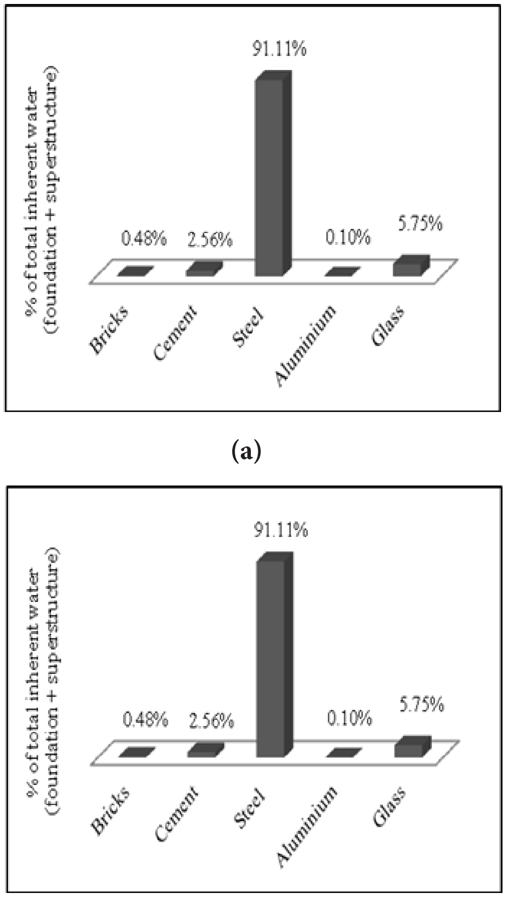
Material	Embodied water coefficient in kl/unit	Source
Brick	0.71 kl/m^3	Bardhan S. Assessment of water resource consumption in building construction in India. Ecosystems and Sustainable Development VIII, WIT Transactions on Ecology and the Environment, 2011, 144, 93 - 102.
Cement	1 kl/metric ton	Comprehensive Industry Document on Vertical Shaft Kiln Based Mini Cement Plants. Comprehensive Industry Document Series: COINDS/64/2006-2007. CPCB, Ministry of Environment & Forests.
Steel	200 kl/metric ton	Manual on Water Supply and Treatment, 3rd edn, 1999 May. Central Public Health and Environmental Engineering Organization, Ministry of Urban Development.
Aluminium	0.088 kl/kg	McCormack M, Treloar GJ, Palmowski L, Fay R. Embodied water of construction, BEDP Environment Design Guide, 2004, GEN 58, 1 - 8.
Glass	3.42 kl/m^2	Crawford RH. Life cycle water analysis of an Australian residential building and its occupants. Proceedings of the Seventh Australian conference on life cycle assessment: Revealing the secrets of a green market, Melbourne, 2011 March, 9 - 10.

Table 3. Inherent virtual water due to materials of foundation and superstructure for case studies in Kolkata and Pune

Material	Case study in Kolkata						Case study in Pune					
	Inherent virtual water in foundation per unit floor area		Inherent virtual water in superstructure per unit floor area		Total		Inherent virtual water in foundation per unit floor area		Inherent virtual water in superstructure per unit floor area		Total	
A	$B1_K$		$B2_K$		$C_K = B1_K + B2_K$		$B1_P$		$B2_P$		$C_P = B1_P + B2_P$	
	kl/m^2	%	kl/m^2	%	kl/m^2	%	kl/m^2	%	kl/m^2	%	kl/m^2	%
Bricks	0.0119	0.31	0.0451	0.56	0.0569	0.48	0.0000	0.00	0.1575	2.02	0.1575	1.18
Cement	0.0736	1.95	0.2312	2.85	0.3049	2.56	0.0620	1.11	0.0968	1.24	0.1588	1.19
Steel	3.6999	97.74	7.1386	88.02	10.8386	91.11	5.4985	98.89	6.7551	86.80	12.2536	91.84
Aluminium	0.0000	0.00	0.0117	0.14	0.0117	0.10	0.0000	0.00	0.1319	1.69	0.1319	0.99
Glass	0.0000	0.00	0.6841	8.43	0.6841	5.75	0.0000	0.00	0.6407	8.23	0.6407	4.80
Total	3.7854	100%	8.1107	100%	11.8961	100%	5.5605	100%	7.7819	100%	13.3424	100%

A summary of the inherent virtual water contributed by each of the materials of foundation and super structure for the case studies in Kolkata and Pune along with the total are indicated in Table 3. Percentage contribution of each material for each of the categories is also indicated alongside the respective columns.

The inherent virtual water in foundation (column $B1_K$ and column $B1_P$ of Table 3) indicates that the contribution of steel is the maximum in both the case studies, amounting to 97.74% of the total inherent water of foundation in case of Kolkata and 98.89% of the total inherent water of foundation in case of Pune. The results of the inherent virtual water of materials in superstructure (column $B2_K$ and column $B2_P$ of Table 3) also indicates that the contribution of steel is the maximum in both the case studies, amounting to 88.02% of the total inherent water of superstructure in case of Kolkata and 86.80% in case of Pune. This means that both in case of foundation and superstructure, steel remains as the highest contributor towards the inherent water of a building, and more the use of steel more would be the quantum of inherent water. The total inherent virtual water (inherent water of foundation + inherent water of superstructure) is indicated in column C_K and column C_P of Table 3 for Kolkata and Pune, respectively. The same is also graphically represented in Figure 2. The combined result indicates the contribution of steel as 91.11% in case of Kolkata and 91.84% in case of Pune. However the contribution of all other materials put together is much less significant when compared to steel. It would be interesting to note that the results of both case studies indicate striking similarities. The results also corroborate with the studies carried out by McCormack et al[4] and Crawford et al[5] in Australia and Bardhan[13 14] in India which also indicate that steel is the largest contributor to the inherent virtual water.



(a)

(b)

Figure 2. Inherent water of individual materials as a percentage of total inherent water for case studies in (**a**) Kolkata and (**b**) Pune.

4.2 Induced Virtual Water

The induced virtual water was computed based on the average water use per day at site and the duration of the project. A summary of the computed induced virtual water for the case studies in Kolkata and Pune are indicated in Table 4. Computation of induced water indicates that it could be as high as 7.4627 kl/m^2 of floor area as in case of Kolkata to as low as 2.9282 kl/m^2 in case of Pune.

Unlike the inherent water, that showed striking similarities, the induced water shows a marked difference in the two case studies. The reasons for this when investigated revealed obvious yet interesting facts. The first reason could be attributed to the fact as already mentioned earlier, that, being a water stressed area, the water use in case of Pune during the construction stage is obviously on the conservative side, while in Kolkata, where water is not a major concern, the on-site use of water is rather on the lavish side. The second reason for the higher on-site water use for the case study in Kolkata could be attributed to the fact that an average of 100 workers were staying on-site and hence required water for their daily needs and thereby increasing the water demand, while this was not the case in Pune where an average of only 5 persons (mainly security) stayed on site.

4.3 Total Virtual Water

To arrive at the quantum of total virtual water for the case studies, the inherent virtual water (Table 3) and induced virtual water shown in Table 4 were added and the results are indicated in Table 5 for Kolkata and Pune.

The total virtual water in case of Kolkata worked out to 19.3588 kl/m^2 of floor area and that of Pune 16.2707 kl/m^2 of floor area with an average of 17.81 kl/m^2. The residential case study by Crawford[8] in Australia indicated the total virtual water at 31.4 kl/m^2 of constructed floor area. The higher results of the Australian study could be attributed to the fact that a total of 12 items of work were considered while the present study has considered only 5. The non residential case studies by McCormack et al.[4] in Australia indicates the total virtual water at 20.1 kl/m^2 of constructed floor area which is closer to the findings of the present study although the Australian study included the embodied water of services, such as air-conditioning, fire protection, electrical, hydraulic and lifts as well. The study by Meng et al.[10] in China calculated the virtual water at 20.83 m^3 per m^2 of floor area. The study by Bardhan[13 14] in Kolkata found the total virtual water at 27.604 kl/m^2 of constructed floor area and 26.8102 kl/m^2 of constructed floor area respectively considering four materials.

Table 4. Induced virtual water of case studies in Kolkata and Pune

Water use at site on account of water extraction from bore well	**Case study in Kolkata**				**Case study in Pune**			
	Water used/day	Water used/month	Total induced virtual water for entire duration of project	Induced virtual water per m^2 of floor area	Water used/day	Water used/month	Total induced virtual water for entire duration of project	Induced virtual water per m^2 of floor area
	D_K	$E_K = D_K$ * 25 days	$F_K = E_K$ * project duration	$G_K = F_K$ / total floor area	D_P	$E_P = D_P$ * 25 days	$F_P = E_P$ * project duration	$G_P = F_P$ / total floor area
	kl/day	kl/month	kl	kl/m^2	kl/day	kl/month	kl	kl/m^2
Total	**160.00**	**4000**	**152000**	**7.4627**	**46.00**	**1150**	**50600**	**2.9282**

Table 5. Total virtual water of case studies in Kolkata and Pune

Case study Kolkata					**Case study in Pune**				
Inherent virtual water			Induced virtual water	Total virtual water	Inherent virtual water			Induced virtual water	Total virtual water
Materials in foundation	Materials in superstructure	Total	Consumption during construction		Materials in foundation	Materials in superstructure	Total	Consumption during construction	
kl/m^2	kl/m^2	kl/m^2	kl/m^2	kl/m^2	kl/m^2	kl/m^2	kl/m^2	kl/m^2	kl/m^2
$H1_K$	$H2_K$	$I_K = H1_K + H2_K$	J_K	$K_K = I_K + J_K$	$H1_P$	$H2_P$	$I_P = H1_P + H2_P$	J_P	$K_P = I_P + J_P$
3.7854	8.1107	11.8961	7.4627	19.3588	5.5605	7.7819	13.3424	2.9282	16.2707

For a better understanding of the quantum contribution of inherent virtual water and induced virtual water to the total virtual water, a percentage analysis of the same was carried out and the results are indicated in Figure 3. It is evident that the inherent water has the highest contribution ranging from 61.45% of the total virtual water in case of Kolkata to as high as 82.00% of the total virtual water in case of Pune. It could therefore be concluded that the inherent water of the materials of construction is far more significant than the induced water. The results conform to earlier findings of studies by McCormack et al.[4] in Australia and Bardhan[13,14] in India which also found the inherent virtual water components to be much more significant than the induced virtual water component.

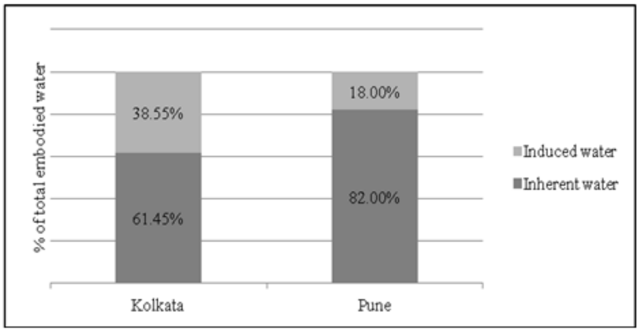


Figure 3. Inherent virtual water and induced virtual water as a percentage of total virtual water for case studies in (**a**) Kolkata and (***b***) Pune.

To understand the significance of the quantum of virtual water, the total virtual water for the case studies i.e. 394300 kl for Kolkata and 281157 kl for Pune was computed against the operational water demand. Considering operational water demand of 150 litres per capita per day and a family of five members, the quantum of embodied water translates to water requirement of 1440 families for one whole year for Kolkata and 1027 families for one whole year for Pune. The average works out to 1233 families for one whole year. Considering the same operational water demand per dwelling unit, the results could also be expressed in terms of the operational water demand of each case study based on the number of constructed dwelling units. This works out to 6.89 years of operational water demand in case of Kolkata which has 210 constructed dwelling units. For Pune it works out to 7.13 years of operational water for its 144 constructed dwelling units. The average works out to 7.01 years of operational water. This is quite a significant amount that cannot be ignored.

5. Conclusion

It could be safely concluded from the two case studies that the inherent virtual water of the materials of construction is more significant when compared to the induced virtual water. Which basically means that the water embodied in the materials of construction is far more significant than the actual water use during construction. The present study considered only five materials of construction and it would be needless to state that if more materials are considered the quantum of inherent virtual water would be even higher. This confirms to the earlier finds of studies in Australia and India. Thus the choice of materials and the quantity plays a significant role in the virtual water content of buildings.

Steel was found to be the major contributor towards the virtual water of a building, and this corroborates with other research findings from Australia and India.

It was also found that the induced virtual water quantity can vary significantly based on the availability / scarcity of water and the number of workers staying on-site.

The virtual water of the case-studies in Kolkata and Pune were found to be 19.35 kl/m^2 and 16.27 kl/m^2 respectively with an average of 17.81 kl/m^2 of constructed floor area. This translates to the operational water demand of 1233 families for one whole year. It could also be translated to an average operational water demand for 7.01 years. This is a significant amount of fresh water that is consumed by the buildings that goes unnoticed.

There is therefore an urgent need to address the issue of pre-operational water management of buildings and carry forward this field of research to fill in the missing links.

This research work is based purely on data collection from case studies and information on embodied water of various construction materials. While the first part is dependent on voluntary sharing of information by the owners and builders, the second part is dependent on the co-operation of the manufacturing industries. Scanty and poor record keeping of water consumption was a major stumbling block for the research, which needs to be overcome in the interest of better resource management.

It is beyond doubt that water is a scarce commodity. When we talk of “save water” we are always targeting the actual water use post construction, that is, the operational water. Virtual water content of buildings has been given very little thought till date and it is of utmost significance that we target this sector for a better understanding of water usage patterns during construction. With a better understanding of the virtual water of buildings, the present policies that concentrate mainly on the operational water may have to be reviewed to encompass the virtual water as well.

6. Acknowledgements

The authors are immensely grateful to the University Grants Commission for the financial assistance rendered to this research work and recognizing the need for research in the area of virtual water.

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