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Water footprint in civil construction: use and impacts of masonry

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Abstract - The water footprint is an indicator of water consumption that considers its appropriation directly and indirectly. The aim of this research was to calculate the blue water footprint (WF_{blue}) of three different masonry (perforated ceramic block - PCB; solid ceramic brick - SCB and concrete block - CB), of way to identify the masonry that has the best water performance and which inputs contribute significantly. The necessary inputs for the construction of one square meter of each masonry were identified and quantified, considering or not mortar coating. After collecting data on water consumption of intermediate products and water consumption in the preparation of mortars, the calculation of water consumption by material, by WF component and by masonry was performed. The results indicated consumptions of 67.64; 75.05 and 270.85 L/m², for masonry without PCB, SCB and CB coating, respectively. Considering mortar coating, consumptions of 364.02 were identified; 371.43 and 567.24 L/m²for the PCB, SCB and CB masonry, respectively. The mortar coating was responsible for a large part of the water consumption in masonry (52.25 to 81.42% of WF_{blue}), resulting in 296.38 L/m² of masonry. $WF_{blue,indirect}$, corresponded to the higher water consumption of masonry and mortar coating.

Keywords: Concrete block. Perforated ceramic block. Solid ceramic brick. Vertical sealing. Water consumption.

Pegada hídrica na construção civil: uso e impactos de alvenarias

Resumo – A pegada hídrica é um indicador de consumo de água que considera sua apropriação direta e indireta. O objetivo desta pesquisa foi calcular a pegada hídrica azul (PH_{azul}) de três alvenarias diferentes (bloco cerâmico perfurado - CF; tijolo cerâmico maciço - CM e bloco de concreto - BC), de forma a identificar a alvenaria que apresenta melhor desempenho hídrico e quais insumos contribuem significativamente. Os insumos necessários para a construção de um metro quadrado de cada alvenaria foram identificados e quantificados, considerando ou não revestimento argamassado. Após a coleta dos dados de consumo de água dos produtos intermediários e consumo de água na preparação das argamassas, foi realizado o cálculo do consumo de água por material, por componente de PH e por alvenaria. Os resultados indicaram consumos de 67,64; 75,05 e 270,85 L/m², para alvenaria sem revestimento CF, CM e BC, respectivamente. Considerando o revestimento argamassado, foram identificados consumos de 364,02; 371,43 e 567,24 L/m² para as alvenarias CF, CM e BC, respectivamente. O revestimento argamassado foi responsável por grande parte do consumo de água nas alvenarias (52,25 a 81,42% da PH_{azul}), resultando 296,38 L/m² de alvenaria. A $PH_{azul,indireta}$ correspondeu ao maior consumo hídrico das alvenarias e do revestimento argamassado.

Palavras-chave: Bloco de concreto. Bloco cerâmico furado. Tijolo cerâmico maciço. Vedações verticais. Consumo hídrico.

Huella hídrica en la construcción civil: uso e impactos de la mampostería

Resumen – La huella hídrica es un indicador del consumo de agua que considera su apropiación directa e indirectamente. El objetivo de esta investigación fue calcular la huella hídrica azul (PH_{blue}) de tres mamposterías diferentes (bloque cerámico perforado - CF; ladrillo cerámico macizo - CM y bloque de hormigón - BH), de manera de identificar la mampostería que presenta el mejor desempeño hídrico. y qué insumos contribuyen significativamente. Se identificaron y cuantificaron los insumos necesarios para la construcción de un metro cuadrado de cada mampostería, considerando o no revestimiento de mortero. Luego de recolectar datos de consumo de agua de productos intermedios y consumo de agua en la elaboración de morteros, se realizó el cálculo de consumo de agua por material, por componente PH y por albañilería. Los resultados indicaron consumos de 67,64; 75,05 y 270,85 L/m², para mampostería sin revestimiento CF, CM y BH, respectivamente. Considerando el revestimiento de mortero, se identificaron consumos de 364,02; 371.43 y 567.24 L/m² para las albañilerías CF, CM y BH, respectivamente. El revestimiento de mortero fue responsable de gran parte del consumo de agua en albañilería (52.25 a 81.42% de PH_{blue}), resultando en 296.38 L/m² de albañilería. $PH_{blue, indirecto}$, correspondió al mayor consumo de agua del revestimiento de mampostería y mortero.

Palabras clave: Bloque de concreto. Bloque cerámico perforado. Ladrillo cerámico macizo. Sellado vertical. Consumo de agua.

Introduction

Water is a strategic natural resource (Tundisi and Matsumura-Tundisi 2020), essential to sustain all forms of life and also necessary in industrial processes. However, it is a finite and vulnerable resource (Tundisi and Matsumura-Tundisi 2020) and under pressure from climate change, population growth, higher living standards, greater industrialization and widespread urbanization (Larsen et al. 2016).

Water is a critical factor for all the Sustainable Development Goals - SDGs, of the Agenda 2023 of the United Nations - UN, since it is the basic food of the human species and is also the origin of all food for all other species (Ferraz et al. 2020). SDG 6 seeks to ensure the availability and sustainable management of water and sanitation for all (Guimarães et al. 2020).

If measures to reduce water consumption are not adopted by 2030, water reserves could shrink by up to 40% as approximately 20% of aquifers are overexploited, which could lead to soil erosion and salt water entering these reservoirs, and consequently access to clean water worldwide will be further reduced (Ferraz et al. 2020).

The lack of quality water compromises economic and social development and the population's quality of life (Tundisi and Matsumura-Tundisi 2020). Therefore, issues such as the amount of fresh water available and its consumption need to be discussed among all spheres of economic development (Ferraz et al. 2020). Among the main economic sectors that generate employment and are responsible for the heating up of the market are agriculture and civil construction – although there is an individualization of economic activities, they are not unrelated, and reflect on the multiple uses of water resources.

These are activities responsible for constituting our way of being in the world, and their interactions are responsible for the impacts on water resources. Although there are data on the incorporation of water in agricultural products, there is little data in the scope of civil construction products, which suggests that their products are the next targets of water footprint studies – WF (Bardhan and Choudhuri 2016; Montoya 2020).

WF can be divided into blue components (WF_{blue}) - appropriate water volume and removed from the total runoff flow, green (WF_{green}) - appropriate rainwater volume, and gray (WF_{grey}) - volume of water necessary to assimilate pollutants (Montoya 2020, Santos et al. 2020). As WFs are determined in terms of water volume, it is possible to determine whether the greatest water consumption occurs in its use as a source or as a depository (Hoekstra et al. 2011; Montoya 2020).

In this work the Blue WF was measured, since blue water resources are considered scarcer and have higher costs than green water (Hoekstra et al., 2011). In addition, the use of rainwater in the production of construction inputs or even on the construction site is not considered significant, adding to the lack of data in the literature on this subject, the green WF was not measured. The grey WF, on the other hand, expresses water pollution in terms of polluted volume. Due to lack of data, this component of WF was not measured either.

Water management has stood out within the scope of environmental management, and WF represents an important tool in this regard. This can be demonstrated by the elaboration of standards such as ABNT ISO 14046:2017 *Environmental management - Water footprint - Principles, requirements and guidelines* (ABNT 2017), which provides an indicator of water appropriation for the market, and, recently, the elaboration of ISO 46001:2019 Water efficiency management systems — Requirements with guidance for use (*Water efficiency management systems - Requirements with guidance for use*), configuring important regulatory instruments in private policies, increasing the credibility of WF's methodology.

Regarding WF studies associated with civil construction, it was found that the consumption of water per square meter of construction in a building in India was 27,604 liters, and of this total, 92.75% corresponded to water incorporated in the materials used. In the Bardhan construction (2011), corroborating what was observed by Bardhan and Choudhuri (2016). The comparison of the volume of virtual water (water incorporated in materials and water used during construction) and operational water (water used during the use of buildings) of two buildings built in India showed that the amount would be sufficient to supply the buildings per 6.89 and 7.13 years, respectively (Bardhan and Choudhuri 2016).

Arosio et al. (2019) sought to save fresh water associated with the adoption of innovative concrete mixes – the second most consumed product in the world, second only to water (Helene and Andrade 2017). The authors defined that the use of marine aggregates as a substitute for terrestrial aggregates enables a reduction of up to 12% in WF, and associated with the use of seawater as a replacement for fresh water, allows a reduction of up to 84% in WF. Hosseinian and Ghahari (2020) studied the relationship between structural parameters and the WF of residential buildings. The authors concluded that some materials have better water performance than others, associated with the same function. These studies indicate that the choice of materials and their quantities play an important role in building water consumption.

Masonry is the most used sealing in Brazil, unlike American or European countries that use sealing considered lean - characterized by high productivity and low waste, being called "clean construction". Among the types of masonry, those that use ceramic bricks - drilled or solid, and concrete blocks are the most used, and are the object of study of this work.

Although there are studies on some construction materials, there are no studies that account for the WF of different masonry, allowing for comparisons. Accounting for the WF of different products that are associated with the same function - different construction methods for masonry, which are used as a vertical fence for buildings - allows you to define which product has better water performance (lower water consumption), collaborating with the water savings associated with construction sector still in the production process.

WF_{blue} knowledge of masonry allows and encourages the reduction of water consumption, with optimization in production processes. In the long term, the determination of the water performance of other systems and construction products may result in some classifications and labeling based on direct and indirect water consumption. Current building performance rating systems neglect the water consumption associated with the production process of the inputs used ($WF_{blue,indirect}$), and of the building ($WF_{blue,direct}$), limiting themselves to the operational use of buildings.

From the point of view of civil construction, the results reported in this article seek to contribute to the reduction of water consumption by choosing different materials associated with the same function. Therefore, this research counted the blue water footprint (WF_{blue}) of three different types of masonry used as vertical fences in buildings (masonry with solid ceramic brick - SCB, drilled ceramic block - CB and concrete block - CB), to identify the masonry with the best water performance. In addition, the contributions of the component materials in each masonry and the influence of the mortar coating on them were identified.

Material and methods

Objects of study

The methodology used in this research was based on Hoekstra et al. (2011), in which four phases are defined for the complete assessment of WF. In this research, phases one and two were carried out, which consist of defining goals and scope and accounting for the WF_{blue} of the masonry.

The first phase concerns the definition of the goal and scope of the water footprint with the the study, outlining the objective and scope, clarifying the the objective and scope, clarifying the reasons for its realization, whether will be considered only one step of a process or a geographically delimited area geographically delimited area, among other details. It is important to point out that the division into phases is not meant to make the process plastered; the author claims that these are guidelines whose processes foreseen in each phase can interact with each other and even move from one phase to the next.

The second phase refers to water footprint accounting.This phase consists of surveying the inputs and outputs of water for each stage of the life cycle studied, and must observe the determinations of ISO 14046:2017.

The WF_{blue} study was carried out considering three masonry, produced with three different blocks/bricks and laid with mortar: solid ceramic brick – SCB, perforated ceramic block – PCB and concrete block – CB. The WFs of each uncoated and uncoated masonry were analyzed. The evaluated coating consisted of roughcast and a single mass, applied on both sides of the masonry. The masonry and coating specifications are described in Table 1.

Table 1. Specifications of the masonry and mortar coating used for the accounting of $WF_{blue.}$

Masonry	Block dimensions	Wall thickness	Settlement mortar	Coating (two sides)	
SCB	5 x 10 x 20 cm	10 cm	1:2:8 (cement, lime and sand)	Roughcast 1:3 (cement and sand)	single mass 1:2:8 (cement, lime and sand)
PCB	9 x19 x 19 cm	9 cm			
CB	14 x 19 x 39 cm	14 cm			

SCB – solid ceramic brick. PCB – perforated ceramic block. CB – concrete block.

Scope and research objectives

The scope of interest of the research covers both WF_{blue}, direct and $WF_{blue,indirect}$, $WF_{blue,direct}$ considers the water used in construction sites (last stage of the masonry production process), and $WF_{blue,indirect}$ is the water incorporated in the inputs used.

The WF_{blue} of transporting materials to cities and/or construction sites was not considered, as this research seeks not to be limited to a specific city and/or region. In addition, WF_{blue} for equipment and WF_{blue} for the work of masons, servants and machine operators were not considered.

Due to the fact that researches that study the amount of water incorporated in products are recent, data were collected from national and international bibliographic references, without limitation of period.

Identification and quantification of intermediate products

Masonry are final products, however, in the production process of these masonry, other products are used, called intermediates, which are still objects of study in this research. To identify and quantify the inputs and services required for the production of final products, the unitary compositions of masonry, provided by SINAPI - *Sistema Nacional de Preços e Índices para a Construção Civil* (CEF 2019), were considered. This tool helps in the preparation of quantitative and budgets in civil construction, providing data on the consumption of materials and services in the production of a particular final product, obtained on the national scene.

The general composition of inputs necessary for the construction of one square meter of each masonry are shown in Table 2. These are the objects of study considered as intermediate products necessary for the constitution of masonry (final products).

Table 2. General composition for obtaining 1 m^2 of masonry without mortar coating.

Code	Components	Unit	Quantity/Masonry		
	Intermediate Products/Masonry		**SCB**	**PCB**	**CB**
7258	Solid ceramic brick (5 x 10 x 20 cm)	unid.	83		
7266	Ceramic block (sealing masonry) of 9 x 19 x 19 cm	unid.		27.93	
651	Concrete fence block 14x19x39 cm (class C - NBR 6136)	unid.			13.35
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	0.0052	0.0114	0.0119
1106	CH-I hydrated lime for mortar	kg	0.6275	1.7062	1.7932
1379	Portland Cement Compounds CP II-32	kg	0.9413	1.9194	2.0174

For the analysis of masonry with mortar coating, roughcast and single mass were considered. The unitary compositions of roughcast application services (item 87879 of SINAPI) and of the single mass (item 87529 of SINAPI) consider the labor of workers and the volume of mortar required to apply the coating on 1 m^2 of masonry, being of 0.0042 m^3 of mortar for roughcast and 0.0376 m^3 of mortar for a single mass.

The compositions of mortar coatings (crumbstone and single mass) both in application and in preparation present the unitary compositions of the roughcast application services and single mass in one square meter of masonry, however, it is noteworthy that coating on both sides of the masonry was considered – resulting in two square meters of mortar coating. In the same way as in the laying mortar, the compositions do not consider water consumption in the preparation of roughcast mortars and a single mass.

The composition of the mortar coating (roof and single mass) for both sides of the masonry – that is, application on 2 m^2, is shown in Table 3.

Table 3. Composition for obtaining a mortar coating composed of roughcast and a single mass to be applied on both sides of the masonry.

Code	Components	Unit	Amount
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m^3	0.0080
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	0.0872
1106	CH-I hydrated lime for mortar	kg	13.0923
1379	Composite Portland cement CP ll-32	kg	18.3112

The general compositions of inputs necessary for the construction of one square meter of each masonry, considering roughcast coating and a single mass on both sides, are shown in Table 4.

Table 4. General composition to obtain 1 m^2 of masonry with mortar coating on two sides.

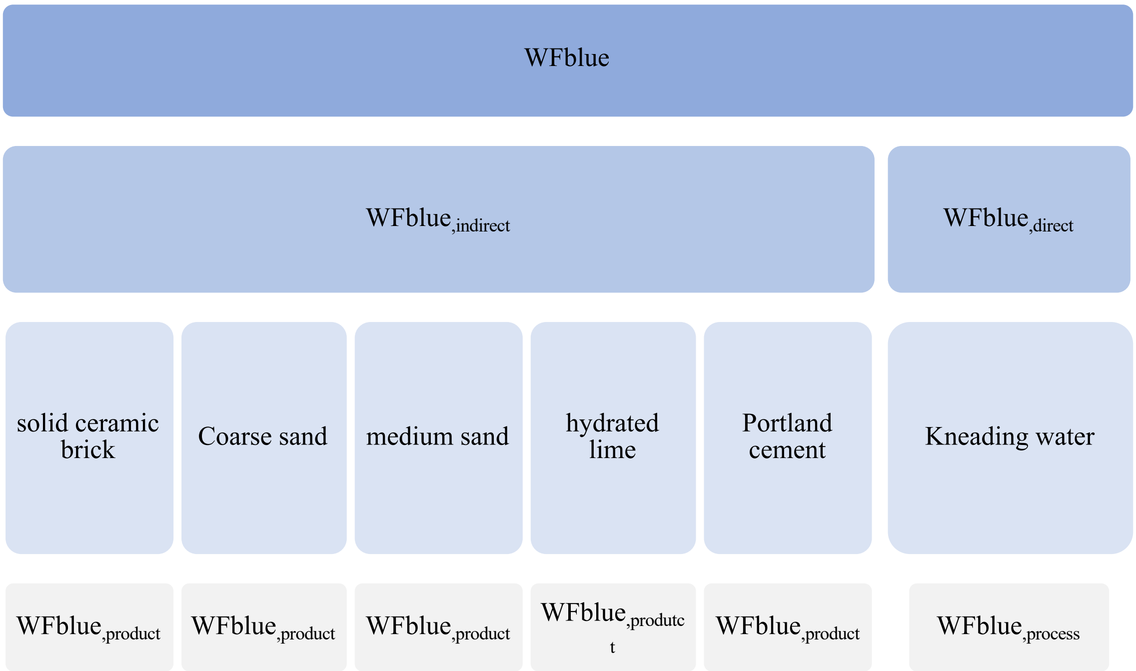
Code	Components	Unit	Amount		
	Intermediate Products/Masonry		**SCB**	**PCB**	**CB**
7258	Solid ceramic brick (5 x 10 x 20 cm)	unid.	83		
7266	Ceramic block (sealing masonry) of 9 x 19 x 19 cm	unid.		27.93	
651	Concrete fence block 14 x 19 x 39 cm (class C - NBR 6136)	unid.			13.35
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m^3	0.0080	0.0080	0.0080
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	0.0925	0.0986	0.0992
1106	CH-I hydrated lime for mortar	kg	13.7198	14.7985	14.8856
1379	Portland Cement Compounds CP II-32	kg	19.2525	20.2306	20.3285

The Unit, identified in the third column of Tables 2 and 4, is also called the Functional Unit (UF), being a standard measurement unit, determined in accordance with practice (Cavallini et al. 2019). It is important to determine the UF considered for each product, as it can be marketed or considered in different quantification units, generating accounting errors.

The water consumption of each product is related to its UF, where the water consumption value refers to one unit of that material (consumption of the volume of water in cement production). The relationship between water consumption and the UF of a product is considered its Water Footprint Coefficient – WFC, in this work, expressed in liters of water per functional unit (L/UF) (Cavallini et al. 2019).

Figure 1 illustrates the relationship between WF_{blue}, $WF_{blue,indirect}$ e $WF_{blue,direct}$ and which WF components the inputs (intermediate products) used in the production of SCB brick masonry represent.

Figure 1. Required inputs for the production of coated SCB brick masonry.



Determination of CWF of intermediate products

The determination of the water consumption of the intermediate products identified above (Table 5) was carried out based on bibliographic data. To determine reference WFC values, the following criteria were adopted:

a) Intermediate products that presented only one result in the literature, this value was considered for calculation. Example: hydrated lime.

b) Intermediate products with more than one coefficient in the literature, values present in studies considered more rigorous were adopted. Example: cement.

c) Intermediate products that presented coefficients in the literature, but were divergent from some characteristic of this work, considerations were made. Examples: SCB brick, PCB block, medium sand and coarse sand.

d) Intermediate products that did not show a coefficient in the literature, compositions were made from CWF of other materials. Example: CB.

Fernandes (2019) describes the composition of the concrete block, in 36 kg of cement, 119 kg of sand, 269 kg of stone dust, 228 kg of gravel and moisture content up to 7% of the dry weight to make 55 blocks.

Table 5. WFC CB determination.

Material	Raw Data (55 blocks)	Raw Data (per blocks)	WFC (L/UF)(source)	CH (L)
Cement	36 kg	0.654 kg/unid	2.126 L/kg (Hosseinian and Nezamoleslami 2018)	1.39 L/unid
Sand	119 kg	2.164 kg/unid	1.38 L/kg (Wernet et al. 2016)	2.99 L/unid
Grit	269 kg	4.891 kg/unid	1.38 L/kg (Wernet et al. 2016)	6.75 L/unid
Pebble	228 kg	4.145 kg/unid	1.38 L/kg (Wernet et al. 2016)	5.72 L/unid
Water	6% de humidity in relation to dry weight	0.711 L/unid		0.711 L/unid
Total				17.559 L/unid

Determination of the $WF_{blue,indirect}$ of the masonry

The $WF_{blue,indirect}$ corresponds to the indirect fresh water consumption of the masonry. That is, throughout the entire production chain of intermediate products, which must be defined according to the production process of each product. In other words, the water consumed from the extraction of inputs to the completion of the manufacture/processing of its intermediate products must be considered.

Of the intermediate product must be related to the necessary quantity of the intermediate product (UF) for the construction of one square meter of masonry, that is, with the values obtained from the unitary and partial compositions (Table 4). This relationship provides the Water Consumption – CH (L/m² of masonry) of the intermediate products: how many L of water that product is responsible for producing 1 m² of masonry. The determination of the CH of the intermediate products allows to identify the contribution of this product in the masonry WF. The sum of the CH of the intermediate products corresponds to the $WF_{blue,indirect}$ of the masonry, expressed in L/m².

Determination of $WF_{blue,direct}$ and $WF_{blue,indirect}$ of masonry

The $WF_{blue,direct}$ from the masonry, corresponds to the water used in the last stage of the production process ($WF_{blue,process}$). In the case of masonry, the last stage of the process corresponds to the addition of water to intermediate products to form mortar, that is, kneading water. $WF_{blue,direct}$ can be defined both at the construction site (when the mortar is prepared on site) and at the industries (when the mortar is machined).

The amount of water used in the preparation of mortars was determined using the water/binder factor (ratio between the amount of water in liters per amount of cement and lime in kilograms) considered to be 0.8 (Rago and Cincoto 1995).

The WF_{blue} of the masonry was determined by the sum of the $WF_{blue,indirect}$ and $WF_{blue,direct}$.

Results

Data on water consumption of intermediary products from bibliographic references were obtained, without limitation in time or space. In general, the data obtained were transformed to obtain their WFC, as there was a mismatch in the units.

Table 6 presents the data obtained from the WFC of the identified intermediate products (Table 4), and their respective sources.

Table 6. Water footprint coefficient (WFC) of intermediate products for masonry production.

Code	Components	FU	WFC (L/FU)	Source
7258	Solid ceramic brick (5 x 10 x 20 cm)	unid.	0.714	Adapted of Bardhan (2011)
7266	Ceramic block (sealing masonry) of 9 x 19 x 19 cm	unid.	1.180	Adapted of Bardhan (2011)
651	Concrete fence block 14 x 19 x 39 cm (class C - NBR 6136)	unid.	17.559	Adapted of Fernandes (2019)
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m^3	2.484	Adapted of Wernet et al. (2016)
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	2.208	Adapted of Wernet et al. (2016)
1106	CH-I hydrated lime for mortar	kg	1.520	Adapted of Saade et al. (2014)
1379	Portland Cement Compounds CP II-32	kg	2.126	Adapted of Saade et al. (2014)

FU – Functional Unit. WFC – Water Footprint Coefficient.

Uncoated masonry

SCB brick masonry

Table 7 shows the CH values of the intermediate products, as well as $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} for SCB brick masonry without mortar coating.

Table 7. Blue water footprint (WF_{blue}) of solid ceramic brick masonry (SCB).

Code	**Components**	**FU**	**WC (L)**	$WF_{blue,indirect}$	$WF_{blue,direct}$	WF_{blue}
			(L/m² of mansory)			
7258	Solid ceramic brick (5 x 10 x 20 cm)	unid.	59.26			75.05
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	11.58			
1106	CH-I hydrated lime for mortar	kg	0.95			
1379	Portland Cement Compounds CP II-32	kg	2.00			
	Kneading water	L			1.26	

FU – Functional Unit. WC – Water Consumption.

The SCB brick masonry presented WF_{blue} in the value of 75.05 L/m², and approximately 98% of this value corresponds to $WF_{blue,indirect}$. Regarding the intermediate products, the SCB brick had the greatest contribution of WF_{blue}, while the hydrated lime had the smallest.

´PCB block masonry

Table 8 shows the CH values of the intermediate products, in addition to the $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} of the PCB block masonry without mortar coating.

Table 8. Blue water footprint (WF_{blue}) of perforated ceramic block masonry (PCB).

Code	Components	FU	WC (L)	$WF_{blue,indirect}$ (L/m² of mansory)	$WF_{blue,direct}$ (L/m² of mansory)	WF_{blue} (L/m² of mansory)
7266	Ceramic block (sealing masonry), 9x19x19 cm	unid.	32.96	64.74		67.64
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	25.10			
1106	CH-I hydrated lime for mortar	kg	2.59			
1379	Portland Cement Compounds CP II-32	kg	4.08			
	Kneading water	L			2.90	

The PCB block masonry presented WF_{blue} in the value of 67.64 L/m², in which about 95% of this value corresponds to $WF_{blue,indirect}$. Regarding intermediate products, the PCB block had the greatest contribution from WF_{blue}, while the hydrated lime had the smallest.

CB masonry

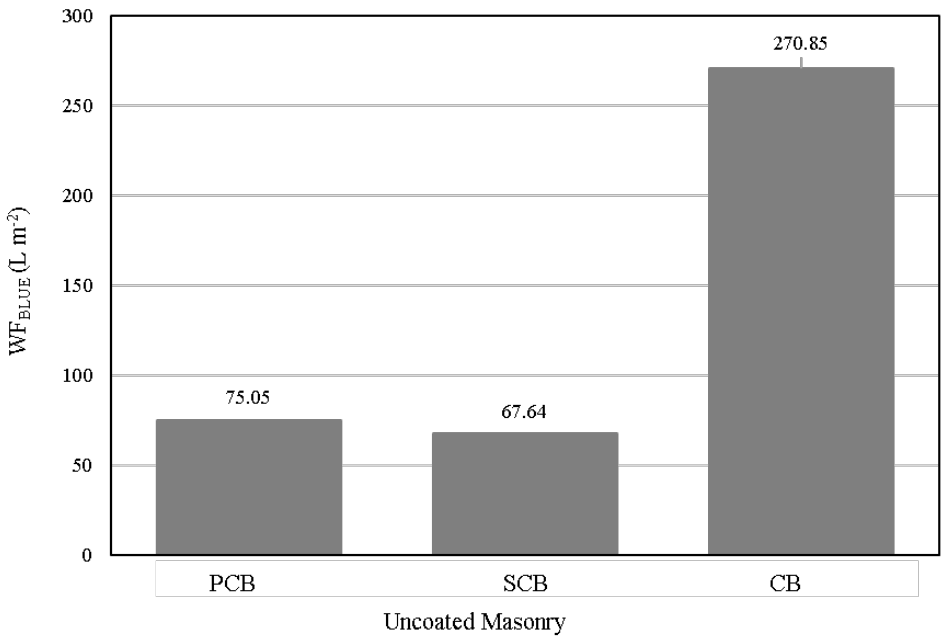
Table 9 shows the CH values of the intermediate products, as well as $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} of CB masonry.

Table 9. Blue water footprint (WF_{blue}) of concrete block masonry (CB).

Code	Components	FU	WC (L)	$WF_{blue,indirect}$ (L/m² of mansory)	$WF_{blue,direct}$ (L/m² of mansory)	WF_{blue} (L/m² of mansory)
7266	Concrete fence block 14x19x39 cm (class C - NBR 6136)	unid.	234.41	267.81		270.85
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	26.38			
1106	CH-I hydrated lime for mortar	kg	2.73			
1379	Portland Cement Compounds CP II-32	kg	4.29			
	Kneading water	L			3.05	

The CB masonry presented WF_{blue} of 270.85 L/m², in which more than 98% of this value corresponds to $WF_{blue,indirect}$. Regarding intermediate products, CB had the greatest contribution from WF_{blue}, while hydrated lime had the smallest. Figure 2 shows the WF_{blue} of masonry without mortar coating.

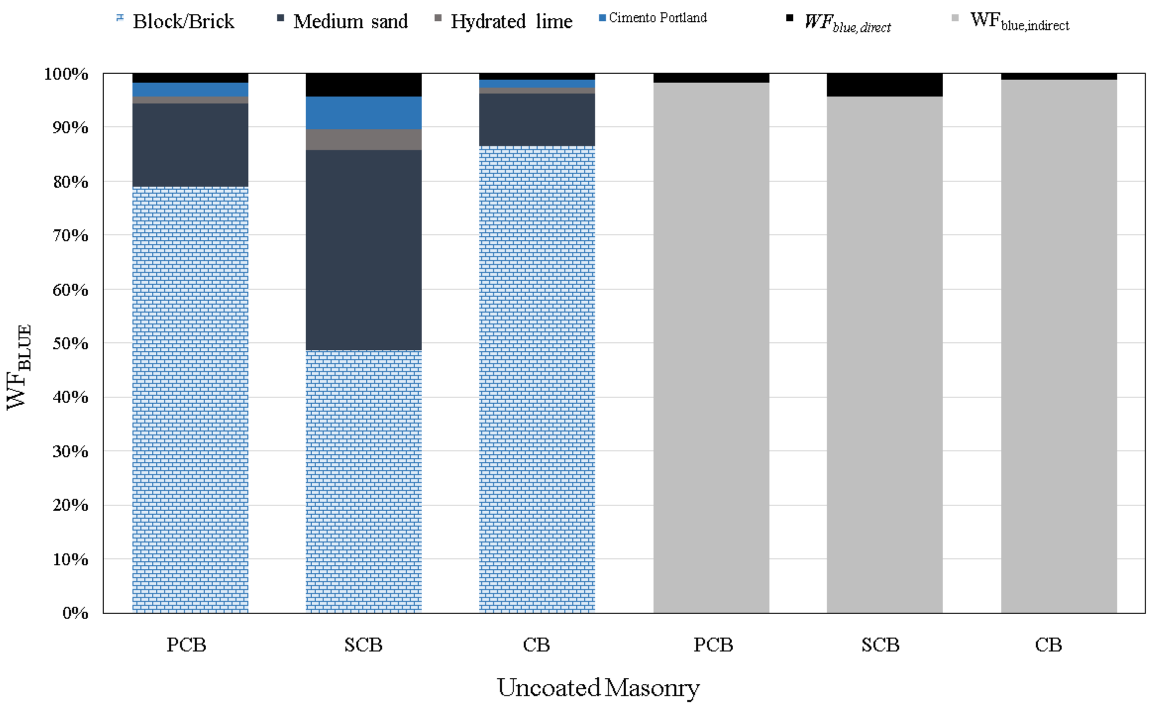
Figure 2. WF_{blue} of masonry without mortar coating.



Without the use of cladding, the SCB brick masonry presented a WF_{blue} 7.41 L/m², 10.96% greater than the PCB block masonry. CB masonry presented a WF_{blue} 195.80 L/m², 260.90% higher than SCB brick masonry and 203.21 L/m² (300.44% higher) compared to PCB block masonry.

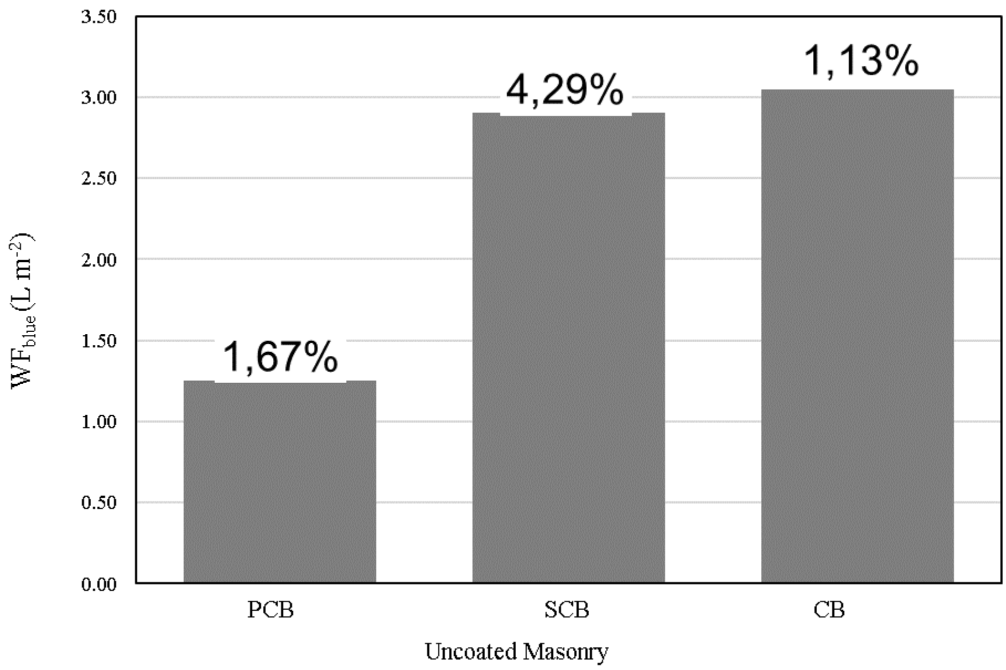
In Figure 3, the contributions of intermediate products and $WF_{blue,direto}$ and $WF_{blue,indirect}$ in the WF_{blue} of masonry without coating mortar are presented.

Figure 3. Contributions of intermediate products and $WF_{blue,direct}$ and $WF_{blue,indirect}$ na WF_{blue} of masonry without mortar coating.



It is observed that the blocks/bricks in their respective masonry were responsible for the greatest water consumption, while hydrated lime was the product that presented the smallest contribution. There is a pattern of water consumption in masonry: blocks/bricks > medium sand > cement > hydrated lime. In addition, it is observed that the smallest contributions in masonry are related to $WF_{blue,directs.}$ Thus, in Figure 4, the $WF_{blue,directs}$ of the masonry are presented.

Figure 4. $WF_{blue,direct}$ of masonry without mortar coating.



It is observed that the highest $WF_{blue,direct}$ from uncoated masonry was related to CB masonry (2.42 times higher than $WF_{blue,direct}$ from SCB brick masonry), followed by PCB block masonry. Despite representing the largest $WF_{blue,direct}$ among masonry, it represents only 1.13% of the WF_{blue} of its masonry.

Coated masonry

SCB brick masonry

Table 10 shows the CH values of the intermediate products, as well as $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} for SCB brick masonry, considering the coating.

Table 10. Blue water footprint (WF_{blue}) of solid ceramic brick (SCB) masonry with mortar coating on two sides.

Code	Components	FU	WC (L)	$WF_{blue,indirect}$ (L/m² of mansory)	$WF_{blue,direct}$ (L/m² of mansory)	WF_{blue} (Lm² of mansory)
7258	Solid ceramic brick (5 x 10 x 20 cm)	unid.	59.26	345.06		371.43
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m³	204.19			
1106	CH-I hydrated lime for mortar	kg	20.85			
1379	Portland Cement Compounds CP II-32	kg	40.93			
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m³	19.82			
	Kneading water	L			26.38	

The SCB brick masonry with coating presented WF_{blue} in the value of 371.43 L/m², in which more than 92% of this value corresponds to $WF_{blue,\ indirect}$. With respect to intermediate products, medium sand had the greatest contribution from WF_{blue}, while coarse sand had the smallest.

PCB block masonry

Table 11 shows the CH values of the intermediate products, in addition to the $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} of the PCB block masonry, considering the mortar coating on both sides.

Table 11. Blue water footprint (WF_{blue}) of perforated ceramic block (PCB) masonry with mortar coating on two sides.

Code	Components	FU	WC (L)	$WF_{blue,indirect}$ (L/m² of mansory)	$WF_{blue,direct}$ (L/m² of mansory)	WF_{blue} (L/m² of mansory)
7266	Ceramic block (sealing masonry), 9x19x19 cm	unid.	32.96	336.00		364.02
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m³	217.71			
1106	CH-I hydrated lime for mortar	kg	22.49			
1379	Portland Cement Compounds CP II-32	kg	43.01			
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m³	19.82			
	Kneading water	L			28.02	

The PCB block masonry with coating on both sides presented WF_{blue} in the value of 364.02 L/m², with 92% of this value corresponding to $WF_{blue,indirect}$. Regarding intermediate products, it presented the greatest contribution from WF_{blue}, while coarse sand presented the smallest.

CB masonry

Table 12 shows the CH values of the intermediate products, as well as $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} for CB masonry, considering the coating.

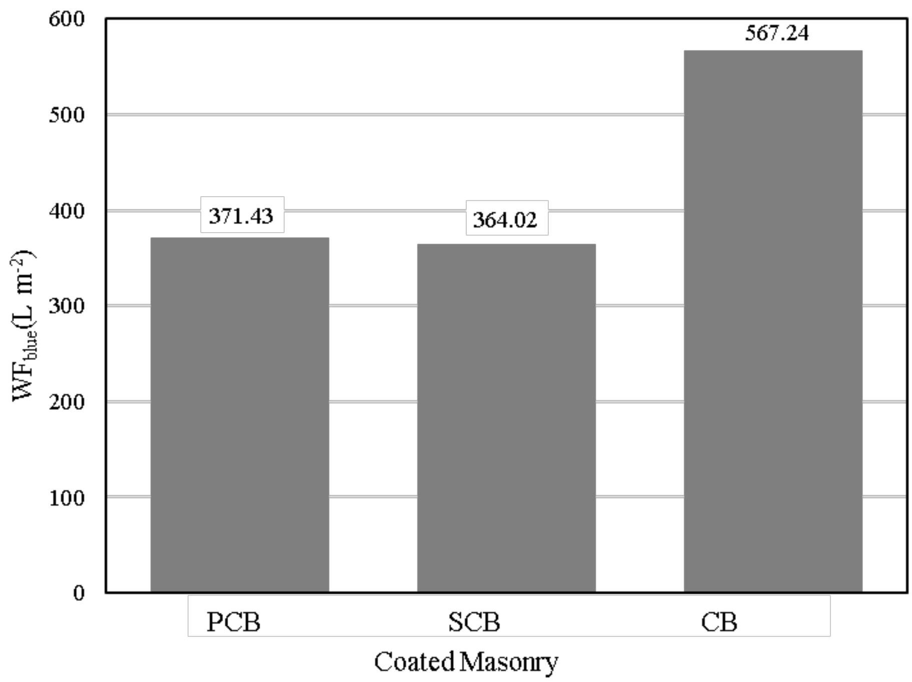
Table 12. Blue water footprint (WF_{blue}) of concrete block masonry (CB) with mortar coating on two sides.

Code	Components	FU	WC (L)	$WF_{blue,indirect}$ (L/m² of mansory)	$WF_{blue,direct}$ (L/m² of mansory)	WF_{blue} (L/m² of mansory)
7266	Concrete fence block 14 x 19 x 39 cm (class C - NBR 6136)	unid.	234.41	539.07		567.24
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m³	218.99			
1106	CH-I hydrated lime for mortar	kg	22.63			
1379	Portland Cement Compounds CP II-32	kg	43.22			
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m³	19.82			
	Kneading water	L			28.17	

The CB masonry with coating on both sides presented a WF_{blue} in the value of 567.24 L/m², with approximately 95% of this value corresponding to the $WF_{blue,indirect}$. Regarding intermediate products, CB had the greatest contribution from WF_{blue}, while sand had the smallest.

Figure 5 shows the WF_{blue} of masonry with mortar coating.

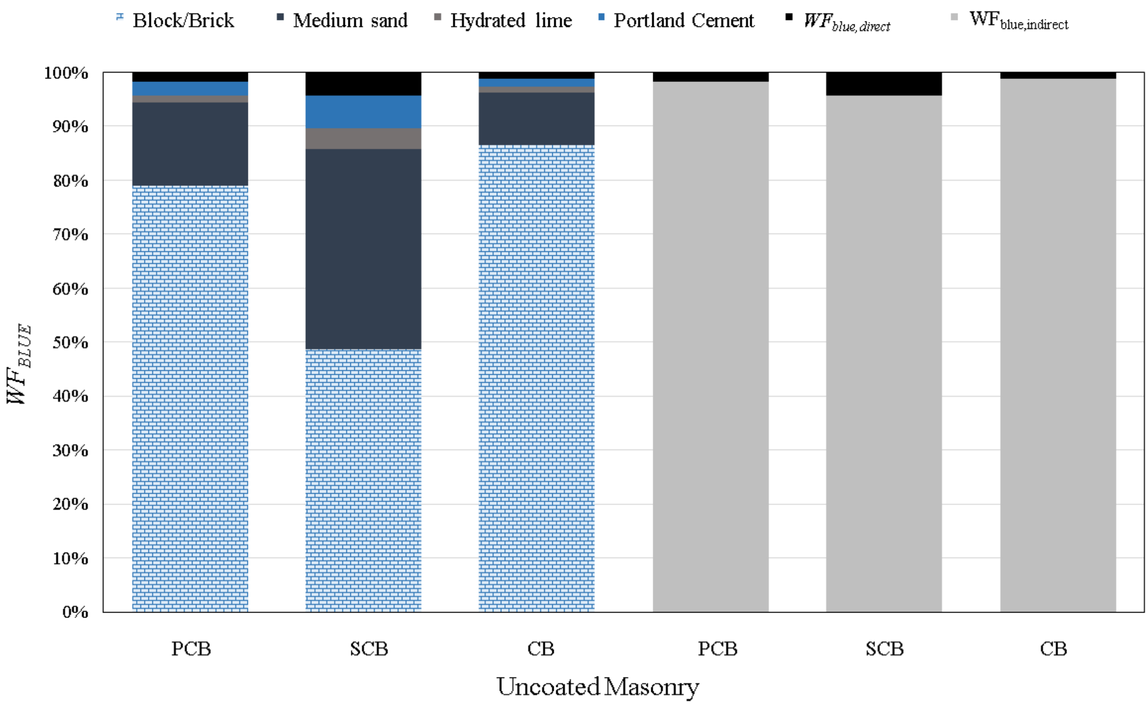
Figure 5. WF_{blue} of masonry with mortar coating.



With mortar coating, SCB brick masonry presented a water consumption 2.04% higher than PCB block masonry (per square meter of masonry), while CB masonry presented a water consumption 52.72% higher than SCB brick masonry is 55.83% larger than ´PCB block masonry per square meter.

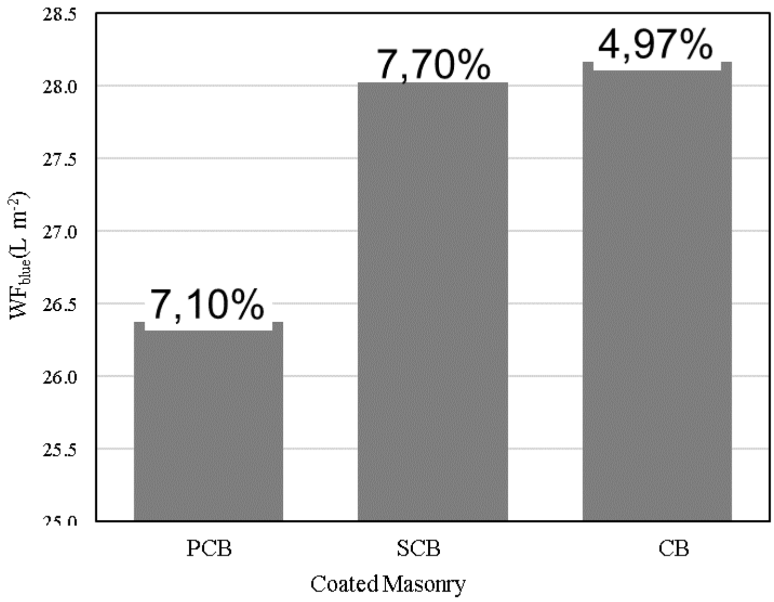
In Figure 6, the contributions of intermediate products and $WF_{blue,direct}$ and $WF_{blue,indirect}$ in the WF_{blue} of masonry with coating mortar are presented.

Figure 6. Contributions of intermediate products and $WF_{blue,direct}$ and $WF_{blue,indirect}$ at WFblue of mortar coated masonry.



It is observed that the medium sand was the intermediate product that presented the greatest contributions in the SCB brick and PCB block masonry. In CB masonry, the block was the product that presented the greatest contribution (as well as when not considering the coating), however, the medium sand also had a great influence on the WF_{blue} of the masonry. Regarding the smallest influence on WF, coarse sand and hydrated lime were the components with lower CH in masonry. In addition, it is observed that the smallest contributions in masonry are related to $WF_{blue,\ direct}$. Thus, in Figure 7 the WF_{blue}, direct of the masonry with mortar coating are presented.

Figure 7. $WF_{blue,direct}$ of masonry with mortar coating.



It is observed that the highest $WF_{blue,direct}$ of uncoated masonry was related to CB masonry, followed by PCB block masonry and SCB brick masonry, however, the differences were more subtle than among masonry without mortar coating. Despite representing the largest $WF_{blue,direct}$ among masonry, it represents only 4.97% of the WF_{blue} of its masonry. Table 13 summarizes the WF_{blue} data of the evaluated masonry, with and without coating.

Table 13. Blue water footprint (WF_{blue}) of coated and uncoated masonry.

		Unit	SCB	PCB	CB
WF_{blue}	Uncoated	L/m^2	75.05	67.64	270.85
	With mortar coating on two sides		371.43	364.02	567.24

Mortar coating

Table 14 shows the CH values for the intermediate products, as well as $WF_{blue,indirect}$, $WF_{blue,direct}$ and WF_{blue} of the mortar coating to be applied on both sides of the masonry.

Table 14. Blue water footprint (WF_{blue}) of the mortar coating composed of roughcast and a single mass to be applied on both sides of the masonry.

Code	Components	FU	WC (L)	$WF_{blue,indirect}$ (L/m^2 of mansory)	$WF_{blue,direct}$ (L/m^2 of mansory)	WF_{blue} (L/m^2 of mansory)
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m^3	19.82	271.26		296.38
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	192.61			
1106	CH-I hydrated lime for mortar	kg	19.90			
1379	Composite Portland cement CP ll-32	kg	38.93			
	Kneading water	L			25.12	

Table 15 shows the contribution of intermediate products and $WF_{blue,indirect}$ and $WF_{blue,direct}$ in relation to the WF_{blue} of the mortar coating to be applied on both sides of masonry.

Table 15. Contributions of intermediate products and $WF_{blue,indirect}$ and $WFb_{lue,direct}$ in relation to WF_{blue} of the mortar coating.

Code	Components	FU	Percentage with respect to WF_{blue}		
			Intermediate Product	Indirect	Direct
367	Coarse sand - deposit/supplier post (removed in the deposit, without transport)	m^3	6.69%	91.52%	
370	Medium sand - deposit/supplier post (removed in the deposit, without transport)	m^3	64.99%		
1106	CH-I hydrated lime for mortar	kg	6.71%		
1379	Composite Portland cement CP ll-32	kg	13.13%		
	Kneading water	L			8.48%

The mortar coating presented a WF_{blue} of 296.38 L/m^2, in which more than 91% of this value corresponds to $WF_{blue,indirect}$ indirect. In relation to intermediate products, medium sand had the greatest influence on water consumption and coarse sand had the least influence.

In determining the influence of the water consumption of the mortar covering in relation to the masonry, the WF_{blue} of the mortar covering corresponded to 79.79% of the WF_{blue} of the SCB brick masonry, to 81.42% of the WF_{blue} of the PCB block masonry and to 52 .25% of the WF_{blue} of CB masonry.

Discussion

The Water Footprint methodology was used to determine the water consumption of masonry, in order to consider the water consumption from the production of inputs to the execution of the work. Data were obtained from bibliographic references, and adjustments were made to make the data compatible.

In general, the $WF_{blue,indirect}$ of the evaluated masonry presented the greatest contribution in relation to the WF_{blue} of the masonry, as well as the WF_{blue} of the mortar coating. This consumption is related to the production and processing of intermediate products, most of the times disregarded when estimating the water consumption of some civil construction product.

When the mortar coating was not considered, the indirect WF_{blue} ranged from 95.71 to 98.87% of the WF_{blue}. When considering the coating, the $WF_{blue,indirect}$ also remained superior to the $WF_{blue,direct}$, but it ranged from 92.30 to 95.03% of the WF_{blue}. This difference can be explained by the greater use of mixing water for mortars when coating is used, since for uncoated masonry, the mixing water corresponds only to that incorporated in the laying mortar.

$WF_{blue,direct}$, therefore, made a small contribution (up to 4.29% of the WF_{blue} of uncoated masonry, and up to 7.70% of the WF_{blue} of coated masonry), with the water used in the last processing step for the kneading of mortars. Sometimes, this is the only consumption considered, but it is minimal compared to $WF_{blue,indirect}$. Likewise, studies on water incorporated in buildings in India indicated that the amount of induced water ($WF_{blue,direct}$) represented 18 to 38.55% of the total amount of water, while the water inherent in products ($WF_{blue,indirect}$) represented 61.45 to 82.00% of the total amount of water (Bardhan and Choudhuri 2016).

In the comparison of $WF_{blue,directs}$ from masonry, considering or not the mortar coating, CB masonry presented the highest water consumption, followed by PCB block masonry and by SCB brick masonry. Despite having the highest water consumption in liters, $WF_{blue,directs}$ from CB masonry, was responsible for a small contribution to the WF_{blue} of its masonry (1.13% of the WF_{blue} of the uncoated masonry and 4.97% of the WF_{blue} of the masonry with coating). Despite corresponding to a small contribution of WF_{blue} from masonry, there were important differences between $WF_{blue,directs}$, with a difference of up to 2.42 times between $WF_{blue,directs}$ from SCB brick masonry and CB masonry.

This means that the amount of water needed at the construction site for the execution of CB masonry is more important than for other masonry. In general, the most noticeable water consumption is that which occurs directly, in the case of masonry, the water used to knead the mortar. However, the water consumption to be attributed to masonry, as seen in this work, is related to its entire production chain. Considering only consumption that occurs directly is a mistake. Therefore, measures to reduce the water consumption of masonry should cover not only the construction site ($WF_{blue,direct}$), but also the materials industry, related to the extraction, transport and processing of raw materials to obtain intermediate products ($WF_{blue,indirect}$). The production process of these products must be evaluated, identifying stages with high water consumption, in order to optimize this consumption.

Regarding the intermediate products of masonry with mortar coating, medium sand presented the greatest contribution in SCB brick and PCB block masonry (between 54.97 and 59.81% of WF_{blue}) and in mortar coating (64.99% of WF_{blue}). In CB masonry, the intermediate product with the greatest contribution was the block, with 41.32%.

Barreto (2015) studied the water incorporated in concrete and obtained for a fck of 30 Mpa the total amount of 12,745 L/m3. Of these, 12,554 L/m3 correspond to the consumption of inputs (98.51%) and 191 L/m3 correspond to water used for the mixture (1.49%) – results similar to those defined in this study. For concrete, sand was also the product that presented the greatest contribution – 53.14%.

On the other hand, coarse sand was the product that had the lowest influence on the WF_{blue} of all masonry when considering the mortar coating (between 3.49 and 5.45% of the WF_{blue}). The low contribution of coarse sand is due to its low consumption in the square meter of masonry, as it is only used in the coating mortar. The contribution of water to mortar kneading ($WF_{blue,\ direto}$) was 4.97 to 7.70% of the WF_{blue} of the masonry and 8.48% of the WF_{blue} of the mortar coating.

When disregarding the mortar coating of masonry, a pattern of influence on water consumption is observed: block/brick > medium sand > cement > hydrated lime. Although lime has the smallest participation in the WF_{blue} of masonry, studies evaluating the impact of the life cycle of internal masonry in Brazil concluded that lime is the product that most contributes to radiation, greenhouse effect and atmospheric pollution (Condeixa et al. 2014). In addition, the study presented data on the other materials that make up masonry, and concluded that brick is responsible for about 40% of the impacts of most factors analyzed, as well as sand, responsible for about 30%.

As civil construction consumes a large amount of materials, decision-making on specifications reflects on the building itself, as well as on the environment. Therefore, carrying out studies that assess the various performances of masonry is necessary to enable reductions in environmental damage. Environmentally, it is an activity that consumes a significant amount of inputs, which, in turn, demands a large amount of raw materials and energy for its production, whose processes result in harmful impacts on the environment. The contribution of water to the mixing of laying mortars ($WF_{blue,direct}$) was 1.13 to 4.29% of the WF_{blue} of the masonry when the mortar coating was not used. In this sense, the present study recommends the deepening of such observations for the establishment of public policies that denote sustainability to the civil sector.

There was a great influence of the mortar coating on the WF_{blue} of the masonry (from 52.25 to 81.42% of the WF_{blue}). The mortar coating is responsible for, among other functions, regularizing the sealing surface, serving as a base for another coating or acting as the final finish, in order to collaborate with the aesthetics. Often, the mortar coating is used in order to adjust the plumb and alignment of the walls – a consequence of the poor settlement of the blocks. As a result, a large amount of mortar is used, in addition to what is estimated and recommended. In addition, it should be noted that there is a large loss of coating mortar in its application. Improvements in application technique can contribute to a reduction in water consumption (Caldas et al. 2020). The excessive use of the coating and its losses are aggravated by its large water consumption. To reduce the impact, it is recommended to prioritize masonry without coating or a more careful selection of coating application methods, such as the rolled roughcast technique, which presents significant reductions in relation to conventional roughcast, due to the lower material consumption of the first technique. Another strategy that has been increasingly found in research is the use of alternative materials, in the great majority, waste as a substitute for Portland cement for the production of mortars, in addition to studies with alternative mixtures for mortar with grey and rainwater reuse.

It was observed that the difference in water consumption between masonry that used coating mortar was 2.04 to 55.83%, and that the difference in water consumption between masonry that did not use coating mortar was more important - 10 .96% to 300.44%. These are differences that stand out when we consider that all masonry has the same function: vertical sealing. Despite this, it is noteworthy that without the use of coating mortar, the function of masonry is not fulfilled, especially if exposed to bad weather.

The evaluated masonry presents two important differences between them: the variation in the necessary amount of cement, lime and sand, and the use of different blocks/bricks. However, from the unitary and partial compositions, it was observed that there was no great variation between the amount of products used – suggesting that there were important differences in the contributions of blocks/bricks.

Regarding the WF_{blue} of masonry with mortar coating, the PCB block presented the smallest contribution with 9.06% of the WF_{blue} of its masonry, followed by the SCB brick with 15.95% of the WF_{blue} of its masonry and by CB with 41.32% of the WF_{blue} of your masonry. When the mortar coating is disregarded, the influence of the blocks was even more evident: it was the material with the greatest contribution of WF_{blue} of all masonry, in which the PCB block presented a contribution of 48.74% of the WF_{blue} of its masonry, followed by the brick SCB with 78.96% of the WF_{blue} of its masonry and CB with 86.54% of the WF_{blue}. It is suggested that CB's contribution was more important due to the use of some inputs in its production, such as cement and sand, which are considered together with the water used in the preparation and production of the block - that is, the CB presents WF_{blue}, direto and WF_{blue}, indirect for the purposes of this study.

Bardhan (2015) quantified the WF_{blue} of hollow and solid concrete blocks, and concluded that the WF_{blue} of hollow CB corresponds to 0.714 L/un. It is noteworthy that the study by Bardhan (2015) considered only the water used in the production process of the blocks, that is, direct WF_{blue}. In this research, CB presented WF_{blue} of 17.56 L/un, however, considering $WF_{blue,\ direto}$ (responsible for 0.711 L/un – 4.05% da WF_{blue}) and $WF_{blue,indirect}$ (responsible for 16,849 L/un – 95,95% da WF_{blue}). It is observed that the direct WF_{blue} have similar values. However, this reinforces the problem of not considering the direct WF_{blue} of products, leading to erroneous conclusions about the performance of materials when compared.

Comparing masonry without mortar coating, PCB block masonry had the best water performance: 67.64 L/m², followed by SCB brick masonry with 75.05 L/m² and CB masonry with 270.85 L/m². Likewise, when considering the mortar coating, the water performance of the masonry remained: PCB block masonry with 364.02 L/m², followed by SCB brick masonry with 371.43 L/m² and by CB masonry with 567.24 L/m².

With the intention of providing data on the consumption of water from conventional masonry used in Brazil, this work helps decision makers in choosing materials that result in less negative impacts on the environment, especially with regard to water resources.

It is important to point out that there is a lack of data on water consumption for some civil construction products, and this causes the WF to be masked or not accounted for as a whole. The calculation and identification of the WF of different products allows the creation of a database, which allows the choice of the material with the best water performance. When the WF study follows ISO prerogatives, they can be used based on an environmental certification program (Sampaio 2019). So, as a consequence, in the long term, buildings can be labeled and classified according to their water consumption, related to their entire production chain, and not just water consumption during their useful life or at the construction site.

With implementation of ABNT NBR ISO 14046:2017 Environmental management - Water footprint - Principles, requirements and guidelines, and recently ISO 46001:2019 Water efficiency management systems, and recently ISO 46001:2019 Water efficiency management systems - Requirements with guidance for use, studies on quantification of water incorporated in products they relate to the applicability of ISO to the market, collaborating with the dissemination of the WF indicator to society, and, more than that, it seeks to achieve water efficiency. As a result, data such as those reported in this work have an opportunity for a market sequence, facilitated by the ISO.

Although generally the focus of work is on direct, masonry WF_{blue}, it showed a contribution of up to 4.29% of the WF_{blue} of masonry without cladding, and up to 7.70% of the WF_{blue} of masonry with cladding. Considering only the direct WF_{blue}, the largest contribution (up to 95.71%) is neglected. Therefore, measures that can be taken to reduce water consumption in masonry are related to investments in improvements and enhancements in the production chain of inputs. Research and analysis of products with lower water consumption to substitute hydric costly products can be a measure to reduce impacts.

From the the results obtained, it was observed that this indicator can be applied to the productive activity productive activity under study, filling gaps that had not been explored until now.

Conclusions

Prior to this study, there was no knowledge about how much water was used to build masonry - regardless of the type of brick or block being chosen. Erroneously, one thought only of the amount of water used to mix the mortars. The construction method was chosen based on cost, thermal performance, acoustic performance, availability of material or labor, but could not be chosen based on the environmental appeal related to water consumption.

In this research it was found that there are important differences in the WF_{blue} of the masonries, in which PCB block masonry showed the best water performance, followed by SCB brick masonry and CB masonry, considering or not the mortar coating. The knowledge of the water consumption of different components that present the same function makes it possible to choose a masonry in favor of its water performance, i.e., lower water consumption. In the future, it is expected to classify building systems according to this consumption, allowing, for example, labeling of these systems based on this aspect.

Limitations were encountered in the development of this research, mainly related to the lack of data on water consumption of construction inputs. A greater number of studies on the water component of these products helps to adjust gaps and improve work in this context. Thus, future studies that analyze the entire production chain of the most varied inputs of civil construction are recommended, as well as studies on the gray component of these products.

There were important differences in the WF_{blue} of the masonry, in which the PCB block masonry presented the best water performance, followed by the SCB brick masonry and the CB masonry, considering or not the mortar coating.

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Data availability: The data are part of the Masters dissertation of the first author. The thesis is available in the University repository (https://cms.ufmt.br/files/galleries/95/Disserta%C3%A7%C3%B5es%202021/Dc0a224c617df93b38426325290f3fd5c9fabe026.pdf).

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