Cumulative Energy Requirements Analysis of the Use Phase of a New Product 'Swimitation^{TM} Bath'

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Swimitation^{TM} is a novel concept of water procedure, developed by an Estonian company OÜ Waterflight, providing training and relaxation simultaneously. Lying in the Swimitation bath, a user moves arms and legs while air is blown through water. This study analyzed the environmental profile of Swimitation bath, focusing on the energy requirement of use phase. I considered energy requirements for the provision, heating, filtration, circulation, disinfection, air blowing and end treatment of water as well as heating, ventilation and lightning. Swimitation was compared with water aerobics in a large swimming pool. The result of the analysis indicated that in swimitation, the highest source of energy consumption is water heating. In total, Swimitation consumes 9,2 kWh while water aerobics, in case of a Finnish swimming pool, 27,4 kWh of primary energy per visit. I conclude that Swimitation is a relatively energy efficient water procedure, providing relaxation and exercises. However, energy requirement of Swimitation is still significant, providing serious reduction challenge.

1. Introduction

Goals

Swimitation is a concept, developed by an Estonian company OÜ Waterflight, which introduces a new relaxation kind of water sport, combining training and relaxation simultaneously. Swimitation bath is designed for a single human to lie backstroke in water while the shape of bath edges enables an extensive movement of arms and legs (Fig 1). The bath is equipped with a training chair in the center as well as air blowers for massage and relaxation.

The aim of this study was to assess and communicate the environmental profile of the product. The other aim was to find environmentally the best way for further design of the product as well as to optimize the product use.

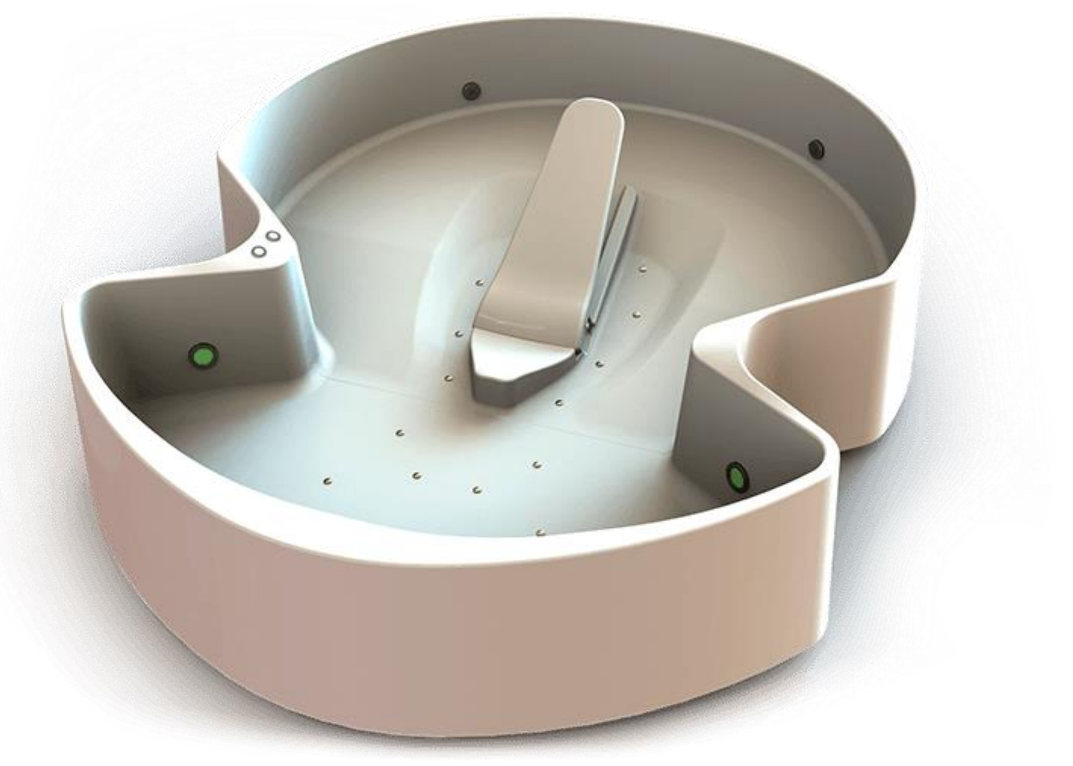

Fig 1. Design of Swimitation^{TM} bath (OÜ Ten Twelve, 2014)

Conceptual framework

It was assumed that the critical environmental aspect is energy requirement while the critical life cycle phase is use phase. Hence, for the simplification of the analysis, instead of a full life cycle assessment, only energy requirement of only the use phase of the product was considered (Fig 2). It was assumed that energy credit is not generated in the system.

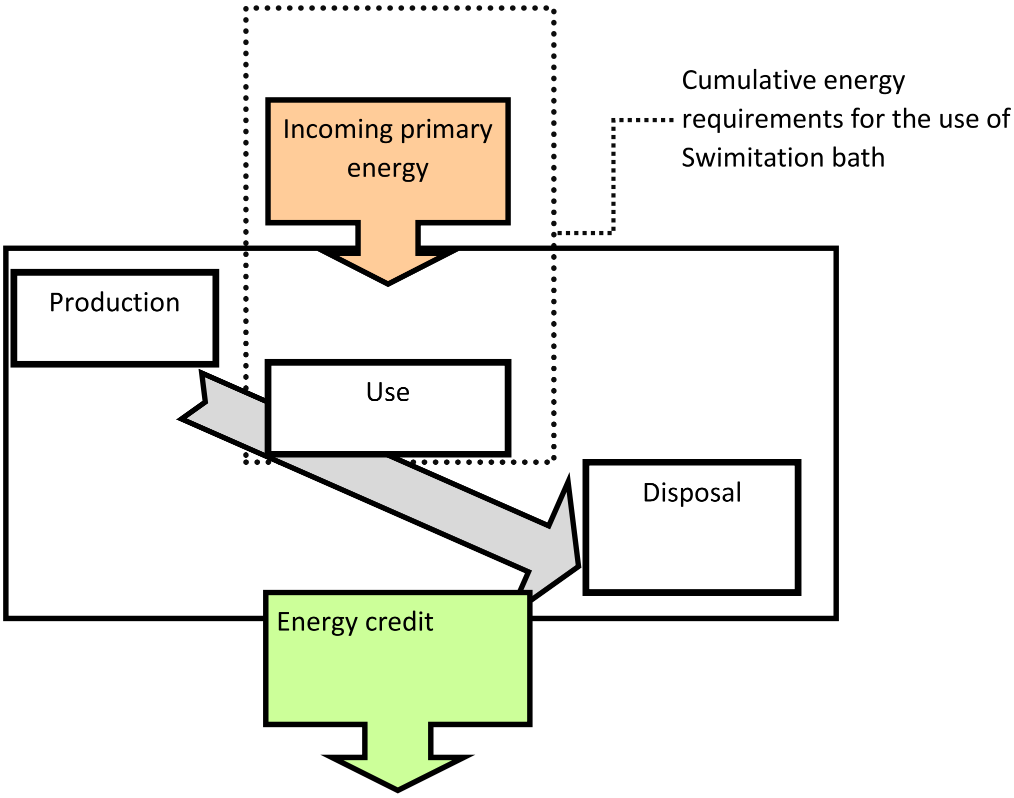

Fig 2. System boundaries of this study in relation with Cumulative Energy Requirements Analysis conceptual framework

2. Methodology

Cumulative Energy Requirements Analysis ($CERA_u$) for the use phase of the product was conducted, following the principles of Fritsche et al. (1999). The result of the analysis is a quantification of total embodied primary energy for the provision of a service unit by the investigated product. In addition to the direct energy requirements, such as for heating the water and ventilating air, the analysis also considers indirect energy flows such as energy for the production of water, wastewater management etc.

Basic assumptions

For the assessment of relative eco-efficiency of the new product, a reference product service system, providing similar primary function, was chosen. This was public swimming pool providing water aerobics.

I attempted to describe the average, most likely or typical physical product parameters and use characteristics. It was assumed that both analyzed devices – swimming pool and Swimitation bath – would be in public use. It was also assumed that a visit to water aerobics consumes all the pool resources equally with other visit types, serving, hence, as an average visit to public swimming pool.

The chosen functional unit was visit. Hence, for the Swimitation bath, the energy requirement was calculated per one visit. Correspondingly, the study calculated energy requirement for one visit of swimming pool.

The analysis comprised the following requirements for providing the function: supply of water for bath, heating of water, management of wastewater, local water purification (filtering) and circulation, air blow in bath, use of chlorine, heating and ventilation of indoor air and lightning of the system (Fig 3). For simplification, the analysis excluded chemicals which energy requirements were assumed insignificant. It was assumed that chemicals for the regulation of pH of chlorinated water are energetically very cheap to produce while in very low concentration in water. For indoor air management, while the study included heating and ventilation, I excluded conditioning, air movement, condensation control, dilution and dehumidification, all judged to require additional energy insignificantly. Need to take shower before and after bathing, was also excluded from the analysis because, although consuming significantly energy, taking shower is a very similar need in case of both studied alternatives. In the same reason I excluded from the analysis the energy need for the transportation of customer. Whatever the consumption alternative, the transportation need would be probably similar.

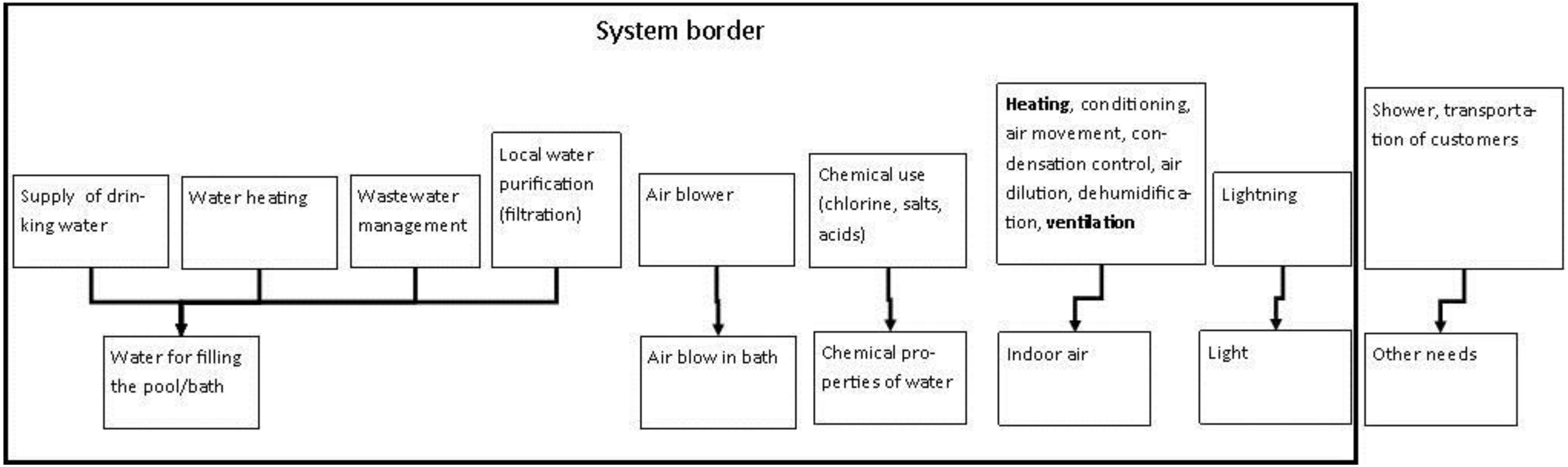

Fig 3. System boundaries in CERAu of Swimitation^{TM} bath and public swimming pool

Mathematical model

To calculate CERAu, a deterministic steady state mathematical model was established in MS Office Excel 2013. Energy requirement was calculated as the weekly average ratio between energy consumption and number of visits as:

$$ER = \frac{\mathrm{E}}{\mathrm{S}}$$

ER – energy requirement, kWh/visit;

E – energy consumption, kWh;

S – service, # of visits.

Total energy requirement consists of nine parts as presented in the following equation:

$$ER = ERws + ERwh + ERww + ERwf + ERwc + ERab + ERah + ERav + ERl$$

ERws – energy requirement for water supply;

ERwh - energy requirement for water heating;

ERww – energy requirement for wastewater management;

ERwf – energy requirement for local water purification (filtration) and circulation;

ERwc - energy requirement for chlorination;

ERab - energy requirement for air blowing inside bath;

ERah - energy requirement for air heating;

ERav - energy requirement for air ventilation;

ERl – energy requirement for lightning;

Each partial energy requirement was calculated separately according to the following equations.
Energy requirement for water supply:

$$ERws = \frac{Vw}{S} \times \frac{Ews}{Vw}$$

Vw – volume of water consumed in the bath, m3;

Ews – energy consumption for water supply, kWh;

and:

$$Vw = Vbath \times Nf$$

Vbath – water volume to fill the bath, m3

Nf – number of volumes water changed during the time period, -

For water aerobics**, energy requirement for water heating** was acquired directly from literature. For Swimitation, it was calculated from the following formulae.

$$ERwh = ERwr + ERwk$$

ERwr – energy requirement for heating up input water (rising temperature to the desired level);

ERwk – energy requirement for keeping water temperature in the same level (balancing heat loss from evaporation);

while:

$$ERwr = \frac{\mathrm{dT} \times \mathrm{Vw} \times \mathrm{cp}}{\mathrm{S}}$$

dT – heating rate, K;

cp – specific heat capacity for water; cp = 1,16 kWh/m3/K;

and:

$$ERwk = \frac{\mathrm{dTaw} \ \times \mathrm{ks} \ \times \mathrm{A}}{\mathrm{S}}$$

dTaw – temperature difference between water surface and air above that, K;

ks – surface heat loss factor, kW/m2/K;

A – pool surface area, m2.

Energy requirement for wastewater treatment:

$$ERww = \frac{Vw}{S} \times \frac{Eww}{Vw}$$

Eww – energy consumption for wastewater treatment.

For water aerobics, **energy requirement for water filtration and circulation** was acquired directly from literature. For Swimitation, it was calculated from the following equation:

$$ERwf = \frac{Pwf \ \times twf}{S}$$

Pwf – power of water filtration and circulation pump, kW;

twh – working time of the pump during the investigated time period, h.

Energy requirement for chlorine in water:

$$ERwc = \frac{c \ \times Vw \ \times ewc}{S \ \times 1\,000}$$

c – concentration of chlorine, mg/l;

ewc – energy consumption density for the supply of chlorine, kWh/kg.

Energy requirement for air blowing in Swimitation:

$$ERab = \frac{Pab \ \times tab}{S}$$

Pab – power of air blower, kW;

tab – working time of air blower during the investigated time period, h.

Energy requirement for air heating:

$$ERah = \frac{Eah}{A} \times \frac{A}{S}$$

Eah – energy consumption for air heating, kWh

Energy requirement for air ventilation was for water aerobics acquired directly from literature while for Swimitation this was calculated according to the equation:

$$ERav = \frac{C \times Va \times PS}{S \times 3600}$$

C – air change, h-1;

Va – indoor room volume, m3;

PS – specific fan power, W / (l/s).

Energy requirement for lightning was calculated as:

$$ERl = \frac{El}{A} \times \frac{A}{S}$$

El – energy consumption for lightning, kWh.

First, the requirement of **final energy** was calculated. Later, final energy numbers were converted to the requirement of **primary energy**.

Data

Input data for the assessment of energy requirement were mostly obtained from literature survey (Table 1). The input parameters for the swimming pool, such as rate of visits, physical parameters, energy needs and sources, were obtained mostly from a Finnish case study, Kirkkonummi bath, by Saari & Sekki (2008). It was assumed that of all visits in the spa complex, 50% visited the large swimming pool. Water replacement rate (equal with consumption rate) for public swimming pool was assumed equal with the US standard of 7 gallons per visitor. The input parameters for Swimitation bath were obtained mostly from a vision of Uustal (2014). Various literature sources indicated the energy intensity of the production of clean water, wastewater management, production of chlorine, embodied primary energy etc.

It was assumed that the consumed electricity is generated from coal, with conversion rate of 2,55 (Gustafson et al., 2010) while heat was assumed generated from fossil gas with the rate of 1,05. As an exception, maintaining water temperature (not heating up) in Swimitation bath was assumed using electricity. Following Saari & Sekki (2008), 50% of energy for air ventilation was assumed originated from electricity and other 50% from heat energy (rough approximation). It was assumed that production of chlorine, water supply and wastewater treatment is provided, using only electric energy.

Table 1. Data and assumptions for CERAu of Swimitation™ bath and reference products

	SWIMITATION	DATA SOURCES	WATER AEROBICS IN SWIMMING POOL	DATA SOURCES
water volume, m3/unit	1,0	Uustal, 2014	540	Saari & Sekki, 2008
water surface area, m2	4,75		360	Saari & Sekki, 2008
concentration of chlorine, mg/l	1,5		1,5	Carpenter et al., 1999
power of filtration and circulation pumps, kW	0,5		data not needed	
working time of pump, h/week	168		data not needed	
Temperature difference between water and air, K	10	Assumption	data not needed	
Surface heat loss factor, kW/m2/K	0,013		data not needed	
Water heating requirement, K	25			
water residence time (change interval), h	60	Uustal, 2014	data not needed	
volume of water used, m3/week	2,8		38	ANSI, 2009
use rate, # visits/week	84		1442	Saari & Sekki, 2008
duration of visit, h	0,75		0,83	White, 1995
energy requirement for water supply, kWh/m3	2,95	Mo et al., 2011	2,95	Mo et al., 2011
energy requirement for water heating, kWh/pool-m2/yr.	Data not needed		1007	Saari & Sekki, 2008
energy requirement for wastewater management, kWh/m3	0,78	Kenway et al., 2008	0,78	Kenway et al., 2008
energy requirement for aeration, kW/m3	0,8	Uustal, 2014	Not applicable	
energy requirement for air heating, kWh/pool-m2/yr.	332	Saari & Sekki, 2008	332	Saari & Sekki, 2008
energy requirement for water filtration, kWh/pool-m2/yr.	data not needed		503	Saari & Sekki, 2008
energy requirement for air ventilation	0,34 kW	Nuaire, 2011	1387 kWh/pool-m2/year	Saari & Sekki, 2008
energy requirement of chlorine, kWh/kg	0,5	Saxton et al., 1974	2,9	Saxton et al., 1974

3. Results

Comparison of the studied products and their use ways revealed that Swimitation required just 4,47 kWh of final energy and 9,18 kWh of primary energy per visit (Fig 4 and 5). The largest source of energy requirement was by far water heating, forming 44% of the total primary energy requirement.

In total energy demand, 'water aerobics' appeared higher than Swimitation, requiring 16,5 kWh of final energy and 27,4 kWh of primary energy per visit. Although water heating was significant (19% of total primary energy requirement), the largest energy consumption source was air ventilation (12,0 kWh of primary energy per visit, 44% of total demand).

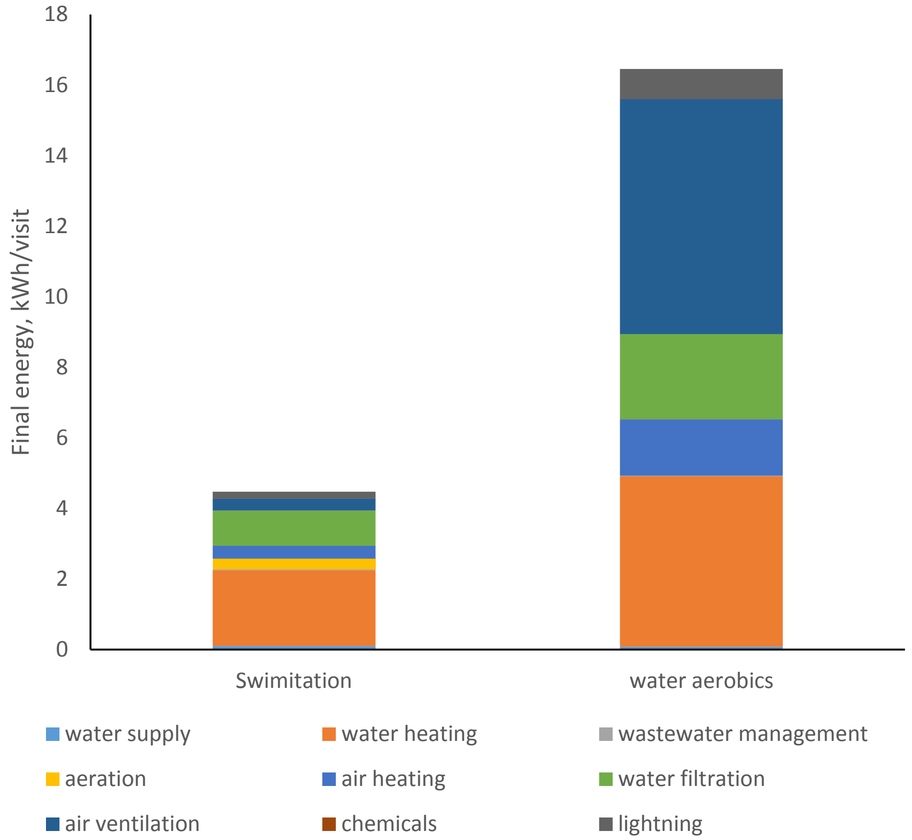

Fig 4. Final energy required for a bath visit

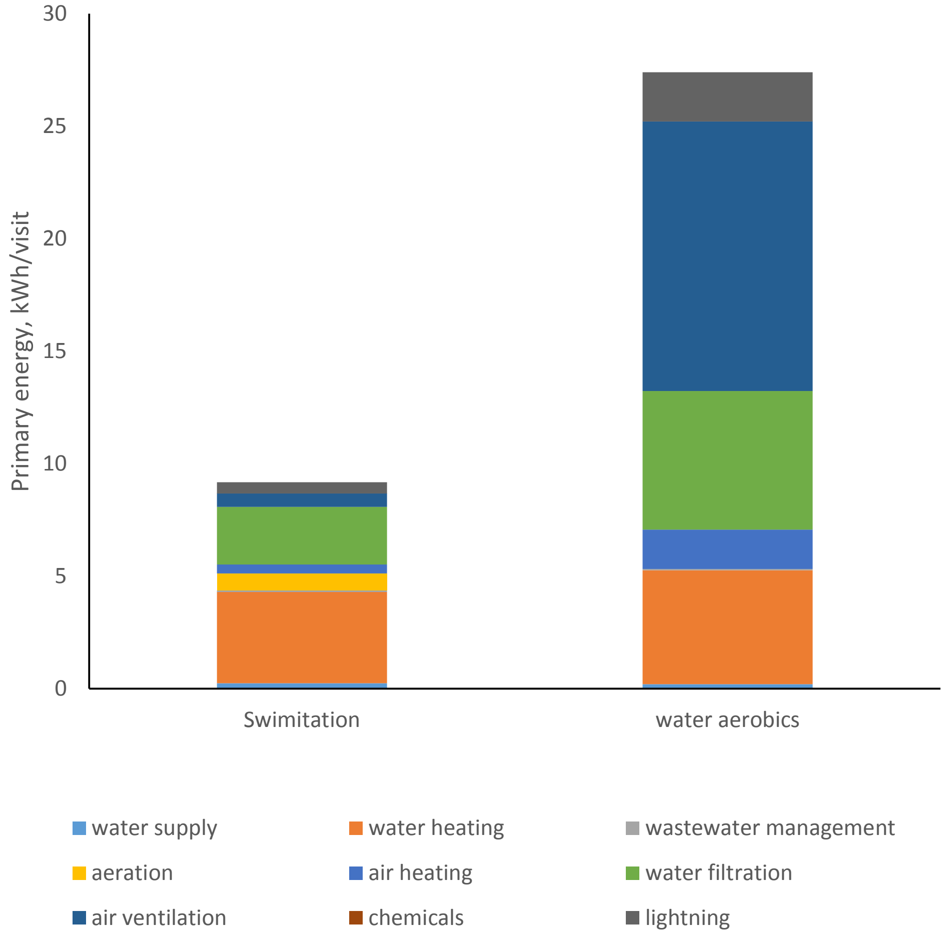

Fig 5. Primary energy required for a bath visit

4. Conclusion

Swimitation appeared more energy efficient water procedure than water aerobics. Yet, it must be noted that these two different baths cannot provide an equal service. Swimitation has several disadvantages (e.g. limited movement) while also advantages such as combined training process, privacy and new experience.

I conclude that setting the objective of providing both relaxation and exercises in water, Swimitation, although requiring a significant amount of both electric and heat energy, still serves as a relatively energy efficient solution. While energy consumption is estimated to be the critical swimming pool, relatively environmental friendly product.

Nevertheless, I must admit that this study enclosed only use stage of the entire life cycle of the product and only energy aspect of various environmental impacts. Clearly, manufacturing and end-of-life stages have also significant impacts, possibly very different from alternative products. Considering also other environmental impacts such a material flows, emissions or toxicity aspects, we could make much more confident conclusions.

Due to high rate of assumptions and low number of investigated cases, this study cannot pretend to present a globally universal comparison of energy requirements of water procedures. Rather, this study should be considered as a very likely situation, indicating major proportions.

The study demonstrated that the potential environmental impact of Swimitation bath depends very much on how it is used. As the largest source of energy requirement is water heating, I recommend to focus energy-saving efforts to reduce both heat loss via evaporation as well as to reduce water replacement need. For instance, evaporation can be reduced by converging water and air temperature as well as by covering water surface by nighttime and other non-use periods. Energy could be also saved in swimitation by isolating the bath capsule from the surrounding space. Water replacement need can be reduced by better local treatment. However, local water treatment – filtration, chlorination etc. – requires also energy.

In addition, various other ways – use of renewable energy, application of energy recovery (heat exchangers) etc. – exist to improve energy efficiency of both Swimitation and water aerobics. Therefore, in addition to the product choice, the energy profile depends on the design of the wider service provision system.

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Kokkuvõte

Swimitation harjutused on uudne, OÜ Waterflight poolt välja töötatud veeprotseduuri kontseptsioon, mis pakub samaaegselt treeningut ja lõõgastust. Swimitation vannis lebades liigutatakse käsi-jalgu ning samal ajal töötab see ka mullivannina. Käesolevas uuringus analüüsiti swimitation vanni ökoloogilist profiili, keskendudes selle kasutusfaasi energiatarbele. Arvesse võeti vee tootmiseks, kütmiseks, filtreerimiseks, tsirkuleerimiseks, desinfitseerimiseks, aereerimiseks ja lõppkäitluseks minev energiakulu, samuti siseruumide kütmine, ventileerimine ja valgustamine. Võrdluseks valiti ligilähedaselt samaväärset hüve pakkuv vesiaeroobika suures ujumisbasseinis. Analüüsi tulemus näitas, et swimitation vanni juures suurima energiatarbega on vee soojendamine. Swimitation harjutused põhjustavad 9,2 kWh globaalseid energiavoogusid ühe külastuse kohta. Vesiaeroobika tarbib aga ühe Soome ujula näitel 27,4 kWh primaarenergiat külastuse kohta. Järelikult on swimitation harjutused võrdlemisi energiatõhus treeningut ja lõõgastust pakkuv veeprotseduur. Sellegipoolest, svimitation vanni energiakulu on oluline, pakkudes väljakutset selle vähendamiseks.