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Comparing the energy implications of FRP and concrete residential construction in a hot arid climate

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ABSTRACT

Housing prices in Israel have become exceptionally prohibitive, and this includes single family housing. Conventional construction is mainly cement and concrete based, and this has significant negative impacts on cost, time and environment. Can modern industrialized processes and materials alleviate such issues? This paper compares a conventional cement concrete residential building with one made of Fiber Reinforced Polymer (FRP) composite material. It assesses the relative advantages of each one in terms of overall energy implications during their life cycle. Results show that the FRP house has an advantage of higher thermal resistance, which leads to lower energy consumption during cold periods of the year. Onsite erection time savings is another significant advantage price-wise. Low thermal mass of the FRP option is a disadvantage that makes it more energy consuming during summer. The main disadvantage is the noticeably higher Embodied Energy (EE) of the FRP in the production phase (cradle-to-gate) in comparison to the parallel concrete house EE for the same phase. The main tools used were EnergyPlus for thermal simulations and Simapro for LCEA.

1. Introduction

1.1. Energy aspects of residential construction in Israel

The market of residential building in Israel is mostly masonry construction, with concrete being the most common structural and building material [7,46], as in many other countries [1,11].[1] Current housing prices have become prohibitive, especially for young couples and families, with a 4 bedroom apartment costing an average of over 155 monthly average salaries (normalized by average apartment price and average monthly salary in 16 urban localities), with the more expensive localities demanding well over 200 monthly salaries, and prices constantly on the rise (current average salary is approximately 33,600 US$/y – [9,35,40]). Apartment prices are rising and one of the main factors is the construction cost [30], which stands today on an average of 35% of the materials and construction works total cost in Israel [26]. One of the main strategies suggested to ameliorate this is the industrialization of construction, i.e. “the use of technologies, methods and processes which make intensive use of tools and knowledge, aimed at the reduction of manpower and time needed, alongside the improvement of construction” [31]. Fiber Reinforced Polymer (FRP) construction, a fully standardized and industrialized technology [4,23,38], can lower the cost of raw material, as well as the cost of construction and assembly works and, not least, construction time [24,43,45,47,50].

In addition to financial considerations, concrete has energy and environmental implications. The production of its base material, cement, and concrete itself, are energy intensive and account for significant energy use and CO_2 emissions, with each ton of cement produced being responsible for one ton of CO_2 emitted [39]. The insulation that concrete buildings provide is very poor relative to other building materials, e.g. Autoclaved Aerated Concrete (AAC), wood and steel construction incorporating insulation panels, and other solutions. Florentin et al. [18] have demonstrated the potential Operational Energy (OE) savings in changing concrete blocks with AAC, as well as the obvious advantages in Embodied Energy (EE) of Hempcrete substituting AAC. Huberman and Pearlmutter [20] have shown the relative advantages of different materials within a given geographic context, by using Life Cycle Energy Analysis (LCEA) combining both EE and OE for the life span of a

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[1] Some of the documents cited here are not available in English. We have nevertheless opted to include them due to lack of alternative sources, and have double checked them for accuracy and relevance.

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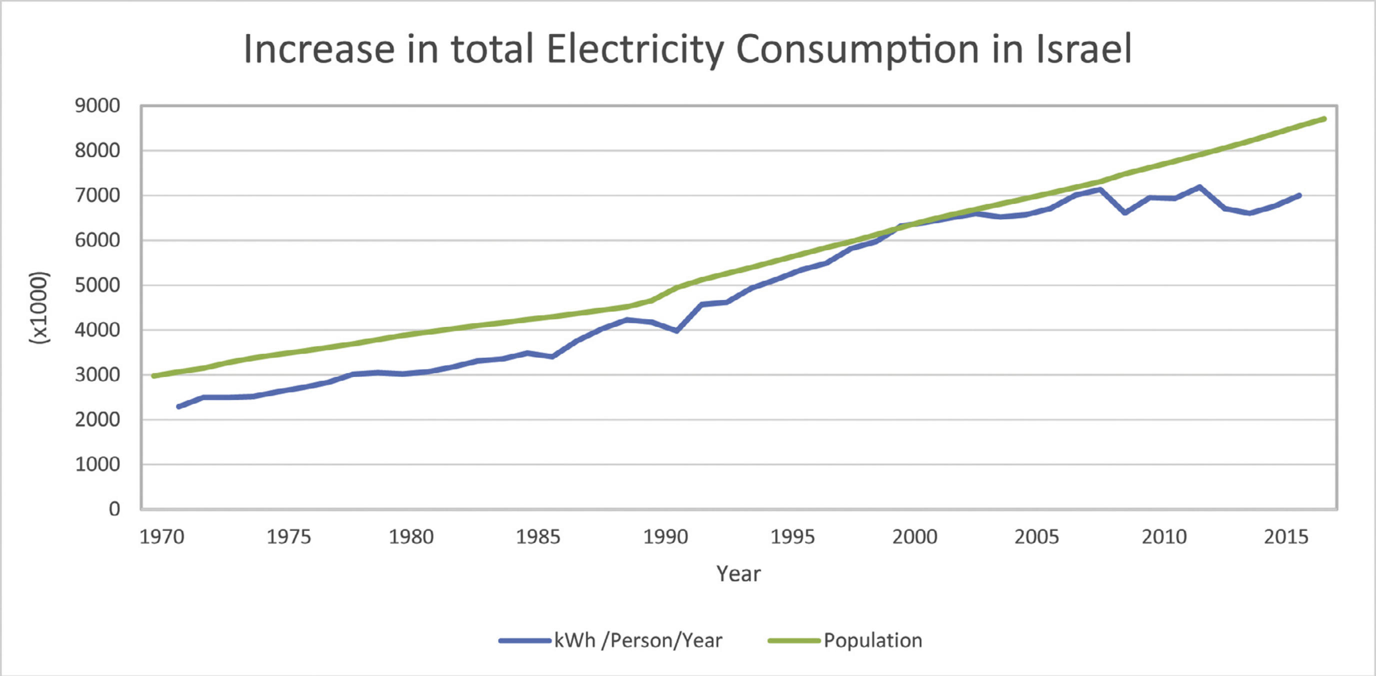


Fig. 1. Increase in total electricity consumption in Israel, 1970–2016 and population growth (source: [8,16,48]).

building. Pearlmutter et al. [37] created the first LCEA data base for building materials in Israel, thus enabling the locus specific energy conservation comparison of different construction practices. Israeli standard SI 1045 stipulates the use of thermal insulation on all building envelope elements, though it defines the lower threshold of insulating values [41]. With air conditioning as the main cooling and heating method, Israel's energy consumption is high and constantly rising, with the residential sector accounting for over 30% of all consumers [3,8,22,27] (Fig. 1).

Life Cycle Energy Analysis (LCEA) is used to assess the overall energy used by a building during its life span. LCEA uses energy as the only measure of environmental impact and relates to different forms of energy source, e.g. oil, coal, electricity and natural gas [17,42]. It is a simplified tool for measuring energy efficiency by comparing the embodied energy (EE) of a building to its operational energy (OE), thus indicating potential life cycle energy efficiency and conservation strategies.

For example, thermal insulation has a certain EE, but LCEA can be used to estimate the net savings over the building's lifetime and estimate the operational time needed to equalize the initial EE cost by the ongoing OE savings [6,21,37,44].

The energy used by the consumer is known as delivered energy and a considerable amount of primary energy source is used to produce it. It varies by means of production (for example, coal-fired or gas powered stations in the case of Israel). Consequently, energy should be measured in terms of primary energy sources embodied in the delivered energy.

To get 1 unit of electricity in Israel, on average, 3.12 units of natural energy resources are used. This ratio of 3.12 to 1 for electricity production, is called the primary energy factor for electricity [49]. Primary energy is proportional to energy-related CO_2 emissions. Therefore, primary energy is a more appropriate measure of the environmental implications of energy use than delivered energy.

It is important to differentiate between LCEA and other similar assessment methods. Life Cycle Assessment (LCA) is a methodological framework that estimates and assesses the environmental impacts attributable to the life cycle of a product. Such impacts may include climate change, stratospheric ozone depletion, tropospheric ozone creation, eutrophication, acidification etc. [25]. Different studies define different goals and scopes, which also may well predefine the data collected, often defined as Life Cycle Inventory (LCI). The stage at which environmental relevance of all inflows and outflows of the system is described and analyzed is referred to as Life Cycle Impact Assessment (LCIA). As far as the construction sector is concerned, LCA may be performed for different scales, items, products or systems – different functional units and within different system boundaries. A growing literature covers all of these yet needs to be carefully read to avoid misinterpretation of results. For example, Asdrubali et al. [2] performed "cradle to grave" LCA on three conventional Italian buildings aiming at optimizing their energy needs throughout all stages of their life. Monteiro and Freire [32] performed LCA of a house, comparing the results of seven exterior wall systems assessed by three different LCIA methods, identifying discrepancies between results obtained by different methods. What one includes in the analysis and how broadly the system boundaries are defined may well predefine the analysis results. In a study on eleven alternative insulation materials applied on a single-family house in Spain, aimed at the optimization of insulation thickness and resulting benefits, a sensitivity analysis of the LCA and Life Cycle Costing (LCC) results shed light on the advantages of less conventional materials such as sheep wool and recycled cotton, not obvious choices in everyday practice [6]. Zhu et al. [50] employed LCEA to assess the saving potential of prefabrication in residential buildings in China. Incidentally, they discuss FRP, albeit only as a choice for reinforcing and/or connecting-binding structural material.

Further in this paper, the difference in LCEA between reinforced concrete and FRP is analyzed, with EE calculations based on a cradle-to-gate framework, since there are no local data on FRP for the specific purpose. This is an important issue in light of worldwide efforts to lower the amounts of carbon dioxide emitted to the atmosphere to mitigate the global warming effect.

1.2. Research objective

The aim of this research is to compare a conventional concrete structure with the relatively new construction technology based on FRP.

The objective is also to examine the advantages and disadvantages of FRP in various areas. The question asked is whether residential buildings and houses made of FRP, complemented by an advanced insulating wall and roofing infill, can replace conventional concrete buildings, especially single family detached and semi-detached houses, which still comprise over 20% of the Israeli residential units construction market [10]. The environmental impact of a prototypical FRP house, as well as costs, is calculated and compared to those of a similar conventional concrete house to draw a complete picture and have appropriate tools to decide what would be the preferable material to build a house.

1.3. Significance of the research

The FRP structure technology is a new and advanced approach in the building sector. It has been already fully implemented in the industrial sector in structures such as cooling towers, bridges, marine decks etc.

FRP is known as a lightweight material, which allows to achieve accuracy in construction, lower transportation energy due to low weight, resistance to corrosion and pests, lower construction costs and waste. All this aims at looking into alternative materials and technologies for small scale private house construction which accounts for a significant part of the Israeli residential market. The knowledge on FRP structure technology can change the concept of construction in the building sector and furthermore lead to important advantages such as lower housing prices due to much lower mass of material used, easy and fast installation and low maintenance due to its being corrosion and pest resistant, not least since many areas of Israel tend to suffer from termites.

1.4. Methodology

Two single family house models of identical floor area (approximately 100 m^2, with minor discrepancies stemming from the specific technologies, products and modules) and volume, one built with concrete and assorted finish materials, and one built with FRP and assorted finish materials (Fig. 2), were assessed in terms of EE and simulated for the assessment of their OE in terms of heating and cooling only during a Typical Meteorological Year (TMY). The data file used was that for the Beit Dagan Meteorological Station, representing SI 1045 Zone B, the Lowlands, where the largest part of the population is concentrated, and where most of the new construction is taking place. Each one of the models was analyzed separately in exactly the same methods and steps, and the two options were compared in their entirety of energy use through their life span, estimated to be 50 years. Although subjectively chosen, the system boundaries, including life span, are assumed to be realistic. The EE of both prototypes has been assessed including all materials, products and items assumed to be integral to each of them (e.g., reinforcing steel for the concrete option, bolts and nuts for the FRP one).

Several tools were employed to gather, calculate, analyze and achieve desirable results. EE was calculated by means of a special questionnaire, which was prepared to collect EE data from producers/manufacturers of building materials. A cradle-to-gate approach was preferred, due to lack of local data on the FRP transportation implications. LCEA was performed with SimaPro7.1 software [42] using Ecoinvent database (Econinvent, n.d.) [13]. 3D modelling of a prototypical building was done using Google SketchUp [19] with a special EnergyPlus plugin, as well as SolidWorks 3D modeling software [12]. Thermal simulation and energy consumption assessment was done using the dynamic simulation software EnergyPlus, version 2.11 [14] and ENERGYui software [29].

2. Results and analysis

2.1. Thermal results comparison

According to the thermal analysis results, hourly consumption was compared between the two cases by subtracting the FRP house hourly consumption from the concrete house one to get the difference. This was then plotted on a timescale to better illustrate and understand the consumption prevalence of each option across the whole year (Fig. 3). Set indoor temperatures for the simulations were 24 °C and 20 °C for summer and winter respectively. It may be noted that during winter, there is higher consumption in the concrete prototype compared to the FRP (positive values), but during summer, the concrete prototype consumes less than the FRP (negative values). The cause for this discrepancy is the natural night ventilation during summer, due to the concrete house's higher internal thermal mass acting as a heat sink, thus having the ability to store more energy and moderate indoor temperatures. Fig. 4 shows a typical summer day with the peak of the concrete structure curve being much lower, due to the effect of delay in temperatures described in thermal mass related literature (e.g., [36]).

In addition, during transition seasons, there are usually several days with very high temperatures, heat waves ("hamseen" in Arabic, or "sharav" in Hebrew) characterized by sudden and sharp temperature rise compared to the temperatures of the previous days. During such events, the concrete house maintains low indoor temperatures despite extreme outdoor ones, unlike the FRP house, which needs a significant amount of energy to cool the internal space during such events, and these peaks can be seen on Fig. 3, points A, B, C, D, E.

During a typical summer day, the concrete house is clearly the preferable option (Fig. 4). The main reason for this is the provision of night ventilation programmed for the simulation in the summer season. Since concrete has much higher thermal mass than FRP, the thermal advantages of concrete are clearly dominant. It can be noted that starting at 07:00 the electricity consumption of the concrete option is higher and starts earlier, due to lower insulating properties, but between 13:00–17:00 this stabilizes at approximately 1.6 kWh, contrasting the FRP option with continuously increasing consumption until it reaches the peak of 2.8 kWh at approximately 16:30. Here it is clear that, under the specific climate's conditions, higher insulation is not enough for hot summer days and the advantage that comes from thermal mass is definite.

During a typical winter day there is a clear advantage for the FRP house due to lower energy consumption in the evening hours (Fig. 5). The reason for this effect is better insulation. FRP panels used for the house envelope have a 66 mm thick layer of polyurethane insulation with conductivity value of 0.0254 W/m°K, compared to regular expanded polystyrene (common in local heavyweight construction) of 50 mm thickness with conductivity value of 0.04 W/m°K.

Thermal mass is a less dominant parameter in winter period, since there is no natural ventilation during this period and solar radiation in the specific building design is not enough for solar gains during the day in the specific climatic zone and specific weather station data, due to cloudy or overcast skies (included in the TMY data file). The insulation of the FRP house has a conductivity value of 0.025 W/m°K and in the case of the insulated

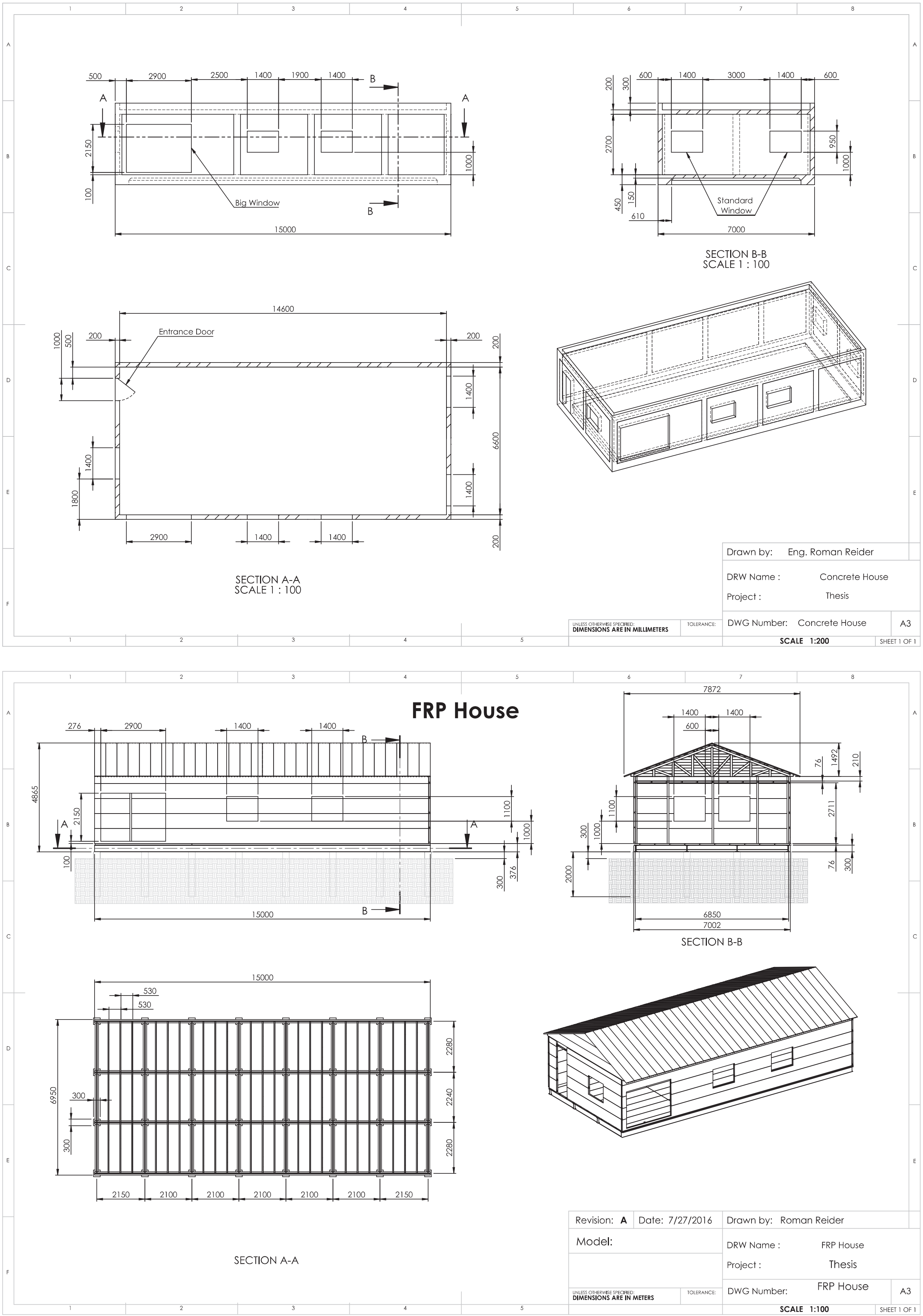


Fig. 2. Two single family residential building prototypes – concrete (top) and FRP (bottom) – used in simulations.

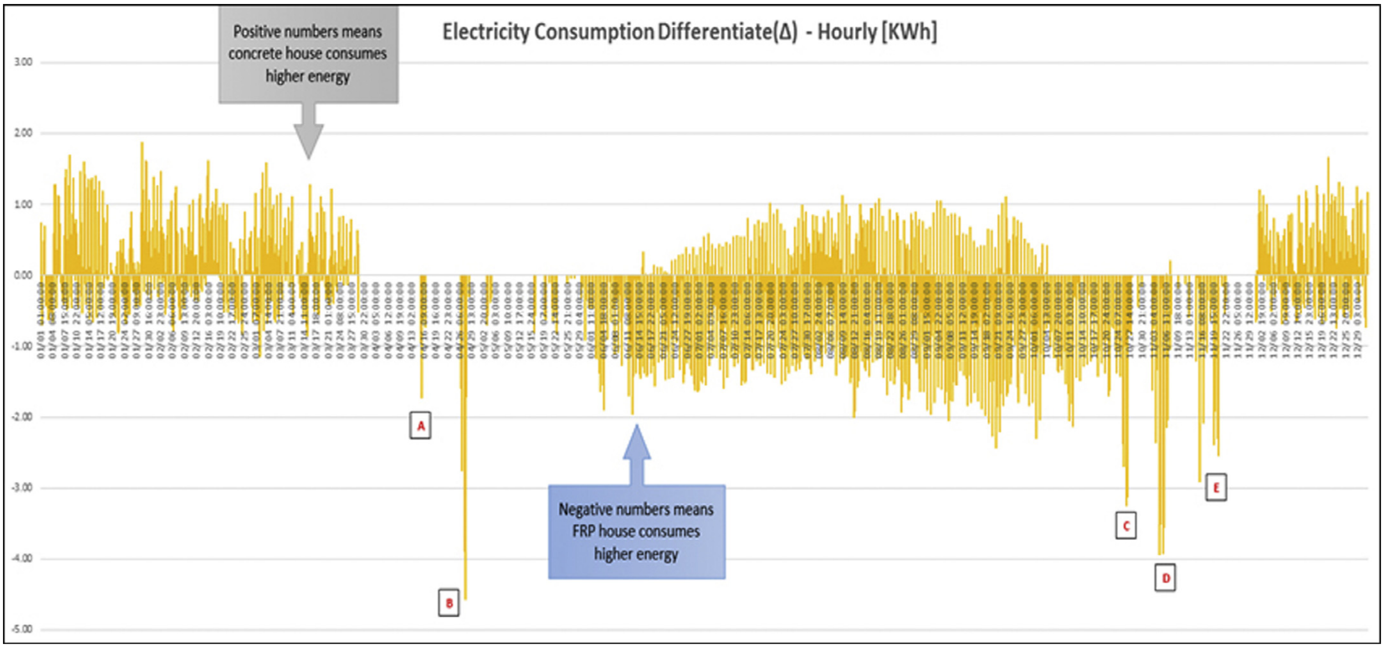


Fig. 3. Energy consumption difference between concrete and FRP houses simulated. Positive numbers mean higher energy consumption by concrete house, negative numbers mean higher energy consumption by FRP house.

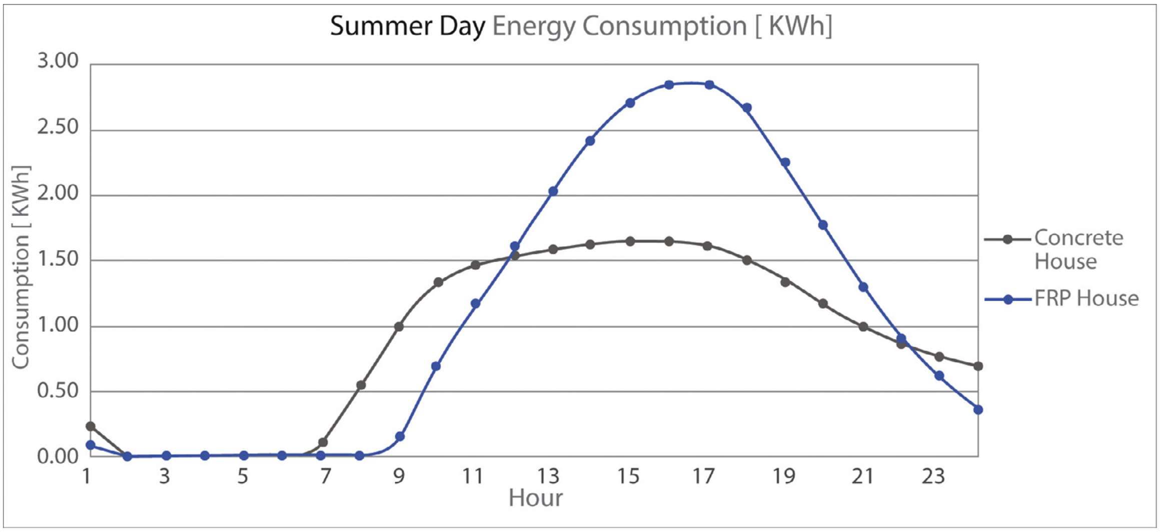


Fig. 4. Typical summer day energy consumption of concrete and FRP houses.

concrete house the insulation layer has a conductivity value significantly higher – 0.04 W/m°K. In addition, the lightweight FRP house needs auxiliary energy to only heat the volume of air (due to lack of thermal mass), whereas overcast skies with little or no direct radiation will cause the higher thermal mass of concrete to start cooling, which will demand more auxiliary energy to keep its mass warm alongside the volume of air.

Average global solar radiation data for the Beit Dagan station throughout a year are presented in Table 1. The maximum radiation in January at noon (1.47 [MJ/m^2]) is more than two times lower than during the same time in July (3.32 [MJ/m^2]).

The comparison of the two options (Table 2a) shows a non-negligible discrepancy between them. The concrete house option has 19.2% lower yearly consumption (OE) than the FRP house option. This is in spite of the FRP option's advantage during the winter season, when it has a lower consumption as mentioned above. However, transition season peaks and thermal mass differences were in favor of the concrete option.

In order to perform a wider, more realistic analysis and examine the sensitivity of both houses to lack of insulation or night ventilation, the concrete house was simulated without the 50 mm insulation layer of expanded polystyrene, a practice still common in ordinary and low cost buildings in Israel, despite the mandatory standard SI 1045. The results are more than 2 times higher than the insulated option and 2 times higher than the original FRP option (Table 2b). Consequently, the insulation parameter has a dramatic impact on the overall thermal performance, as expected.

The FRP option was then simulated without an air gap between the ground and house floor, a solution that could prove problematic due to humidity penetration and other potential issues, yet assumed to have certain thermal advantages. The difference between this option and the original FRP option is 100 kWh for one year and therefore insignificant.

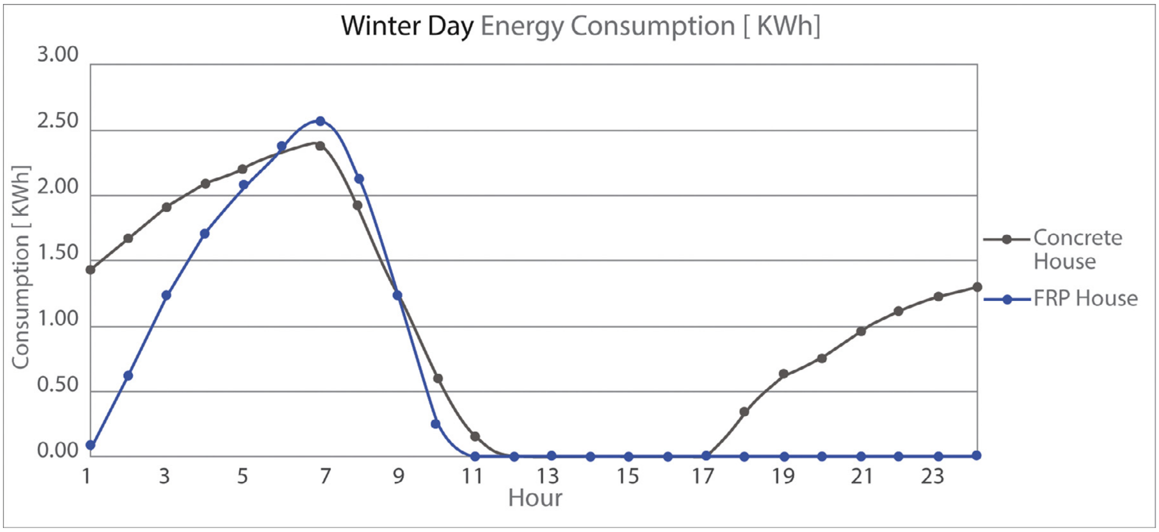


Fig. 5. Typical winter day energy consumption of concrete and FRP houses.

Table 1
Global solar radiation averages for Beit Dagan station [5].

Global solar radiation averages [MJ/m^2]													
Measurement period: 1991–2005													
Hours	January	February	March	April	May	June	July	August	September	October	November	December	Yearly
5–6			0.01	0.09	0.25	0.31	0.22	0.12	0.05	0.02			0.11
6–7	0.01	0.05	0.22	0.54	0.78	0.9	0.77	0.61	0.47	0.29	0.11	0.03	0.4
7–8	0.25	0.4	0.74	1.14	1.43	1.52	1.4	1.28	1.14	0.85	0.53	0.29	0.91
8–9	0.7	0.94	1.33	1.72	2.07	2.18	2.03	1.84	1.7	1.4	1.04	0.72	1.47
9–10	1.12	1.38	1.81	2.26	2.64	2.8	2.68	2.51	2.23	1.81	1.45	1.14	1.99
10–11	1.41	1.69	2.2	2.68	3.03	3.24	3.15	2.98	2.68	2.16	1.7	1.44	2.36
11–12	1.53	1.85	2.49	2.87	3.19	3.43	3.36	3.22	2.91	2.34	1.77	1.5	2.53
12–13	1.47	1.85	2.41	2.82	3.12	3.36	3.32	3.17	2.85	2.23	1.69	1.42	2.48
13–14	1.29	1.65	2.19	2.53	2.84	3.08	3.04	2.88	2.52	1.88	1.42	1.18	2.21
14–15	0.97	1.29	1.73	2.05	2.34	2.59	2.56	2.38	1.97	1.37	0.95	0.8	1.75
15–16	0.52	0.81	1.16	1.44	1.7	1.96	1.94	1.71	1.31	0.76	0.43	0.35	1.17
16–17	0.12	0.3	0.54	0.77	1.01	1.23	1.21	0.98	0.59	0.2	0.05	0.04	0.59
17–18		0.02	0.08	0.2	0.36	0.53	0.51	0.31	0.08				0.26
18–19					0.02	0.06	0.06	0.01					0.04
Daily	9.39	12.23	16.84	21.11	24.78	27.19	26.25	24	20.5	15.31	11.15	8.92	18.14

Table 2
Electricity comparison between the two prototypes: a. Electricity consumption (OE) summary; b. Electricity consumption (OE) summary, concrete option without insulation, and FRP option without upper and lower air gaps; c. Results of both options without night ventilation.

a. Electricity consumption (OE) summary for the two options			
Concrete house option		FRP house option	
Concrete total consumption in summer day kWh	21.50	FRP total consumption in summer day kWh	26.27
Concrete total consumption in winter day kWh	24.23	FRP total consumption in winter day kWh	14.21
Concrete total yearly consumption kWh	4157.30	FRP total yearly consumption kWh	5144.58
b. Electricity consumption (OE) summary for concrete option without insulation and FRP option without upper and lower air gaps			
Concrete house without insulation		FRP house without air gap	
Concrete total consumption in summer day kWh	48.95	FRP total consumption in summer day kWh	26.72
Concrete total consumption in winter day kWh	39.95	FRP total consumption in winter day kWh	14.40
Concrete total yearly consumption kWh	10,273.79	FRP total yearly consumption kWh	5245.55
c. Results of both options without night ventilation			
Concrete house without night ventilation		FRP house without night ventilation	
Concrete total consumption in summer day kWh	33.59	FRP total consumption in summer day kWh	32.52
Concrete total consumption in winter day kWh	22.96	FRP total consumption in winter day kWh	14.21
Concrete total yearly consumption kWh	6839.21	FRP total yearly consumption kWh	6991.02

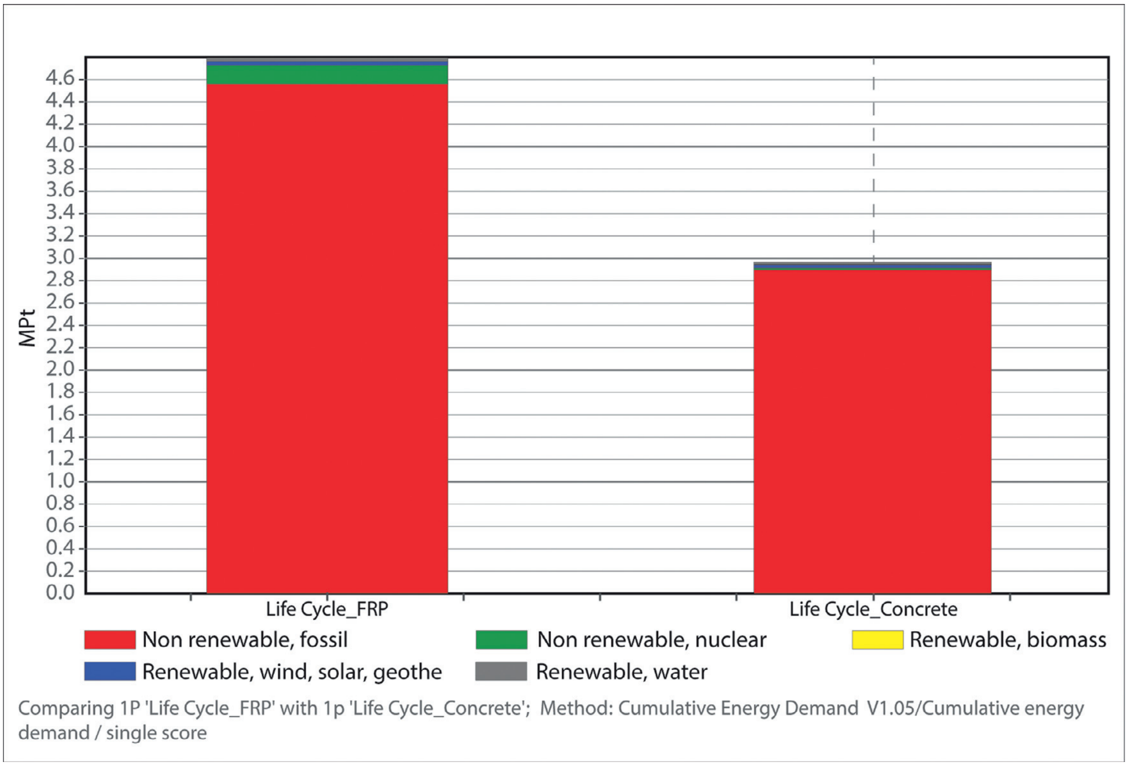
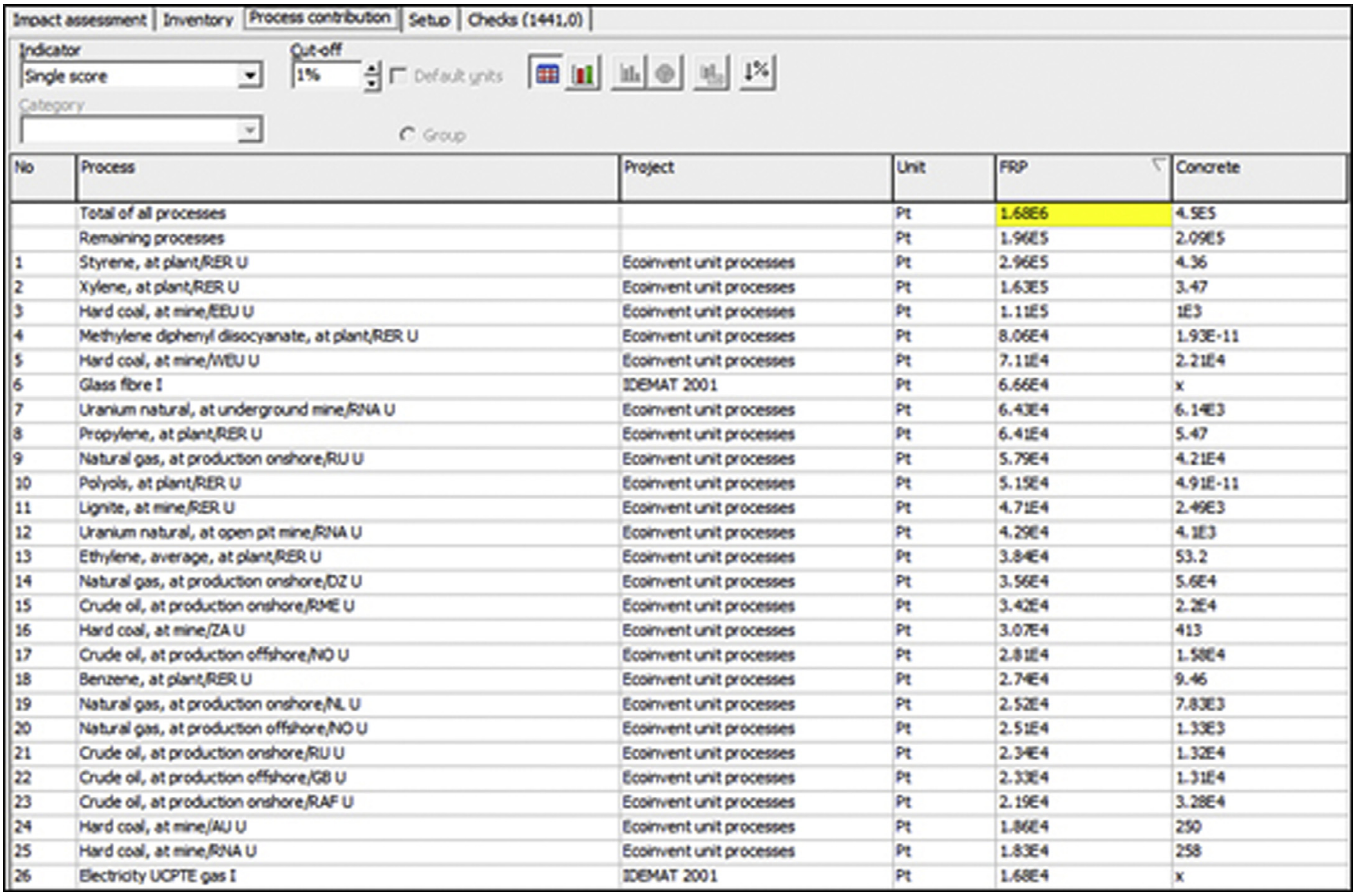


Fig. 6. Comparing concrete and FRP life cycle EE analyses.



Indicator: Single score

Cut-off: 1%

☐ Default units

No	Process	Project	Unit	FRP	Concrete
	Total of all processes		Pt	1.68E6	4.5E5
	Remaining processes		Pt	1.96E5	2.09E5
1	Styrene, at plant/RER U	Ecoinvent unit processes	Pt	2.96E5	4.36
2	Xylene, at plant/RER U	Ecoinvent unit processes	Pt	1.63E5	3.47
3	Hard coal, at mine/EEU U	Ecoinvent unit processes	Pt	1.11E5	1E3
4	Methylene diphenyl diisocyanate, at plant/RER U	Ecoinvent unit processes	Pt	8.06E4	1.93E-11
5	Hard coal, at mine/WEU U	Ecoinvent unit processes	Pt	7.11E4	2.21E4
6	Glass fibre I	IDEMAT 2001	Pt	6.66E4	x
7	Uranium natural, at underground mine/RNA U	Ecoinvent unit processes	Pt	6.43E4	6.14E3
8	Propylene, at plant/RER U	Ecoinvent unit processes	Pt	6.41E4	5.47
9	Natural gas, at production onshore/RU U	Ecoinvent unit processes	Pt	5.79E4	4.21E4
10	Polyols, at plant/RER U	Ecoinvent unit processes	Pt	5.15E4	4.91E-11
11	Lignite, at mine/RER U	Ecoinvent unit processes	Pt	4.71E4	2.49E3
12	Uranium natural, at open pit mine/RNA U	Ecoinvent unit processes	Pt	4.29E4	4.1E3
13	Ethylene, average, at plant/RER U	Ecoinvent unit processes	Pt	3.84E4	53.2
14	Natural gas, at production onshore/DZ U	Ecoinvent unit processes	Pt	3.56E4	5.6E4
15	Crude oil, at production onshore/RME U	Ecoinvent unit processes	Pt	3.42E4	2.2E4
16	Hard coal, at mine/ZA U	Ecoinvent unit processes	Pt	3.07E4	413
17	Crude oil, at production offshore/NO U	Ecoinvent unit processes	Pt	2.81E4	1.58E4
18	Benzene, at plant/RER U	Ecoinvent unit processes	Pt	2.74E4	9.46
19	Natural gas, at production onshore/NL U	Ecoinvent unit processes	Pt	2.52E4	7.83E3
20	Natural gas, at production offshore/NO U	Ecoinvent unit processes	Pt	2.51E4	1.33E3
21	Crude oil, at production onshore/RU U	Ecoinvent unit processes	Pt	2.34E4	1.32E4
22	Crude oil, at production offshore/GB U	Ecoinvent unit processes	Pt	2.33E4	1.31E4
23	Crude oil, at production onshore/RAF U	Ecoinvent unit processes	Pt	2.19E4	3.28E4
24	Hard coal, at mine/AU U	Ecoinvent unit processes	Pt	1.86E4	250
25	Hard coal, at mine/RNA U	Ecoinvent unit processes	Pt	1.83E4	258
26	Electricity UCPTE gas I	IDEMAT 2001	Pt	1.68E4	x

Fig. 7. Process contribution details of Concrete and FRP life cycles comparison – assembly and material only.

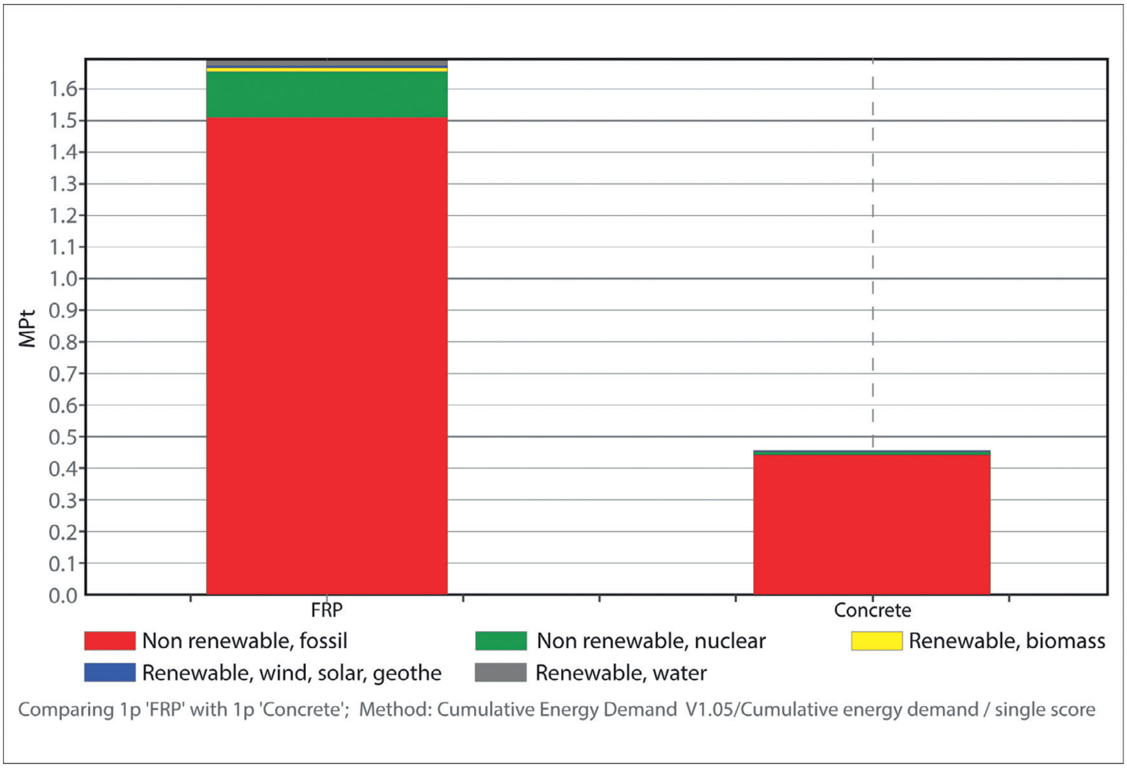


Fig. 8. Embodied energy summary chart of Concrete and FRP life cycles comparison – assembly and material only.

To highlight the effect of night ventilation, both options were analyzed and simulated without night ventilation (Table 2c). It is clear, that there is a significant increase of 164.5% in energy consumption (OE) in the concrete case and of 136% in the FRP case. The concrete option is more sensitive to night ventilation, since the thermal mass is much higher than the FRP thermal mass, corroborating results of previous studies [28].

Generally speaking, the FRP option is more energy efficient only in comparison to the uninsulated concrete option. In the rest of the cases, the concrete option is a better choice.

2.2. Cost comparison

The price of the concrete structure was calculated to be 358,781 NIS and that of the FRP structure is 350,828 NIS (approximately US$ 99,000 and 96,800 respectively), which is almost equal.[2]

Besides the materials costs, there are several significant factors, which cannot be easily quantified and converted to direct cost. For example, the average time needed to build a concrete structure is approximately 9 months [34]. On the other hand, an FRP structure, defined as prefabricated production, can be built in three months [33], which is 3 times shorter than the concrete building case, where the builders' working hours during much longer periods can have substantial cost implications, and construction time may be affected by weather and other external factors.

It should be noted that the concrete industry provides prefabricated products possibilities, but in this paper we only consider the option of a standard heavy concrete structure casted onsite, which is the most common for single family housing and other small or medium size structures in Israel, as those discussed here.

In addition, a single family house or other small scale FRP construction does need special tools and heavy machinery as in the concrete case. This can have an important environmental advantage and be cost effective. The FRP option has also a clear advantage of precision of the materials, components and the end product, since the prefabricated profiles are cut in ±1 mm tolerance. That is obviously not the case in the concrete option, where the tolerances are often as inaccurate as ±10 mm or more and concrete corrections can be time and money consuming.

Of course, these two options are two different types of buildings – a concrete house is a heavy construction and a FRP house is a lightweight construction, while the parameters like construction time, documentation, authorities' approvals and other preparations have different scenarios and shall not be covered in this paper. Nevertheless, it is obvious that from the construction cost perspective, the FRP option is much more attractive with its time efficiency and precision.

2.3. LCEA comparison

While comparing between the concrete and FRP options in light of LCEA analysis, (Fig. 6), life cycle EE is higher in the FRP case than the concrete on (4.8×10^6 MJeq and 2.97×10^6 MJeq respectively). The resulting difference is 1.83×10^6 MJeq, about 38% in favor of the concrete option.

Of course, the OE consumption has a more significant role in the final calculation - 85% for the concrete option and 65% for the FRP option. However, if comparing materials production and assembly LCEA only, then according to Figs. 7 and 8, it seems that the main contributors of EE, which make the FRP case less attractive, are the main polyester ingredients, e.g. styrene, xylene, methylene etc. The production processes of these and similar chemicals are much more energy intensive, therefore the EE value of FRP material (1,680,000 MJeq) is 2.7 times higher than the concrete EE value (450,000 MJeq), despite the fact concrete in itself is an energy intensive material, especially, though not only, because of the cement production processes [15].

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[2] This is a rough estimate of the envelope only, and does not include land value, finish materials, or infrastructures and other building systems.

Nevertheless, it should be noted that FRP is relatively new and there are no statistics regarding its lifetime. Due to the fact that the lifecycle of a house is assumed to be 50 years, the numbers are in favor of concrete, but if proven that FRP has a longer life span, the calculation should be revised and maybe the FRP option will be more attractive.

3. Summary and conclusions

This research aimed at investigating the LCEA of the potential use of FRP, a relatively new building material, in the construction of single family houses in Israel. To achieve this, a prototypical single family house was designed and simulated both in terms of EE and OE over a life span of 50 years and finally compared in terms of energy and cost efficiency.

The tools used included SolidWorks and Sketchup for 3D modeling; SolidWorks CFD, EnergyPlus and ENERGYui for dynamic thermal simulation, and SimaPro 7.1 for the LCEA. The tools proved to be sufficient in terms of output data and precision. For cost analysis official government databases and FRP production company database were used to estimate the cost of both structures.

Comparison of the two options was based on the overall energy usage and the financial implications of the construction and operation of the two models. In general it may be stated with a great degree of certainty that the insulated concrete option performs better thermally compared with the FRP option. Additionally, in light of overall EE the concrete option outperforms the FRP option. The conclusions present a more detailed analysis of the two models and their comparison based on a number of the parameters used (thermal insulation, thermal mass, ventilation, etc.) and the insights gained through the simulations.

FRP is a relatively new type of material, which can be used in various applications, e.g., aerospace, marine, automotive, building etc., due to its light weight, high strength, corrosion resistance, precision assembly and other advantages. However, so far it is rarely used in residential building construction, since it is relatively new, its price is relatively high and its availability is limited in comparison with concrete. So far, its main uses in construction have been as structural and reinforcing elements, but not as a complete building system.

The thermal resistance of special FRP panels used in this research is higher than conventional expanded polystyrene used in the concrete option, but thermal mass is much lower in the FRP option – an advantage in transportation and construction. As a result, the thermal performance of an FRP house is approximately equal to that of the concrete house. Yet the energy advantages of summer night ventilation are considerably higher in the concrete case, since it has a higher thermal mass, which, when night-cooled, will act as a heat sink during the next day. The insulation of the concrete house is a significant parameter in light of energy efficiency of the house and if removed, the energy consumption will double.

The FRP house with better insulation has less energy consumption during the winter season, but higher energy consumption than the concrete house during the summer season, even though it has better insulation.

Although the FRP house has much lower mass than its concrete counterpart, the total EE of materials and assembly works is higher than the concrete one's.

It is obvious that FRP is a relatively expensive material. Hence, to reduce cost, other, conventional and less expensive, materials can be used in some cases, which could noticeably reduce the cost of the house system. For example, in the case of roofing, the standard roof tile solutions are more cost effective (though not necessarily more energy efficient).

The cost of the FRP and concrete house prototypes simulated here is almost equal, but the ease of assembly, precision and onsite erection time savings make the FRP option more attractive pricewise.

The total EE of FRP is noticeably higher than the EE of the concrete option, due to the use of chemicals with significant EE and due to higher electricity consumption.

The concrete house materials and assembly have relatively low impact on the overall EE in comparison with the future OE consumption, hence it is a preferable option from the LCEA perspective.

Conflict of interests declaration

The authors declare that no conflict of interests exists, and that the research and ensuing paper have not been funded by any person or entity which may have financial benefits from or interests in the specific work.

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