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Development for Sustainable Construction System Glass Fiber Reinforced Gypsum (GFRG) in Egypt Using Nanotechnology

Mohamed Said Meselhy ElSaeed

Department of Architecture, Faculty of Engineering, Fayoum University, Fayoum, Egypt

Email address:
Dr.meselhy@waveegypt.com

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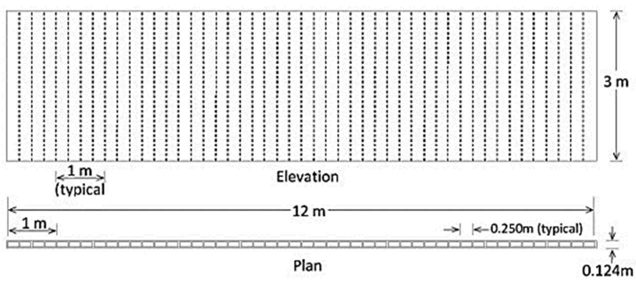
Abstract: One of the mile stones for the success of construction projects is the project management triangle (time, cost and quality). During the past decade, a lot of construction systems have been developed to this triangle. GFRG system was one of these systems (for example that was established in Australia), it fulfilled LEED certificate for construction materials. When it is compared with traditional systems in Egypt, Glass Fiber Reinforced Gypsum (GFRG) system superior to traditional systems in time, cost in case of repetitive projects and quality. The world awareness for sustainability have increased lately in different aspects, thermal comfort is one of the main sustainable aspects that influence users. This paper aims to study thermal comfort for GFRG system in Egypt and comparing with traditional systems, it also aims to study the nanotechnology to develop this construction material in order to increase thermal comfort performance.

Keywords: Aerogel, Nanotechnology, GFRG, Thermal Comfort, Egypt

1. GFRG Definition

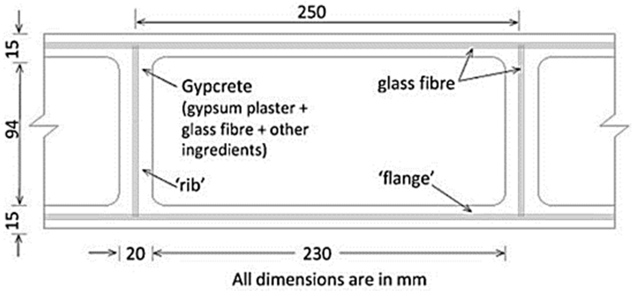
GFRG is the abbreviation for glass fiber reinforced gypsum. It is the name of a new building panel product, made essentially of gypsum plaster, reinforced with glass fibers, and is also known in the industry as GFRG [2]. This product, suitable for rapid mass-scale building construction, was originally developed and used since 1990 in Australia. GFRG is of particular relevance to India, where there is a tremendous need for cost-effective mass-scale affordable housing, and where gypsum is abundantly available as an industrial by-product waste. The product is not only eco-friendly or green, but also resistant to water and fire. GFRG panels are presently manufactured to a thickness of 124 mm, a length of 12 m and a height of 3 m, under carefully controlled conditions. The panel can be cut to required size [3]. Although its main application is in the construction of walls, it can also be used in floor and roof slabs in combination with reinforced concrete. The panel contains cavities that may be filled with concrete and reinforced with steel bars to impart additional strength and provide ductility. The panels may be unfilled, partially filled or fully filled with reinforced concrete as per structural requirement.



Source: GFRG/Rapidwall Building Structural Design Manual

Figure 1. *Typical Cross Section of GFRG Panel.*

GFRG building panels are presently manufactured as GFRG, for the typical dimensions and material properties described in the manual. Typical dimensions of a GFRG building panel are 12.0 m*3.0 m *0.124 m, as shown in Fig. 1. Each 1.0 m segment of the panel contains four ‘cells’. Each cell is 250 mm wide and 124 mm thick, containing a cavity 230 mm*94 mm, as shown in Fig. 2. The various cells are inter-connected by solid ‘ribs’ (20 mm thick) and ‘flanges’ (15 mm thick), comprising gypsum plaster, reinforced with 300 - 350 mm glass fiber roving [10], located randomly but centrally. The skin thickness is 15 mm and rib thickness is 20 mm.



Source: GFRG/Rapidwall Building Structural Design Manual

Figure 2. *Enlarged View of a Typical Cell.*

2. GFRG Uses

In typical multistoried constructions involving the use of GFRG as load bearing structural walling, the connections between cross walls and with the foundations and floor/roof are achieved through reinforced concrete filling or R. C beams. All GFRG wall panels at the ground floor are to be erected over a network of RC plinth beams supported on suitable foundation [6].

Figure 3. *Erection of GFRG panels over plinth beam at site [9].*

GFRG panel can also be used for intermediate floor slab/roof slab in combination with RC. The strength of GFRG slabs can be significantly enhanced by embedding reinforced concrete micro beams. For providing embedded micro beams, top flange of the respective cavity is cut and removed in such a way that minimum 25 mm flange on both end is protruded. RC concrete screed of minimum 50 mm thickness is provided above the GFRG floor panel, which is reinforced with weld mesh of minimum size of 10 gauge 100 mm × 100 mm [7]. This RC screed and micro beam act together as series of embedded T-beams. The thickness of the RC screed, reinforcement and interval of embedded RC micro beams depends on the span and intensity of imposed load. The connectivity between the horizontal tie beam, embedded RC micro beams, concrete screed and vertical rods in GFRG wall, and ensures perfect connection between floor/roof slab and walling system [5].

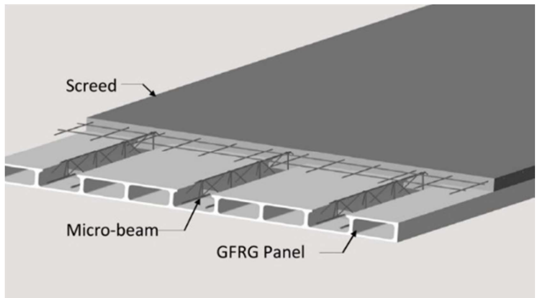


Figure 4. *GFRG floor slab with micro beam and screed Installation [8].*

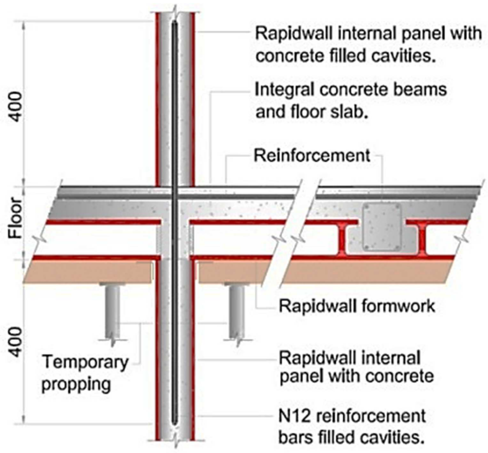


Figure 5. *GFRG Floor.*

3. GFRG Projects

Figure 6. *Apartments, Parafield Gardens S. A, Australia Completed November 2002, 2350 M² External and Internal Load bearing Rapidwall [14].*

Figure 7. *Apartments, Mawson Lakes S. A., Australia. Completed September 2004, 6709 M² load bearing Rapidwall [14].*

Figure 8. *Apartment Residences, West Beach S. A., Australia. Completed November 2005, 910 M² Load bearing external and internal Rapidwall [14].*

Figure 9. *Holliday Housing, New Caledonia Completed March 2009, 3800 M² Load bearing external & internal Rapid wall [14].*

4. Thermal Comparison Between Traditional Work and GFRG

Traditional system is meant to be masonry work (Hollow brick units) in addition to concrete slabs, covered with plaster (Cement plaster). The dimensions for bricks and plaster will be considered as schedule below. This paper will study thermal performance for different cases for traditional system as schedule below, using the following U-Value equations. This study was applied upon base model using software "Design Builder"; the dimension for this base model is 3 m width, 3 m length and 3 m height.

4.1. U-Value Calculations

U = 1/Rt

U = U-Value (W/m^2. C)

Rt = Overall Thermal Resistance (m^2. C/W)

Rt = Ro + Σ R + Ri

Ro = Outer Air-Film Resistance = 0.055 m^2. C/W

Ri = Inner Air-Film Resistance = 0.123 m^2. C/W

R = L / K

L = Material Width (m)

K = Thermal Conductivity (W/m. C)

$$Rt = Ro + \sum R + Ri$$
$$= 0.055 + L1/K1 + L2/K2 + \ldots\ldots + Ln/Kn + 0.123$$

Table 1. *U-Value Analysis for Traditional systems (12 mm), (25 mm) & GFRG.*

Wall	Material Layers	L (m)	K (W/m. C)	R=L/K	Rt (m^2. C/W)	U-Value (W/m^2. C)
	Outer air-film			0.055		
	Cement plaster	0.02	0.95	0.021		
Traditional System (12 cm)	Hollow brick units	0.12	0.60	0.20	0.42	2.38
	Cement plaster	0.02	0.95	0.021		
	Inner air-film			0.123		
	Outer air-film			0.055		
	Cement plaster	0.02	0.95	0.021		
Traditional System (25 cm)	Hollow brick units	0.25	0.60	0.416	0.636	1.57
	Cement plaster	0.02	0.95	0.021		
	Inner air-film			0.123		
	Outer air-film			0.055		
	Gypsum plaster	0.0145	0.42	0.0345		
GFRG System	Concrete	0.094	1.44	0.065	0.312	3.20
	Gypsum plaster	0.0145	0.42	0.0345		
	Inner air-film			0.123		

Table 2. *Annual Thermal comfort analysis for Traditional system (12 mm).*

	Month		Discomfort		Comfort
			Hot	Cold	
Wall 1	1	January	0%	35%	65%
	2	February	22%	11%	67%
	3	March	39%	4%	57%
	4	April	67%	0%	33%
	5	May	95%	0%	5%
	6	June	100%	0%	0%
	7	July	100%	0%	0%
	8	August	100%	0%	0%
	9	September	100%	0%	0%
	10	October	100%	0%	0%
	11	November	67%	8%	25%
	12	December	21%	10%	69%

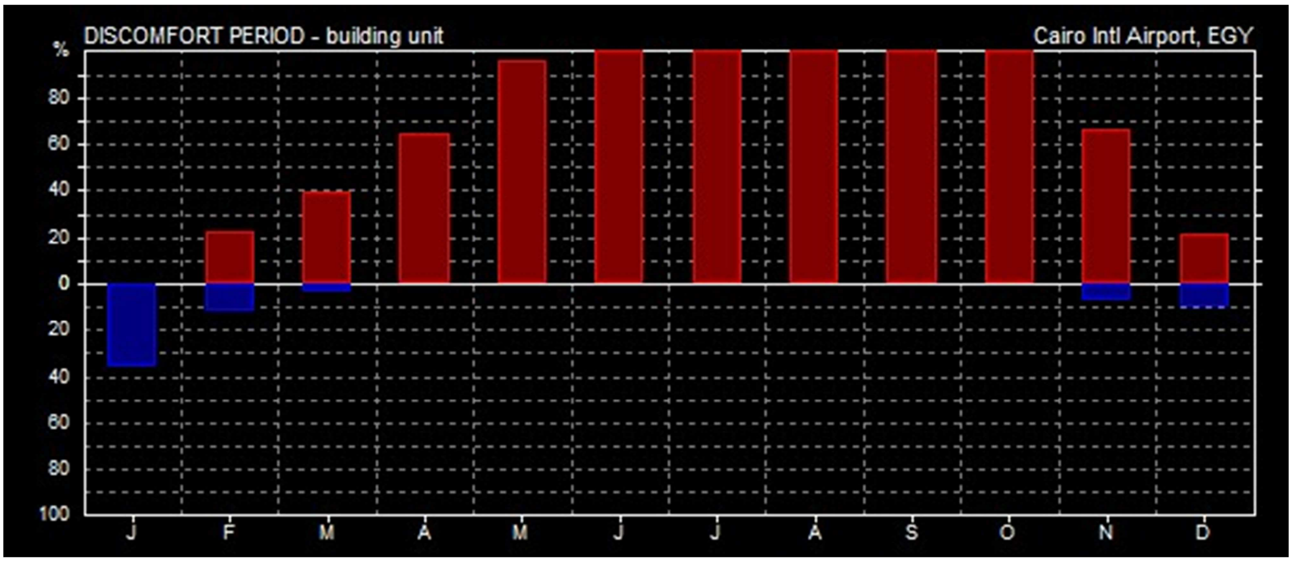


Figure 10. *Annual Thermal comfort analysis Traditional System (12 cm).*

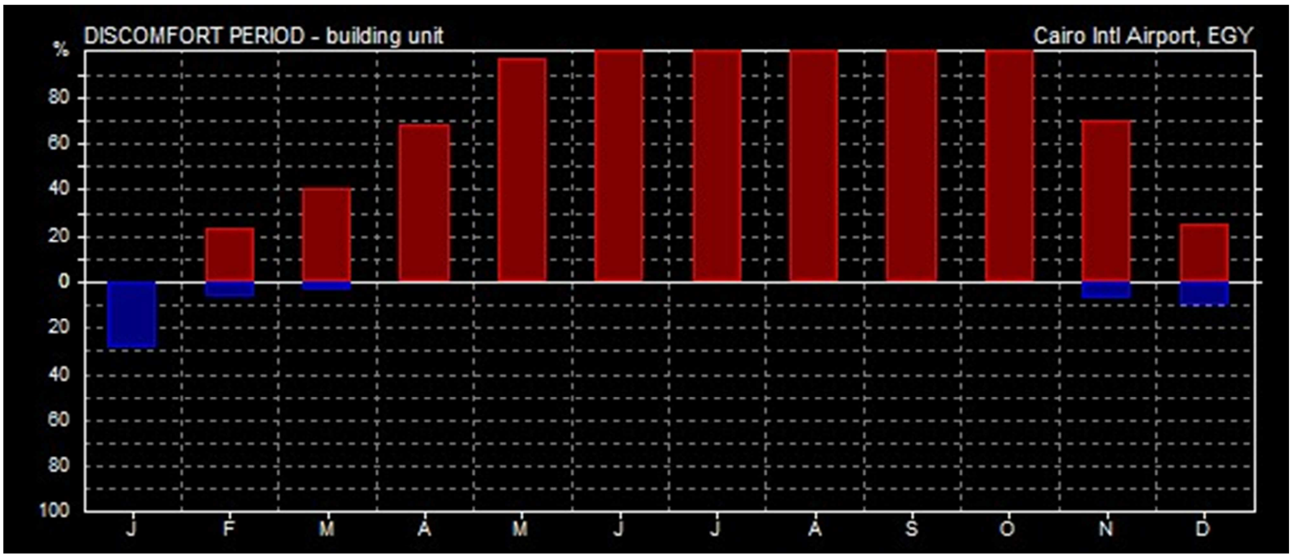


Figure 11. *Annual Thermal comfort analysis Traditional System (25 cm).*

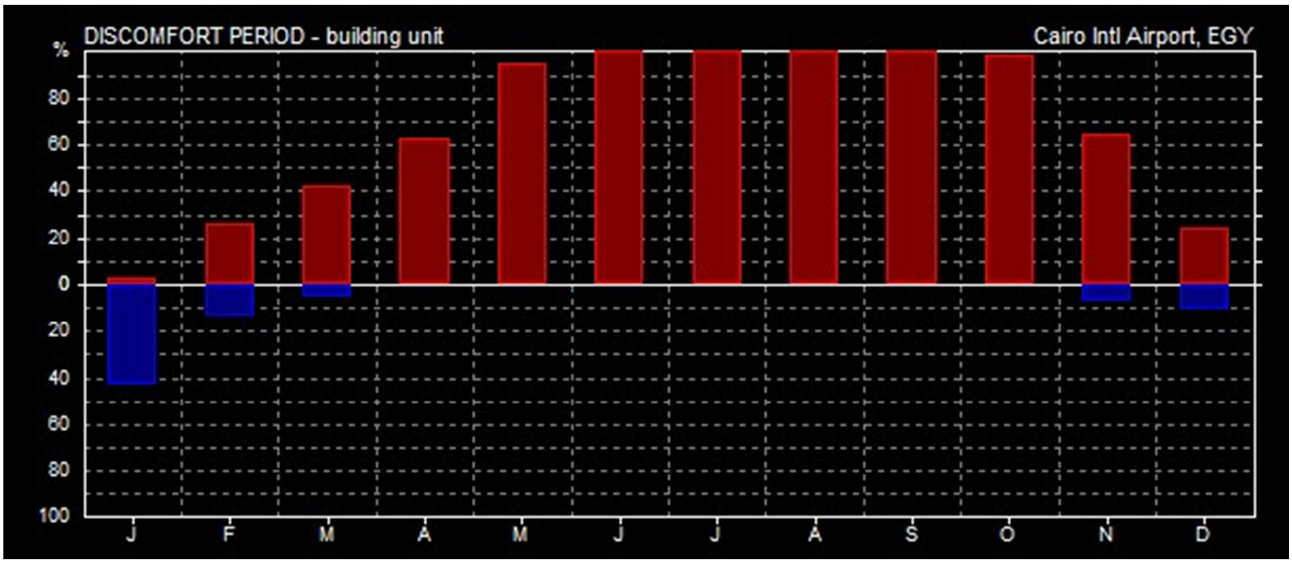


Figure 12. *Annual Thermal comfort analysis GFRG system.*

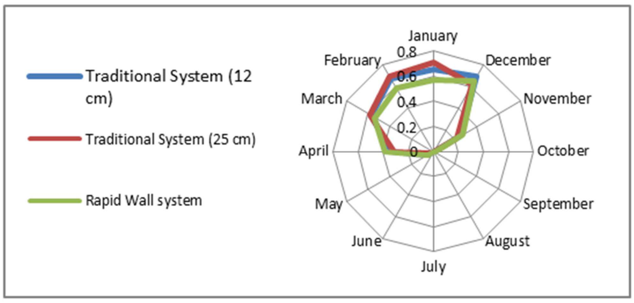


Figure 13. *Thermal Comfort Analysis.*

Figure 13 shows that there is no remarkable difference between different systems studied above, so it is required to have additional input to have remarkable impact upon thermal comfort zone for the base model.

Table 3. *Annual Thermal comfort analysis for Traditional system (25 mm).*

	Month		Discomfort		Comfort
			Hot	Cold	
Wall 2	1	January	0%	29%	71%
	2	February	24%	7%	69%
	3	March	40%	2%	58%
	4	April	69%	0%	31%
	5	May	97%	0%	3%
	6	June	100%	0%	0%
	7	July	100%	0%	0%
	8	August	100%	0%	0%
	9	September	100%	0%	0%
	10	October	100%	0%	0%
	11	November	70%	8%	22%
	12	December	28%	10%	62%

Table 4. *Annual Thermal comfort analysis GFRG system.*

	Month		Discomfort		Comfort
			Hot	Cold	
Wall 3	1	January	2%	41%	57%
	2	February	28%	14%	58%
	3	March	41%	5%	54%
	4	April	62%	0%	38%
	5	May	95%	0%	5%
	6	June	100%	0%	0%
	7	July	100%	0%	0%
	8	August	100%	0%	0%
	9	September	100%	0%	0%
	10	October	99%	0%	1%
	11	November	65%	8%	27%
	12	December	25%	10%	65%

4.2. Nanotechnology in Construction

Nanotechnology and nanomaterials offer interesting new opportunities in the construction industry and architecture, for example through the development of very durable, long-lived and at the same time extremely lightweight construction materials. Novel insulation materials with very good insulation values are already available on the market, enable a thermal rehabilitation of buildings in which conventional insulation is not possible, and can help to improve energy efficiency [11]. A wide range of methods for the treatment of surfaces is also available, including glass, masonry, wood or metal; the goal is to improve functionalities as well as extend the lifetime of the materials. Such surface coatings also promise to conserve resources, for example water, energy and cleaning agents. Although the research sector has been reporting intensively about new Nano-technological developments, the reality shows that "Nano-products" in the construction industry continue to play a subordinate role and currently merely occupy niche markets. The construction business is considered to be conservative, and innovations often have a difficult time breaking into the market. One of the main reasons for this is the continued high prices. Currently, nanomaterials – and therefore "Nano-products" – are still considerably more expensive than the conventional alternatives due to the required production technology. Construction materials are generally used in large amounts: small price differences can enormously increase overall costs when considering the total volume of a building or other structure. Moreover, the technical performance of new products must first be demonstrated. In buildings, the calculated time spans are in the range of 20 to 30 years, making it difficult for example to apply a coating with a durability of only 1 to 3 years [12]. Longer-term, practical experience with many Nano-products is still lacking, and we simply know too little about their product life. Accordingly, the construction industry for the time being prefers to rely on proven, conventional products. Nano-technological applications and products, their availability and their performance in the construction industry are currently very limited. A survey conducted in 2009 in the European construction sector showed that most respondents (~75%) were unaware of whether they were working with "Nano-products" or not. This is also partly because there is no mandatory labeling of nanomaterials in building materials: the prefix "Nano" – like in many other branches – is used in advertising a product only if the manufacturers have justified hopes of improved sales. Often, it is not evident to users whether a Nano-product actually contains nanomaterials, what nanomaterials might be involved and in what amounts they may be present. Not all products that feature the term "Nano" actually contain nanomaterials. Often, the term "Nano" merely refers to structures in the Nano size range, for example the pore size of a particular material, or to the size of structures that form when a mortar hardens. The use of the designation "Nano" in product claims and advertising has again been declining in recent years [12].

4.3. Aerogel Nanomaterials

Nano technology materials are now have great impact upon construction and design phase, Aerogel is considered one of the nanotechnology materials that participated in construction industry. Aerogels are highly porous solid materials which can consist of 99% air [1]. Aerogel is an excellent hypervelocity space debris capture medium due to the fact that it is a highly porous material with a tortuous microstructure made up of Nano-scale particles forming aggregates. [13]. Comparable to an ultra-fine sponge, this miracle material has its origin – like many other inventions – in space technology. As highly efficient insulators and extremely fine filters, aerogels have made important contributions to space research for years. Aerogel material can be used as aerogel tiles and aerogel granulate [4].

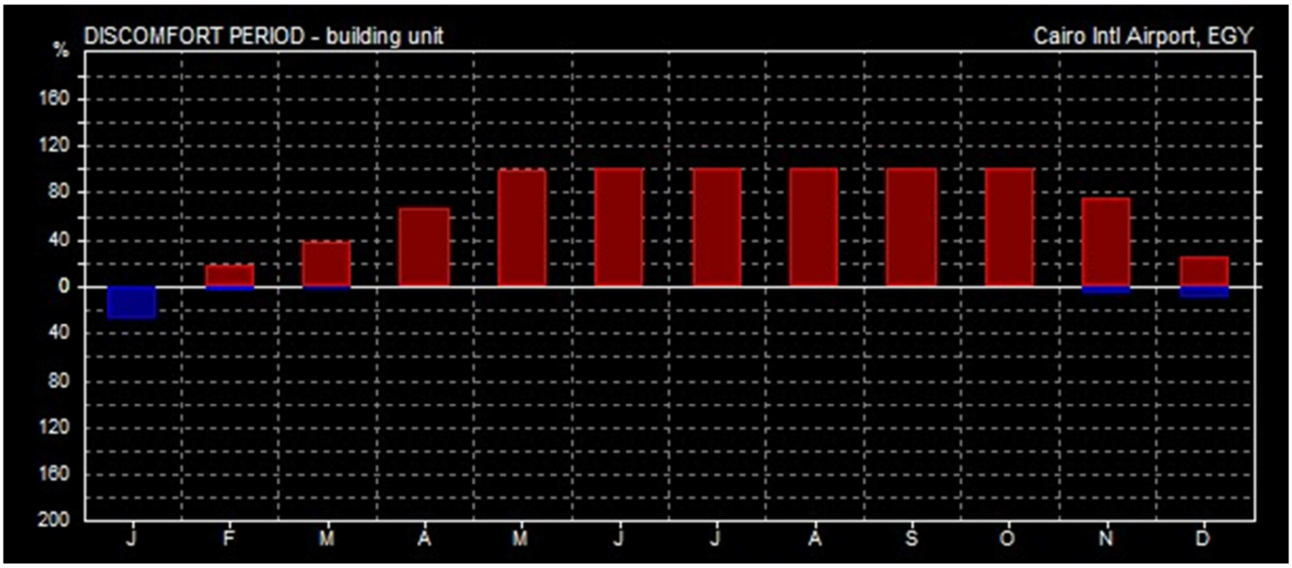


Figure 14. *Annual Thermal comfort analysis GFRG system after Aerogel tiles.*

Table 5. *U-Value Analysis for GFRG system after adding Aerogel tiles and Aerogel Granulate.*

Wall	Material Layers	L (m)	K (W/m. C)	R=L/K	Rt (m^2. C/W)	U-Value (W/m^2. C)
Aerogel tiles	Outer air-film			0.055	0.65	1.522
	Aerogel tiles	0.0254	0.021	1.21		
	Gypsum plaster	0.0145	0.42	0.0345		
	Concrete	0.094	1.44	0.065		
	Gypsum plaster	0.0145	0.42	0.0345		
	Inner air-film			0.123		
Aerogel granulate	Outer air-film			0.055	0.532	1.87
	Aerogel granulate	0.004	0.018	0.22		
	Gypsum plaster	0.0145	0.42	0.0345		
	Concrete	0.094	1.44	0.065		
	Gypsum plaster	0.0145	0.42	0.0345		
	Inner air-film			0.123		

Table 6. *Annual Thermal comfort analysis GFRG system after Aerogel tiles.*

	Month		Discomfort		Comfort
			Hot	Cold	
Wall 4	1	January	0%	28%	72%
	2	February	19%	1%	80%
	3	March	39%	1%	60%
	4	April	64%	0%	36%
	5	May	94%	0%	6%
	6	June	100%	0%	0%
	7	July	100%	0%	0%
	8	August	100%	0%	0%
	9	September	100%	0%	0%
	10	October	100%	0%	0%
	11	November	75%	4%	21%
	12	December	22%	8%	70%

Table 7. *Annual Thermal comfort analysis GFRG system after Aerogel Granulate.*

	Month		Discomfort		Comfort
			Hot	Cold	
Wall 4	1	January	0%	35%	65%
	2	February	15%	5%	74%
	3	March	34%	0%	61%
	4	April	58%	0%	42%
	5	May	94%	0%	6%
	6	June	100%	0%	0%
	7	July	100%	0%	0%
	8	August	100%	0%	0%
	9	September	100%	0%	0%
	10	October	100%	0%	0%
	11	November	63%	8%	29%
	12	December	16%	118%	73%

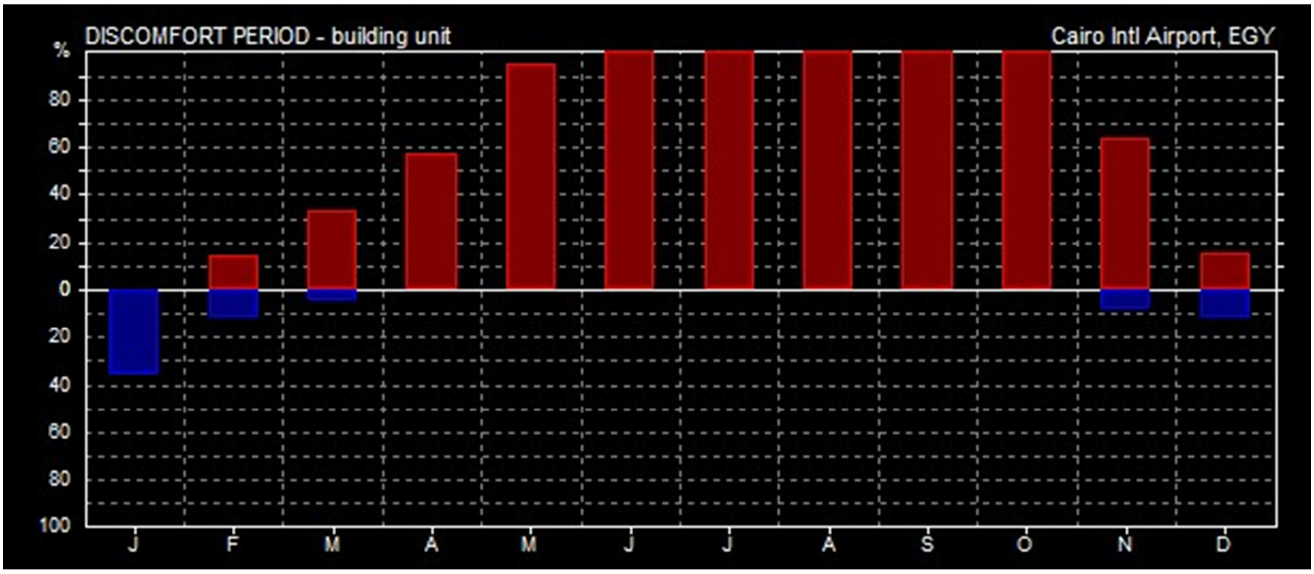


Figure 15. *Annual Thermal comfort analysis GFRG system after Aerogel Granulate.*

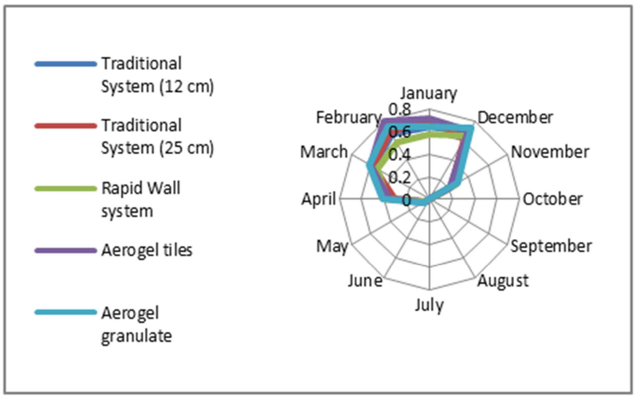


Figure 16. *Thermal Comfort Performance.*

5. Conclusion

1. After adding aerogel materials (tiles and granulate), the thermal comfort performance is slightly improved during the period from November to April. This improvement was below our expectations for thermal comfort performance.
2. When we compared traditional system with GFRG system, the thermal comfort performance was almost the same;
3. Thermal conductivity factor in GFRG was higher than expected due to filling of concrete to the cavity of GFRG system in external walls especially.
4. Structural analysis need to be considered in next studies in this field, in order to minimize the usage of concrete filling in different walls in GFRG system.
5. Despite the usage of nanotechnology materials to adapt thermal comfort performance for materials, we must not ignore the sustainable treatments for thermal comfort.

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