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Energy performance analysis of integrating building envelopes with nanomaterials

Ahmed Rashwan, Osama Farag, Wael Seddik Moustafa *

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

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Abstract

The energy consumption in Egypt has increased sharply in the past few years, and ultra-energy efficient technologies are desperately needed for the national energy policy. This paper discusses and explores the possibilities offered by the use of nanomaterial technology which integrates with building envelope to improve the Energy efficiency and reduce energy consumption in buildings by the use of energy simulation software. The current study was aimed at testing the thermal performance of the Nano Thermal Model (NTM) and measuring heat-Transfer Rate, especially the quantity of Heat gain/loss through fabric, compared to conventional building envelope materials (baseline model) under typical Egypt-Aswan weather conditions. The results indicate the use of nanomaterials can improve the thermal performance of a building in hot dry climate like Egypt, that especially needed cooling loads during the summer months. It also shows that the nanomaterials integrated with the envelope of the future building will achieve the lowest scientifically and empirically recorded values of heat transition in the field of construction. This lowest rates of the fabric heat transfer through the envelope is up to 72% when comparing the performance of the wholly Nano Thermal Model to the traditional model improved.

Keywords: Energy consumption; Energy efficiency; Nanomaterials; Nano Thermal Model; Thermal performance

1. Introduction

The sector of architecture, engineering and construction may accept a wide range of Nanotechnology applications and the nanomaterials. There is an increasing rate of spending and financial support for developing the nanomaterial technology with the target of gaining short run profits for their great commercial value (Ge and Gao, 2008). Architectural Engineering and construction technology which are based on nanomaterials experience a lot of significant changes and constant developments that were the most important results of the chief technologies in the 21st century. Creating all the suitable conditions for achieving accuracy at the molecular and atomic level in materials engineering has led to production of materials of many unique qualities which in turn has provided new and promising solutions for many problems such as; reducing the rate of heat absorption in the outer envelope of the building, fire resistance, avoiding energy loss, resources conservation, reducing pollution, raising the internal environment efficiency, extending the life span of the building materials, lowering the costs of maintenance and processing, reducing and controlling the construction loads and

* Corresponding author.
E-mail address: wael_seddik@yahoo.com (W.S. Moustafa).
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increasing the tensile strength in the structural elements, etc. (Lalbakhsh and Shirazpour, 2011).

Therefore, the nanomaterials integrated with the envelope of the building are considered excellent economic alternatives which save a lot of money while raising the efficiency of the constructed environment and addressing the future environmental challenges (Lalbakhsh and Shirazpour, 2011). Nanomaterial technology will serve to provide much more internal and external architectural designs with human senses interaction due to the freedom given to the architects to develop the function and format to meet the various needs of users.

2. Background of nanomaterials

The term Nano is the literal derivative of the Greek word "Nanos" which means "dwarf" or a very small thing (Qian and Juan, 2004). Overall, the nanomaterials can be defined according to the scientific committee of the European Union as "Materials which have one or more external dimensions or an internal structure which can exhibit new properties compared to the same materials without the nanometric characteristics, or they are a sort of materials which are composed of separate functional parts and many of them have one or more dimensions with a measure of 100 nanometre or less".

3. An overview of energy performance analysis

3.1. Background of energy performance of the building envelope

Climate change and increasing energy costs have drawn large attention to energy performance and efficiency. In 2010, electricity consumption in residential (39.9%), industrial (32.7%), commercial (8.1%) and governmental (4.6%), buildings reached 58% of total electric energy demand in Egypt. Different studies have shown that the primary energy supply will not meet the demand starting from 2015; this gap is widening after 2020 (NREA, 2010). As a result, the demand for building envelope analysis, in which the physical separator of the building's interior and the exterior environment is evaluated, has increased. Rising energy costs, government regulations, new construction techniques and materials, and growing concerns about occupant health are further boosting this demand.

Minimising heat transfer through the building envelope is crucial for reducing the need for space heating and cooling. In cold climates, the building envelope can reduce the amount of energy required for heating; in hot climates, the building envelope can reduce the amount of energy required for cooling. A building envelope is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions (Sadineni et al., 2011). The inputs to Envelope-Related Energy Demand are areas of envelope elements (external walls, roofs and windows), U-values of envelope materials and site related parameters, concerning temperature and solar irradiation (Granadeiro et al., 2013).

The thermal energy performance of the building envelope and sustainability is significant to achieve optimal performance of buildings. Moreover, researches have shown that building envelopes contribute more than 50% of the embodied energy distribution in major building elements in residential buildings; it also contributes approximately 50–60% of the total heat gain in buildings (Mwasha et al., 2011).

3.2. The fabric heat transfer

Whenever there is a temperature difference between the conditioned indoor space of a building and outdoor ambient, heat is lost from buildings through the fabric of the building itself (roof, walls, floor, windows and doors) and through infiltration of cold air via any holes and gaps (Oxford, 2013). This is known as fabric heat gain or loss, depending upon whether heat transfer is to the building or from the building, respectively. The fabric heat transfer includes sensible heat transfer through all the structural elements of a building, but does not include radiation heat transfer through fenestration. Exact analysis of heat transfer through building structures is very complex, as it has to consider (Nptel, 2013):

1. Geometrically complex structure of the walls, roofs etc. consisting of a wide variety of materials with different thermo-physical properties.
2. Continuously varying outdoor conditions due to variation in solar radiation, outdoor temperature, wind velocity and direction etc.
3. Variable indoor conditions due to variations in indoor temperatures, load patterns etc.

For the fabric heat transfer calculations, the indoor conditions are generally assumed to be constant to simplify the analysis.

4. Model verification

4.1. Content and scope of the study

The research has done the empirical study – complementary of the analytical study at the level of design concepts and their contributions to the sustainable building assessment systems – relating to designing a thermal model to simulate the energy performance in the future architecture of a nano building constructed with nano materials which is illustrated in detail in the previous analytical study.

The empirical part aims at selecting the thermal performance for the nano model and indicating rates of saving energy consumption, rates of gained and lost energy, rates of internal thermal loads. This is done by comparing the nano model with the standard model and traditional building materials – to investigate the possibility of achieving sustainability through implementing the comprehensive points and high rates of performance of energy that represents the greatest relative weight in all sustainable building assessment systems.

The empirical study was designed to include the structure of the envelope of the nano building and conducting the study at various levels of design to ensure achieving the required rates of energy performance at each level apart, then examining the whole model so that the study involves examining the performance of the following elements:

- Paints, coatings and insulation materials in the envelope of the building "Thermal Model Solids".
- Windows and openings in the envelope of the building "Thermal Model Voids".

Fig. 1 shows the chosen base case thermal model in the study. When making the comparison among the above mentioned elements regarding nanomaterials (solids and voids), all other factors such as occupancy schedules, operation schedules, orientation, ventilation rates, infiltration rates and internal design conditions are the same as shown in Fig. 2. All measures and empirical tests were done using the methods of simulation and analysing the building's energy with advanced software through Autodesk Ecotect

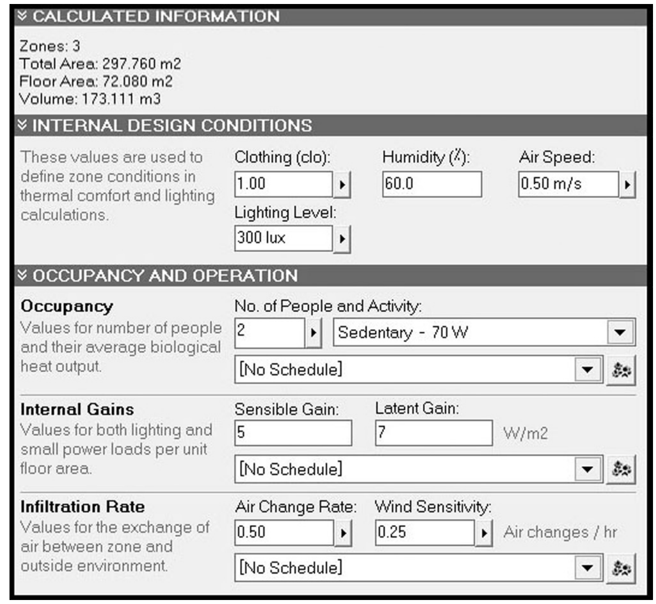


Figure 2. The calculated information of the thermal base case for zone3.

Analysis 2011 software. From comparison between different computer based programs, study chooses to use Ecotect program because of its facilities with respect to make a perfect induction about thermal performance of building and

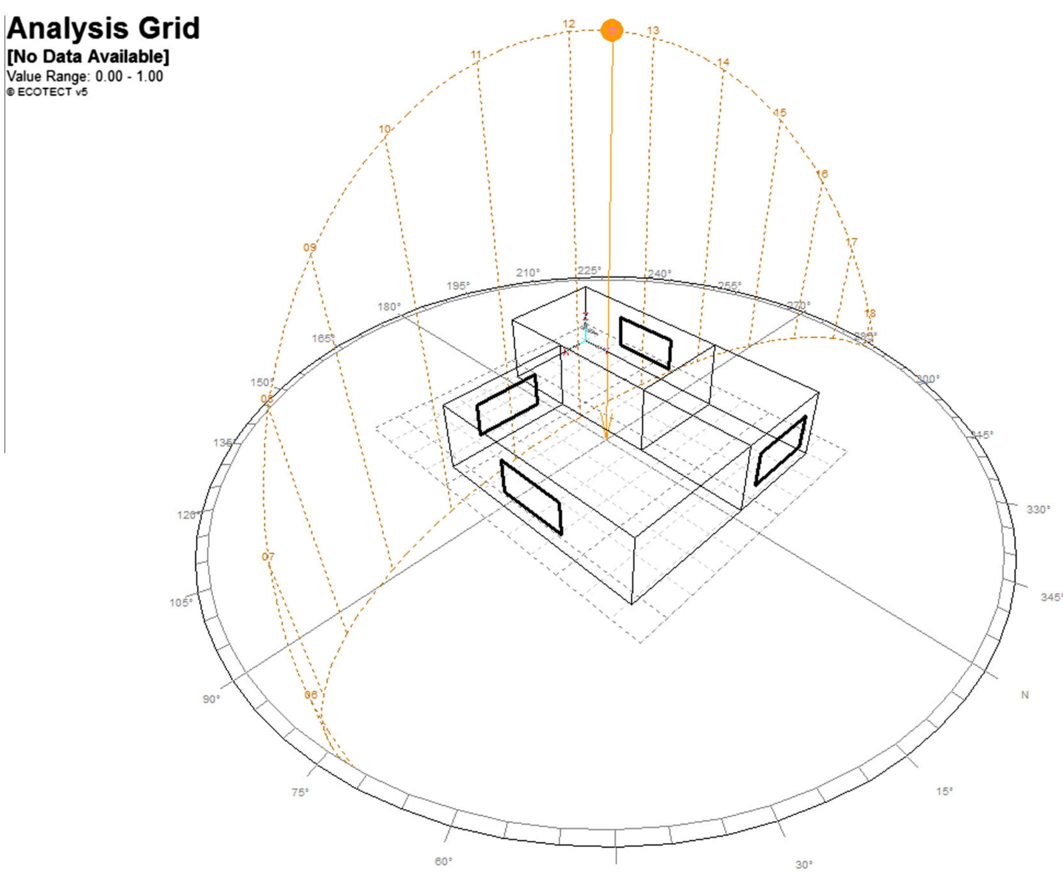


Figure 1. The base case thermal model/Autodesk Ecotect Analysis 2011.

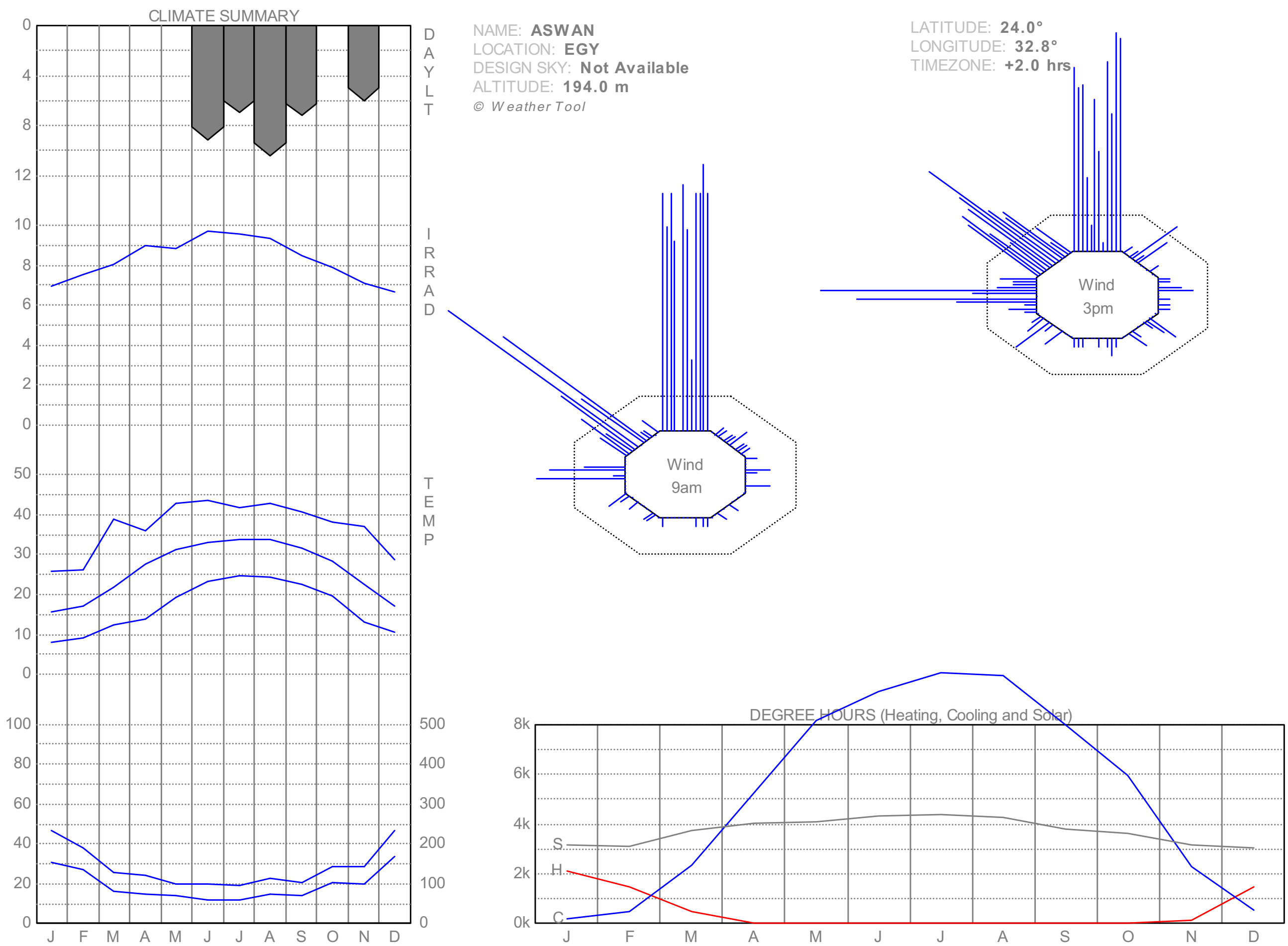
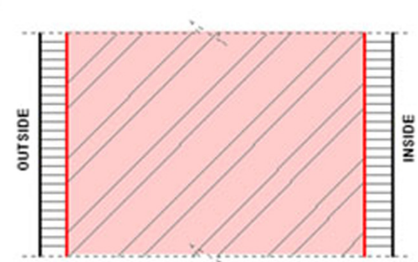


Figure 3. Summary of climatic conditions in Aswan city during the simulation.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Plaster Building	30.0	1250.0	1080.000	0.500	85
2.	Brick Masonry Medium	250.0	2000.0	836.800	0.711	25
3.	Cement Plaster Building	30.0	1250.0	1080.000	0.500	85

U-Value (W/m2.K):	1.540
Admittance (W/m2.K):	4.340
Solar Absorption (0-1):	0.1
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.22
Thermal Lag (hrs):	10.57
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	310.0
Weight (kg):	575.000

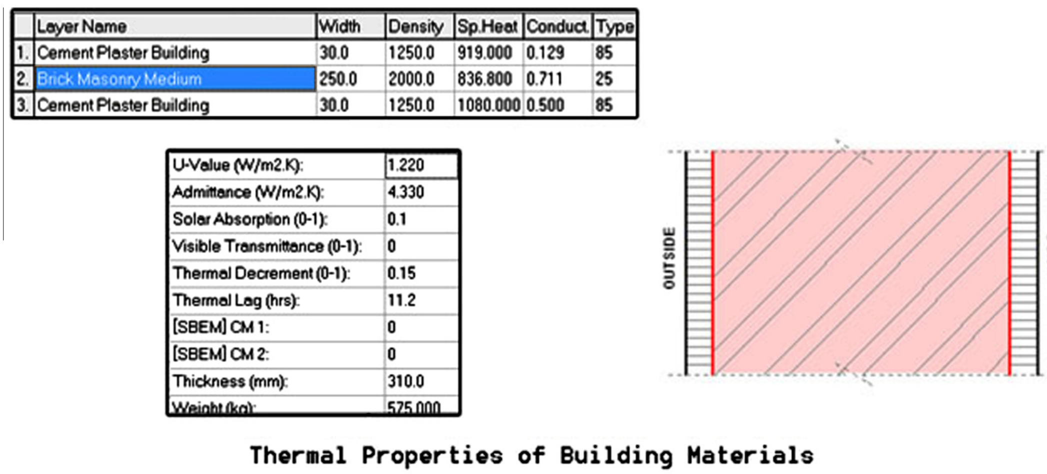


Thermal Properties of Building Materials

Figure 4. Thermal properties of the baseline model materials A – Paints and coatings.

wonderful user interface which is easily used by architects (Crawley et al., 2008). All results are put into diagrams, tables and charts, and then they were compared and analysed comprehensively to indicate what is concluded in this respect.

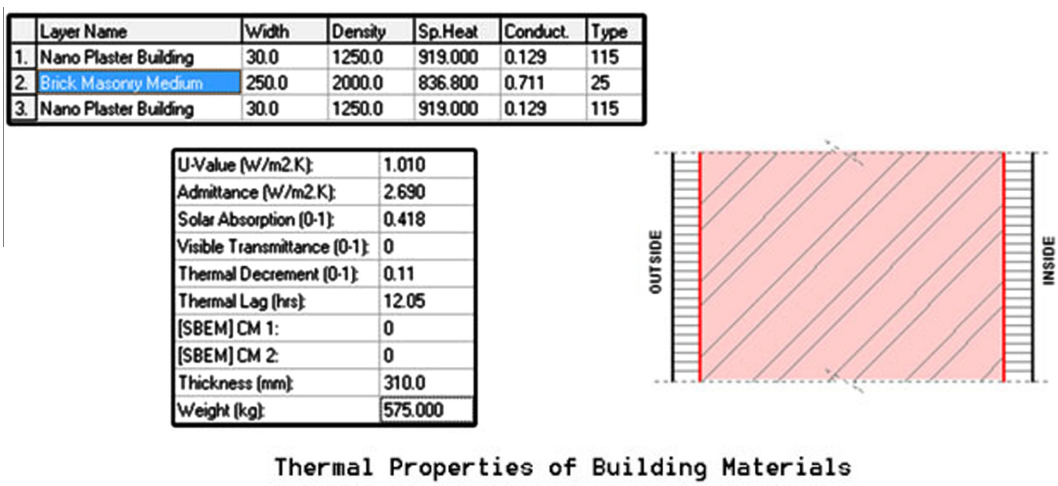
The rates of thermal flow through the envelope of the building were also measured given the value of whole thermal transmission of the model's elements and calculating the rates of heat exchange and total heat exchange of the outer envelope.



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Plaster Building	30.0	1250.0	919.000	0.129	85
2.	Brick Masonry Medium	250.0	2000.0	836.800	0.711	25
3.	Cement Plaster Building	30.0	1250.0	1080.000	0.500	85

U-Value (W/m2.K):	1.220
Admittance (W/m2.K):	4.330
Solar Absorption (0-1):	0.1
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.15
Thermal Lag (hrs):	11.2
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	310.0
Weight (kg):	575.000

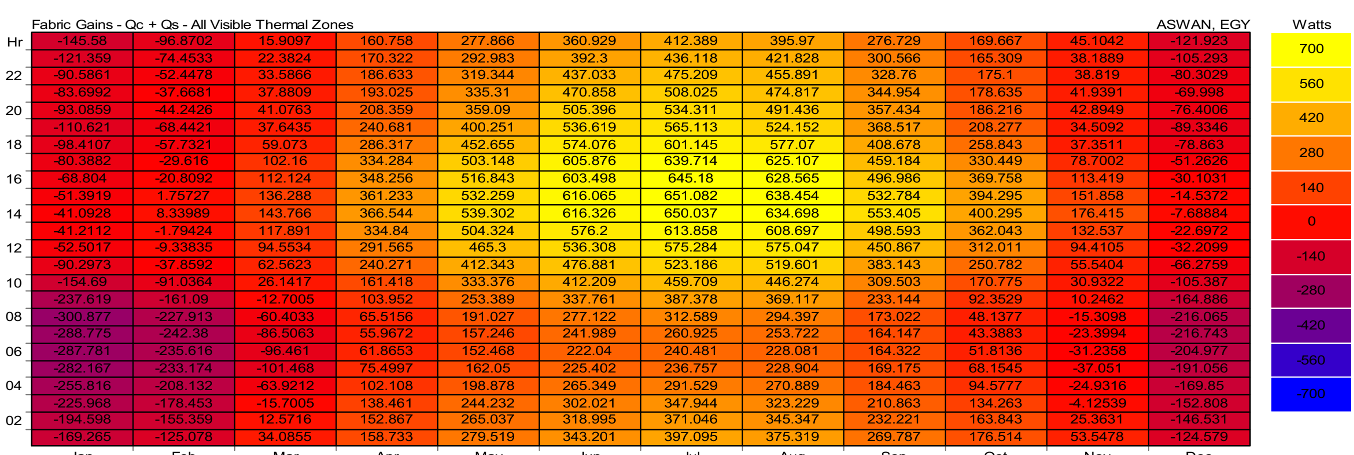
Figure 5. Thermal properties of the baseline model materials B – Paints and coatings.



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Nano Plaster Building	30.0	1250.0	919.000	0.129	115
2.	Brick Masonry Medium	250.0	2000.0	836.800	0.711	25
3.	Nano Plaster Building	30.0	1250.0	919.000	0.129	115

U-Value (W/m2.K):	1.010
Admittance (W/m2.K):	2.690
Solar Absorption (0-1):	0.418
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.11
Thermal Lag (hrs):	12.05
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	310.0
Weight (kg):	575.000

Figure 6. Thermal properties of the Nano model materials – Paints and coatings.



Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	-145.58	-96.8702	15.9097	160.758	277.866	360.929	412.389	395.97	276.729	169.667	45.1042	-121.923
	-121.359	-74.4533	22.3824	170.322	292.983	392.3	436.118	421.828	300.566	165.309	38.1889	-105.293
22	-90.5861	-52.4478	33.5866	186.633	319.344	437.033	475.209	455.891	328.76	175.1	38.819	-80.3029
	-83.6992	-37.6681	37.8809	193.025	335.31	470.858	508.025	474.817	344.954	178.635	41.9391	-69.998
20	-93.0859	-44.2426	41.0763	208.359	359.09	505.396	534.311	491.436	357.434	186.216	42.8949	-76.4006
	-110.621	-68.4421	37.6435	240.681	400.251	536.619	565.113	524.152	368.517	208.277	34.5092	-89.3346
18	-98.4107	-57.7321	59.073	286.317	452.655	574.076	601.145	577.07	408.678	258.843	37.3511	-78.863
	-80.3882	-29.616	102.16	334.284	503.148	605.876	639.714	625.107	459.184	330.449	78.7002	-51.2626
16	-68.804	-20.8092	112.124	348.256	516.843	603.498	645.18	628.565	496.986	369.758	113.419	-30.1031
	-51.3919	1.75727	136.288	361.233	532.259	616.065	651.082	638.454	532.784	394.295	151.858	-14.5372
14	-41.0928	8.33989	143.766	366.544	539.302	616.326	650.037	634.698	553.405	400.295	176.415	-7.68884
	-41.2112	-1.79424	117.891	334.84	504.324	576.2	613.858	608.697	498.593	362.043	132.537	-22.6972
12	-52.5017	-9.33835	94.5534	291.565	465.3	536.308	575.284	575.047	450.867	312.011	94.4105	-32.2099
	-90.2973	-37.8592	62.5623	240.271	412.343	476.881	523.186	519.601	383.143	250.782	55.5404	-66.2759
10	-154.69	-91.0364	26.1417	161.418	333.376	412.209	459.709	446.274	309.503	170.775	30.9322	-105.387
	-237.619	-161.09	-12.7005	103.952	253.389	337.761	387.378	369.117	233.144	92.3529	10.2462	-164.886
08	-300.877	-227.913	-60.4033	65.5156	191.027	277.122	312.589	294.397	173.022	48.1377	-15.3098	-216.065
	-288.775	-242.38	-86.5063	55.9672	157.246	241.989	260.925	253.722	164.147	43.3883	-23.3994	-216.743
06	-287.781	-235.616	-96.461	61.8653	152.468	222.04	240.481	228.081	164.322	51.8136	-31.2358	-204.977
	-282.167	-233.174	-101.468	75.4997	162.05	225.402	236.757	228.904	169.175	68.1545	-37.051	-191.056
04	-255.816	-208.132	-63.9212	102.108	198.878	265.349	291.529	270.889	184.463	94.5777	-24.9316	-169.85
	-225.968	-178.453	-15.7005	138.461	244.232	302.021	347.944	323.229	210.863	134.263	-4.12539	-152.808
02	-194.598	-155.359	12.5716	152.867	265.037	318.995	371.046	345.347	232.221	163.843	25.3631	-146.531
	-169.265	-125.078	34.0855	158.733	279.519	343.201	397.095	375.319	269.787	176.514	53.5478	-124.579

Figure 7. Rates of fabric heat transfer through the envelope of the baseline model A – Paints and coatings.

The model and the nanomaterial data were taken from the researches and scientific and technical reports of the research which follow the companies and organizations specified in Nanotechnology that play a central role in affecting the rates of energy consumption (Oxford, 2013; Nansulate, 2013; Nanogel, 2013; Dowcorning, 2013).

Figure 8. Rates of fabric heat transfer through the envelope of the baseline model B – Paints and coatings.

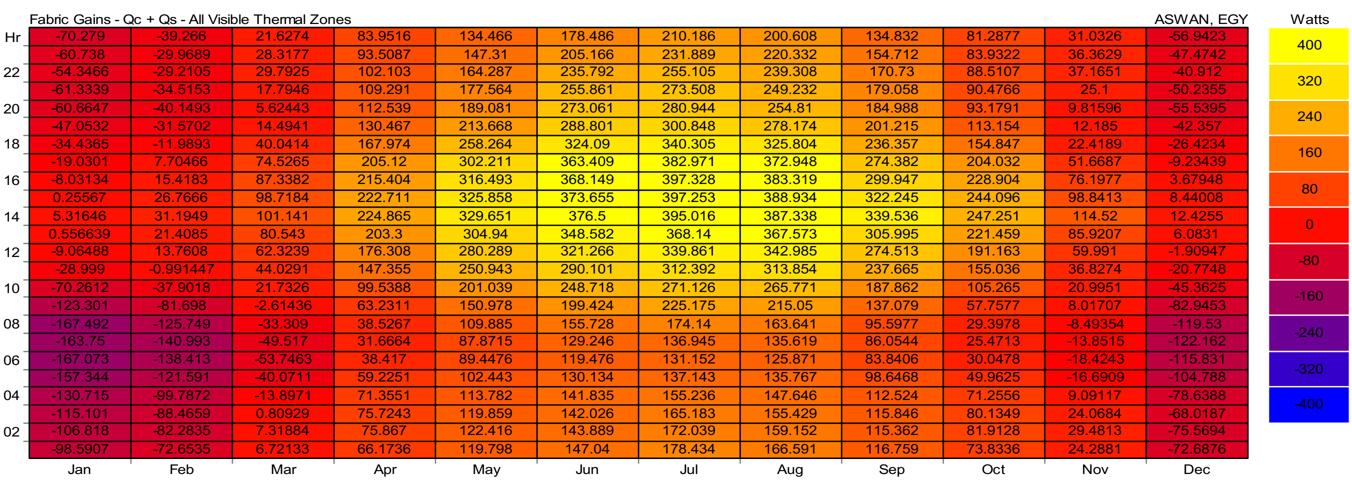
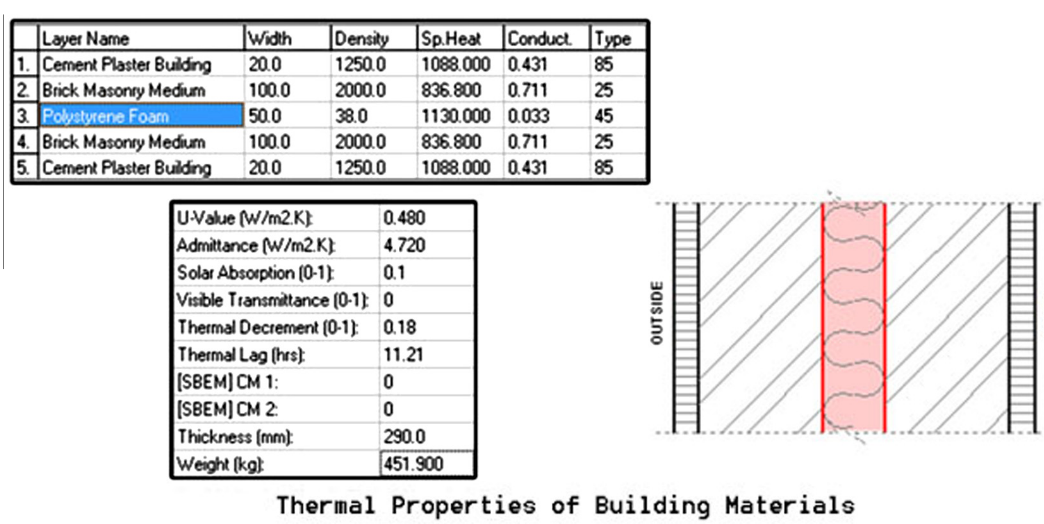


Figure 9. Rates of fabric heat transfer through the envelope of the Nano model – Paints and coatings.



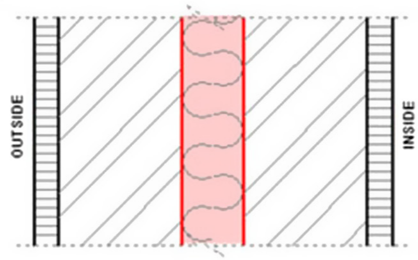
	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Plaster Building	20.0	1250.0	1088.000	0.431	85
2.	Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
3.	Polystyrene Foam	50.0	38.0	1130.000	0.033	45
4.	Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
5.	Cement Plaster Building	20.0	1250.0	1088.000	0.431	85

U-Value (W/m2.K):	0.480
Admittance (W/m2.K):	4.720
Solar Absorption (0-1):	0.1
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.18
Thermal Lag (hrs):	11.21
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	290.0
Weight (kg):	451.900

Figure 10. Thermal properties of the baseline model materials – Thermal insulation of external walls.

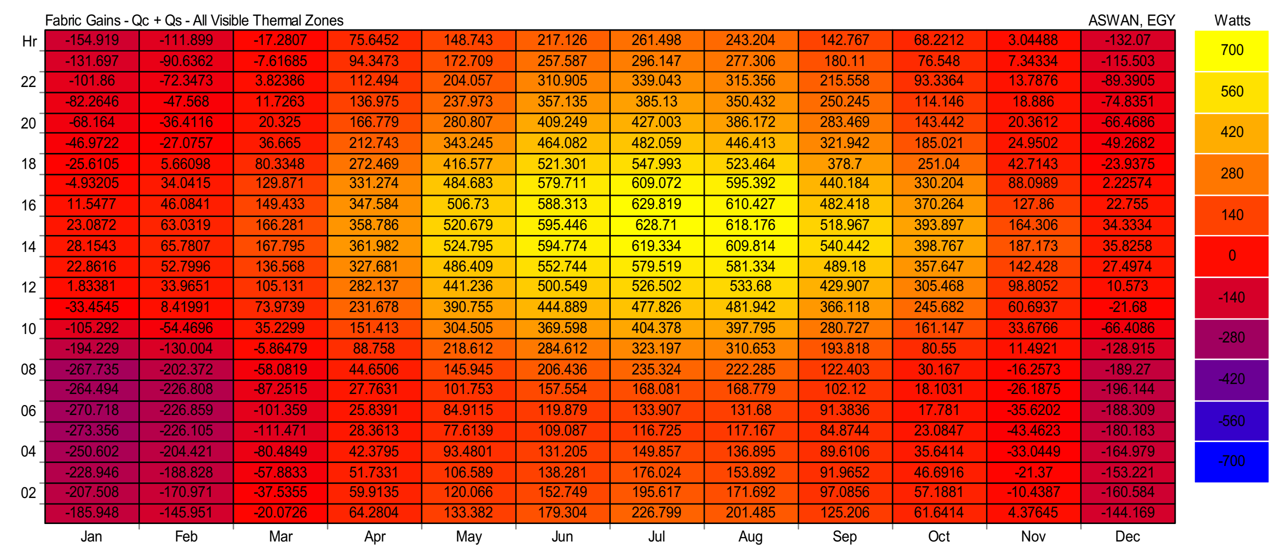
	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Plaster Building	20.0	1250.0	1088.000	0.431	85
2.	Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
3.	Vacuum Insulation Panel	50.0	186.0	800.000	0.003	45
4.	Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
5.	Cement Plaster Building	20.0	1250.0	1088.000	0.431	85

U-Value (W/m2.K):	0.060
Admittance (W/m2.K):	4.770
Solar Absorption (0-1):	0.389412
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.1
Thermal Lag (hrs):	16.48
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	290.0
Weight (kg):	459.300



Thermal Properties of Building Materials

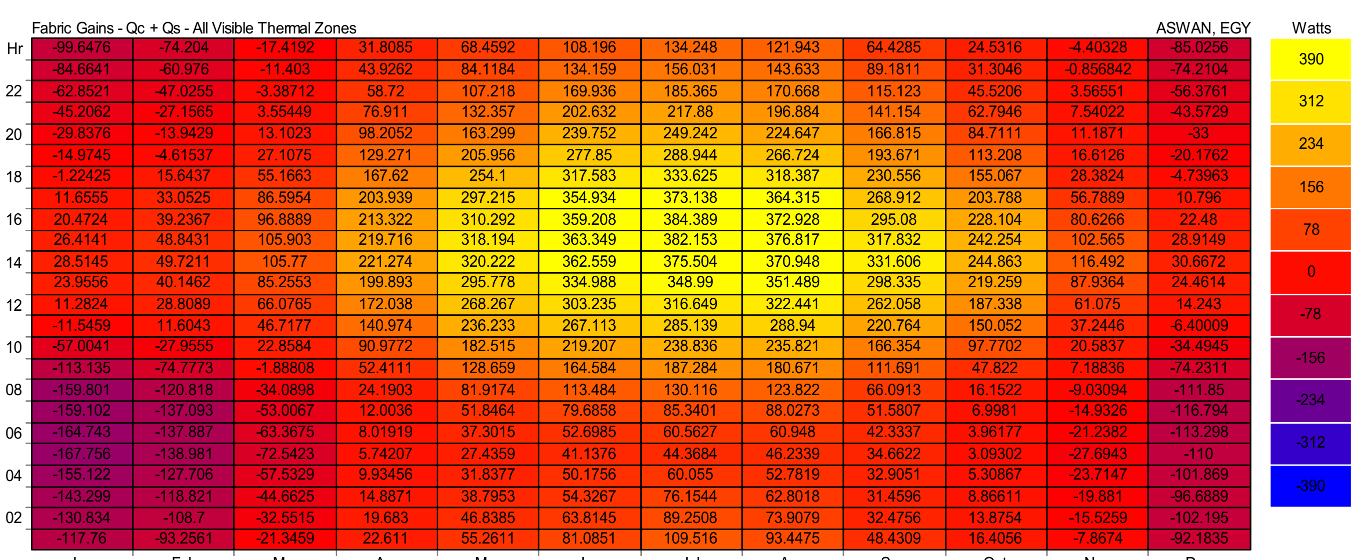
Figure 11. Thermal properties of the Nano model materials – Thermal insulation of external walls.



Fabric Gains - Qc + Qs - All Visible Thermal Zones — ASWAN, EGY

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	-154.919	-111.899	-17.2807	75.6452	148.743	217.126	261.498	243.204	142.767	68.2212	3.04488	-132.07
	-131.697	-90.6362	-7.61685	94.3473	172.709	257.587	296.147	277.306	180.11	76.548	7.34334	-115.503
22	-101.86	-72.3473	3.82386	112.494	204.057	310.905	339.043	315.356	215.558	93.3364	13.7876	-89.3905
	-82.2646	-47.568	11.7263	136.975	237.973	357.135	385.13	350.432	250.245	114.146	18.886	-74.8351
20	-68.164	-36.4116	20.325	166.779	280.807	409.249	427.003	386.172	283.469	143.442	20.3612	-66.4686
	-46.9722	-27.0757	36.665	212.743	343.245	464.082	482.059	446.413	321.942	185.021	24.9502	-49.2682
18	-25.6105	5.66098	80.3348	272.469	416.577	521.301	547.993	523.464	378.7	251.04	42.7143	-23.9375
	-4.93205	34.0415	129.871	331.274	484.683	579.711	609.072	595.392	440.184	330.204	88.0989	2.22574
16	11.5477	46.0841	149.433	347.584	506.73	588.313	629.819	610.427	482.418	370.264	127.86	22.755
	23.0872	63.0319	166.281	358.786	520.679	595.446	628.71	618.176	518.967	393.897	164.306	34.3334
14	28.1543	65.7807	167.795	361.982	524.795	594.774	619.334	609.814	540.442	398.767	187.173	35.8258
	22.8616	52.7996	136.568	327.681	486.409	552.744	579.519	581.334	489.18	357.647	142.428	27.4974
12	1.83381	33.9651	105.131	282.137	441.236	500.549	526.502	533.68	429.907	305.468	98.8052	10.573
	-33.4545	8.41991	73.9739	231.678	390.755	444.889	477.826	481.942	366.118	245.682	60.6937	-21.68
10	-105.292	-54.4696	35.2299	151.413	304.505	369.598	404.378	397.795	280.727	161.147	33.6766	-66.4086
	-194.229	-130.004	-5.86479	88.758	218.612	284.612	323.197	310.653	193.818	80.55	11.4921	-128.915
08	-267.735	-202.372	-58.0819	44.6506	145.945	206.436	235.324	222.285	122.403	30.167	-16.2573	-189.27
	-264.494	-226.808	-87.2515	27.7631	101.753	157.554	168.081	168.779	102.12	18.1031	-26.1875	-196.144
06	-270.718	-226.859	-101.359	25.8391	84.9115	119.879	133.907	131.68	91.3836	17.781	-35.6202	-188.309
	-273.356	-226.105	-111.471	28.3613	77.6139	109.087	116.725	117.167	84.8744	23.0847	-43.4623	-180.183
04	-250.602	-204.421	-80.4849	42.3795	93.4801	131.205	149.857	136.895	89.6106	35.6414	-33.0449	-164.979
	-228.946	-188.828	-57.8833	51.7331	106.589	138.281	176.024	153.892	91.9652	46.6916	-21.37	-153.221
02	-207.508	-170.971	-37.5355	59.9135	120.066	152.749	195.617	171.692	97.0856	57.1881	-10.4387	-160.584
	-185.948	-145.951	-20.0726	64.2804	133.382	179.304	226.799	201.485	125.206	61.6414	4.37645	-144.169

Figure 12. Rates of fabric heat transfer through the envelope of the baseline model – Thermal insulation of external walls.



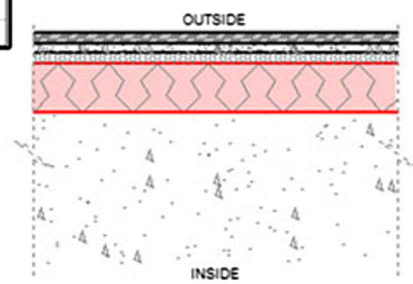
Fabric Gains - Qc + Qs - All Visible Thermal Zones — ASWAN, EGY

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	-99.6476	-74.204	-17.4192	31.8085	68.4592	108.196	134.248	121.943	64.4285	24.5316	-4.40328	-85.0256
	-84.6641	-60.976	-11.403	43.9262	84.1184	134.159	156.031	143.633	89.1811	31.3046	-0.856842	-74.2104
22	-62.8521	-47.0255	-3.38712	58.72	107.218	169.936	185.365	170.668	115.123	45.5206	3.56551	-56.3761
	-45.2062	-27.1565	3.55449	76.911	132.357	202.632	217.88	196.884	141.154	62.7946	7.54022	-43.5729
20	-29.8376	-13.9429	13.1023	98.2052	163.299	239.752	249.242	224.647	166.815	84.7111	11.1871	-33
	-14.9745	-4.61537	27.1075	129.271	205.956	277.85	288.944	266.724	193.671	113.208	16.6126	-20.1762
18	-1.22425	15.6437	55.1663	167.62	254.1	317.583	333.625	318.387	230.556	155.067	28.3824	-4.73963
	11.6555	33.0525	86.5954	203.939	297.215	354.934	373.138	364.315	268.912	203.788	56.7889	10.796
16	20.4724	39.2367	96.8889	213.322	310.292	359.208	384.389	372.928	295.08	228.104	80.6266	22.48
	26.4141	48.8431	105.903	219.716	318.194	363.349	382.153	376.817	317.832	242.254	102.565	28.9149
14	28.5145	49.7211	105.77	221.274	320.222	362.559	375.504	370.948	331.606	244.863	116.492	30.6672
	23.9556	40.1462	85.2553	199.893	295.778	334.988	348.99	351.489	298.335	219.259	87.9364	24.4614
12	11.2824	28.8089	66.0765	172.038	268.267	303.235	316.649	322.441	262.058	187.338	61.075	14.243
	-11.5459	11.6043	46.7177	140.974	236.233	267.113	285.139	288.94	220.764	150.052	37.2446	-6.40009
10	-57.0041	-27.9555	22.8584	90.9772	182.515	219.207	238.836	235.821	166.354	97.7702	20.5837	-34.4945
	-113.135	-74.7773	-1.88808	52.4111	128.659	164.584	187.284	180.671	111.691	47.822	7.18836	-74.2311
08	-159.801	-120.818	-34.0898	24.1903	81.9174	113.484	130.116	123.822	66.0913	16.1522	-9.03094	-111.85
	-159.102	-137.093	-53.0067	12.0036	51.8464	79.6858	85.3401	88.0273	51.5807	6.9981	-14.9326	-116.794
06	-164.743	-137.887	-63.3675	8.01919	37.3015	52.6985	60.5627	60.948	42.3337	3.96177	-21.2382	-113.298
	-167.756	-138.981	-72.5423	5.74207	27.4359	41.1376	44.3684	46.2339	34.6622	3.09302	-27.6943	-110
04	-155.122	-127.706	-57.5329	9.93456	31.8377	50.1756	60.055	52.7819	32.9051	5.30867	-23.7147	-101.869
	-143.299	-118.821	-44.6625	14.8871	38.7953	54.3267	76.1544	62.8018	31.4596	8.86611	-19.881	-96.6889
02	-130.834	-108.7	-32.5515	19.683	46.8385	63.8145	89.2508	73.9079	32.4756	13.8754	-15.5259	-102.195
	-117.76	-93.2561	-21.3459	22.611	55.2611	81.0851	109.516	93.4475	48.4309	16.4056	-7.8674	-92.1835

Figure 13. Rates of fabric heat transfer through the envelope of the Nano model – Thermal insulation of external walls.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Ceramic Tiles	10.0	2000.0	850.000	1.200	25
2.	Cement Mortar	10.0	1650.0	920.000	0.720	35
3.	Sand	10.0	2240.0	840.000	1.740	45
4.	Polystyrene Foam	50.0	38.0	1130.000	0.033	45
5.	Concrete Floor	150.0	2300.0	656.900	0.753	35

U-Value (W/m2.K):	0.520
Admittance (W/m2.K):	5.040
Solar Absorption (0-1):	0.1
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.32
Thermal Lag (hrs):	7.52
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	230.0
Weight (kg):	405.800



Thermal Properties of Building Materials

Figure 14. Thermal properties of the baseline model materials – Thermal insulation of external roofs.

4.2. Location and climate

The research study was conducted in the city of Aswan – as a standard model for cities with very hot and dry climate in Egypt. It is the capital of Aswan governorate and the most important city in Nuba – the cultural region which was the southern gate of Egypt for a long time and which lies on the east bank of the River Nile.

The above variables were formulated under the climate stability of the region in Aswan city and under the constancy of all the additional building factors except those included in the variables of the study. The climatic conditions during the experiment are summarised in Fig. 3.

5. Validation tests

5.1. Paints and coatings of the envelope of the building "Solids – Part A"

The thermal model in the empirical study was assumed by designing the section of the envelope provided with traditional, nano paints and coatings and indicating the thermal and physical characteristics and comparing rates of thermal behaviour and performance of the materials used in the alternatives studied as shown below.

The Baseline model [A] (traditional building materials). See Fig. 4.

(1) The outer layer: traditional paints – cement layer, 30 mm thick.
(2) Brick masonry layer: 250 mm thick.
(3) The internal layer: traditional paints – cement layer, 30 mm thick.

The Baseline model [B] (traditional building material + outer Nano materials). See Fig. 5.

(1) The outer layer: Nano paints layer, 30 mm thick.
(2) Brick masonry layer: 250 mm thick.
(3) The internal layer: traditional paints – cement layer, 30 mm thick. See Fig. 5.

The Nano model (Nano materials). See Fig. 6.

(1) The outer layer: Nano paints layer, 30 mm thick.
(2) Brick masonry layer: 250 mm thick.
(3) The internal layer: Nano paints layer, 30 mm thick.

5.1.1. Comparison of the thermal performance of paints and coatings

The performance of the Baseline model [A]. (See Fig. 7).

The performance of the Baseline model [B] (traditional building materials + outer Nano materials). (See in Fig. 8).

The performance of the Nano model (Nano materials). (See Fig. 9):

5.2. Thermal insulation of the building envelope "Solids – Part A"

5.2.1. External walls

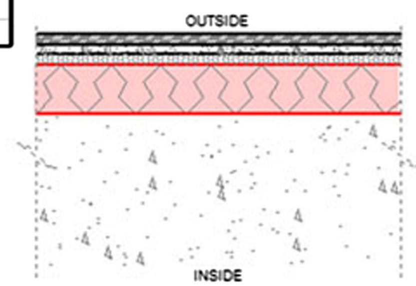
The thermal model in the study was assumed by designing the section of the envelope provided with traditional or Nano thermal insulation and indicating the thermal and physical characteristics and comparing rates of thermal behaviour and performance of the materials used in the alternatives studied as shown below.

The Baseline model (traditional building materials). See Fig. 10.

(1) The outer layer: traditional paints – cement layer, 20 mm thick.
(2) Brick masonry layer: 100 mm thick.
(3) Thermal insulation layer: polystyrene foam, 50 mm thick.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Ceramic Tiles	10.0	2000.0	850.000	1.200	25
2.	Cement Mortar	10.0	1650.0	920.000	0.720	35
3.	Sand	10.0	2240.0	840.000	1.740	45
4.	Vacuum Insulation Panel	50.0	186.0	800.000	0.003	45
5.	Concrete Floor	150.0	2300.0	656.900	0.753	35

U-Value (W/m2.K):	0.060
Admittance (W/m2.K):	5.070
Solar Absorption (0-1):	0.131765
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.19
Thermal Lag (hrs):	12.66
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	230.0
Weight (kg):	413.200



Thermal Properties of Building Materials

Figure 15. Thermal properties of the Nano model materials – Thermal insulation of external roofs.

Fabric Gains - Qc + Qs - All Visible Thermal Zones — ASWAN, EGY

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	-122.591	-74.0095	40.4968	195.082	320.389	404.339	456.185	438.439	312.675	204.757	59.0781	-101.739
	-98.3204	-48.7866	51.484	208.094	337.31	434.108	478.717	464.616	342.229	206.478	61.4968	-83.5851
22	-67.4775	-28.2524	64.862	224.472	363.674	476.596	513.003	495.798	374.27	218.397	69.5688	-58.5182
	-60.9484	-14.935	64.6343	226.744	372.377	500.284	537.369	509.388	382.192	216.562	67.3027	-48.6993
20	-71.8957	-22.0809	62.8492	232.761	385.511	523.607	551.952	515.333	385.066	215.424	62.2497	-56.3014
	-91.6233	-49.7016	51.4842	250.082	408.225	534.527	562.049	529.457	383.034	224.259	47.984	-72.7621
18	-99.4115	-61.5795	48.4132	260.928	425.18	538.342	565.019	544.924	390.852	246.355	40.6464	-74.1149
	-112.167	-64.0371	64.709	279.272	445.467	540.583	574.021	561.834	404.622	282.769	58.4515	-73.6436
16	-130.029	-84.4706	48.2328	268.183	430.722	509.582	550.725	535.48	408.507	293.784	67.1186	-80.0367
	-124.42	-78.0417	52.7955	265.617	425.781	502.686	535.512	525.066	422.81	301.114	85.7077	-76.5698
14	-118.695	-75.0184	56.1829	264.653	425.907	493.757	525.366	510.762	440.832	303.395	108.071	-74.1958
	-118.012	-83.39	31.0226	236.945	392.792	456.085	490.28	486.419	391.209	269.553	66.5442	-87.3136
12	-119.054	-80.9187	19.8916	204.163	363.82	428.414	464.837	463.167	353.969	231.128	37.3326	-88.444
	-135.965	-90.5659	4.84082	174.036	329.697	386.684	434.888	430.79	305.927	189.009	9.84964	-106.314
10	-176.743	-120.827	-10.504	116.02	274.128	345.684	393.341	382.032	253.191	131.838	0.0391554	-129.71
	-233.311	-164.297	-25.7613	79.6247	219.838	300.095	352.002	333.529	204.854	73.8914	-2.51042	-167.536
08	-292.276	-219.778	-57.7612	56.9145	174.266	255.502	297.677	278.428	159.527	43.1326	-16.4368	-211.113
	-276.666	-230.447	-78.3483	55.7837	155.692	240.285	263.092	254.558	162.885	44.394	-20.527	-210.152
06	-272.311	-221.199	-85.3218	63.9258	156.016	228.285	250.62	236.209	168.298	53.1323	-26.4072	-197.465
	-265.314	-218.138	-92.1256	78.0506	167.344	235.897	248.351	240.004	177.391	70.46	-32.3669	-181.843
04	-237.693	-191.111	-56.8769	105.378	205.14	279.641	304.232	282.955	196.711	97.6892	-20.6659	-159.989
	-207.854	-162.134	-11.8093	141.961	251.921	319.972	362.018	335.799	225.66	137.32	-1.3524	-140.209
02	-177.077	-142.021	16.1351	161.035	279.165	340.713	388.308	361.861	247.181	170.156	25.0999	-135.007
	-149.672	-109.351	42.6609	174.4	304.796	374.992	426.35	403.899	290.404	190.475	53.5807	-110.474

Watts: 600, 480, 360, 240, 120, 0, -120, -240, -360, -480, -600

Figure 16. Rates of fabric heat transfer through the envelope of the baseline model – Thermal insulation of external roofs.

(4) Brick masonry layer: 100 mm thick.
(5) The internal layer: traditional paints – cement layer, 20 mm thick.

The Nano model (Nano materials). See Fig. 11.

(1) The outer layer: traditional paints – cement layer, 20 mm thick.
(2) Brick masonry layer: 100 mm thick.
(3) Thermal insulation layer: Nano Vacuum Insulated Panel, 50 mm thick.
(4) Brick masonry layer: 100 mm thick.
(5) The internal layer: traditional paints – cement layer, 20 mm thick.

5.2.2. Comparison of the thermal performance of thermal insulation of external walls

The performance of the Baseline model (traditional building materials). See Fig. 12.

The performance of the Nano model (Nano materials). See Fig. 13.

5.3. External roofs

The thermal model in the empirical study was assumed by designing the section of the outer envelope provided with traditional or nano thermal insulation and indicating the thermal and physical characteristics and comparing rates of thermal behaviour and performance of the materials used in the alternatives studied as shown below:

The Baseline model (traditional building materials). See Fig. 14.

(1) The outer layer: ceramic tiles, 10 mm thick.
(2) Cement mortar layer: 10 mm thick.
(3) Sand layer: 10 mm thick.
(4) Thermal insulation layer: polystyrene foam, 50 mm thick.
(5) The internal layer: concrete floor, 150 mm thick.

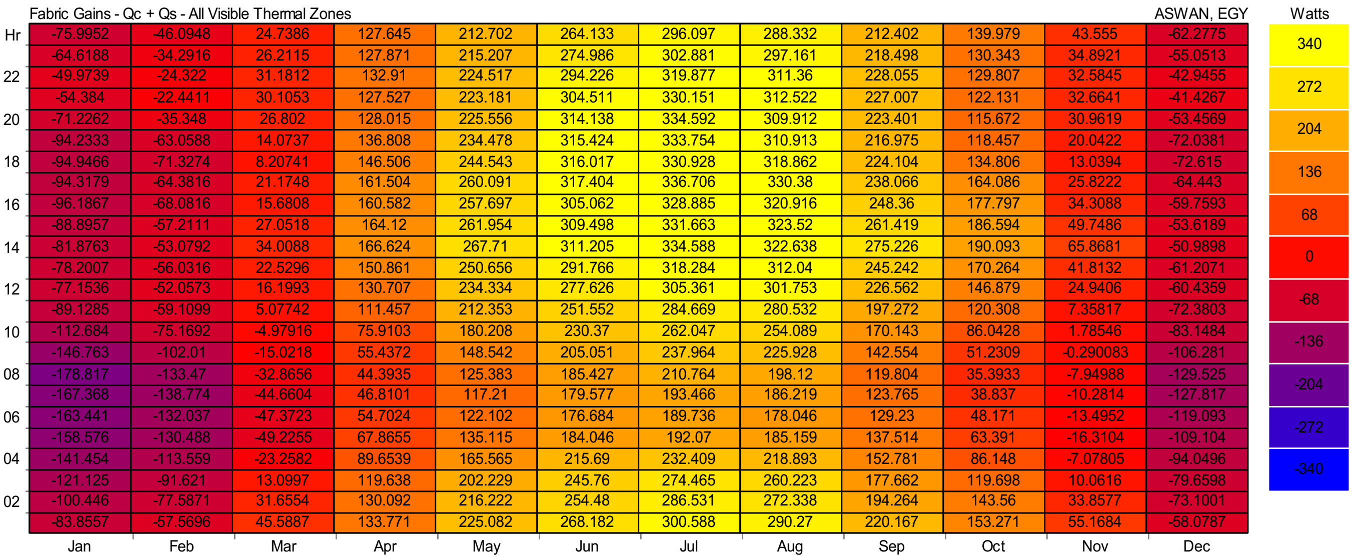


Figure 17. Rates of fabric heat transfer through the envelope of the Nano model – Thermal insulation of external roofs.

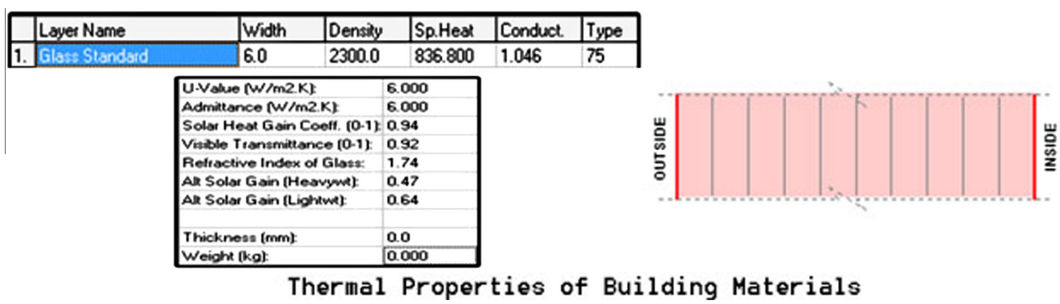


Figure 18. Thermal properties of the baseline model materials – Single glazed glass.

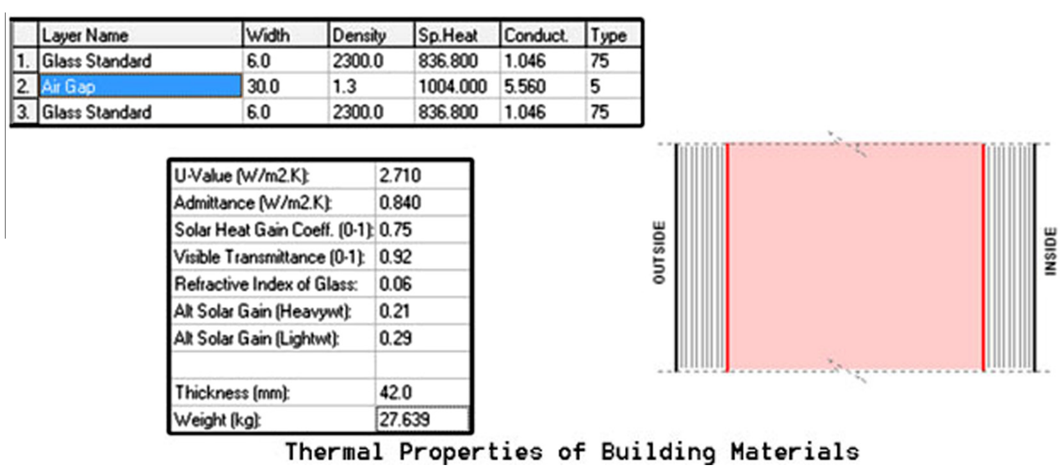


Figure 19. Thermal properties of the baseline model materials – Double glazed glass.

The Nano model (Nano materials). See Fig. 15.

(1) The outer layer: ceramic tiles, 10 mm thick.
(2) Cement mortar layer: 10 mm thick.
(3) Sand layer: 10 mm thick.
(4) Thermal insulation layer: Nano Vacuum Insulated Panel, 50 mm thick.

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Glass Standard	10.0	80.0	800.000	0.012	75

U-Value (W/m2.K):	0.990
Admittance (W/m2.K):	0.990
Solar Heat Gain Coeff. (0-1):	0.94
Visible Transmittance (0-1):	0.92
Refractive Index of Glass:	1
Alt Solar Gain (Heavywt):	0.47
Alt Solar Gain (Lightwt):	0.64
Thickness (mm):	10.0
Weight (kg):	0.800

Thermal Properties of Building Materials

Figure 20. Thermal properties of the Nano model materials – NanoGel glass.

Fabric Gains - Qc + Qs - All Visible Thermal Zones — ASWAN, EGY

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	-357.348	-256.154	-26.4025	210.661	396.388	557.815	664.365	621.717	384.665	204.063	29.1501	-302.833
	-303.384	-205.787	-6.8339	248.033	446.033	645.244	735.96	695.335	463.701	214.884	31.2949	-265.424
22	-224.76	-156.014	22.269	295.726	522.545	768.71	837.756	788.402	548.451	255.539	42.3349	-201.062
	-177.783	-95.8918	41.0023	342.484	593.027	872.246	941.669	865.198	622.753	297.218	54.2679	-162.016
20	-151.126	-70.1197	64.7529	402.908	682.839	988.439	1035.09	940.739	692.836	352.677	63.0204	-144.2
	-131.3	-73.0294	89.4768	497.082	808.907	1092.78	1140.44	1056.56	761.74	435.349	67.1063	-126.209
18	-98.2331	-32.4533	151.717	603.939	943.824	1192.97	1252.03	1198.23	863.263	563.951	89.7289	-85.1423
	-71.5818	13.2753	243.781	712.82	1075.1	1292.54	1361.42	1333.03	974.441	722.649	173.025	-42.5983
16	-58.3696	16.1565	256.239	728.192	1100.02	1281.59	1376.19	1337.2	1047.42	795.522	237.713	-14.7655
	-41.1936	48.818	286.34	743.81	1119.65	1291.06	1366.82	1344.67	1116.76	837.74	307.22	4.53108
14	-30.748	52.7634	292.418	748.441	1130.71	1289.69	1349.1	1324.2	1171.96	847.513	364.947	7.9765
	-39.1747	22.7721	222.502	671.915	1043.8	1191.77	1257.55	1259.31	1046.74	754.173	258.43	-20.7859
12	-70.3201	-1.20454	165.719	575.133	951.379	1089.65	1154.95	1168.86	927.556	643.026	167.46	-45.4499
	-137.356	-47.0805	106.879	477.312	845.224	966.804	1052.49	1061.72	788.836	517.928	86.372	-108.466
10	-280.903	-165.291	38.7332	305.548	666.757	817.037	903.764	891.507	614.863	342.719	41.6063	-189.92
	-467.004	-317.459	-32.7186	182.109	488.792	644.398	742.335	713.289	439.319	170.403	10.844	-318.327
08	-636.936	-479.242	-136.273	97.9159	338.26	485.022	560.391	530.609	289.921	67.6377	-39.5048	-450.395
	-623.386	-533.295	-201.601	69.946	249.722	390.778	420.337	421.418	255.521	46.3282	-58.9058	-464.708
06	-635.139	-528.154	-233.128	66.7212	213.833	310.813	346.346	335.249	234.165	46.5911	-80.2938	-445.868
	-640.673	-531.105	-263.799	73.5048	197.269	283.205	298.863	298.041	221.167	59.6755	-101.493	-426.306
04	-588.72	-483.09	-195.965	106.451	239.37	340.741	383.113	349.092	230.956	88.3537	-81.2151	-388.82
	-535.568	-437.115	-124.083	149.52	295.156	381.563	470.867	418.286	250.599	130.981	-54.3582	-358.689
02	-479.251	-395.178	-71.4558	174.049	332.121	415.599	518.789	460.65	267.706	169.824	-19.6954	-370.488
	-420.981	-326.811	-22.5952	187.595	367.572	482.312	595.01	538.73	343.465	188.945	25.4884	-323.772

Watts: 1400, 1120, 840, 560, 280, 0, -280, -560, -840, -1120, -1400

Figure 21. Rates of fabric heat transfer through the envelope of the baseline model – Single glazed glass.

Fabric Gains - Qc + Qs - All Visible Thermal Zones — ASWAN, EGY

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	-122.591	-74.0095	40.4968	195.082	320.389	404.339	456.185	438.439	312.675	204.757	59.0781	-101.739
	-98.3204	-48.7866	51.484	208.094	337.31	434.108	478.717	464.616	342.229	206.478	61.4968	-83.5851
22	-67.4775	-28.2524	64.862	224.472	363.674	476.596	513.003	495.798	374.27	218.397	69.5688	-58.5182
	-60.9484	-14.935	64.6343	226.744	372.377	500.284	537.369	509.388	382.192	216.562	67.3027	-48.6993
20	-71.8957	-22.0809	62.8492	232.761	385.511	523.607	551.952	515.333	385.066	215.424	62.2497	-56.3014
	-91.6233	-49.7016	51.4842	250.082	408.225	534.527	562.049	529.457	383.034	224.259	47.984	-72.7621
18	-99.4115	-61.5795	48.4132	260.928	425.18	538.342	565.019	544.924	390.852	246.355	40.6464	-74.1149
	-112.167	-64.0371	64.709	279.272	445.467	540.583	574.021	561.834	404.622	282.769	58.4515	-73.6436
16	-130.029	-84.4706	48.2328	268.183	430.722	509.582	550.725	535.48	408.507	293.784	67.1186	-80.0367
	-124.42	-78.0417	52.7955	265.617	425.781	502.686	535.512	525.066	422.81	301.114	85.7077	-76.5698
14	-118.695	-75.0184	56.1829	264.653	425.907	493.757	525.366	510.762	440.832	303.395	108.071	-74.1958
	-118.012	-83.39	31.0226	236.945	392.792	456.085	490.28	486.419	391.209	269.553	66.5442	-87.3136
12	-119.054	-80.9187	19.8916	204.163	363.82	428.414	464.837	463.167	353.969	231.128	37.3326	-88.444
	-135.965	-90.5659	4.84082	174.036	329.697	386.684	434.888	430.79	305.927	189.009	9.84964	-106.314
10	-176.743	-120.827	-10.504	116.02	274.128	345.684	393.341	382.032	253.191	131.838	0.0391554	-129.71
	-233.311	-164.297	-25.7613	79.6247	219.838	300.095	352.002	333.529	204.854	73.8914	-2.51042	-167.536
08	-292.276	-219.778	-57.7612	56.9145	174.266	255.502	297.677	278.428	159.527	43.1326	-16.4368	-211.113
	-276.666	-230.447	-78.3483	55.7837	155.692	240.285	263.092	254.558	162.885	44.394	-20.527	-210.152
06	-272.311	-221.199	-85.3218	63.9258	156.016	228.285	250.62	236.209	168.298	53.1323	-26.4072	-197.465
	-265.314	-218.138	-92.1256	78.0506	167.344	235.897	248.351	240.004	177.391	70.46	-32.3669	-181.843
04	-237.693	-191.111	-56.8769	105.378	205.14	279.641	304.232	282.955	196.711	97.6892	-20.6659	-159.989
	-207.854	-162.134	-11.8093	141.961	251.921	319.972	362.018	335.799	225.66	137.32	-1.3524	-140.209
02	-177.077	-142.021	16.1351	161.035	279.165	340.713	388.308	361.861	247.181	170.156	25.0999	-135.007
	-149.672	-109.351	42.6609	174.4	304.796	374.992	426.35	403.899	290.404	190.475	53.5807	-110.474

Watts: 600, 480, 360, 240, 120, 0, -120, -240, -360, -480, -600

Figure 22. Rates of fabric heat transfer through the envelope of the baseline model – Double glazed glass.

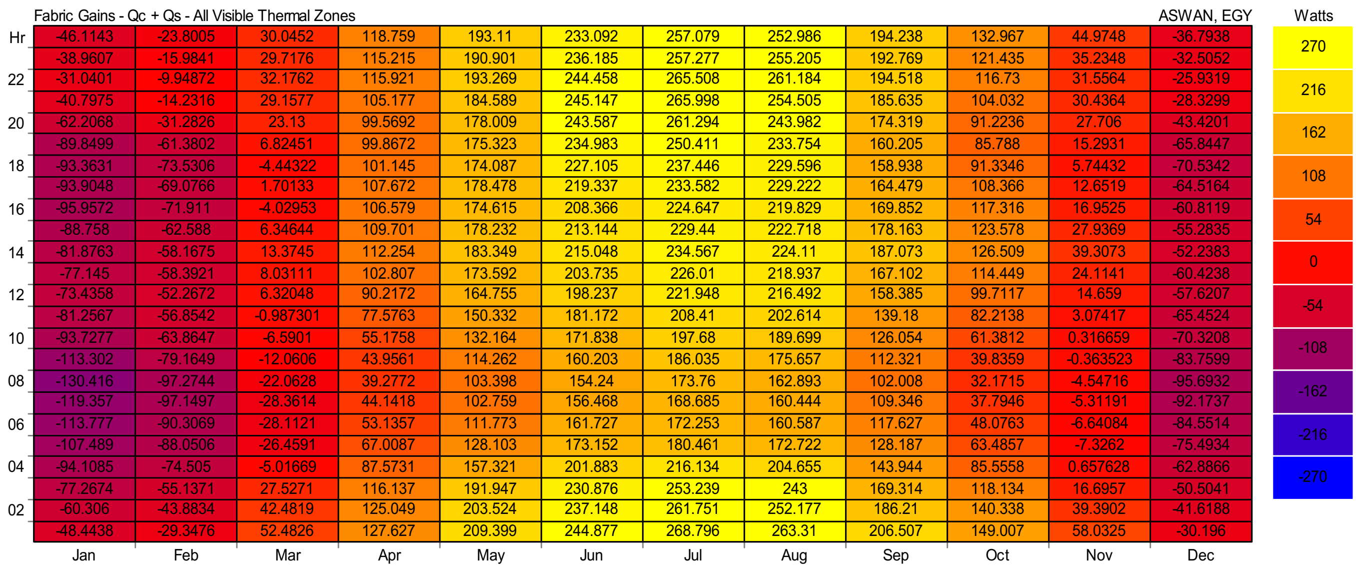


Figure 23. Rates of fabric heat transfer through the envelope of the Nano model – NanoGel glass.

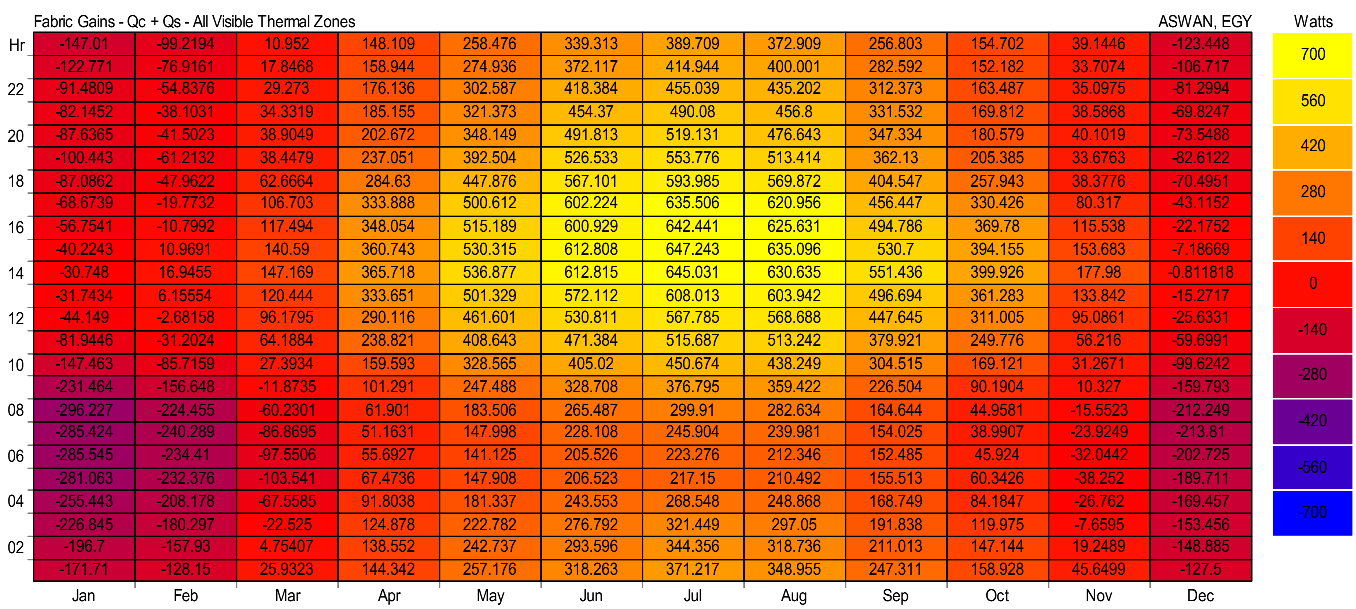


Figure 24. Rates of fabric heat transfer through the envelope of the baseline model.

(5) The internal layer: concrete floor, 150 mm thick.

5.3.1. Comparison of the thermal performance of thermal insulation of external roofs

The performance of the Baseline model (traditional building materials). See Fig. 16.

The performance of the Nano model (Nano materials). See Fig. 17.

5.4. Windows and opening of the building envelope "Voids – Part B"

The thermal model in the empirical study was assumed by designing the section of the envelope provided with traditional or Nano glass indicating the thermal and physical characteristics and comparing rates of thermal behaviour and performance of the materials used in the alternatives studied as shown below:

The Baseline model (traditional building materials):

(A) Single glazed glass: one layer of glass, 6 mm thick. See Fig. 18.
(B) Double glazed glass: two panes of glass (low-e), 6 mm thick. See Fig. 19.

The Nano model (Nano materials). See Fig. 20.
One layer of NanoGel glass, 10 mm thick.

5.4.1. Comparison of the thermal performance of glass windows

The performance of the Baseline model (Single glazed). See Fig. 21.

The performance of the Baseline model (Double glazed – Low e). See Fig. 22.

The performance of the Nano model (Nano materials). See Fig. 23.

5.5. The overall thermal performance of the building envelope

The performance of the Baseline model (traditional building materials). See Fig. 24.

The performance of the Nano model (Nano materials). See Fig. 25.

6. Discussion and conclusion

From the comparison among all the previous cases and simulation studies which are summarised in Figs. 26–28, we can conclude that:

- The thermal performance of the Nano paints was totally better than that of the traditional paints. It reduced the rates of the heat exchange process outcome through the outer envelope to 40% in the case of the external and internal

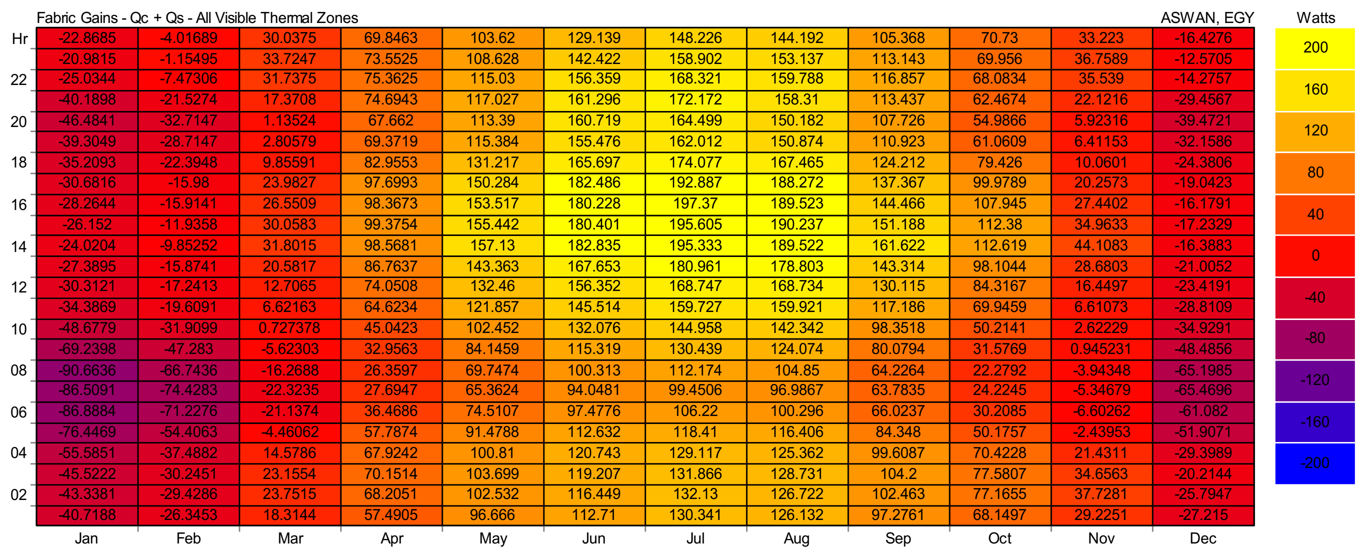


Figure 25. Rates of fabric heat transfer through the envelope of the Nano model.

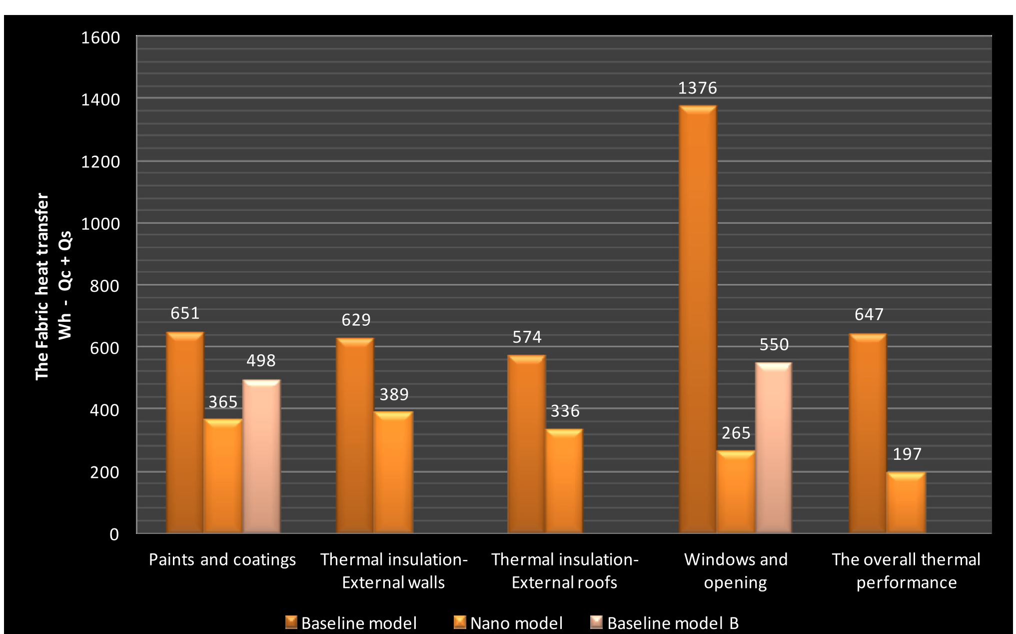


Figure 26. Achieving the lowest value recorded scientifically of heat transfer values of Nano model which amounted to over 70% when compared to the baseline model.

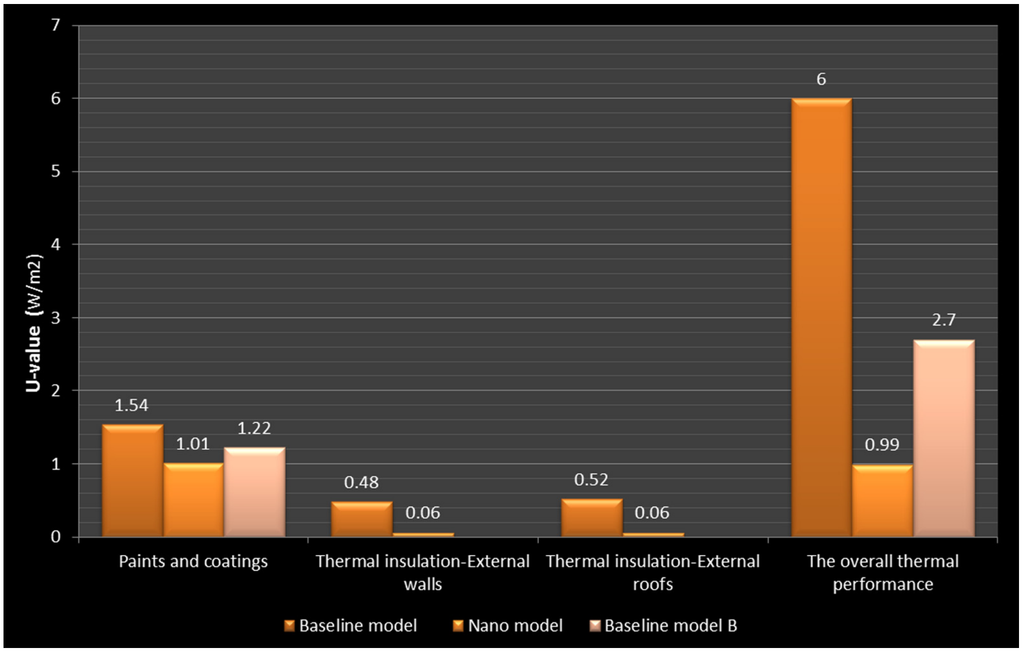


Figure 27. Achieving ultra-low U-values and advanced performance of Nano model less than baseline model.

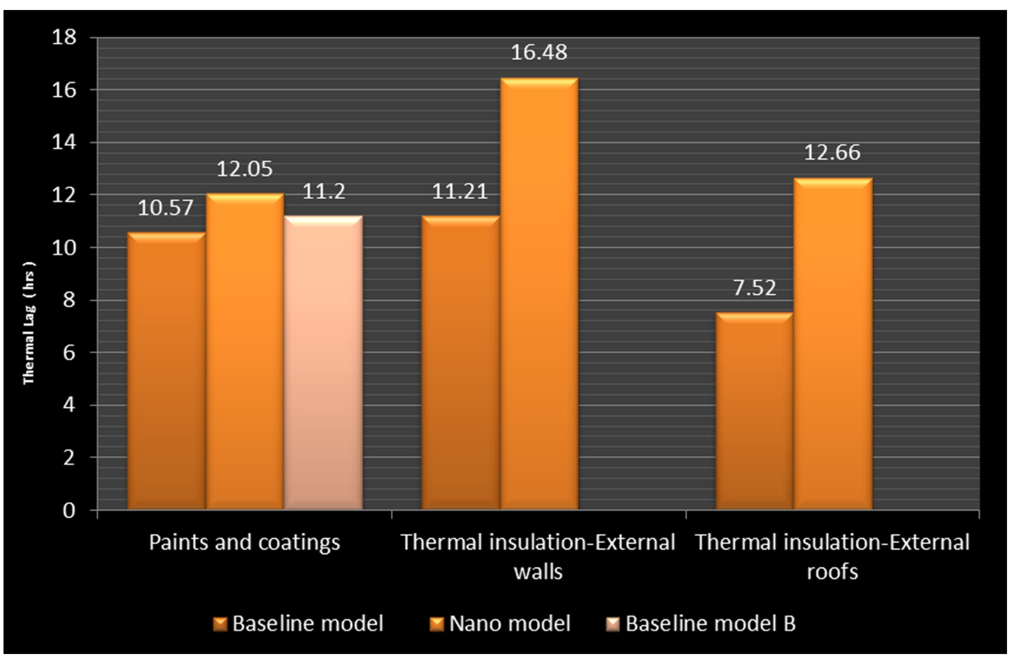


Figure 28. Increasing the thermal lag values of Nano model compared to the baseline model.

surfaces and up to 30% in the case of the external surfaces only. This confirms the possibility of access to convergent rates in the thermal performance in both cases.

- Using the Nano insulating layers in the outer walls can achieve better values of fabric heat transfer than walls insulated with the traditional substances (such as polystyrene) which were of the best insulating substances that have high rates of performance. The study concluded that Thermal transmittance coefficient (U-value) is eight (8) times less than traditional insulation materials, which has resulted in reducing rates of fabric heat transfer through the envelope by 45%.
- Achieving optimal values of Thermal transmittance coefficient (U-value) of the roof insulation that is nine (9) times less than traditional insulation materials, as well as reducing the outcome of fabric heat transfer between the outer environment and the inner space by 44%.
- The significant influence of windows in the building envelope on the thermal performance and heat exchange processes can be achieved by using Nano glass material.

They led to reduction in the heat exchange processes over the windows made of single monolayer glass by 81%. This value was 55% with respect to the windows made of dual-layer low-emission glasses, which are of the best types in reducing rates of thermal transition and enhancing the thermal performance of the inner space.

- The nanomaterials integrated with the envelope of the future building achieved the lowest scientifically and empirically recorded values of heat transition in the field of construction. The lowest rates of heat exchange in the envelope is up to 72% when comparing the performance of the wholly Nano Thermal Model to the traditional model improved.
- Using the nanomaterials can improve the thermal performance of a building, especially needed cooling loads during the summer months, and achieve an ultra-low U-value and advanced performance of fabric gains (Walls: 40% – roofs: 44% – Windows: 81% – Overall: 72%) less than baseline model.
- The thermal lag value of the Nano paints (12.05 h) and Nano insulation (walls: 16.48 h – roofs: 12.66) was better than that of the traditional insulation materials.

References

GE Z., Gao Z., 2008, Applications of nanotechnology and nanomaterials in construction, advancing and integrating construction education, research & practice, pp. 235–240.

Lalbakhsh, E., Shirazpour, P., 2011. Nanomaterial for Smart Future, Buildings. IPCBEE25, pp. 80–81.

Qian, L., Juan, P., 2004. Application of nanotechnology for high performance textiles. J. Textile Apparel 4, 1–2.

Sadineni, S., Madala, S., Boehm, R., 2011. Passive building energy savings: a review of building envelope components. Renewable and Sustainable Energy Reviews 15 (8), 3617–3631.

Granadeiro, V., João, C., Vítor, L., José, D., 2013. Envelope-related energy demand: a design indicator of energy performance for residential buildings in early design stages. Energy Buildings, 215–223.

Mwasha, A., Williams, R., Iwaro, J., 2011. Modeling the performance of residential building envelope; The role of sustainable energy performance indicators. Energy Buildings 43, 2108–2117.

Building fabric and housing stock. University of Oxford. <www.eci.ox.ac.uk/research/energy/downloads/40house/chapter05.pdf> (accessed July 20, 2013).

NREA, 2010. Energy in Egypt annual report 2009/2010. Cairo: NREA; New and Renewable Energy Authority.

Crawley, D.B., Hand, J., Kummert, M., Griffith, B.T., 2008. Contrasting the capabilities of building energy performance simulation programs. Building Environ., 0360-1323 43 (4), 661–673.

NPTEL, Cooling and Heating Load Calculations. <nptel.iitm.ac.in/courses/Webcoursecontents/IIT%20Kharagpur/Ref%20and%20Air%20Cond/pdf/R%26AC%20Lecture%2034.pdf> (accessed July 20, 2013).

Nansulate Home and Industrial Thermal Insulation and Asset Protection Coatings. <http://www.nansulate.com/homeprotect.htm> (accessed September, 2013).

High Performance Insulation – Dow Corning. <http://www.dowcorning.com/content/construction/landing/hpinsulation.aspx> (accessed September 25, 2013).

Nanogel – the highest R-value insulation. Boston General Contractor – American Building Technologies. <http://www.americanbuildingtechnologies.com/weatherization/insulation/nanogel-higest-R-Value-insulation/> (accessed September, 2013).