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IMPROVING THE FIRE PERFORMANCE OF HIGH-RISE BUILDINGS' FAÇADE WITH NANO-THERMAL INSULATING MATERIALS

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ABSTRACT:
Nowadays High-rise buildings' fires due to façade materials have been a noteworthy problem which attracts a lot of media attention due to their high risk and losses among people and property. These fire cases still occur until this year as Abbco Tower in Sharjah, and Business Centre in Ankara and Madrid tower in Madrid. One of these materials which caused fire spreading along the façade is the usage of combustible traditional thermal insulating materials. But nanotechnology offers insulation materials with better thermal conductivity that may be a good alternative for the existing thermal insulating materials. The objective of this paper is to study the performance of the most famous traditional and Nano-thermal insulating materials in order to reach better thermal insulating material to improve the façade fire performance according to SP105 fire test. To obtain this objective, SP105 fire test criteria was used to judge the validity to use these materials in high-rise buildings' facade, pyrosim software and smokeview to help in modeling and viewing the results. This paper concluded that the Nano-thermal insulating materials can provide the façade with better fire performance as they passed the SP 105 test criteria. But this paper recommends applying this large-scale test on site and studying other points on the performance of these materials to get internationally certified and also try to found a way to decrease these materials' cost.

KEYWORDS: Nano-thermal insulating material, Traditional thermal insulating materials, Aerogel, Vacuum insulating panels, Pyrosim.

تحسين أداء واجهات المباني العالية ضد الحريق بمواد عزل حراري بتقنية النانو

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الملخص:
في الأونه الأخيرة، كانت حرائق المباني العالية الناتجة عن مواد الواجهات مشكلة جديرة بالملاحظة حيث أنها جذبت اهتمام وسائل الإعلام بسبب المخاطر و الخسائر الكبيرة بين الأشخاص و الممتلكات الناتجة عنها. و لا تزال هذه الحرائق تحدث حتي هذا العام مثل برج أبكو في الشارقة و مركز الأعمال في أنقرة و برج مدريد في مدريد. و من هذه المواد التي تسببت في انتشار الحريق علي واجهات المباني العالية هي مواد العزل الحراري التقليدية القابلة للاشتعال. لكن تقنية النانو تقدم مواد عزل ذات موصلية حرارية أفضل، قد تكون بديلاً جيداً لمواد العزل الحراري الحالية. الهدف من هذا البحث هو دراسة أداء أشهر أنواع مواد العزل التقليدية و النانوية من أجل الوصول إلي أفضل مواد عزل حراري لتحسين أداء الواجهة إثناء الحريق وفقاً لاختبار الحريق اس بي ١٠٥. للوصول إلي هذا الهدف، تم استخدام معايير اختبار الحرائق اس بي ١٠٥ للحكم

علي صلاحية استخدام هذه المواد في واجهة المباني العالية، واستخدام برامج بيروسيم و سموكفيو في نمذجة و عرض النتائج. استنتجت هذه الورقة البحثية أن مواد العزل الحراري النانوية يمكن أن توفر للواجهة أفضل اداء ضد الحريق لأنها اجتازت معايير اختبار SP 105 . و لكن هذه الورقة توصي بتطبيق هذا الاختبار في الموقع و دراسة النقاط الآخري حول أداء هذه المواد للحصول علي اعتماد دولي و كذلك محاولة إيجاد طريقة لخفض اسعار هذه المواد.

الكلمات المفتاحية: مواد نانوية للعزل الحراري، مواد تقليدية للعزل حراري، ايروجيل، الواح العزل الفراغي، بيروسيم.

1. INTRODUCTION

The high-rise buildings' façade is one of the complex parts of the building which acts like a shell as it is designed to protect the building against surrounding outdoor climate. So while designing these facades, some properties required to be considered [13]. Recently, designers put a lot of considerations while designing the façade to provide the building with better energy performance, reduce air and water infiltration as well as give the building a unique appearance. But they neglected the fact that they should put the fire properties of the façade in their consideration while designing, which led to several fire incidents where the façade is the main reason for fire propagation through high-rise buildings [13].

The high-rise buildings' fires was proved to be more serious and traumatic than those of low-rise buildings. As Pershakov V., (2016) mentioned that the fires in buildings of 25 storey or more is 3-4 times more victims than 9-16 storey buildings [17]. The fires in High-rise buildings is considered more serious than of the fires in low-rise buildings due to the high number of occupant that needed to be evacuated in case of fire, as well as the mixed use of high-rise buildings [11].

According to Bonner M., Rein G., Wegrzynski W., Papis B. & Rein G., (2019), there are a rapid increase in the number of fires along high-rise buildings' façade by about 4.8 fires per year until now as shown in figure (1) so the problem of high-rise buildings' fires has not been solved yet [4].

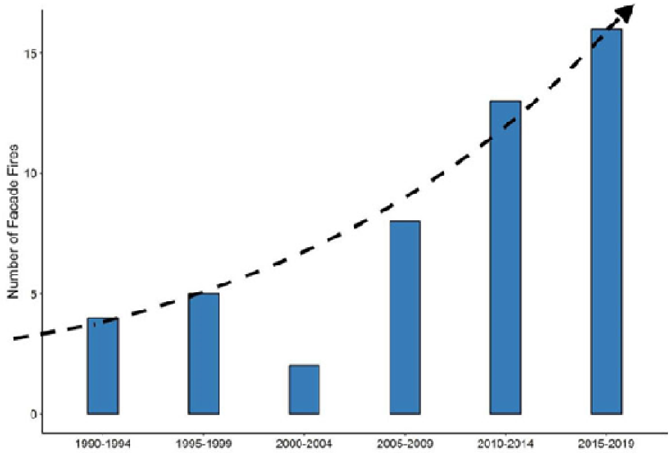


Figure (1): The figure illustrates the number of fire cases along high-rise buildings' facades from 1990 till 2019 [4]

And due to this increase in the number of high-rise buildings' fires, façade composition began to be studied carefully to discover the reason behind those fire cases. As mentioned before the façade is a complex part of high-rise buildings as it consists of many items as cladding, insulation, joints …Etc. This paper will focus only on thermal insulating materials as it was proved that the excessive use of these traditional thermal insulating materials contributes to fire spread along high-rise buildings' façade [16].

Recently, studies made on real fire cases showed that traditional insulating materials played a main role in fire spreading along high-rise buildings' façade due to their combustibility [16].

Traditional thermal insulating materials as polystyrene and polyurethane which was made of organic materials, is widely used in high-rise buildings to provide energy saving. But in case of fire occurrence, the flames spreads quickly on their surface and they produce a lot of toxic gases and smoke as well [9].

As high-rise buildings faces these hazards of fire spreading along their facades due to the traditional insulating materials, recently nanotechnology offered a better thermal insulation materials with higher thermal conductivity and does not produce toxic gases while burning [3]. These materials will not prevent the fire occurrence but they delay it to provide the occupant enough time to escape.

2. OBJECTIVE

This paper contributes to improve the fire performance of high-rise buildings' facades and increase fire-resistant time of them, for the aim of decreasing the damages and losses among people or property caused by those fires. This research aims to make a comparison between the mostly famous traditional thermal insulating materials as well as Nano-thermal insulating materials by testing them through SP105 fire test to figure out the best thermal insulating material with best fire-resistant time.

3. METHODOLOGY

A large-scale test is used to scenario the façade components to comprises a realistic results. As a single wall building of two-storey height above the fire chamber is used to test thermal insulating materials according to SP105 fire test criteria. Pyrosim software (version 2019.3.1204, 2002-2020 copyright) is used as an interface for Fire Dynamic Simulator (FDS) to help building the model, testing these materials as well as giving graphical results. While smokeview (version 6.7.7) was used for viewing the results of the realistic simulation [18].

3.1 SP 105 MODEL DESCRIPTION

Large-scale tests is used to test façade materials and claddings which are non-load bearing. There are many large-scale tests according to countries regulations but SP 105 fire test will be used in this paper. This fire test evaluates the large-scale facade fire where the model used is a single wall building of dimension (4m width x 6m height) and an aerated concrete is used to support the main cladding or material as shown in figure 2. The source of fire is 60 liter of heptane fuel burning in the tray of dimension (0.5m width x 2m length x 0.1m height). The façade is exposed to fire for 15 minutes [2,9].

Some devices are put in the model to help indicate the realistic result; three thermocouples are placed at the base of the eave which is placed on the top of the wall to measure the temperature and solid-phase device is placed in the center of the first window to measure the heat flux as illustrated in the below figure 2 [2,13]. SP 105 fire test has criteria for approval of the materials tested on large-scale façade as these criteria is only applied for the materials or claddings used for building of more than 8-storey height that is impossible for the firefighter to reach externally [2].

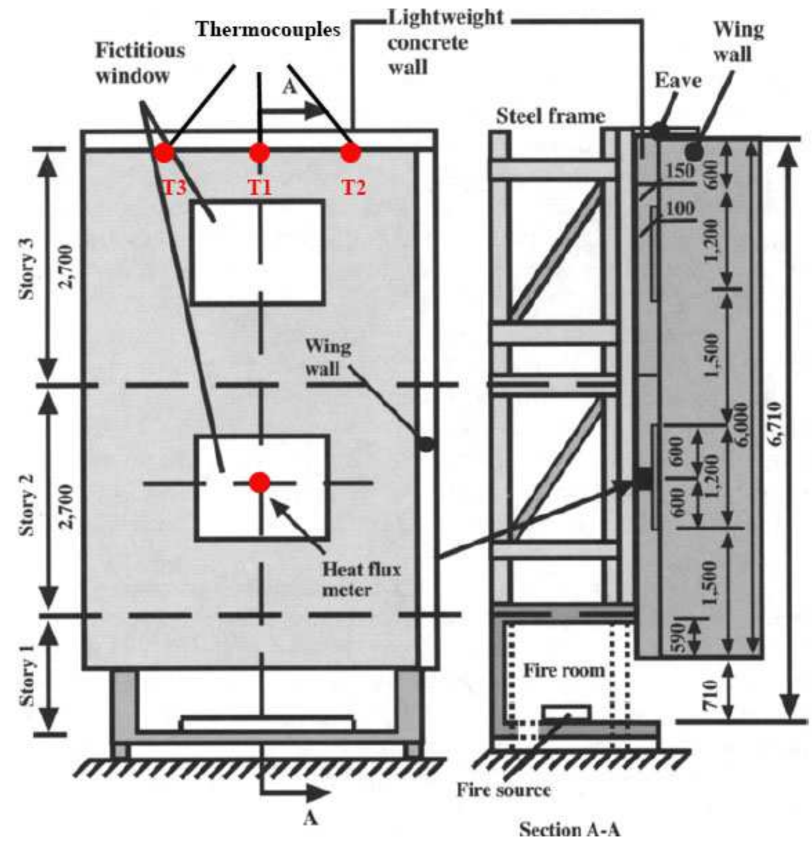


Figure (2): The figure illustrates model used in simulating SP 105 fire test [9]

SP 105 fire test has criteria for approval of the materials tested on large-scale façade as these criteria is only applied for the materials or claddings used for building of more than 8-storey height that is impossible for the firefighters to reach externally. These criteria will be illustrated in the following table 1 [13].

Table (1): Criteriaof Material Approval Of Sp 105 Fire Test [13]

	Maximum Temperature (°C)	Flame Spread	Heat Flux
Criteria for Approval	Temperature should not reach 500°C or higher in the first two minutes. Or Temperature should not reach 450°C or higher in the first 10 minutes at the eave.	There should not be a damage caused by the fire in the material higher than the bottom of the second window.	The heat flux measured should not exceed 80 KW/m^2.

3.2 Traditional Thermal Insulating Materials

Nowadays, designers tend to create a façade which can be easily installed as well as save energy so they changed the use of the old thermal insulating materials (e.g. glass wool and stone) to the traditionally used insulations (e.g. EPS, XPS and PUR). But the use of these traditional thermal insulation materials exposed the façade to higher risk which is the rapid fire spread along the façade in high-rise buildings [12].

3.2.1 Expanded Polystyrene (EPS)

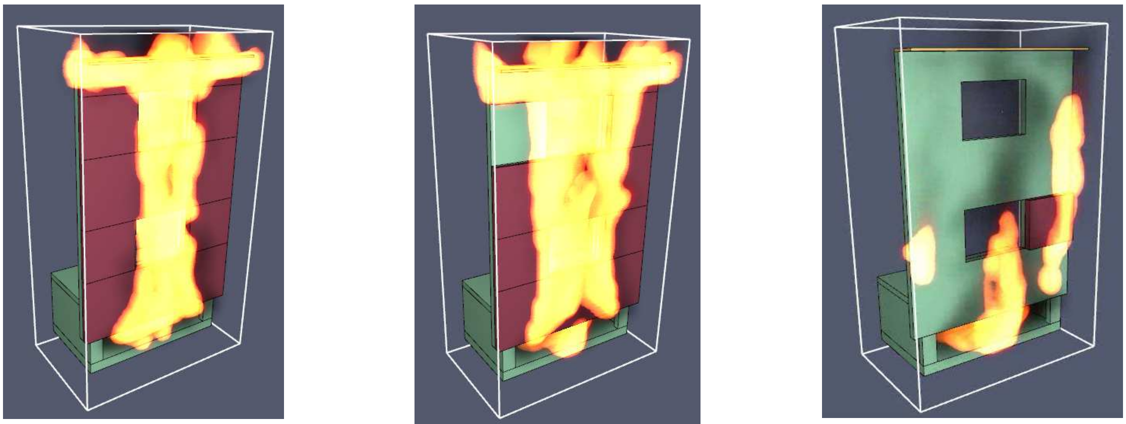
Designers preferred thermal insulations as EPS as they are easily installed, has a light weight and a low heat transmission. But the use of EPS in high-rise buildings' façade created a rapid fire spread along them and produces toxic gases and smoke which put the occupant of the building as well as the firefighters in high risk. EPS also can create a high risk at site if it was stored with high quantity and was exposed to high temperature [12].

Table (2): PHYSICAL PROPERTIES OF EXPANDED POLYSTRENE [10,14]

Physical Properties	
Density (Kg/m^3)	40
Specific Heat (KJ/Kg.K)	1.45
Thermal Conductivity (W/m.K)	0.034
Ignition Temperature (°C)	300-350
Heat Release Rate (KW)	1160

A façade with EPS as an insulating material is tested by using Pyrosim for 1000 secs where EPS is placed on the front of the façade and have a concrete layer as a support for this insulating material. After testing EPS, the following result is concluded:

Firstly, the EPS started ignition at 30 secs where the temperature started to increase and the frame spread rapidly as it reached the bottom of first window by 40 secs as well as the bottom of second window by 45 secs. And the fire reached the eave at the end of the wall at 53 secs as shown in figure (3-a). The EPS thermal insulating material started to decay at 75 secs until it is fully decayed by 340 secs as shown figure (3-b&c). This means that in real situation after nearly 5 mins or less the structure of the building will be exposed to direct fire.



a. At 53 secs

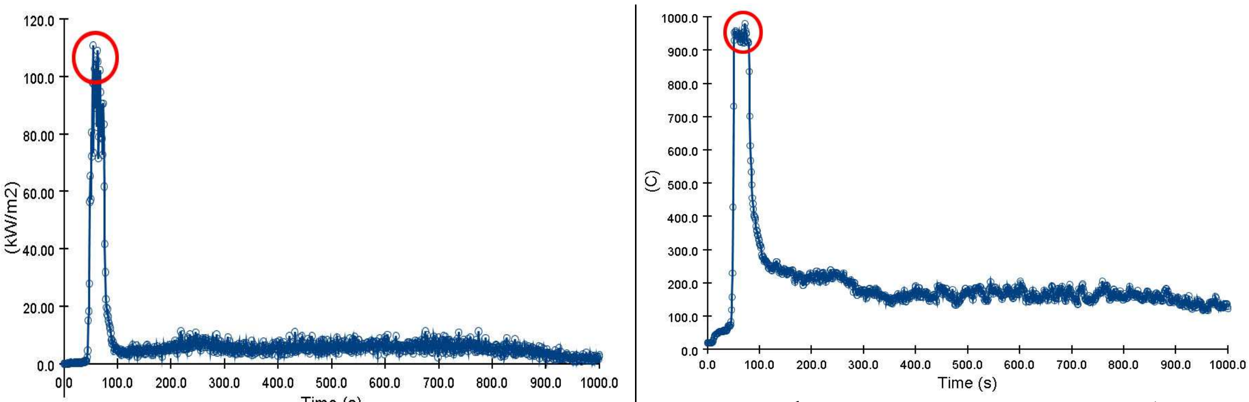
b. At 75 secs

c. At 310secs

Figure (3): the figure illustrates the progress of fire propagation along the EPS insulating material
Source: The Researcher

Secondly, according to temperature values appeared in the below graph, it begins to increase rapidly after the façade started to ignite until it reached its max about 1000 °C at (T1) in the 53 secs and slight lower in (T2 and T3) when the façade was completely on fire and then it decreased suddenly at 100 secs where already about 1/3 of the façade was decayed and then remains constant until it decreased gradually at 250 secs to 350 secs where almost all the façade was decayed and then it remained constant till the end shown in figure (4-b).

Thirdly, according to heat flux curve, it also reached its max 110 KW/m^2 at the same time and then started to decrease suddenly at 100 secs and it remains nearly constant almost the same value until the end of the text as shown in figure (4-a).And in case of EPS, the heat release rate was very high as it reached about 10000 KW which was meant to be about 2500 KW in this fire test.



a. Heat flux

b. Temperature at T1

Figure (4): this figure shows the change in temperature at T1 as well as heat flux in EPS test.
Source: The Researcher

3.2.2 Polyurethane (PUR)

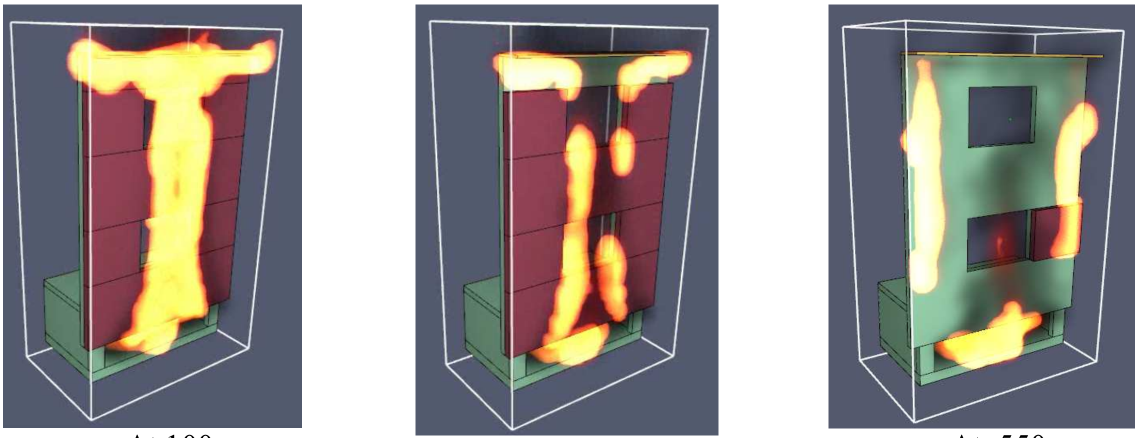
Polyurethane is used nowadays in high-rise buildings due to their advantages as it is considered as a light weight insulating material as their density is adjustable according to different performances required, it is a good thermal and sound insulating material and have low water absorption and good chemical resistance as well as energy saver [11]. But many buildings which used PUR as an insulating materials caught fire due to their high flammability as Tamweel and Al Tayer Towers and many other buildings.

Table (3): Physical Properties of Polyurethane [10,20].

Physical Properties	
Density (Kg/m^3)	40-60
Specific Heat (KJ/Kg.K)	1.40-1.50
Thermal Conductivity (W/m.K)	0.035
Ignition Temperature (°C)	300-400
Heat Release Rate (KW)	1000

After putting the PUR as a thermal insulating material on the façade and examining it for 1000 secs, the following results is concluded:

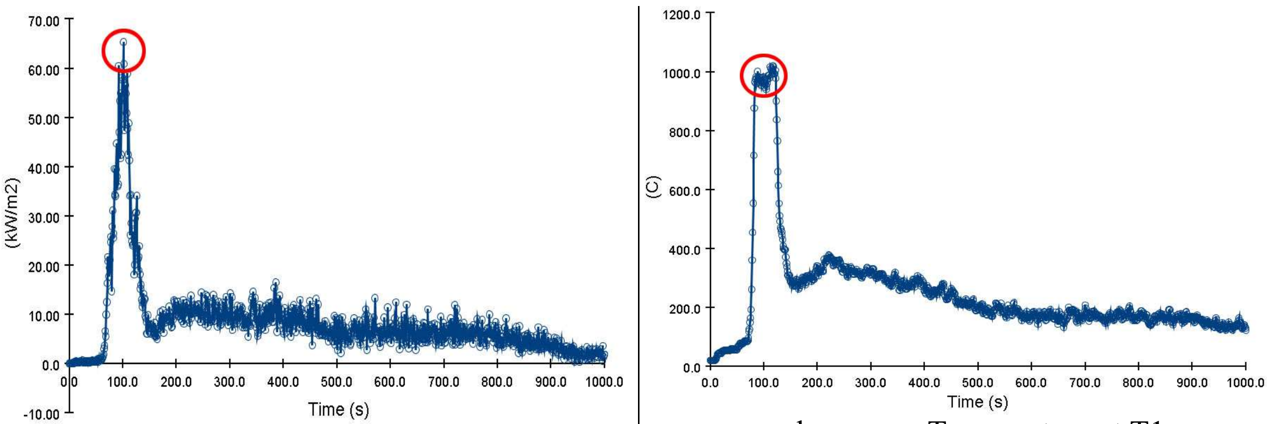
Firstly, the façade started ignition at 55 secs and the flames reached the sill of the first window at 65 secs and after another 10 secs, the flames reached the bottom of the second window above the fire chamber. The flames spread rapidly until it reached the eave at 100 secs as shown in figure (5-a). This insulating material is slightly better than EPS as it is started to decay at 138 sec and the material was fully decayed at 605secs as shown in figure (5-b&c).



a. At 100 secs   b. At 138secs   c. At 550 secs

Figure (5): the figure illustrates the progress of fire propagation along the PUR insulating material
Source: The Researcher

Secondly, in the heat flux curve, it is noticed that the heat flux was nearly zero at first for about 50 secs and it increased suddenly to reach its max value 68 KW/m^2 at 100 secs where the façade was fully ignited. Then it dropped to about 5-10 KW/m^2at 140 secs where the façade started to decay gradually and it decreased slightly until it almost reached zero at 1000 secs as provided in figure (6-a).
Thirdly, while in the temperature curve, the temperature reached its peak 1000 °C at 100 secs. And then when the façade material was about to decay, the temperature started to decrease gradually as illustrated in figure (6-b).The heat release rate of this process reached 7000 KW which is slightly lower than that of EPS but it is still very high.



a. Heat flux   b. Temperature at T1

Figure (6): this figure shows the change in temperature at T1 as well as heat flux in PUR test.
Source: The Researcher

3.3 NANO-THERMAL INSULATING MATERIALS

Nanotechnology is considered a unique technology which proved its good performance in many fields of architecture. One of these fields was the thermal insulating materials as it offers some good insulating materials which have high thermal conductivity as well as thermal insulating property. There are many types of these Nano-thermal insulations as Aerogel, Vacuum insulating panel, Nano-ceramic and others [3]. This paper will discuss the most famous Nano-insulating materials which are Aerogel and Vacuum insulating panels.

3.3.1 Aerogel

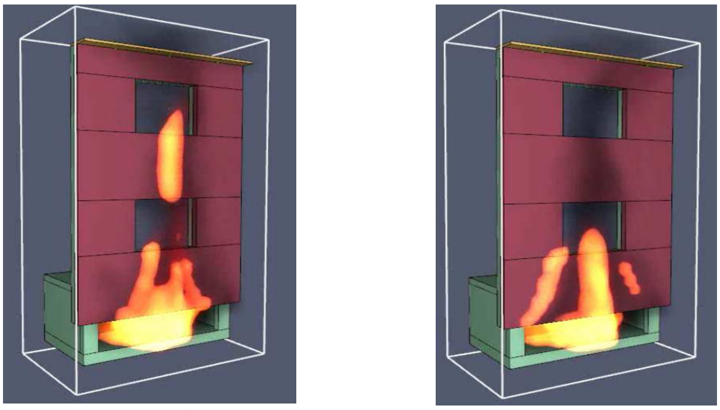
Aerogel is considered a good Nano-thermal insulating material with low density, high thermal conductivity, good sound insulation properties and high transparency. As it gives 40% better thermal insulation than the traditional fiberglass. Aerogel can be used in internal or external spaces as transparent wall panels, windows and skylight. It does not have any environmental problems and they are recyclable. Aerogel is presented in the market in many products as Aerogel thermal insulation blanket, self-adhesive insulating strips and Nano porous translucent glass [6,19,8].

Table (4): Physical Properties Of Aerogel [10,5,6]

Physical Properties	
Density (Kg/m^3)	70
Specific Heat (KJ/Kg.K)	0.8
Thermal Conductivity (W/m.K)	0.2
Ignition Temperature (°C)	650-800
Heat Release Rate (KW)	400

Aerogel materials was applied on the façade and exposed to fire for 1000 secs, the following results was concluded:

Firstly, in case of Aerogel, the speed of fire propagation was very slow as material start ignition at 145 secs which is better than the two previous materials. The flames reached the bottom of the first window at 185 secs and it started spreading slowly until it reached its maximum height which is the bottom of second window at 340 secs as shown in figure (7-a). And then the flames started to go out gradually until the end of the test. There was no decay in the material for the whole test duration as appeared in figure (7-b).

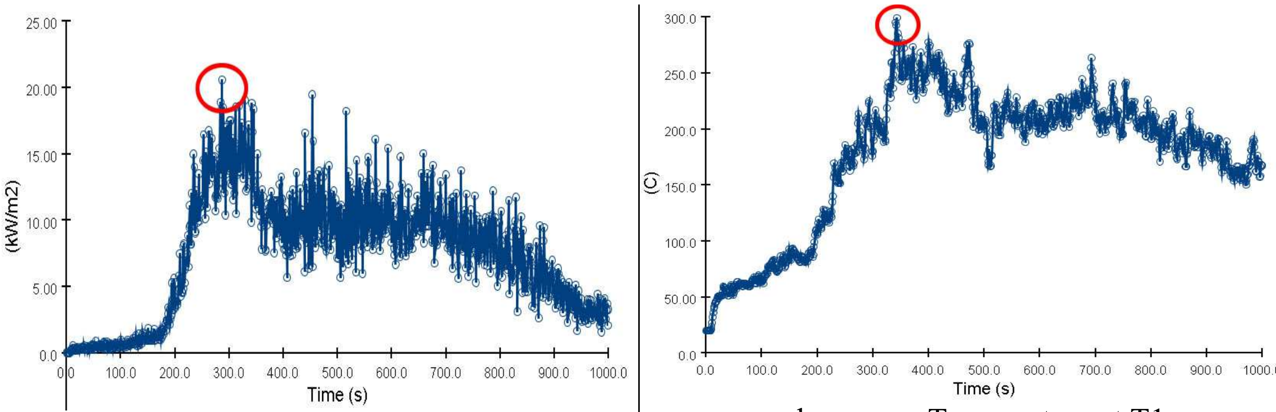


a. At 340 secs   b. At 990 secs

Figure (7): the figure illustrates the progress of fire propagation along the Aerogel insulating material
Source: The Researcher

Secondly, in the heat flux curve, it is appeared as shown in the below figure (8-a) that the peak value was about 20 KW/m^2 at nearly 300 secs where the façade started to ignition and then the heat flux decreased gradually till the end of the 1000 sec. it is clearly noticed that the values of heat flux is very low compared with the tested traditional insulating materials.

Thirdly, according to the measured temperature at (T1) where (T2&T3) are always slightly lower, the temperature increased gradually until it reached its maximum value of nearly 300 °C at 340 secs when the flames reached its maximum height then it started decreasing gradually as illustrated in figure (8-b).



a. Heat flux

b. Temperature at T1

Figure (8): this figure shows the change in temperature at T1 as well as heat flux in Aerogel test.
Source: The Researcher

3.3.2 Vacuum Insulating Panels

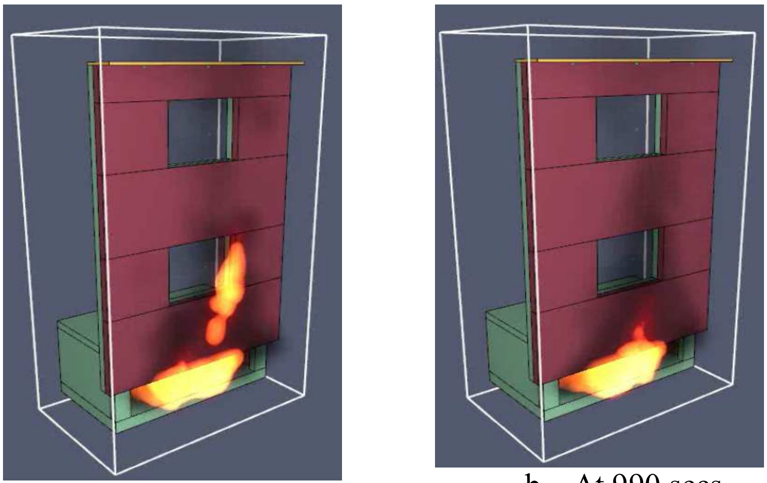
VIP can give better thermal insulation than traditional insulating materials by ten times with smaller thickness. VIPs are composite thermal insulating panels which consist of kernel and envelope. VIPs can be used in new construction or renovation and they are used floors, roofs and even facades. Their life span can reach up to 50 years [6,1,8].

Table (5): PhysicaL Properties Of Vacuum Insulating Panels[6,1,7]

Physical Properties	
Density (Kg/m^3)	150-300
Specific Heat (KJ/Kg.K)	0.8
Thermal Conductivity (W/m.K)	0.005
Ignition Temperature (°C)	1000-1200
Heat Release Rate (KW)	450

Vacuum Insulating Panels were applied to the single wall façade and tested for 1000 secs and the following results were noticed:

Firstly, it was concluded that this material have an amazing fire resistance performance as it started ignition at 310 secs which is much better of all the above insulating materials. The flames extended till its maximum height as it reached the top of the first window at 520 secs as shown in figure (9-a) and the flames' height started to decrease smoothly till the end of the test as illustrated in figure (9-b).

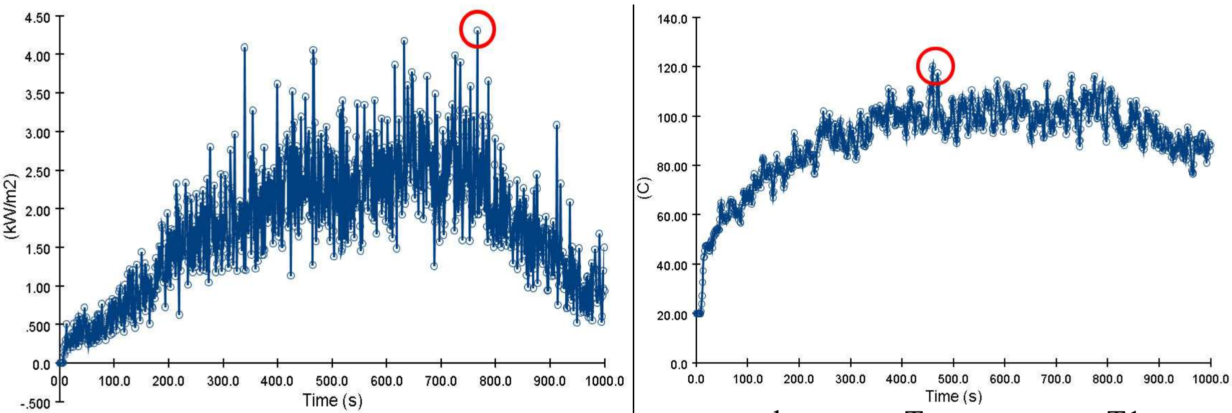


a. At 520secs

b. At 990 secs

Figure (9): the figure illustrates the progress of fire propagation along the Vacuum insulating panels
Source: The Researcher

Secondly, in the heat flux curve, it reached the maximum value at 800 secs which is 4.2 KW/m^2 which is very small value even compared with Aerogel. And it started to decrease gradually till 1000 secs. Thirdly, from the temperature curve, it is concluded that the maximum temperature read by the test was 120 °C at 480 secs which is considered a very small value compared with the previous thermal insulating materials. Then the temperature started to decrease slowly till the end of the test.



a. Heat flux

b. Temperature at T1

Figure (10): this figure shows the change in temperature at T1 as well as heat flux in Vacuum Insulating Panels test.
Source: The Researcher

4. RESULTS

The results will depend on the criteria of approval for SP 105 fire test which was mentioned before. As SP 105 fire test is used to test the fire performance of the façade materials for high-rise building. From the below table (6), it is concluded that EPS and PUR did not pass this test so they must be prohibited from being used in high-rise buildings due to their high flammability. While Aerogel and Vacuum insulating panels has passed this test so designer should begin to use this materials instead of other traditional insulating materials.

Table (6): Results Of Applying Sp 105 Fire Test on Tested Materials

Material	Criteria of Approval		
	Maximum Temperature (°C)	Flame Spread	Heat Flux
EPS	Failed 1000 °C at 53 secs	Failed Material fully decayed	Failed 110 KW/m^2
PUR	Failed 1000 °C at 100 secs	Failed Material fully decayed	Passed 68 KW/m^2
Aerogel	Passed 300 °C at 340 secs	Passed No decay occurred	Passed 20 KW/m^2
VIP	Passed 120 °C at 480 secs	Passed No decay occurred	Passed 4.2 KW/m^2

5. RECOMMENDATION AND CONLUSION

From this paper, it was concluded that Nano-thermal insulating materials can be used as an alternative for traditional thermal insulating materials to provide the façade with better fire performance.

So it is recommended that further studies to be applied on those materials to check their safety in case being used in high-rise buildings' facades. And to be tested by those large-scale tests as SP 105 and other to be certified internationally that they can be used safely. And it is recommended to put an end for the usage of those combustible traditional thermal insulating materials.

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