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The Development of Paint with Silica Aerogel for Thermal Insulation and Energy Saving

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ABSTRACT

An objective of this research is to assess the thermal insulation and energy savings of paint that has been combined with silica aerogel. This research conducted by testing paint with silica aerogel (PSA) compared with insulation paint and typical paint. This research tested 3 paints by painting them on model boxes (one for each paint) and exposing them to the light for the same amount of time without a shadow effect. The result has shown that PSA had the best result. A suitable mixer ratio of silica aerogel is 0.5 percent to make it practical and cost-effective. When comparing rooms painted with PSA to rooms painted with typical paint, the temperature was 4 degrees Celsius lower. PSA may also save 10 percent on air-conditioning electricity, with 6 months payback period. PSA has good performance and the cost-effectiveness of PSA compared to typical paint is the electricity cost savings and is more usable than insulation paint for thermal insulation and price. PSA was painted on the building of Wat Phachoomtham school in Chainat province of Thailand for the local community. It could lower inside temperature and was suited for tropical conditions.

1. INTRODUCTION

Global warming causes the temperature to increase significantly. Therefore, the innovation that involves thermal Insulation has become very popular, especially in residential buildings. Many countries across the globe are promoting energy efficiency materials. Thailand lies in the subtropics near the equator the sun shines most intensely, the temperature of 35-40 degrees Celsius rise to 43-45 degrees Celsius on the heat index. Most paint in the market can be used as a coating to decorate a surface and substrate but few of them can be used to protect the heat because these paints are inexpensive and use in low-cost projects. On the other hand, insulation paint is mixed with ceramic or titanium for heat refection and thermal reduction. A disadvantage of insulation paint or ceramic paint is a limited life span. Overtime ceramic or titanium lose their heat reflection properly to zero. According to Yodyingyong [1], he mentioned that Guinness World Record recognizes a silica aerogel as the world's best heat insulation. Silica aerogel has a high surface area, is highly porous and lightweight, low thermal conductivity, soundproof, lightweight, and waterproof. Silica aerogel can be used in thermal insulation, waterproof, and soundproof material. Wang [2] studied thermal insulation and strength of silica aerogel which had high performance of thermal insulation. From the study of silica aerogel-containing materials for buildings' thermal insulation by Mendes [3] showed that silica aerogel mixing materials for buildings, such as panels, blankets, cement, mortars, concrete, glazing systems, solar collector covers. Silica Aerogel can be mixed with different materials such as mixed with glue for coating, mixed with gypsum cement (PU) for composite boards and mixed with polymer for coating. Silica Aerogel can be made of agriculture's by-products. Worathanakul [4] studied silica aerogel that made of ground bagasse ash. Jongsuwanpaisan [5] studied Silica aerogel from husk to learn moisture absorber. In Thailand, there are abundant agricultural's by-products that can be used to make silica aerogel. Another paint study, Chaiyakul [6] had studied paint and heat reduction in buildings which researched heat reduction of buildings from using typical paint and heat reflecting paint. The results founded that paint colour had affected the in-model air temperature. The white painted sample box had lower inside air temperatures than the grey painted sample box. The difference was increased when the wall was affected by radiation from the sun. Antonaia *et al.* [7] had studied acrylic paint during the summertime of the Mediterranean. It showed acrylic paint had helped reduce labor cost and materials cost by 50%. Mariappan, Agarwal and Ray [8] studied titanium dioxide (TiO_2) that mixed in paint and mixed with ammonia and painted on a steel structure to see how it could prevent swollen on the surface. This study had compared to regular paint. The result was very obvious the right ratio of titanium dioxide and ammonia

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can prevent swollen paint surfaces significantly. Jeong *et al.* [9] had studied Microencapsulated Phase-Change Materials (MPCM) which is mixed in paint and test how it could prevent heat in roof material. Research shown MPCM helped reduce building energy consumption. Bozaky [10] tested a liquid called Nano Ceramic Thermal insulation coating (NCT). Its binding materials are a mixture of synthetic rubber and other polymers. After mixing with the raw material and its binder. Results had shown NCT has low thermal conductivity and heat mirror effect of this material. The other research for thermal insulation of building materials, Ratanachotinun [11] studied the insulation of autoclaved aerated concrete with perforation in Thailand. A feasibility study of glass solar chimney wall building for thermal insulation by Ratanachotinun [12] and the effectiveness of glass solar chimney walls by open frame used for insulation wall building by Ratanachotinun [13]. In past research, none of the studies had done silica aerogel to mixed in the paint. The main reason was the cost of silica aerogel too high, and it had to be imported. Nowadays, silica aerogel can be produced in Thailand. With its properties, silica aerogel is suitable to mix with paint and use to prevent heat better than other products in the market. However, Thailand and other countries have never been used silica aerogel and consider its cost and feasibility. This research is to develop and study the feasibility of practical application of paint with silica aerogel (PSA) for thermal insulation and energy saving, comparing with typical paint and insulation paint, testing for energy saving by electricity consumption and analyzing economic value for using with building and local community Thailand.

2. RESEARCH METHODOLOGY

2.1 Tools, Equipment and Sample Materials

(1) Typical paint was acrylic emulsion paint. Insulation paint was acrylic emulsion paint with ceramic for heat reflection and silica aerogel materials.
(2) Sample boxes size 1x1x1 meter have 3 boxes showed in Figure 1 and substrates of painting as cement bonded particleboard, 0.01 meter of thickness.
(3) Data logger to monitor the temperature for 24 hours. Analyze inside temperature compared to outside temperature during the daytime. Also, monitor solar radiation and infrared or thermal photo by instruments showed in Figures 2 to 6.

Fig. 1. Sample boxes size 1x1x1 meter.

Fig. 2. Datalogger brand Vernier, version LabQuest2.

Fig. 3. Stainless steel temperature probe.

Fig. 4. Surface temperature probe.

Fig. 5. Pyranometer for solar radiation.

Fig. 6. Infrared camera Brand Fluke, Version TIS10.

2.2 Research Method

The three (3) sample boxes size 1x1x1 meter main structure was steel. Walls were built with cement temperature insulation board. Between the walls had been insulated. The walls painted in each box with one kind of paint on the heat exit side. These sample boxes were located in Chandrakasem Rajabhat University (CRU). Three paint specimens were painted according to the sample boxes code 1-time primer and 2 times paint. Each box was installed temperature probs and pyranometer measurement Vernier datalogger version Labquest2 at both sides and showed in Figure 7. Please note each box was painted with one specimen to compare heat reduction capacity. The synthesis of silica aerogel for this research was drying hydrophobic silica and the average dimension of silica aerogel particles of 100 micron. For silica aerogel, trialed at 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3% of paint weight. There are two reasons we mixed silica aerogel with those percentage, cost of silica aerogel is expensive and too much silica aerogel makes paint become very to work showed in Figure 7. The testing boxes were painted by one side of the wall in each box, the quantity of applied paint as 0.047 l/m2 per coat and put them facing the sun. Painting area is 1 m^2 each and three boxes were tested at the same condition. The location of the probes in the boxes, stainless steel temperature probe was fixed in the air of center boxes and surface temperature probe was fixed on the center of surface wall (Figure 7). The data collection was conducted in 3 seasons, summer, rainy and winter The data analysis were the average of 3 days per season and the data was explored 24 hours a day and thermal photo of the surface of the tested wall, examined the best portion of silica aerogel. The best portion of silica aerogel will be used in CRU classrooms showed in Figure 8 and substrates of painting as brick wall, 0.10 meter of thickness. Next step, we would paint inside and outside classrooms we collected data and compare electricity usage of air condition before and after PSA paint had applied and feasibility analysis for economic value. This testing will conduct in the hottest summer in 2019. In the later, the researcher would use PSA paint in building of Wat Phachoomtham school in Chainat province of Thailand.

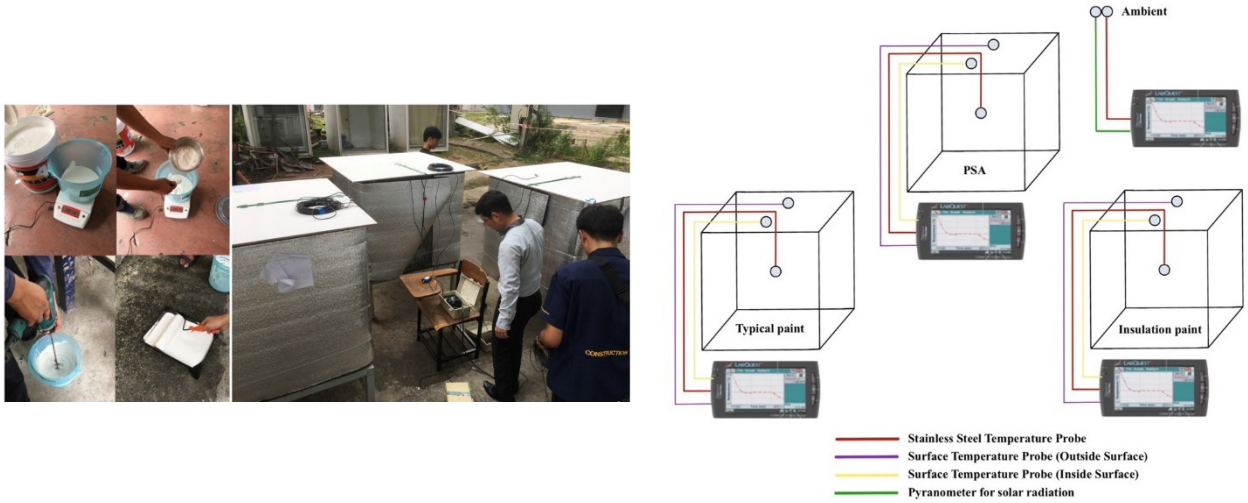

Fig. 7. Mixing silica aerogel in paint, measurement and equipment install layout

Fig. 8. Recording temperature and electricity consumption saving from PSA in sample classroom.

3. RESULT

3.1 Data Analysis for Suitable Silica Aerogel Ratio

Data analysis is divided into three (3) seasons, can explain the results of the calculation as follows:

The 3-days of data collection and average data during the rainy season found that sample boxes that use PSA in 0.5 percent have the lowest indoor temperature and lower than the typical paint and insulation paint about 0.62 and 0.85 degree Celsius by respectively and below the outside temperature of 1.66 degrees Celsius by the maximum outside temperature of 34.49 degrees Celsius (showed in Figure 9).

The 3-days of data collection and average data during the winter season found that sample boxes that use PSA in 0.5 percent have the lowest indoor temperature and lower than the typical paint and insulation paint about 0.30 and 1.10 degree Celsius by respectively and below the outside temperature of 1.11 degrees Celsius by the maximum outside temperature of 33.14 degrees Celsius (showed in Figure 10).

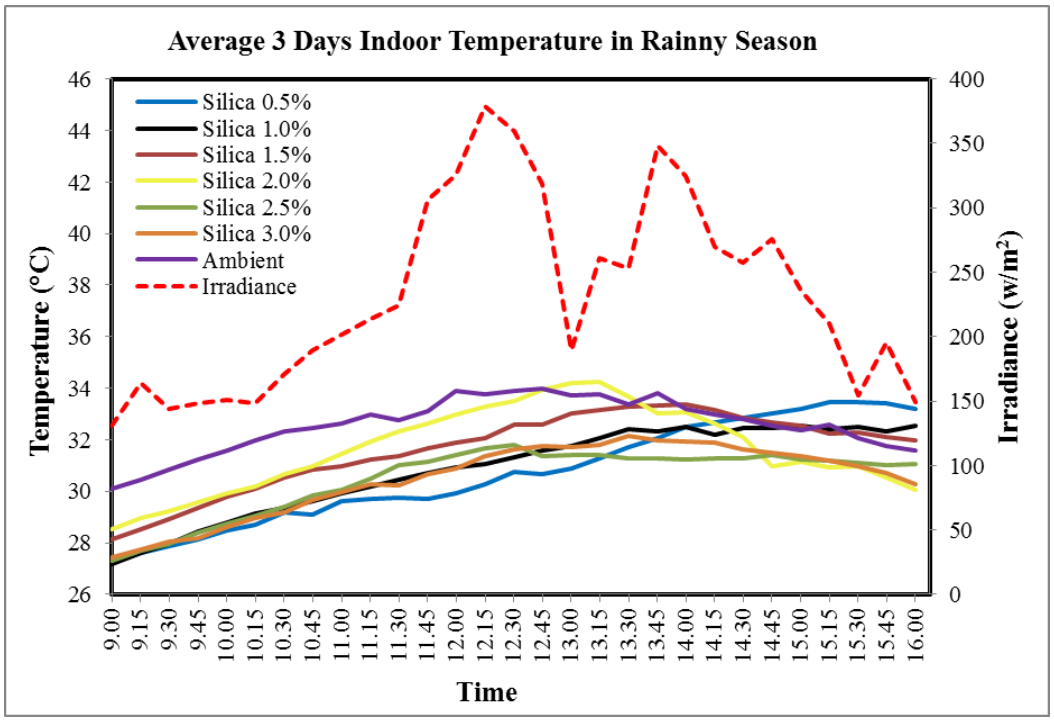

Fig. 9. Comparision of indoor temperature for silica aerogel ratio surveying of rainy season.

The 3-days of data collection and average data during the summer season found that sample boxes that use PSA in 2.5 percent have the lowest indoor temperature and lower than the typical paint and insulation paint about 10.53 and 10.64 degree Celsius by respectively and below the outside temperature of 9.97 degrees Celsius by the maximum outside temperature of 41.04 degrees Celsius (showed in Figure 11). For three (3) seasons, PSA, typical paint and insulation paint tests were unidirectional, with higher irradiation affecting higher surface temperatures as well.

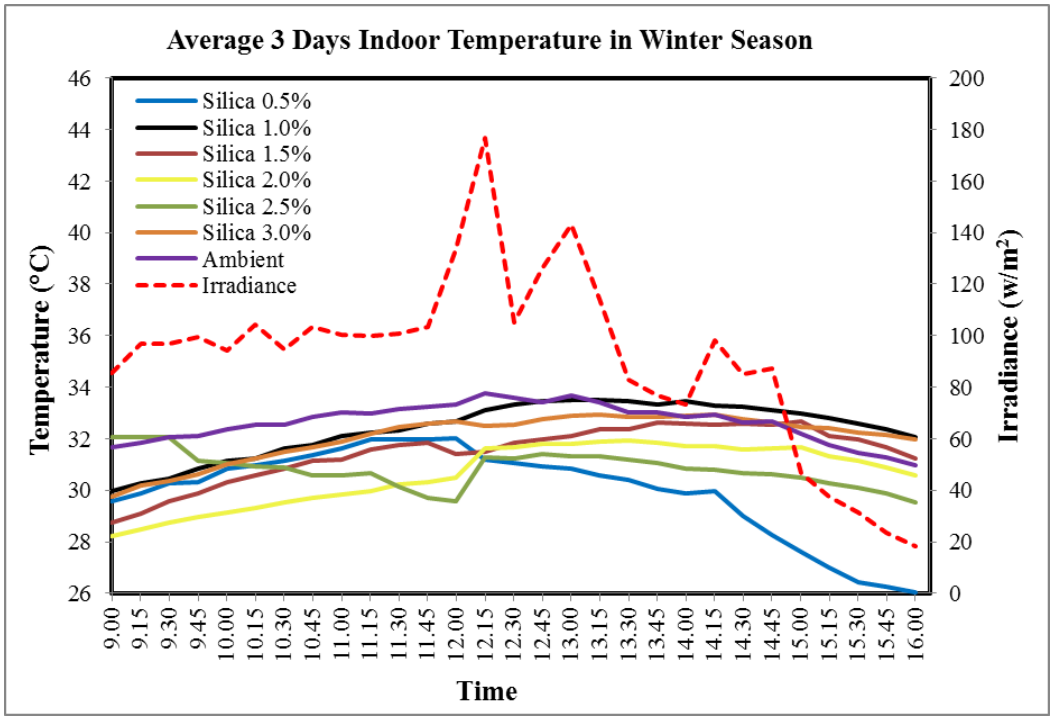

Fig. 10. Comparision of indoor temperature for silica aerogel ratio surveying of winter season.

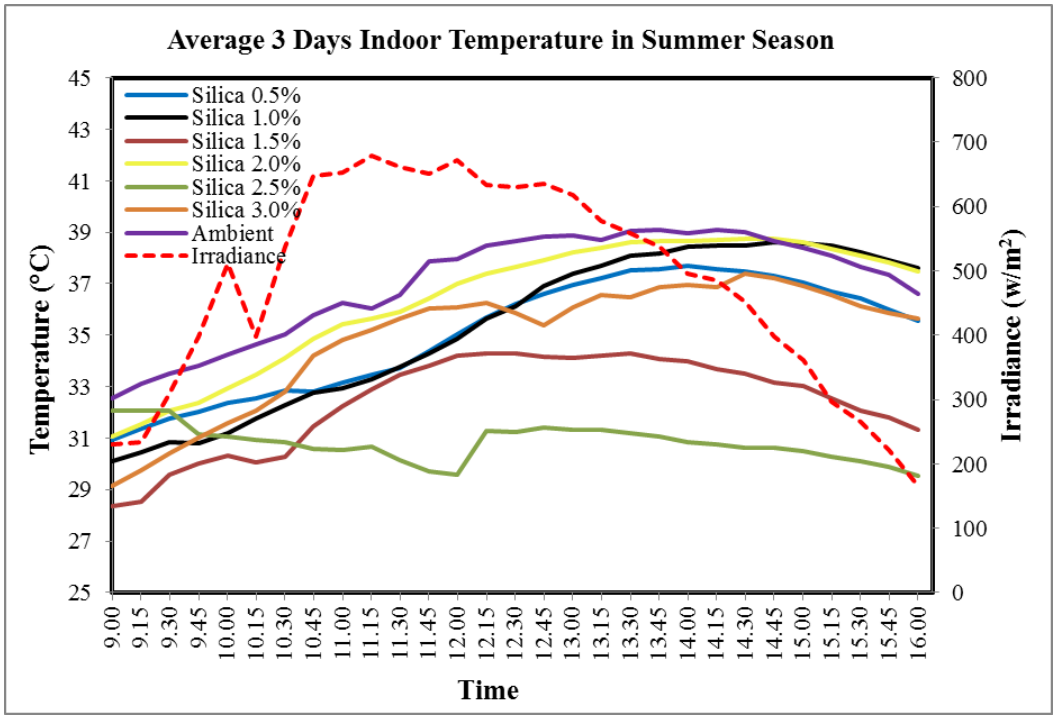

Fig. 11. Comparision of indoor temperature for silica aerogel ratio surveying of summer season.

An analysis of the suitability of silica aerogel proportions found that when applying the temperature differences inside the sample box, the painted silica aerogel mixes with the external temperature by combining the differences all season, finding that the silica proportions of 2.5 percent are the most significant

differences in the overall external and internal temperature, but the cost for the silica proportion of 0.5 percent is the lowest follow by Equation 1. The results of the analysis shown in Tables 1, 2 and 3 concluded that the 0.5 percent of silica aerogel ratio was most suitable and the cost of 2.16 US$/m^2 which is cheaper than the use of insulation paint at 3.68 US$/m^2 which is mixed by ceramic and higher cost of material. So it is worth investment. The researcher then used the mixing and paint mixing and paint to test applications for the actual-sized room.

$$PSSA = \left[(A / A_{max}) x \left(2 - \left(B / B_{min}\right)\right] x100 \right. \quad (1)$$

Where PSSA = The percentage of suitable silica aerogel ratio A = Total difference of temperature for all seasons, A_{max} = The maximum total difference of temperature, B = The cost of paint and B_{min} = The minimum cost of paint.

Table 1. The cost of typical paint, insulation paint and PSA.

Percent Silica Aerogel in PSA (%)	Cost USD/m^2	Cost of typical paint USD/m^2	Cost of insulation paint USD/m^2
0.5	2.16		
1	2.49		
1.5	2.81	0.82	3.68
2	3.13		
2.5	3.46		
3	3.78		

Table 2. The different of indoor temperature and the cost of PSA for all seasons.

Percent. Silica Aerogel	Indoor Temp, Rainy season	Indoor Temp, Summer season	Indoor Temp, Winter season	Total Diff.	Cost, USD/m^2
0.5	30.65	37.57	31.18	7.45	2.16
1	31.57	38.19	33.12	3.97	2.49
1.5	32.59	34.09	31.49	8.68	2.81
2	33.93	38.67	31.62	2.63	3.13
2.5	31.36	31.06	31.28	13.15	3.46
3	31.77	36.86	32.50	5.72	3.78

Table 3. The percentage of suitable silica aerogel ratio.

Percent. Silica Aerogel (%)	Suitable Temp. (Unit)	Suitable Cost (Unit)	Suitable Silica Aerogel Ratio (%)
0.5	0.57	1.00	56.65
1	0.30	0.85	25.69
1.5	0.66	0.70	46.35
2	0.20	0.55	11.06
2.5	1.00	0.40	40.43
3	0.43	0.26	11.11

3.2 Effectiveness of PSA in Practical Room

The results testing of the sample box show that the 5% of silica aerogel ratio is suitable for actual use. Therefore, it is the silica ratio used to test the practical room. The performance test of PSA with the classroom walls of the building within Chandrakasem Rajabhat University (CRU), the location of the three-wall test classroom located on the south, east and north and the top floor of the building for maximum sunlight. Painting the walls inside and outside the classroom uses the 0.5 percentage of suitable silica aerogel ratio and data collecting to 7 days during time 8:00 to 16:00 and 2 air conditioners are turned on and set the temperature to 25 degrees Celsius. The result showed in Figure 12. found that the average temperature in the south of room was 24.33, lower than the average weekly temperature of 28.52 degrees Celsius for the before painted PSA, the average ambient temperature of 31.64 degrees Celsius and the average solar radiation of 188.23 w/m^2. These results are the same as that of the east and north. The average temperature reducing in the CRU testing classroom was 4 degrees Celsius. While the 0.5 percentage of silica aerogel ratio for the sample box testing has a temperature difference of 1.82 degrees Celsius. This demonstrated that the use of PSA in the CRU classroom had a lower temperature performance compared to typical paint with better performance than the sample box experiment.

Analysis of the feasibility of the application of PSA by analyzing the energy savings of air conditioners from the installation of the in-room electricity meter during the data collection according to Table 4. to assess the value of commercial investment. The result found that the value of the electricity meter decreased by 33 units per week or decreased by about 10 percent. The cost of electricity per unit is approximately 0.13 US$ per unit, thus saving 4.26 US$ per week and the breakeven point of PSA is approximately 0.5 years (106.45 US$ per tank, 200 m^2 of 2 paint times and 1 tank with 5U.S. Gallons). Therefore, the cost-effectiveness of PSA compared to typical paint is the electricity cost savings, and compared to insulation paint, it is better heat-insulating performance and lower cost.

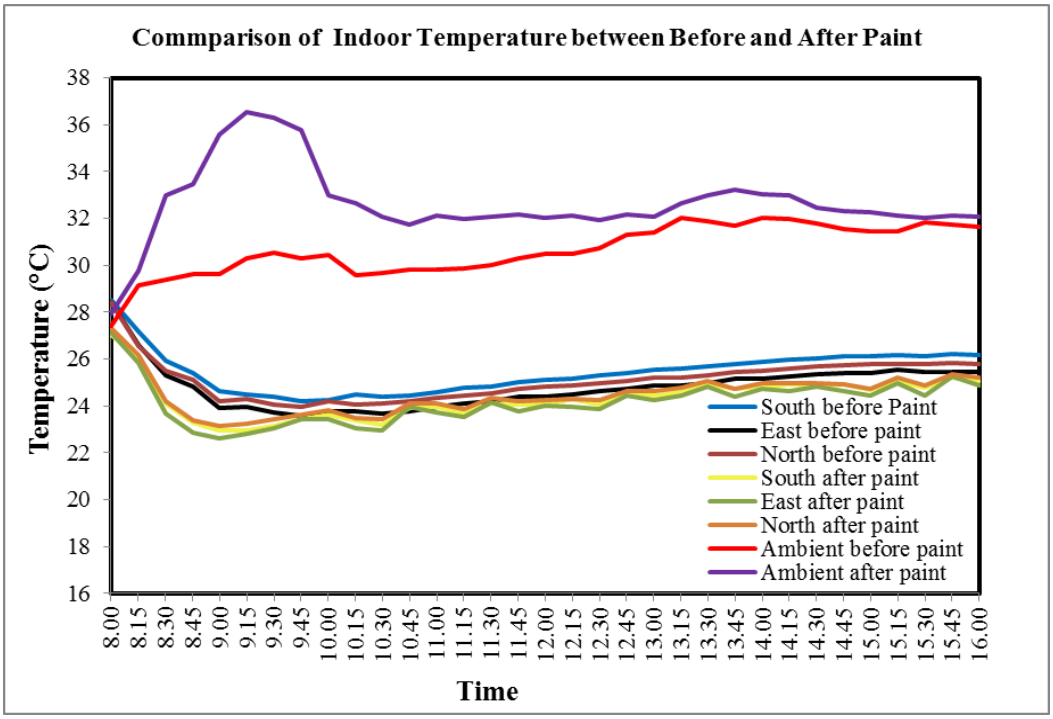

Fig. 12. Comparision of indoor temperature CRU classroom for before and after painted PSA.

Table 4. The value of electricity energy saving from using PSA in CRU classroom.

The cost of electricity before paint (US$)	The cost of electricity after paint (US$)	The cost of electricity energy saving (US$)
39.74	35.48	4.26

Surveying for thermal photo of CRU wall classroom, PSA in a proportion of 0.5 percent painted to the walls of the building (right side of Figure 13) and compared to the typical paint (left side of Figure 13) using an infrared camera, finding that the wall surface painted with silica aerogel was lower than about 1.2°C.

3.3 The using of PSA in the community of Thailand

PSA for painting of Wat Phachoomtham school building in Chainat province of Thailand showed in Figure 14 found that surface temperature could reduce 10 degrees Celsius of difference compared with typical paint.

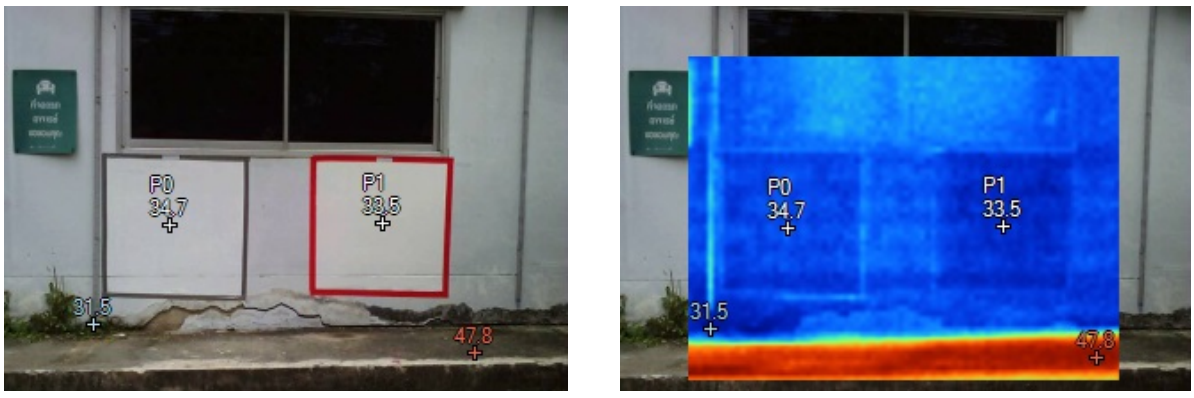

Fig. 13. Thermal photo of CRU wall classroom.

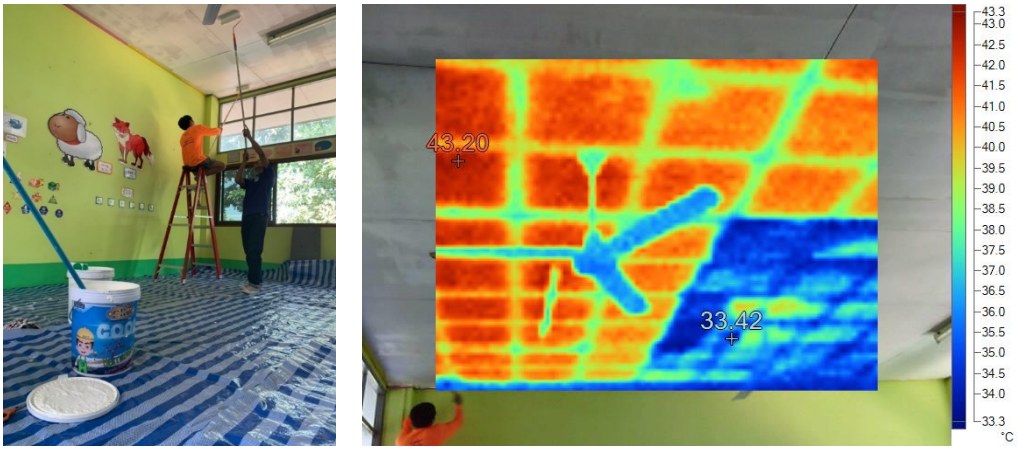

Fig. 14. Using PSA and different of temperature in building of Wat Phachoomtham school in Chainat province of Thailand.

4. CONCLUSION

The development of PSA for thermal insulation and energy saving concluded that using PSA reduced indoor temperature compared with using the insulation paint and typical paint, suitable for tropical condition and effective around year. The suitable ratio of silica aerogel was the 0.5 percent of paint weight which had the reasonable cost for commercial investment at 2.16 US$/m2 which was cheaper than the insulation paint at 3.68 US$/m2. Therefore, PSA is more usable than insulation paint for thermal insulation and price reasons. The painting of PSA for building (CRU classroom) could reduce average indoor temperature about 4 degrees Celsius compared with the room of typical paint and the electricity energy saving as 10 percent of electricity consumption for air condition. The use of PSA in the CRU classroom had a lower temperature performance compared to typical paint with better performance than the sample box experiment. So, applying PSA to a real-sized room has good performance and the cost-effectiveness of PSA compared to typical paint is the electricity cost savings. The breakeven point of PSA was 6 months. For the local community for Thailand location, PSA was used for repainting at building of Wat Phachoomtham school in Chainat province of Thailand and could reduce indoor temperature effectively. Industrial production will reduce the cost of PSA cheaper, which will make them more cost-effective to use. The next research should develop more color shade for consumer interest.

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