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IeGRESAFE 2022

E-PROCEEDING OF

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"Sustaining the Resilient, Beautiful and Safe Cities for a Better Quality of Life"

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IEGRESAFE 2022

"Sustaining the Resilient, Beautiful and Safe Cities for a Better Quality of Life"

ORGANISED BY

Gresafe_Cities RIG
The University of Queensland, Australia
Kampus Hijau UiTM Perak

CO-ORGANISED BY

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THE STUDY ON THERMAL PERFORMANCE AND DAYLIGHTING OF TRANSPARENT CONCRETE

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Abstract

Concrete is the most used building material in the world. Modern technology studies and research developments have enhanced the quality and innovation of concrete. Transparent concrete is concrete that has light-transmitting properties which transmit light through the optical fibre. Optical fibres are reinforced in the conventional concrete mixture from one face to another face, which allows direct sunlight to transmit through it. Daylighting factor is one of the fundamental qualities of the energy efficiency of a building. The thermal performance is also crucial to providing comfort to the building occupants. The literature studies cover the light transmittance and thermal performance of transparent concrete. Selected literature studies are reviewed based on the related topic, Asian countries, and countries with a similar climate to Malaysia. This research applies the quantitative method which was focused on the experimental study of transparent concrete. The overall result indicates improvement on light transmission and thermal performance as the plastic optical fibre increased compared to conventional concrete. The total average surface temperature of transparent concrete shows a difference of 0.989°C lower than conventional concrete. This experiment's significant contribution is that using more plastic fibre optic reduces thermal conductivity and heat gain while allowing for greater daylighting. Finally, transparent concrete shows effectiveness in light transmission and thermal resistance which can contribute to building industry on green building and sustainable design. However, further studies on thermal performance with a longer duration are required to analyse the thermal heat loss.

Keywords: *Concrete, Daylighting, Optical Fibre, Thermal Performance, Translucent Concrete.*

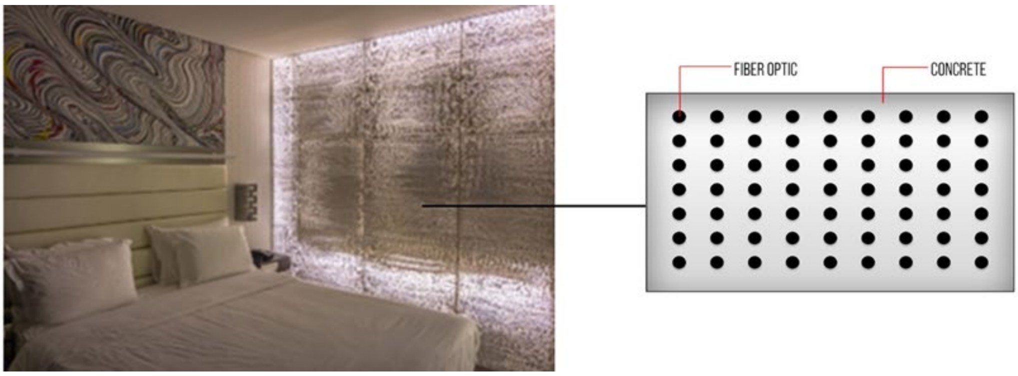
INTRODUCTION

Concrete has been utilised since the Roman era although its essential components have not changed. Common concrete is made of cement, sand, aggregates, and water. Engineers have developed many types of concrete by using new technology (Shetty et al., 2019). Transparent concrete, also known as light transmission concrete or translucent concrete, is a new technology form of concrete that transmits light through it using optical fibre. The novel material is also considered as green building material. The transparent concrete is made of cement, very fine sand, and thousands of optical fibres reinforced in concrete from one face to another face that allows directly the light to go through it. (Zhang et al., 2020).

The concept of integrating natural illumination into the architectural design is known as daylighting. Daylighting may have a significant impact on building energy efficiency if effectively designed and constructed (Ahmad & Reffat, 2018). Transparent concrete (Figure 1) is a type of concrete that helps to maximise daylighting. A well-designed daylighting system may reduce lighting energy use while also increasing visual comfort, health, and amenity for inhabitants (Wong, 2017). The daylight factor is a particularly significant consideration in evaluating energy consumption due to artificial lighting application. However, many nations worldwide also employ DST (daylight saving time) as an energy conservation measure (Baloch et al., 2018).

Thermal insulation is a fundamental factor that helps to achieve thermal comfort for building occupants. The major heat transmission mechanisms-conduction, radiation, and convection-can be reduced by implementing appropriate building techniques and material selection (Asadi et al., 2018). According to Abdullah et al. (2016), discomfort issues have been attributed to the effect of solar radiation and climate in tropical countries like Malaysia. Furthermore, many commercial buildings feature glass curtain walls as building façades which causes thermal discomfort for the inhabitants (La Ferla, 2020). Glazed façade is identified as weakest area as it allows heat gain from direct sunlight. The studies shows that highly glazed buildings have substantially higher solar gains than conventional buildings (Hwang & Chen, 2022). The focus of this research is to study and observes the effectiveness of transparent concrete toward improving the daylighting and thermal performance in a building. This study also investigates the result of transparent concrete on accumulating daylighting in a building and optimize the transparent concrete on thermal performance in indoor space of a building by applying transparent concrete.

Figure 1
Example of Transparent Concrete Wall Applied in Bedroom



LITERATURE REVIEW

According to Chiew et al., (2018), the major purpose of transparent concrete is to maximise daylight while reducing electric power use and using optical fibre to detect structural stress. Transparent concrete allows light to penetrate through it, enabling visibility and minimising the amount of light energy required by the structure. Furthermore, it transmitted more light than conventional concrete.

Based on Pilipenko et al., (2018), transparent concrete is aesthetic and architectural purposes such as building envelope and exterior decorative material. The novel material also can be applied on walls, partitions, and ceilings instead of windows and conventional materials. It can be also used in dark spaces or area such as subway stations and tunnels where the light from ground level or exterior transmits into the area. The studies shows that transparent concrete provides 22% light transmittance which is sufficient illumination for residential and commercial buildings (Shitote et al., 2018).

The inclusion of optical fibres in conventional concrete improved the thermal resistance and mechanical properties. Thus, the number or ratio of optical fibres in the concrete mixture also determines the compressive strength even though the transparent concrete is lighter weight compared to conventional concrete (Momin et al., 2014). The studies also show that chopped glass fibre added to a concrete mixture reduced thermal conductivity under high temperatures (Wang et al., 2020). In addition, the use of the material has decreased the thermal conductivity and improved the total thermal resistance (Ahuja & Mosalam, 2017).

Conventional concrete display as raw texture in contrast to transparent concrete, which delivers a unique look and increases aesthetic values in daytime and lantern during the night (Dhanke et al., 2020). During the night, the artificial light in the space or area transmits light towards the exterior wall and enhances the overall aesthetic value of the building. The design and texture of the transparent concrete can be varies depending on the arrangements of the optical fiber during casting the block or panel (Sahithi & Mouunica, 2019).

METHODOLOGY

This research employs quantitative methods by experimental study of physical models for numerical results on daylighting and thermal performance. The experiment was done in Penang, Malaysia. For this experiment, the Sika Grout -215 was used. The ingredient of the material is included with cement, sand, and a maximum grain size of 1.2mm. Coarse aggregates were not used in the experiment to avoid fibre balling. However, 6mm fibreglass chopped strands (Figure 2) were applied to replace coarse aggregates. 1mm poly methyl methacrylate (PMMA) fibre optic cables (Figure 3) were used in this experiment to ensure transparency for the cement concrete block matrix. The parameters applied for this experiment as shown below:

Fixed variables: Ratio of concrete mixture, size, and thickness of concrete block
Manipulated variables: Ratio of poly methyl methacrylate (PMMA) fibre optic
Responding variables: Temperature, light intensity

Figure 2
6mm Fibreglass Chopped Strands

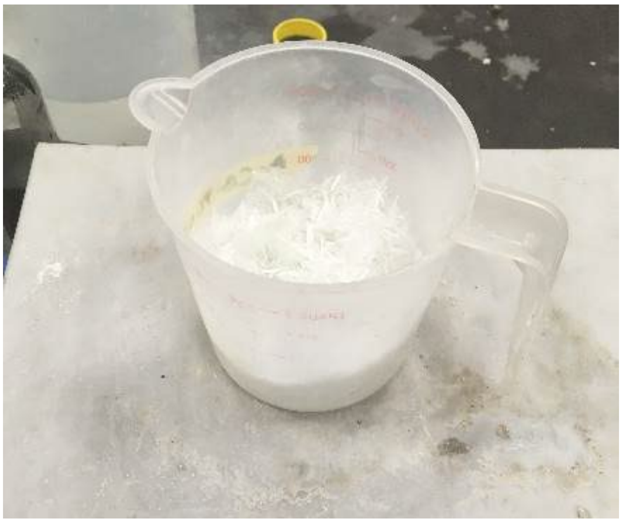
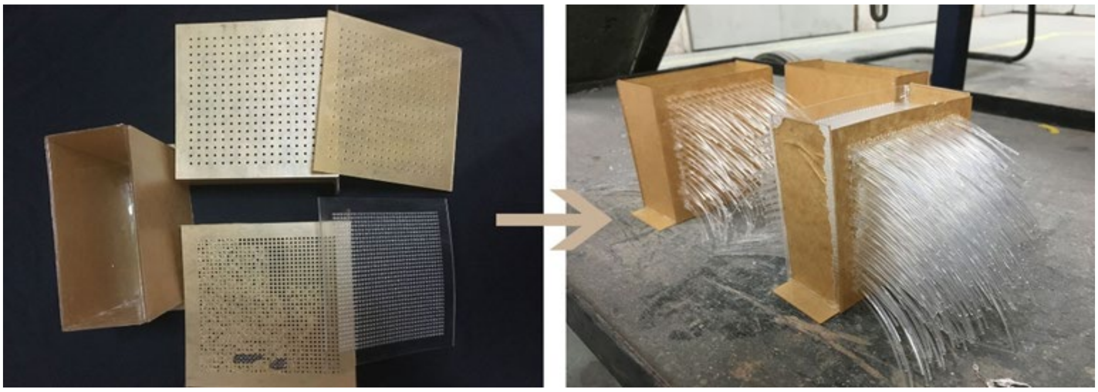


Figure 3
1mm Poly Methyl Methacrylate (PMMA) Fibre Optic Cables

Phase 1: Mould Production Process

The production process of mould for the transparent concrete used a 3mm acrylic sheet and high-duty tape. Initially, the design and dimension of 9cm(L) x 4cm(W) x 9cm(H) were prepared using AutoCAD software to ensure the moulds are accurate in sizes. The number and distance between holes are varied (5mm and 2.5mm) which determines the degree of light transmission and thermal resistance. Then, the prepared mould design was carefully cut using a laser cutter machine and poly methyl methacrylate (PMMA) fibre optics were arranged according to the holes in the mould as shown in Figure 4.

Figure 4
Arrangement of Plastic Fiber Optic in Mould



Phase 2: Mixture and Transparent Concrete Production Process

In the experiment, the coarse aggregates were excluded from the concrete mixture and Sika Grout- 215 were applied to avoid fibre balling issues caused by narrow gap between transparent materials during pouring of high-fluidity concrete in the block. The concrete mix design is summarised in the Table 1 below. The Sika Grout-215 is gradually added into a clean container while continuously mixing with water and fiberglass chopped strands until the consistency is obtained. The mixture was mixed for 3 minutes with a slow-speed drill and the final concrete was produced and poured into a prepared mould with arranged poly methyl methacrylate (PMMA) fibre optic. After room curing for at least 48 hours in the mixing process, the samples were proceeded to 28 days of curing in water and perform with grinding to remove mould.

Table 1
Concrete mix proportion.

Sample Number	Sika Grout-215 (kg)	Water (litre)	Fibreglass Chopped Strands (kg)	Poly Methyl Methacrylate (PMMA) Fiber Optic (Number)
A	1.84	0.31	0.368	-
B	1.84	0.31	0.368	290
C	1.84	0.31	0.368	560

Phase 3: Light Transmittance Test

The light transmittance of the concrete samples was measured by the amount of light passing through the transparent concrete. HANNA HI 97500 portable lux meter shown in Figure 5 was used to measure the illuminance of the transparent concrete. It can be measured in a range of 0.001 to 199.9 Klux. The light source input was from natural sunlight during sunny days. According to Dobrijevic (2022), the month of June was selected because the sun reaches its highest and northernmost points in the sky during June solstice at Malaysia. the study also shows that June solstice delivers the maximum daylight hours of the year 2022. The test was measured by using a lux meter (Klux) as shown in Figure 6 and the result was converted into lux (lx). A box was made up using mounting board to prevent light escape while carrying out the test.

Figure 5
HANNA HI 97500 Portable Lux Meter

Figure 6
Light Illuminance Test

Phase 4: Thermal Test

The thermal test of concrete samples was measured by the amount of heat transferred to the transparent concrete. Flir i7 infrared thermal imaging camera (Figure 7) was used to measure the surface temperature (Celsius). The temperature range of this equipment is -20°C to 250°C. Based on Awang (2021), the study shows the hottest hour of the day occurs between 3 pm to 5 pm which is 3 to 5 hours after noon. It is because of the Earth's surface receives and absorbs heat at a faster rate than it can radiate until the mid- to late afternoon, when the process reverses. However, the local weather shows that 12pm to 2pm has the highest outdoor temperature on the 3 days of the experiment. Both test results were recorded in the range from 12.40pm to 2pm which has an interval of 15 minutes with a total of 30 minutes by placing the transparent concrete under the sun as shown in Figure 8. The total duration of this test took 10 days, but the actual result was recorded for 3 days due to local weather conditions. It is because the thermal test was decided to be done in a clear sky which helps on precision of the result.

Figure 7
Flir i7 Infrared Thermal Imaging Camera

Figure 8
Thermal Imager Test

RESULTS AND DISCUSSION
Effect of Daylighting on Transparent Concrete

The daylighting performance results of three concrete samples were recorded simultaneously. In addition, the result of day 1 (Table 2) shows that the light illuminance of transparent concrete of 560 optical fibre is higher than that of transparent concrete of 290 optical fibre. The result of this experiment varies with different duration due to variations in light illumination receive from sunlight.

However, the result for day 2 (Table 3) and day 3 (Table 4) shows that the transparent concrete with a higher number of fibre optic deliver higher light intensity even though the local weather (°C) differs on 3 days. The Figure 9 shows the image of transparent concrete placed on the mounting board during the daylighting test. The experimental result of average light intensity is shown in the Figure 10 and several observations can be made. The comparison of the overall average result shows the constant result on both transparent concrete samples for 3 days. The result in Figure 10 indicates the fibre optic is able to transmit lights from one face to another face. The result shows addition of fibre optics in the transparent concrete allows more daylighting.

Figure 9
Interior Image of Transparent Concrete

Transparent Concrete (290 Optical Fiber)

Transparent Concrete (560 Optical Fiber)

Table 2
Daylighting test result (Day 1).

7/6/ 2022 (Outdoor Temperature: 31 °C)			
Duration	**Light Illuminance / lux (Daylight)**		
	Conventional Concrete	**Transparent Concrete (290 optical Fibre)**	**Transparent Concrete (560 optical Fibre)**
0 minute	-	245	330
15 Minutes	-	282	325
30 Minutes	-	278	318
Average Light Illuminance	0	268	324

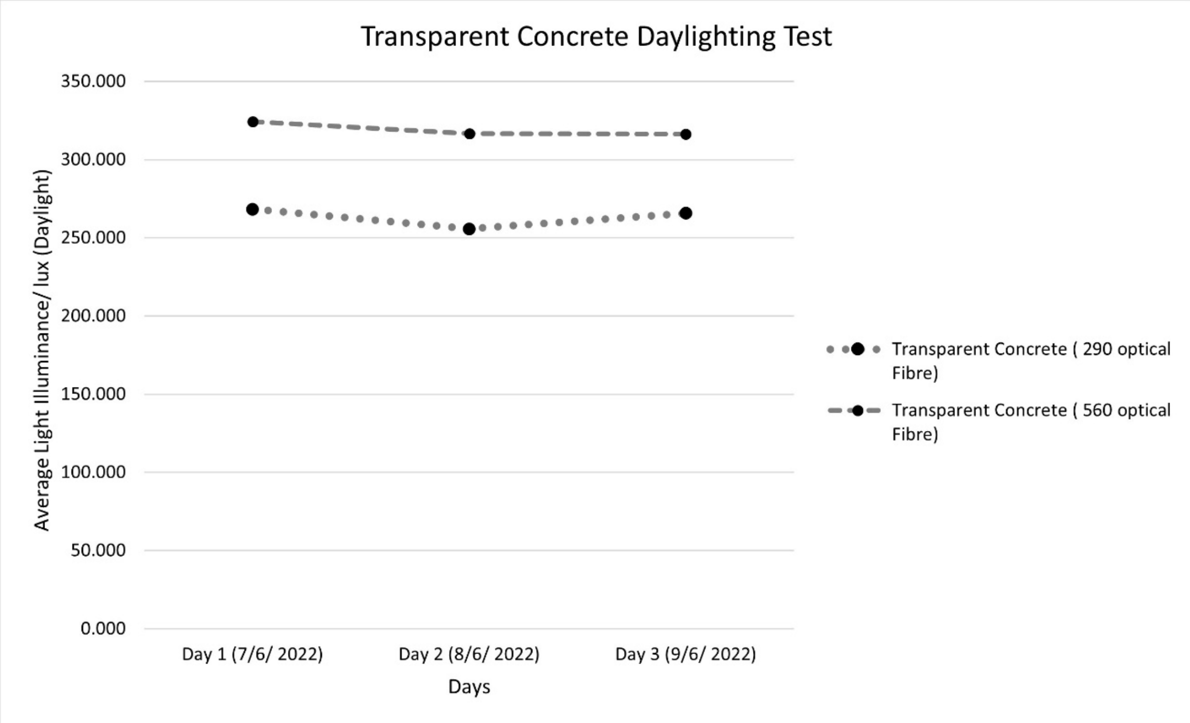
Table 3
Daylighting test result (Day 2).

8/6/ 2022 (Outdoor Temperature: 30 °C)			
Duration	**Light Illuminance/ lux (Daylight)**		
	Conventional Concrete	**Transparent Concrete (290 optical Fibre)**	**Transparent Concrete (560 optical Fibre)**
0 minute	-	237	340
15 Minutes	-	273	312
30 Minutes	-	257	298
Average Light Illuminance	0	256	317

Table 4
Daylighting test result (Day 3).

9/6/ 2022 (Outdoor Temperature: 32 °C)			
Duration	**Light Illuminance / lux (Daylight)**		
	Conventional Concrete	**Transparent Concrete (290 optical Fibre)**	**Transparent Concrete (560 optical Fibre)**
0 minute	-	290	325
15 Minutes	-	297	316
30 Minutes	-	210	308
Average Light Illuminance	0	266	316
Total Average Light Illuminance		**263**	**319**

Figure 10
Total average light illuminance of transparent concrete



Effect of Solar Radiation on Thermal Conductivity of Transparent Concrete

The results of the effect of solar radiation on thermal conductivity of transparent concrete are shown in Table 5, Table 6, Table 7, and Figure 11. The conventional concrete shows the highest average temperature at 0 minute, 15 minutes and 30 minutes compared to transparent concrete of 290 optical fibre and transparent concrete of 560 optical fibre. The thermal image displays the level of heat transferred to the concrete samples.

The blue colour indicates the coolest area and gradually increases to green, yellow, and red indicating the highest temperature of the concrete. The thermal image shows the colour gradually turning from blue to green at the small area at below all 3 concrete samples after 15 minutes. At 30 minutes, the thermal image shows green and yellow gradually developing in bigger areas of the concrete samples. The conventional concrete indicates a larger area with green and yellow colour compared to transparent concrete of 290 optical fibre and transparent concrete of 560 optical fibre. Instead, the transparent concrete of 560 optical fibre results in the smallest area of green and yellow colour based on the thermal image at 30 minutes.

The maximum temperature drops on day 1 between conventional concrete and transparent concrete of 560 optical fibre are 1.44 °C. The maximum temperature drops on day 2 between conventional concrete and transparent concrete of 560 optical fibre are 0.67 °C. The maximum temperature drops on day 3 are 0.87 °C. The total average temperature different between conventional concrete and transparent concrete of 290 optical fibre are 0.433°C. The total average temperature difference between conventional concrete and transparent concrete of 560 optical fibre is 0.989°C. The total average temperature difference between transparent concrete of 290 optical fibre and transparent concrete of 560 optical fibre is 0.556°C.

Based on Figure 11, the overall result shows the thermal conductivity of the concrete with poly methyl methacrylate optical fibre is lower than conventional concrete. It also shows the higher usage of fibre optic has resulted in less thermal conductivity. The highest temperature drops on day 1 with a high surface temperature indicates more effectiveness of fibre optic. Therefore, the plastic fibre optic shows the greatest effect on thermal resistance compared to conventional concrete.

Table 5
Thermal test result (Day 1).

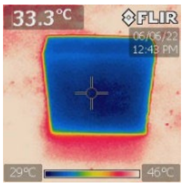
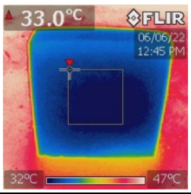
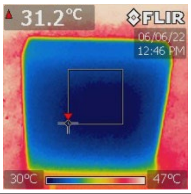
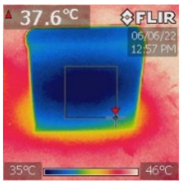
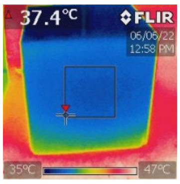
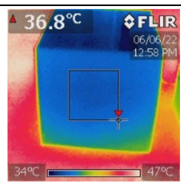
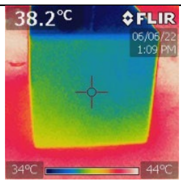
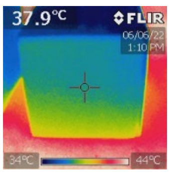
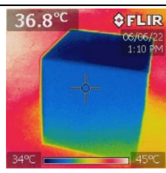
7/6/ 2022 (Outdoor Temperature: 31 °C, 12.40pm)			
Time	**Thermal Infrared image/ Temperature (°C)**		
	Conventional Concrete	**Transparent Concrete (290 optical Fibre)**	**Transparent Concrete (560 optical Fibre)**
0 minutes			
	33.3	33.0	31.2
15 minutes			
	37.6	37.4	36.8
30 minutes			
	38.2	37.9	36.8
Average Temperature	36.37	36.10	34.93

Table 6
Thermal test result (Day 2).

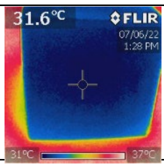
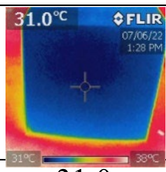
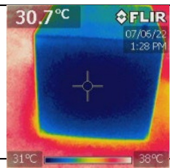
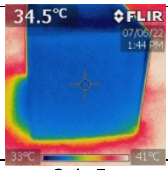
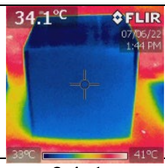
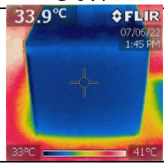
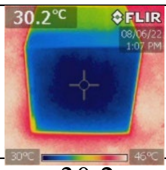
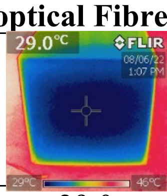
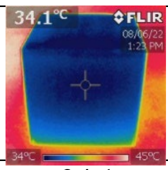
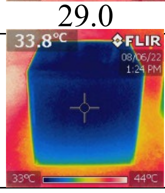
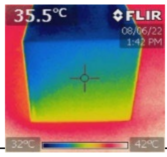
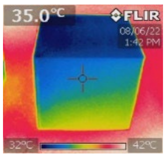
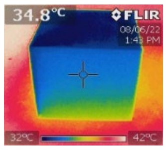
8/6/ 2022 (Outdoor Temperature: 31 °C, 1.00pm)			
Time	**Thermal Infrared image/ Temperature (°C)**		
	Conventional Concrete	**Transparent Concrete (290 optical Fibre)**	**Transparent Concrete (560 optical Fibre)**
0 minutes			
	26.9	26.6	26.4
15 minutes			
	31.6	31.0	30.7
30 minutes			
	34.5	34.1	33.9
Average Temperature	31.00	30.57	30.33

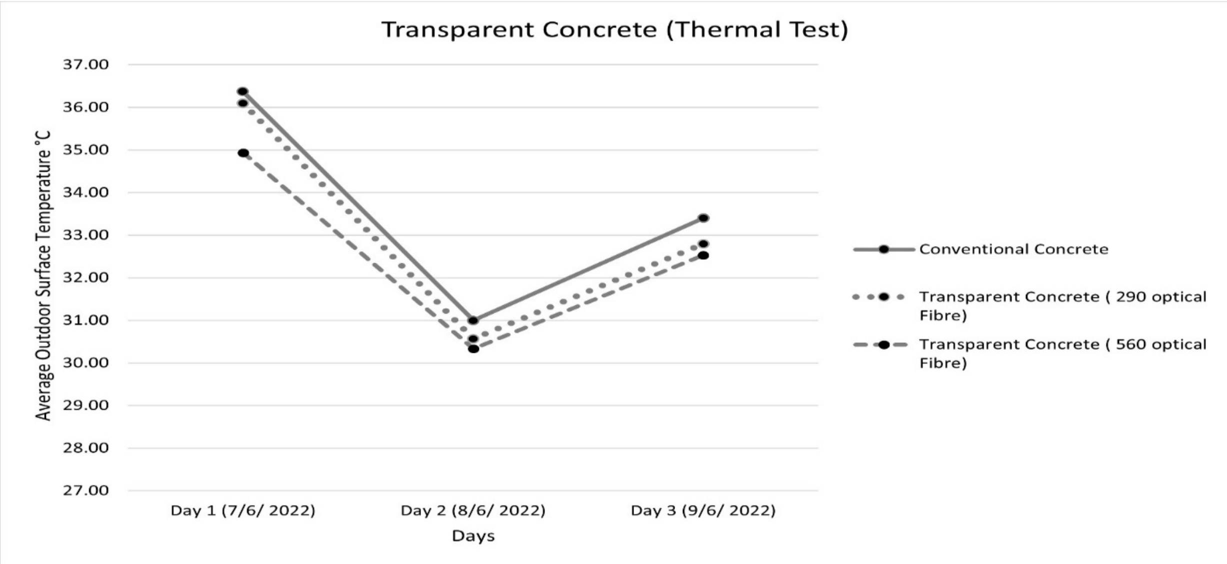
Table 7
Thermal test result (Day 3).

9/6/ 2022 (Outdoor Temperature: 32 °C, 1.00pm)			
Time	**Thermal Infrared image/ Temperature (°C)**		
	Conventional Concrete	**Transparent Concrete (290 optical Fibre)**	**Transparent Concrete (560 optical Fibre)**
0 minutes			
	30.2	29.3	29.0
15 minutes			
	34.5	34.1	33.8

30 minutes			
	35.5	35.00	34.8
Average Temperature	33.40	32.80	32.53

Total Average Temperature	33.589	33.156	32.600

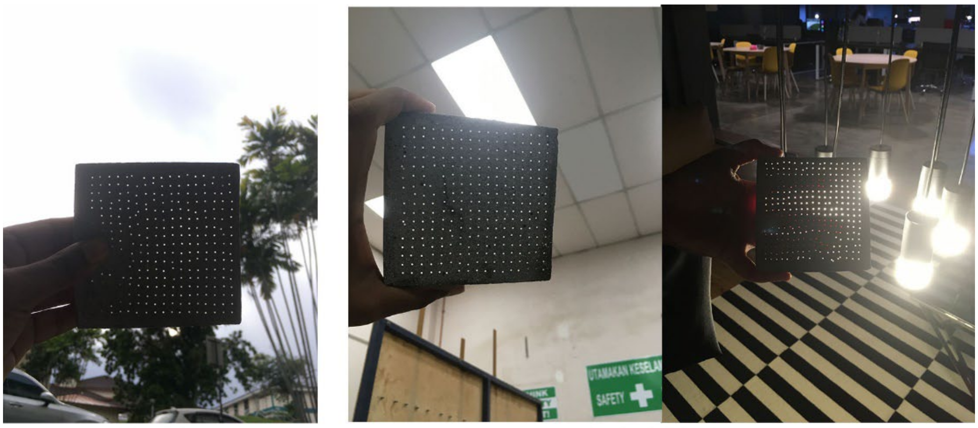
Figure 11
Total average thermal conductivity of transparent concrete



Visual Effects of Transparent Concrete

The Figure 12 below shows that the light transmission is clearly identified on transparent concrete. The surface area of the whole concrete increases as the diameter of the poly methyl methacrylate (PMMA) fibre optic increases, and the light transmission increases as well. The visual shadow effect on the object may vary according to the brightness of the light source. The transparent concrete can also be designed in various arrangements of poly methyl methacrylate (PMMA) fibre optic to indicate the flexibility of the concrete.

Figure 12
Visual effect of transparent concrete



Daylight Artificial Light
Transparent Concrete (290 Optical Fibre)

Daylight Artificial Light
Transparent Concrete (560 Optical Fibre)

CONCLUSION

Based on this study, fiberglass chopped strands in concrete mixture able to improve the constructability, workability to the point where it could be poured firmly into the mould during the process of transparent concrete. This experiment selects fibre optic as the primary material to study the effects of daylighting, thermal and visual effects. The effects of different proportions of poly methyl methacrylate (PMMA) on light transmission and thermal performance are discussed. The concrete samples were placed below sunlight to analyse the light transmission and thermal conductivity of conventional concrete and concrete with fibre optic.

In conclusion, transparent concrete has a distinct light transmittance property that can maximise daylight usage during the daytime. At night the transparent concrete can be visually attractive and welcoming for buildings, furniture, and hardscapes. This study shows the improvement in light transmittance after the percentage and number of optical fibre usage increases. Moreover, it also indicates that the thermal performance was improved using transparent concrete compared to conventional concrete. It shows the lower temperature of the concrete as the number of poly methyl methacrylate (PMMA) fibre optic increases. It indicates that the use of fibre optic improved the thermal conductivity of the concrete.

The main contribution of this experiment indicates that the higher usage of poly methyl methacrylate (PMMA) fibre optic allows more daylighting and lower the thermal conductivity and heat gain. It also changes the perception of more light received, the more the heat conductivity increases. The study can highlight solutions on thermal comfort and high energy usage issues. It also delivers the potential of transparent concrete to increase the energy efficiency of a building. However, there is limitation of data for duration to measure thermal heat loss because of the local weather conditions which influence the temperature of the concrete. Therefore, further studies can explore the study of transparent concrete on thermal heat loss in longer duration which includes day and night temperatures. The study may benefit on lower usage of electricity and air-conditioning which helps to reduce energy consumption especially during daytime.

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