Waste Tyres as Heat Sink to Reduce the Driveway Surface Temperatures in Malaysia

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The development of roads and driveways are on the rise as automobiles are now a necessity to all. This excessive development with its requirements increased the urban heat temperature and the generation of waste tyres. Waste tyre management has therefore been taken seriously by developed countries and since the European directive to ban used tyre products and whole tire disposal from landfill in 2003 and 2006 respectively, many researchers have looked for alternative ways to use the waste tyre. In Malaysia, The Smart and Cool Home Developer attempted to develop an eco-house by utilising waste tyre as the foundation for the driveway and claimed that the buried tyres act as a heat sink for the concrete and reduce the surface temperature of the driveway.

Hence investigations were conducted on two sample houses to investigate this phenomenon. Findings from this pilot study show that waste tyres do act as a heat sink to the concrete driveways which affect the ambient temperature and relative humidity of the immediate surroundings.

Keywords: urban heat temperature, waste tyres, pavement surface temperatures, heat sink

1. URBAN HEAT ISLAND

Temperatures in urban areas are typically warmer than the surrounding rural areas (Bradshaw, 2006) and in the case of Malaysia 2 - 10 ºC difference is normal (Sarat and Eusuf, 2011). The urban heat island effect is caused by the replacement of vegetation with heat energy storing surfaces which build up the solar radiation absorption and reflection in the buildings and on site (Bradshaw, 2006). In addition, the anthropogenic activities through the use of fuels from either mobile or stationary sources, absence of air flow and reduction of heat sinks further increase the surplus of heat balance in cities (Santamouris et al, 2012). Global warming increases ambient temperature and the frequency of heat waves at micro level; indirectly amplifying the cooling load and thus increasing the heat generation.

Pavements cover a substantial percentage of urban and suburban surfaces as they absorb solar radiation, store the energy in the subsurface and discharge it through infrared radiation and convection to their surrounding area after the sun sets. This significant energy affects the temperature at the ground layer of the urban atmosphere. To mitigate the temperature increase, many techniques have been developed and applied, such as the use of advanced materials to decrease, disperse and reflect heat and solar radiation, strategic landscaping, green roofs, solar control systems and heat sink methods where the positive heat dissipate into the ground, water or the ambient air (Santamouris et al., 2012).

Heat sinks according to the American Heritage Science Dictionary (Houghton Mifflin Co., 2005) is ‘an environment capable of absorbing heat from substances within it (and with which it is in thermal contact) without an appreciable change in its own temperature and without a change in its own phase’. Basically a heat sink is an object that transfers thermal energy/heat from a higher temperature to a lower temperature through a medium. The medium is frequently the air and may also be the water.

One strategy to reduce the pavement temperature which was developed in Malaysia by The Smart and Cool Home Developer is by installing layers of waste tyres underneath the concrete driveway (Lian, 2005). Though there are hardcopy and softcopy newspaper articles on this finding, rigorous literature review revealed that there is no scientific evidence yet to elaborate how this application works. Thus, this paper investigates further the performance of waste tyres in reducing the surface temperature of concrete driveways.

2. WASTE TYRES RECYCLING

Waste tyres, a by-product of modernisation are non-biodegradable and a non-hazardous waste that takes an extremely long time to disintegrate. Waste tyres are a unique waste with a lot of potential for recycling. Unfortunately, if left in the open environment or landfill, they create many problems as they are bulky and occupy a large volume of space, hardly compactable and resurface to the top after burial, create a health problem as it becomes a haven for rodents, mosquitoes and other animals that carry diseases (Thiruvangodan, 2006; EPASA, 2010). Uncontrolled burning of tyres in the environment produces thick soot and ash and emits hazardous chemicals, such as polyaromatic hydrocarbons, lead, zinc, benzene and toluene, where the immediate health effects of the exhausted smoke would be irritation to the skin, eyes, mucous membranes, respiratory effects, central nervous system depression and may activate cancer cells. (EPA,1997).

Many developed countries have banned the disposal of waste tyre products and waste tyre itself from landfills (Imperial Innovations Quelle, 2008; Dhir et al., 2001). As such, industries and researchers investigate ways to reclaim its virgin components and recover energy and new materials from waste tyres through the highly technology oriented, expensive and excessive heat processes such as the de-vulcanisation, pyrolysis, gasification and hydrogenation processes (Ramos et al., 2011; Aniza and Rao, 2012).

The development of recycling huge amounts of waste tyres is still extremely poor in Malaysia. Previously, the government has encouraged the building of artificial reefs with waste tyres to raise fish in the sea. However, this practice was abandoned due to the leaching of zinc, benzothiazoles and a range of polyaromatic hydrocarbons released into the waters from the tyres that may restrained the growth of phytoplankton. In addition, the tyres when not strongly bound to the seabed would float during tidal waves; scattered and littered the sea bed and beaches and may also damage coral reefs (CIWMB, 1996; Dhir et al., 2001; Collins et al., 1995). Furthermore, the proposal to have rubberized asphalt road surface utilizing tyre crumbs was also abandoned owing to the high initial construction cost (Thiruvangodan, 2006).

At present, tyre manufacturers collect the waste tyres from tyre workshops for further recycling. Thus, collection is slow and there is a need to reduce storing problems and transportation cost.

Tyres have higher energy content compared to natural fuel sources. Therefore, most of the waste tyres are popularly used as an alternative fuel to supplement heat energy in the heating process of manufacturing cement and paper and thermal boilers to produce electricity (WBCSD, 2008; EPA, 1997). Unfortunately, tyres can only supplement up to 20% of the fuel in a controlled kiln to protect the environment from toxic gas emitted during the burning and maintenance of the kiln itself (Dhir et. al., 2001, Aliapur, 2011). With the increased in urbanisation, waste tyres are being produced all over the world at an alarming rate, thus the need for other forms of recycling becomes a necessity.

For ease of storage and better opportunities for recycling, the reclaiming and recovery of new materials, tyres are compressed or shredded into several sizes to form aggregates. Some are pure while some are still in their original form i.e. with fibres and steel mesh and are given various names depending on the final size (WBCSD, 2008) as shown in Table 1.

3. WASTE TYRES AND THERMAL INSULATION POTENTIAL

Many researchers have explored the potential use of waste tyres in cement mix due to the depletion of natural resources (Mavridou and Oikonomou, 2011). In the attempts to replace aggregates in the mix for cement plaster/coating and structural concrete, the size and purity of tyre rubber influenced the results of the research products (Chou et al., 2007; Ganjian et al., 2009; Nehdi and Khan, 2001).

Thermal performance of rubberised concrete structure and cement mix have been known for quite some time but only recently is this property being explored quite rigorously (Yesilata et al. 2011). Many investigated the freezing and thawing capabilities of cement

Table 1: Waste tyres recycling, reclaiming and recovery uses and by-products

Reclaiming and recovery of tyre material (high technology)		**Recycle tyre –whole tyre or other forms**		
De-vulcanisation	Waste tyre compound	Whole tyre	-	• Retreading, • Tyre derived fuel, • Landscape use • Load bearing wall • Artificial reef
Pyrolysis	Coal/carbon black, oil, steel, gas	Tyre bale	Consists of > 100 tyres, compressed and tied to form tyre brick, size:1.52 x 1.27 x 0.76m, weight: 1 tonne	• Road sub-base • Retaining wall • Acoustic wall
Hydrogenation	Crude synthetic fuels	Aggregates	• Cut size : >300mm • Shred: 50 - 300mm • Chips: 10 to 50mm • Buffing: 1 – 40mm • Granule:1– 10mm • Powder: under 1mm • Fine powder: <0.5mm/ <500µm	• Infill materials in geotechnical works, sub-base for road • Asphalt mix road coatings • Light buildings elements • Landscape products • Polymer base / rubber products
Gasification	Synthetic gases – hydrogen and carbon monoxide			
Electric arc furnace and steelmaking	Steel and carbon			

(Source: Ramos et al., 2011; E.T.R.A, 2002; Aniza and Rao, 2012)

plaster coating of which successes also varied depending on the various amounts and sizes of rubber aggregates and the type of cement used (Turgut and Yesilata, 2009; Yesilata et al., 2009; Turgut and Yesilata, 2008; Siddique and Naik, 2004).

In the freezing and thawing tests, cement mix with tyre rubber powder of less than 20% showed more than 60% durability factors after 300 freezing and thawing cycles; while this is not acceptable at all for coarse rubber tyre mix which are larger in size and with non-uniform air entrapment distribution (Nehdi and Khan, 2001). Stankevicius et al. (2007) further calculated the freezing and thawing resistance of the rubber powder mix cement plaster and the results showed that plaster with the addition of fine rubber waste of 10% has the value of 7 – 8 times higher than typical plaster mixes in preventing plaster cracks during the freezing and thawing test.

Yesilata et al. (2009) tested tyre rubber pieces for thermal insulation properties where 50 x 2mm thick tyre rubber were laid in ordinary concrete and cured for 10 days prior to a dynamic adiabatic-box technique test; with results that showed the thermal property of the concrete was improved by 18.25%. Thermal conductivity of tyre depends on the tyre component, shred sizes, the surrounding conditions it is in and temperature gradient (Edaskär, 2004; CWA, 2004; Sellassie et al., 2007). The bigger the rubber piece the longer it takes to reach steady state temperature (Sellassie et al., 2007). This indicates the increase of thermal resistivity with the increment of size; and when tyre shreds have more wire content as in the tread portion, more thermal conductivity occurs.

Infrastructure works in USA and Europe using tyre shreds and tyre bales as the road sub-base over soft ground do have thermal properties study of the tyre pieces, however the concern is more on the thermal behaviour of the shreds in the freeze-thaw resistance and overheating of the tyres under environmental exposure. The risk of spontaneous combustion of tyre bales is considered low as oxygen has been extracted out when the tyres are compressed and the exposed rubber surfaces are greatly reduced. Furthermore, bales used under the road are compacted and buried under the ground and further cushioned with soil on top avoiding direct contact with sun radiation, thus preventing exothermic reaction of the bales (Winter et al., 2005). Thermal conductivity of tyre shreds is significantly lower than common soil and varies with particle size (Mavridou and Oikonomou, 2011; Khatib, 2009). Investigations on the thermal decomposition of rubber chips concluded that tyre chips decompose at the temperature of 300ºC (Amosova et al., 2004).

3.1 Waste tyres in house construction

Earth-sheltered houses pioneered by architect Michael Reynolds is an environmentally benign construction made from recycled and reclaimed materials (Freney, 2009; Hall 2009; Ip et al. 2005). One of the main feature of the house is the rammed earth tyre wall which acts as retaining wall, load bearing wall and thermal mass to insulate against the cold winters and hot summers (Grindley and Hutchinson, 1996; Hall, 2008; Freney, 2009). The tyre wall is protected from water trickling down from the environment above to enhance its uses as thermal mass for better moderation of the indoor air temperatures (Ip et al., 2005) and prevented from off-gasing by the adobe plaster wall (Freney, 2009).

Figure 1: Aerial view of an 'Earthship".
Source: Reynolds, www.dreamgreenhomes

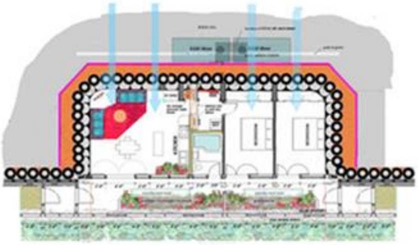

Figure 2: Typical 'Earthship' floor plan.
Source: Reynolds, www.dreamgreenhomes

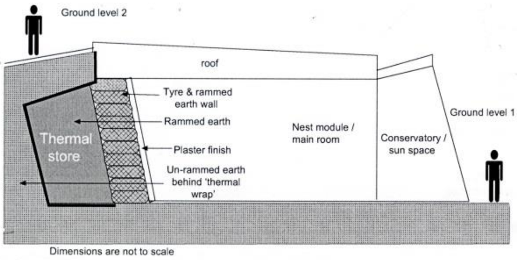

Figure 3: Section of the 'Earthship'.
Source: Ip & Miller, 2009

The rammed earth tyre wall temperature readings taken on vertical and horizontal points exhibit a higher temperature at the top surface of the wall (closer to the roof) and lower temperature as it approaches floor level; while the rammed earth temperatures show the inner surface of the soil closer to the thermal store behind the tyre wall (refer figure 3) has minor changes in temperature while the rammed earth temperature closer to the room surface illustrates more heat variations.

This indicates that the earth inside the tyre wall temperature is affected by its immediate surroundings; when the room heats up during the day, it absorbs the heat and becomes a heat sink, while at night it becomes a thermal mass and slowly releases the heat to regulate the internal temperature (Ip et al., 2005; Ip and Miller, 2009; Grindley and Hutchinson, 1996). However, studies on Earthship does not really investigate the function of the tyre and its capabilities in absorbing the heat and not how the tyres assist in maintaining the soil temperatures.

In other thermal insulation studies by Yesilata et al. (2011), a concrete structure with tyre rubber pieces in the center of the concrete floor and roof and crumb tyre concrete mix walls is able to moderate the room temperatures at an average of 12% improvement throughout a yearly weather fluctuations, compared to a structure without tyre rubber insulation. This illustrates a similar trend of heat sinks to the tyre wall in Earthship.

Therefore, it can be summarised that tyre rubber is a good and cheap material for used as an insulation material in housing development, though more research is required to prove its performance.

4. ECO-HOUSE DEVELOPMENT IN MALAYSIA

According to Calkin (2009), sustainable designs are green designs which are supposed to be eco-friendly with a low carbon footprint and operate on low energy. Some common principles are:

- Use of low-impact materials in buildings - non-toxic, sustainably produced or recycled materials which require little energy to process
- Energy efficiency or low energy – building design to promote less energy usage during its lifetime for cooling or heating
- Quality and durable buildings that will be longer-lasting, better-functioning and need little maintenance
- Design for reuse and recycling
- Healthy Buildings design with the aim to create buildings that are neither harmful to their occupants nor to the larger environment during and after construction. Important emphasis is on indoor environmental quality, especially indoor air quality.

Many Malaysian developers claimed their development are eco-friendly but in actual fact only the landscape design and road construction may be considered as eco-friendly; the houses developed are still made from typical building materials and most of them are fully air-conditioned with solar panel and rainwater harvesting systems being optional to the house owners(www:spsetia.com,www:iskandarmalaysia.com).

The Smart and Cool Home Developer tried to be a true eco-friendly developer by using a few techniques to cool down their built houses which included utilizing aerated concrete block walls, double glazed windows, 'Bernoulli Effect' ceiling design and embedded waste tyre foundation system. In these houses, although are 100% naturally ventilated, windows are advised to be closed during the hot hours of the day to prevent external heat from entering the internal environment, air circulation inside the house is provided via ceiling fan. Moreover, night ventilation is encouraged to promote fresh air changes (Ismail and Rashid, 2011).

At an initial inspection, a barefoot walk on the solar exposed driveway was done to investigate the heat sink phenomena as claimed by the developer. The concrete driveway surface was cool under the bare feet during the sunny and hot afternoon. Further interviews with the developer revealed that beneath the exhibition house (inclusive of the driveway) are three layers of waste tyres which were laid in between ground beams with a layer of damp proof membrane before the concrete slab.

To investigate this phenomenon, two sample houses were selected for this purpose: Sample House 1 (H1) which is the exhibition house itself located in Tasek Kesuma, Beranang District, Selangor. At the time of measurement, the house was under refurbishment and as such, readings in the interior of the house were not allowed. Sample House 2 (H2) is another detached house located in Bangi Golf Resort, Bangi District, Selangor where only two layers of tyres were laid under the exposed driveway with the porch and the interior of the house free from any embedded tyre.

Selection was made based on the locality of the houses and having two different tyre layers to enhance knowledge on the tyre performance as heat sinks. Many other houses built by this developer are located in Melaka and timing was crucial for this pilot study.

5. MEASUREMENTS METHODS

Malaysia as a tropical country has high temperatures and high humidity throughout the year (World Travel Guide 2012). In the west coast of Peninsular Malaysia, April is a transitional period between monsoon seasons. Generally the weather is sunny in the morning with cloudy and/or rainy afternoons with average temperatures between 24° to 34°C (Selective Asia Ltd, 2010).

Readings on the surface temperature of the driveways and porches of the sample houses were conducted for three consecutive days for each house from 17 to 19 April for Sample House 1 and 20 to 22 April, 2012 for Sample House 2. Measurements were made using the following instruments:

a. A hand-held infra-red thermometer to read the surface temperature.
b. A compact thermo hygrometer to measure the relative humidity and ambient temperature held at 1m above ground surface.

Locations of surfaces for measurement were selected based on the duration of surfaces exposed under the sun, in the shade and on the culvert above the open drain which would illustrate the effect of having full ventilation below a concrete slab. Averages of three readings were made for every 30 minutes from 9.30am to 7.00pm.

6. LIMITATIONS OF STUDY

During the days of measuring H1, the weather was sunny in the morning, cloudy in the afternoon with slight drizzling on day 1 and heavy rain on days 2 and 3. While measuring H2, the weather was sunny in the morning, cloudy in the afternoon on days 1 and 2 and with slight rain on day 3. Due to the nature of this investigation being a pilot study, the days with almost similar weather conditions are selected for the purpose of comparison, readings taken on day 1 for H1and day 3 of H 2 are discussed in this paper.

7. DISCUSSION ON RESEARCH FINDINGS

7.1 Sample House 1(H1)

H1 site plan with the selected surface point locations are illustrated in Figure 4. Locations of points 1 and 2 on the neighbour's driveway are also marked for reference. From the three days of

Table 2: Relative humidity, ambient and surface temperatures measurements for House 1 on days 1- 3

Temperature	ST A under sun °C	ST B under sun °C	ST F vent below °C	ST G shade °C	AT sun °C	% RH sun	AT shade °C	% RH shade
Min & max time								
H1D1 12:30pm 9.30am	46.0	45.8	47.2	32.4	35.3	55.1	34.9	57.4
	31.2	33.2	34.2	30.8	31.4	64.3	29.9	72.4
H1D2 12:30pm 7.00pm	47.2	**52.0**	50.4	32.4	**36.0**	50.3	33.2	62.6
	31.6	31.6	31.4	**29.0**	25.1	**93.1**	**24.9**	92.5
H1D3 2.00pm 7.00pm	40.4	39.6	38.2	39.8	30.7	67.9	30.3	70.0
	32.2	31.6	31.2	29.8	28.1	83.0	28.1	81.5

Table 3: Comparison between H1 driveways to neighbour's (NH) driveway on Day 1

Time	NH loc. 1 °C Under Sun	NH loc. 2 °C Under Sun	H1:ST A °C Under sun	AT °C Under sun	RH% Under sun
11:00am	44.4	44.6	38.0	31.5	60.3
3:30pm	53.0	53.4	46.6	35.3	55.1

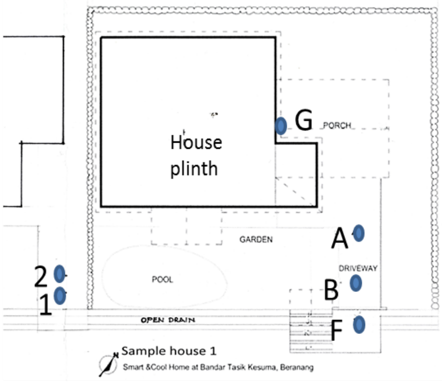

Figure 4: Sample house 1 site plan

data collection, each day's minimum and maximum surface temperatures are presented in Table 2 for discussion. Generally, the ambient temperature (AT) for H1 reached its peak before 2.30pm as it was cloudy and rainy on all three afternoons.

For both points A and B which were under the sun, the differences in temperature may be due to their positions of being either on top of the tyre layers or above the void of the tyres. The absolute maximum surface temperature was at point B which reached 52.0°C when the ambient temperature was 36.0°C; while the absolute minimum surface temperature at point A was 31.2°C which was slightly lower than the ambient temperature. The fluctuation of these surface temperatures against the ambient temperature is between 10 to 16°C.

Surface G which is in the shade has less temperature fluctuations when compared against the ambient temperature taken at a similar location. The temperature fluctuations between the surface temperature G and ambient temperature vary with maximum differences around 3°C.

Surface temperatures of concrete slab at point F above the open drain may be slightly lower or higher than surface temperatures of pavement above the tyres, as they are affected by the ambient temperature, relative humidity and site ventilation. The surface temperatures at point F fluctuates within 1 to 3°C only compared to temperatures at point A and B.

The driveway surfaces temperature of H1's neighbour was taken for sampling purposes only on day 1 as this house was also under renovation and entry was prohibited.

Both driveways are made of similar stamped concrete surfaces. Two surface temperatures of the driveway exposed under the sun are shown in Table 3 with these measurements compared to the H1 driveway measurement at point A. Though these measurements may not be an acceptable comparison in terms of quantity taken, it can be deduced that the concrete surface driveway of H1 is cooler by 6 - 7 °C on that particular day under the same meteorological conditions.

Figure 5 illustrates a line chart of the maximum and minimum ambient and surface temperatures in relation to relative humidity on day 1 which indicates that the surface temperatures increased rapidly with the ambient temperature increment but decreased gradually.

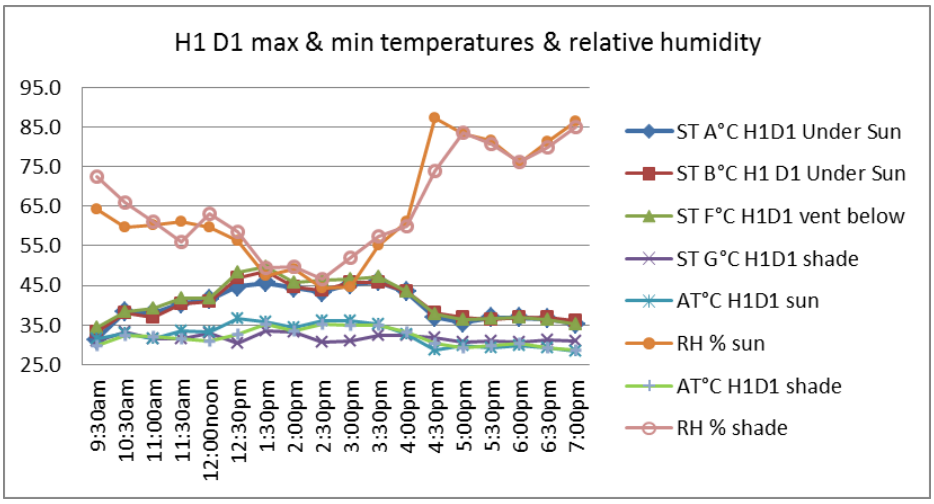

Figure 5: Temperatures and relative humidity for H1 D1

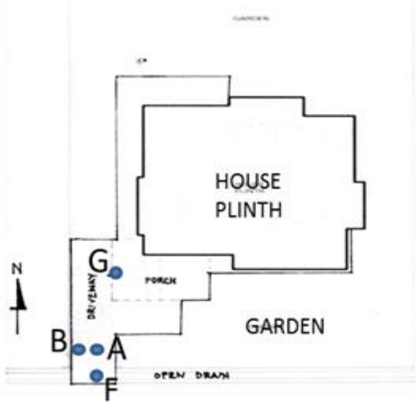

Figure 6: Sample house 2 site plan

7.2 Sample House 2 (H2)

H2 site plan is presented in figure 6 to indicate the surface points selected for measurements. Surface temperature G was under the shade in the morning and received sunlight around 12.00pm. Therefore comparison for this surface temperature can only be considered for readings taken before 12.00pm.

All three surfaces under the sun at points A, B and F had almost similar temperature readings with point B reaching its absolute maximum of 54.2°C while the ambient temperature reached its absolute maximum at 36.9°C on day 3. The fluctuation of absolute surface temperatures at points A and B against the absolute ambient temperatures was between 6 to 17.3°C. Surface temperature G could have gone below or higher than the ambient temperature with similar conditions. Considering the absolute minimum temperatures of mornings only, the temperature fluctuations against the ambient temperature was approximately 2°C.

Surface temperatures of concrete slab at point F above the open drain may be slightly lower or higher than surface temperatures of pavement above the tyres but the temperature fluctuations against the ambient temperature was between -5.6°C to +15.3°C as it is affected by the ambient temperature, relative humidity and when fully ventilated from top and bottom surfaces. Ambient temperature under the sun fluctuated around 12°C, while the relative humidity was higher when the ambient temperature was lower and vice versa.

Figure 7 illustrates the surface temperatures increased exponentially but decreased more gradually compared to H1 D1. Generally H1 had lower surface temperatures than H2 as shown in Figure 8. The trend for the higher surface temperatures in H1 were within the 30s to 40s °C range while for H2 the surface temperatures fluctuated between 30s to 50s°C. H1 had the highest surface temperature of 52 °C at location B with the ambient temperature of 36.0°C at 12.30pm, while H2 had the highest temperature of 54.2°C at point B with the highest ambient temperature of 36.9 °C at 1.30pm. This indicated the ambient temperature of the driveway was affected by the surface radiation from the concrete driveway.

In general, surface temperatures at point G of H1 were cooler and maintained almost similar temperatures throughout the 3 days. This could be attributed to the house having three layers of embedded tyres throughout the ground floor plinth. In H2 the surface temperature at point G was shaded in the morning and received sunlight in the afternoon hence the reason for the sudden temperature hike after 12.00pm. However, its surface temperatures in the morning were slightly lower by 1to 2°C only compared to point G's temperatures in H1.

Table 4: Relative humidity, ambient and surface temperatures measurements for H2 for days 1- 3

Temperature	ST A under sun °C	ST B under sun °C	ST F vent below °C	ST G shade °C	AT sun °C	% RH sun	AT shade °C	% RH shade
Min & max time								
H2D1 2:30pm	48.4	47.0	47.8	46.0	34.3	61.4	31.8	70.4
5:00pm	31.2	**30.2**	30.6	28.8	**25.0**	92.8	25.1	**93.6**
H2D2 3:00pm	47.0	47.4	47.0	44.2	35.0	52.3	31.2	68.4
9:30am	31.2	30.6	27.6	29.4	27.4	84.7	27.4	85.6
H2D3 1:30pm	52.4	**54.2**	52.2	49.4	**36.9**	49.9	34.6	50.7
9:30am	35.2	34.4	29.8	28.8	31.5	70.4	30.1	73.2

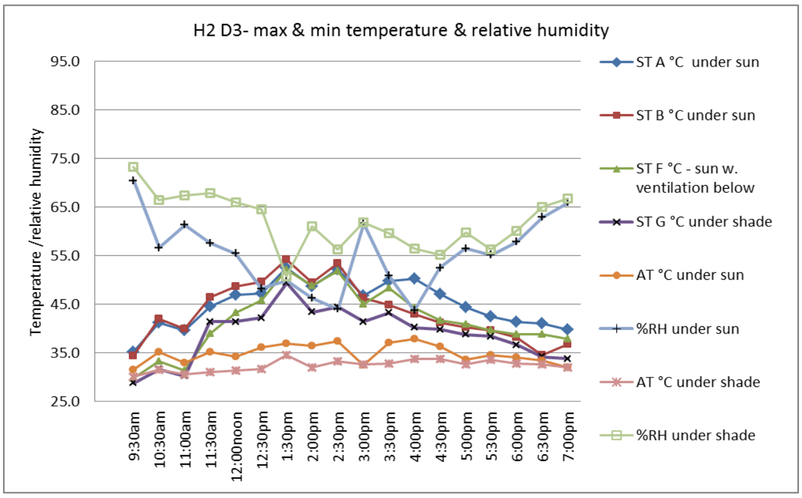

Figure 7: H2 D3- Temperatures in relation to relative humidity

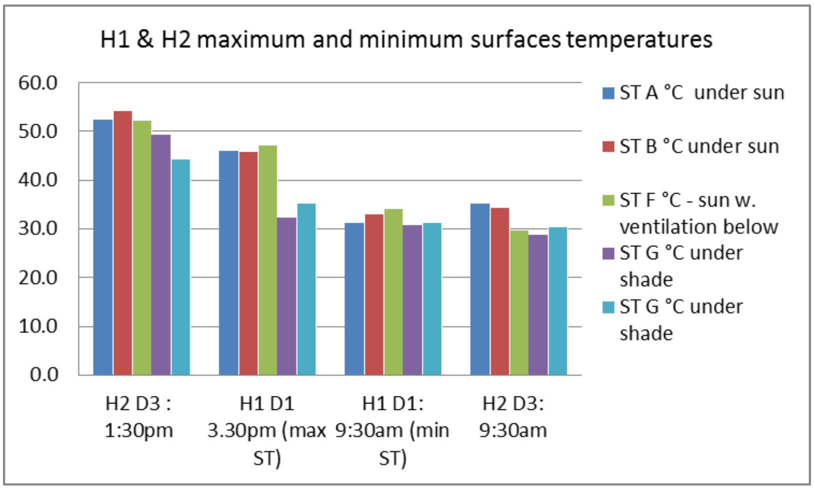

Figure 8: Surfaces temperatures comparison between H1 and H2

The body of waste tyres is black in colour, has a round form and contains a big void filled with ambient air. Black materials are good heat absorbers and emitters while air is the slowest heat transfer medium, thus the temperature difference between points A and B. Both the tyre and the air thermal resistance are affected by the methods of heat transfer within the cavity. In this instance, the tyre conducts the heat received from the concrete while the airspace resistance is affected by heat radiation and conduction from the concrete slab and waste tyres, heat

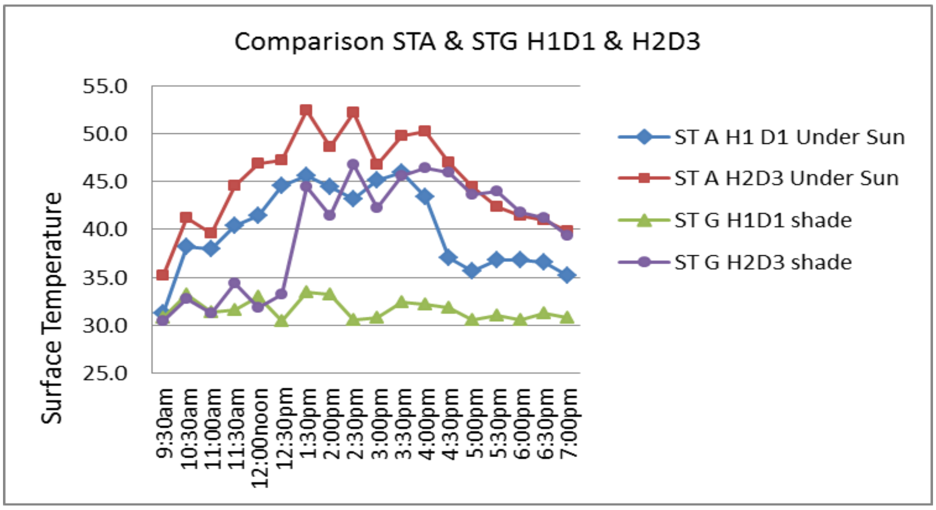

Figure 9: Comparison of surfaces temperatures under the sun and in the shade

convection, if any, from the sub ground. The moisture content of the soil and ambient air within the cavity depends on the heat received from the two solid elements and the depth of the excavation. The deeper the excavation the longer it will take for the heat to sink to the sub-soil as more heat is being absorbed by the tyres which coincides with investigations by Sellasie et al. (2007) where bigger tyre pieces were able to absorbed more heat.

8. CONCLUSIONS

The conclusions deduced from this pilot study are as follows:

1. Generally, a concrete driveway with three tyre layers embedded under it recorded lower surface temperatures than a driveway with 2 tyre layers.
2. An exposed concrete surface with full ventilation is very much affected by the ambient temperature, wind speed and relative humidity.
3. Less tyre layers sink heat faster and increase the surface temperature faster compared to more tyre layers.
4. Waste tyres have the potential to be used as a heat sink to improve the ambient temperature for eco-houses thus reducing the urban heat island at micro level. Pavement surfaces requires no additional maintenance than any typically stamped concrete driveway while simultaneously enables the reduction in the number of waste tyres left in the environment.

Further study on the potential of waste tyres as a heat sink is underway to clarify the mechanics of the heat transfer of the tyre and its effects on the subsoil, surface and ambient temperatures.

9. ACKNOWLEDGMENTS

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Interviews

Mr. **&** Mrs Lincoln Lee from The Smart and Cool Home Developer, date of interview 20. 3. 2012

Prof. Elias Salleh, the Bangi Golf Course (H2) house owner, date of interview 31. 3. 2012

Mr. Thang Thim Chee, the exhibition house (H1) owner, date of interview 29.4.2012