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Thermal Performance Study of White Cement Tiles

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ABSTRACT

Sunlight is a natural source of infinite clean energy. Climate change is increasing cooling and heating energy demands worldwide. Overexposure of sunlight in summer heats up buildings, which in absence of winds and clouds leads to heat island effect. Cooling power demand may be minimized by increasing roof thermal resistance. Reflective rooftop materials cool down building interiors by repelling incident solar heat flux during sultry summer in tropics as well as arid regions. This work reports results of thermal performance study of a white cement natural air conditioning tile. Outside and inside air temperature measurements have shown the tiles restrict inside temperature to be 30±2°C when outside air temperatures vary from 37 to 44°C. Outside and inside temperature differences were found to be 13±5°C. Inside and outside air temperatures of fired clay bricks rooftops were found to be 8-12°C when rooftop air temperature varied from 33 to 40°C. White cement tiles rooftop was found to reduce 5 to 6°C temperature more than equivalent fired bricks rooftops and 5 to 7°C more than equivalent grey cement rooftop buildings. A newly manufactured 1inch thick white cement tile without polyurethane for summer exhibits even superior thermal performance.

KEYWORDS: Cool roof, Sunlight reflectance, Building insulation, Tiles, Paints, Shingles

1. INTRODUCTION

Sun is the ultimate source of energy driving all biochemical processes to convert energy in different forms. Earth itself is also a big source of energy radiating 44.6 TW continuously. Sun sends a radiant flux of 74 PW continuously to planet earth. Sun emits a wide continuum of electromagnetic radiations however light flux reaching earth's surface primarily consists of ultraviolet, visible and infrared radiations. Sunlight is mainly distributed over visible and infrared parts of solar spectrum. Infrared (700-2500nm) contains 52% of solar irradiance spectrum (300-2500nm), visible light (400-700nm) 43% and ultraviolet (300-400nm) 5%. Flat rooftop buildings in arid regions are generally built with grey cement concrete which quickly heat up in summer due to low thermal resistance [1]. The attics bellow sloped tiles in tropical regions get hot due to material thermal inertia. A simple pigmented transparent topcoat on near infrared basecoat on the solid surfaces can increase overall sunlight reflectance of commercial terracotta tiles in UV and visible regions from 0.20-0.40 to 0.80 and 0.95 [2]. Most of solar heat enters into buildings through roof and walls by radiation and conduction mechanism. Building materials are naturally IR reflective which property may be enhanced if necessary by applying coatings. Fired bricks and terracotta tiles have been used since Roman times. Common clay tiles have reflectance of 0.2 to 0.35 which may be coated to improve their thermal performance. Black and white surfaces often have reflectance of 0.1-0.2 and 0.7-0.8 respectively [3]. Reflectance measuring methods are reported in literature [4]. Temperature studies of natural stones show there are heat and chill oasis and islands on surfaces of multicolor marbles and stones due to their different solar reflectance indices. One can sense this difference by standing on multicolor stone floor under sun. Application of white stone on rooftop can effectively minimize sunlight thermal effects [3]. Surface temperatures of white and black coated rooftops may approach 40°C and 65°C for an ambient temperature of 34°C. Temperature increases exponentially over time from morning to afternoon due to roof heat island effect [5].

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Hybrid PVT shingles provide rooftop cooling as well as solar electricity. PVT shingles save energy bills @ 0.4-0.5kWh/m^2 daily in addition to lowering temperature by 5°C compared to uncovered buildings [6]. Reflectivities of natural black, grey and white marbles are 0.07, 0.49 and 0.82 respectively. Natural reflectivities of forests, bare soil, green grass, sand, ice, white paper and snow are 0.08, 0.17, 0.25, 0.40, 0.55, 0.70-0.80 and 0.80-0.90 respectively. Reflectivity depends upon material composition, surface texture and physical orientation but usually shiny surfaces have higher reflectivities than opaque rough surfaces. Marble and stone floors are also brightened with travertine stone after grouting. Common construction materials such as concrete, white enamel, white tiles, white lacquer and silvered mirror have reflectivities of 0.25, 0.70, 0.78, 0.83 and 0.86 respectively. White clay-cement concretes and tiles have general 0.65-0.80 and 0.60-0.80 solar reflectance and 0.85-0.90 and 0.90-0.93 infrared emittance. White painted metals have 0.60-0.75 reflectance and 0.80-0.90 emittance. White, red and black shingles have 0.20-0.30, 0.25-0.30, 0.04-0.05 reflectance and 0.80-0.90 infrared emittance. Reflectance of coatings, paints, cements and shingles declines over time due to weather effects [7]. Methods to fabricate reflective non-white surfaces have been reported in literature [8]. Solar reflectance index (SRI) may be used to express albedo values of rooftop tile, shingle and paint performance. Generally 20% of urban space is roofed that can be cooled by one or other method shown in Fig.1.

Fig.1 Rooftop sun reflective options in market.

Fraction of sunlight reflected by earth's atmosphere is called albedo (a) which is generally 0.3 to 0.4. Surface compositions of urban areas consist of 28% roofs and 16% roadways having albedos of 5-80% and 5-40% respectively. Asphalt and white top cements have average lives of 15 and 25 years with albedos of 5-10% (new) to 15-20% (old) and 70-80% (new) to 40-60% (old) respectively [9]. Metals exhibit higher reflectivities than stones and marbles. Aluminum exhibits reflectivities of 0.92 for 300 to 700nm light spectrum and 0.95% to near infrared radiations. White cement composes of stable metal oxides and sand seems to exhibit outstanding performance to cool the buildings. Temperature difference between rooftop and indoor air is normally 7 to 8°C which increase to 12 to 15 using good quality high reflectance tiles. Rooftop coverings reduce cooling load by 11% at rate of 33.1kWh/m^2. Highly reflective rooftop buildings can save 40 to 50% cooling load in hot humid countries. Effective covering of rooftop can easily produce a temperature difference of 6°C between rooftop and indoor air [10]. Economic studies of building energy savings may be conducted using different techniques [11]. Reflectance and cost of common reflective materials are shown in Table 1.

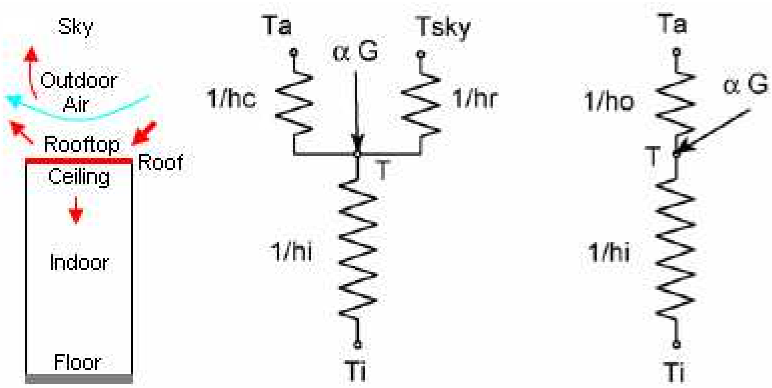
Table 1 High sunlight reflectance materials [9].

Types	**Materials**	**Albedo (%)**	**Cost ($/ft^2)**
Cements	White gravel	40	5-10
	White coated cement	70-80	30-55
	White cement tile	70-80	3-4
Paints	White concrete tile	70-80	9-12
	White coated metal	55-80	3-6
	White coat on black	70-80	2-3
Shingles	White asphalt	35	1-2
	White painted metal	55-80	3-6
	Photovoltaic PVT	50-75	1-2

Power and natural gas selling rates exponentially rise on increase of energy use. As of March 2013 the power and gas rates are RS 8 to 15 per kWh and 106 to 520 per BTU respectively in Pakistan. Inverse energy tariffs, unemployment and lower salary rates are forcing people to opt alternative methods to cope with weather extremities. Solar energy is one of natural source of comfort as well anxiety in summer. This work is an effort to search sunlight reflecting materials to mitigate heat island effect [7]. Energy content of sunlight is generally 1kW/m^2 on roof top accompanied by long wave radiative cooling effect of 60W/m^2. Normally 20 to 95% of incident solar energy is absorbed by roofs depending upon the construction materials [12]. Roof reflectance may be increased by stone tiles, coatings, shingles, white cement and asphalt materials. Heat reflective insulation coatings and materials can reduce monthly building energy demand at rate of 5-6 kWh/m^2 [13]. Total heat transfer coefficient varies from 18 to 26W/m^{2}K. Organic roofing materials such as plastics and woods deteriorate over time. Back reflecting roofing materials slow down heating effects but those themselves start weathering over time. Deposition of environmental pollutions on iron, aluminum, zinc, organic carbon have been reported to be 33-67, 16-50, 1-52 and 2-8mg/m^2, which are limiting factors for metals to be used as reflective surface [14].

2. Building Heat Gain Model

A roof provides protection against the sun, wind and rain. High rain and snow regions use sloped roofs whilst flat roof structure is adopted in others. A single story building in hot humid areas is subjected to solar radiative heat flux, rooftop reflections, wind heat loss, and downward heat flow through roof. Under steady state the rooftop surface temperature is higher than ambient outdoor and indoor temperatures. Outdoor temperature is higher than indoor temperature. Typical rooftop (T), outdoor (T_a) and indoor (Ti) temperatures are 45°C, 38°C and 27°C on a hot summer day. Sky temperature is often taken 2 to 20K lesser than T_a. If h_r, h_c and h_o are radiative, convective and equivalent heat transfer coefficients then building thermal resistance network may be expressed by the model shown in Fig.2.



a. Scenario b. Thermal Network b. Equivalent Network

Fig.2 Steady state heat flow across roof of building [12]

Keeping in mind above scenario we follow Harry's model [12] and Stoecker & Jone's approach [15] and Granja & Labaki [16] considerations to estimate thermal heat flux flow across the roof. Steady state temperature of any surface depends on solar irradiance (G), outdoor ambient temperature, wind velocity, sky temperature, rooftop reflectance (R), absorption (α), emissivity (ε) and roof thermal resistance. Under steady state absorbed solar irradiance (αG) by an insulated surface must equal air convective heat loss ($h_c(T-T_a)$) to environment and thermal radiation loss $h_r(T-T_{sky})$ to sky.

$$\alpha G = h_c(T - T_a) + h_r(T - T_{sky}) = h_o(T - T_a) \quad (1)$$

Rooftop surface temperature may be given by

$$T = \frac{\alpha G + h_c T_a + h_r T_{sky}}{h_c + h_r} = T_a + \frac{\alpha G}{h_o} \quad (2)$$

Under steady state conditions the net input heat flux due to solar radiations must be equal to outdoor and indoor heat flow energies.

$$\alpha G = h_o(T - T_a) + h_i(T - T_i) \quad (3)$$

The thermal heat flux flow rate (q^*) into building interior through the roof $h_i(T - T_i)$ is equal to the difference of input solar irradiance and outdoor air convection and sky radiative heat losses.

$$q^* = \alpha G - h_o(T - T_a) = h_i(T - T_i) \quad (4)$$

From (3) and (4) we obtain

$$T_a - T = (q^* - \alpha G)/h_\circ \quad (5)$$

$$T - T_i = q^*/h_i \quad (6)$$

Adding (5) and (6) we can obtain

$$T_a - T = q^*\left(\frac{1}{h_\circ} + \frac{1}{h_i}\right) - \frac{\alpha G}{h_\circ} = \frac{q^*}{U} - \frac{\alpha G}{h_\circ} \quad (7)$$

Where U is the overall heat transfer coefficient given by

$$\frac{1}{U} = \frac{1}{h_\circ} + \frac{1}{h_r} \quad (8)$$

From (7) under steady state conditions heat flow from outdoor to indoor becomes

$$q^* = \frac{Q^*}{A} = U\left((T_a - T_i) + \frac{\alpha G}{h_\circ}\right) \quad (9)$$

Taking T_a plus $\alpha G/h_o$ as collective solar-air temperature [15] the downward heat flux flow becomes

$$q^* = U(T_{sol-air} - T_i) \quad (10)$$

If sun goes behind clouds then heat flux flow from hot outdoor to relatively colder indoor may be given by

$$q = \frac{Q}{A} = U\Delta T = \frac{\Delta T}{R} = \frac{T - T_i}{R} \quad (11)$$

Where R (=1/U) is roof thermal resistance and ΔT is the temperature difference between rooftop and attics without any illuminating source. In case of sunlight illuminated roof the ΔT becomes the solar air temperature difference $\Delta T_{sol\text{-}air}$.

$$q^* = \frac{Q^*}{A} = U\Delta T_{sol-air} = \frac{\Delta T_{sol-air}}{R} \quad (12)$$

$$\Delta T_{sol-air} = T_a + (\alpha G/h_\circ) - T_i \quad (13)$$

Heat flow increase factor F under solar illumination compared to cloudy scenario may be obtained by dividing equation (13) with (12) as follows

$$F = \frac{q^*}{q} = \frac{Q^*}{Q} = \frac{\Delta T_{sol-air}}{\Delta T} \quad (14)$$

Net heat flux flow in a sunny day from outdoor to indoor is given by

$$q^* = \frac{\Delta T_{sol-air}}{R} = \frac{\Delta TF}{R} = \frac{\Delta T}{R/F} = \frac{\Delta T}{R^*} \quad (15)$$

For T_a-T_i>0 the effective thermal resistance R^* is smaller than R therefore building interiors become soon warm on sunny days. Roof is not the only source of heat the glass windows and walls also conduct outdoor heat into indoor interiors. Sky temperature is taken 10 to 20K lower than T_a else, in case $T_a = T_{sky}$, the daily heat may increase from 193 to 250 kJ/m^2 for clay tiled roofs and 194 to 351 kJ/m^2 in concrete roofs. Indoor temperature of cool roof rooms using natural ventilation may be given by [17]

$$T_i = 0.53T_a + 11.9 \quad (16)$$

Heat flow from rooftop down to indoor air may be given by [1].

$$Q = \Delta T/R \quad (17)$$

Densely populated rooms compared to empty rooms have higher indoor temperatures. The performance of rooftop technologies may be expressed by their thermal performance factor (TPF) index [18].

$$TPI = \frac{\Delta t_{C\max} - \Delta t_C}{\Delta t_{C\max} - \Delta t_{C\min}} \quad (18)$$

Where $\Delta t_{Cmax} = t_{Cmax} - t_m = t_{sol\text{-}air\ max} - t_m$; $\Delta t_{Cmin} = t_{Cmin} - t_m = t_{sol\text{-}air\ max}$ and Δt_C is the elevation above the mean air temperature.

3. Cooling Power Savings

Rooftop surface temperature exceeds surrounding ambient air and indoor attic temperatures during hot summer days. Heat transfer rate (k_q) from hot roof to indoor air is lower in attic type sloped houses compared to flat roof single story buildings. Decrease in heat transfer Δq from rooftop to indoor air by air conditioning results in reduction of solar heat flux ($I\Delta\alpha$) absorption by [19]

$$\Delta q = k_q I \Delta\alpha \tag{19}$$

If electric air conditioner has lesser coefficient of performance COP then it will reduce heat flux flow Δq and increase power demand ΔP by

$$\Delta P = \Delta q / COP \tag{20}$$

Substitution of (19) into (20) gives

$$\Delta P = k_q I \Delta\alpha / COP \tag{21}$$

If solar absorbance is decreased by white cement tiles, paint coating on rooftops then equivalent cooling energy savings (kWh/m^2) may be given by

$$\Delta E = \Delta P \times \Delta t \tag{22}$$

$$\Delta E = \frac{k_q \Delta\alpha}{COP} \int_{t_1}^{t_2} I(t) dt \tag{23}$$

In equation (23) $\int I(t)dt$ is the global horizontal insolation (kWh/m^2) incident on the roof during time t_1 to t_2 which is neutralized by air conditioning. If $\bar{J}$ is average daily insolation ($kWh/m^2.day$), d_{annual} is number of days in a year in which air conditioning is done, and ϕ is the fraction of daily insolation which generates positive downward heat flow then annual insolation load may be given by

$$kWh = \phi \times d_{annual} \times \bar{J} \tag{24}$$

Parameter ϕ depends on the thermal mass of roof, rooftop surface and PCM if used. A typical value of ϕ may be taken 0.5 actual value needs separate modeling. Reduction in average cooling power demand for a house is given by

$$\Delta\bar{P}_{house} = \Delta\alpha_{avg} \times \frac{\Delta P}{\Delta\alpha} \times A_{ceiling} \tag{25}$$

Where ($\Delta P/\Delta\alpha$) is decrease in power demand per unit ceiling area per unit decrease in solar absorbance. At state scale the reduction in electric power demand becomes

$$\Delta\bar{P}_{state} = \Delta\alpha_{avg} \sum_i (\Delta P / \Delta\alpha)_i A_i \tag{26}$$

If f fraction of houses is fitted with sunlight reflecting tiles and N_i houses are air conditioned then $A_i = f \times A_{ceiling} \times N_i$ then national scale reduction in power demand is

$$\Delta\bar{P}_{state} = f \times \Delta\alpha_{avg} \times A_{ceiling} \sum_i (\Delta P / \Delta\alpha)_i N_i \tag{27}$$

Deployment of sunlight reflecting tiles and paints reduces annual cooling electric energy demand (kWh/Yr) by

$$\Delta\bar{E}_{state} = f \times \Delta\alpha_{avg} \times A_{ceiling} \sum_i (\Delta P / \Delta\alpha)_i N_i \tag{28}$$

Independent studies have also confirmed the white cement shingles trip 20 to 23% of cooling power demand [20]. Solar heat flux flows across a flat roof at an average rate of 1-2 W/m^2K. In case of a $180m^2$ uncoated concrete roof home the heat gain amounts to 1890W at an average heat transfer factor (U) of $1.5W/m^2K$ for indoor/outdoor temperature difference of 7°C. As the reflecting tiles increase this difference to average 12°C therefore reduction of equivalent electric cooling energy declines to 1350W that is 28% reduction in cooling energy demand. Domestic electricity demand in Pakistan is 40% (4800MW) of national generation. Approximately 45 to 46% of electricity is used for cooling in Islamabad; this large amount substantially explains the 2160 MW on room cooling. A significant amount of 605 MW can be saved by making the rooftops reflective using white cement asphalt, tiles, stones and paints. Grey cement based materials exhibit undesirable thermal properties. Roof treatment can reduce cooling power demand by 50 to 70% [21]. Upgrading building envelope by incorporating air cavities in walls and reflecting materials on roof top Iraq has exhibited 70-85% reduction in cooling loads [22].

Heat enters into buildings through roof, walls and windows. Hot areas buildings may use tiles to reflect light incident on roof, paints to reflect thermal flux and intelligent windows to control the radiative heat entrance. Several researchers have carried out simulation modeling studies on radiative heat transfer across glass windows [23]. Application of glazed windows and photovoltaic thermal (PVT) shingles reduces net heat flow into building [24]. Use of glazed hybrid PVT tiles can increase thermal performance by circulating air under the PVT channels [25]. Analysis of glazed hybrid PVT was found to exhibit 12.5% electric and 35.5% thermal efficiencies [26]. Use of phase change materials (PCM) as passive thermal conditioners in walls and floors can lower temperature by 3°C [27]. Impact of white coating thickness on reflectance of grey material is shown in Fig. 3.

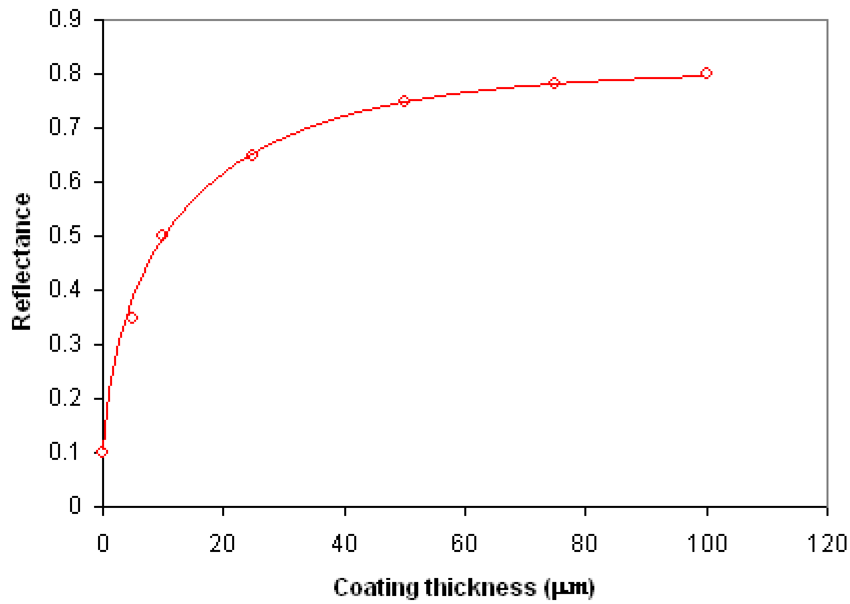


Fig.3 Variation of reflectance by increase in coating thickness

Solid insulation, white cement paint, air insulation, nocturnal, white cement tiles and evaporative cooling techniques have been reported to reduce outdoor indoor temperature difference by 3.5, 5.4, 5.8, 6.7, 11 and 13.2°C in arid areas [28].

4. Weather Extremes Dependent Energy Demand

Sunlight does not fall uniformly on whole of earth. Equatorial regions receive maximum radiations (1468W/m^2) but Northern and Southern regions remain relatively cold. People of hot humid regions consume 40 to 45% of their domestic electricity on building cooling in summer. Overall buildings use 72% of electrical energy in USA [11] where 12% electricity is used on cooling buildings in summer. Electricity demand for cooling in warmer regions is higher than colder areas. Electricity is the cleanest form of energy ever known to humankind. Power demand in building for cooling depends upon heat gain in summer. Solar heat gain may be reduced by use of reflective tiles on rooftops, paints on walls, glaze on glass windows and phase change materials under room floor. Marble floor reflect solar flux and may be cooled from underside by circulating cold air through the channels. People of cold polar-regions spend an equivalent amount of energy on heating as earth irradiance also declines in absence of solar irradiance. Northern and Southern hemisphere countries like Pakistan face equivalently intense hot summers (T>+50°C) and chilly winters (T<-10°C). Regions within ±30° of equator confront extreme heat in summer and equivalent chill in winter. A huge population is located in equatorial belt which needs electricity in summer for cooling and natural gas in winter for heating. Summer persists for 4 months (May to August), Autumn for two months (September to October), winter for four months (November to February), and spring for two months (March to April). Gas demand increases to 5 billion cubic feet in winter and electricity demand rises to

20,000 MW in summer. Annual electricity and gas consumption in an average energy conscious Pakistani home is shown in Fig.4

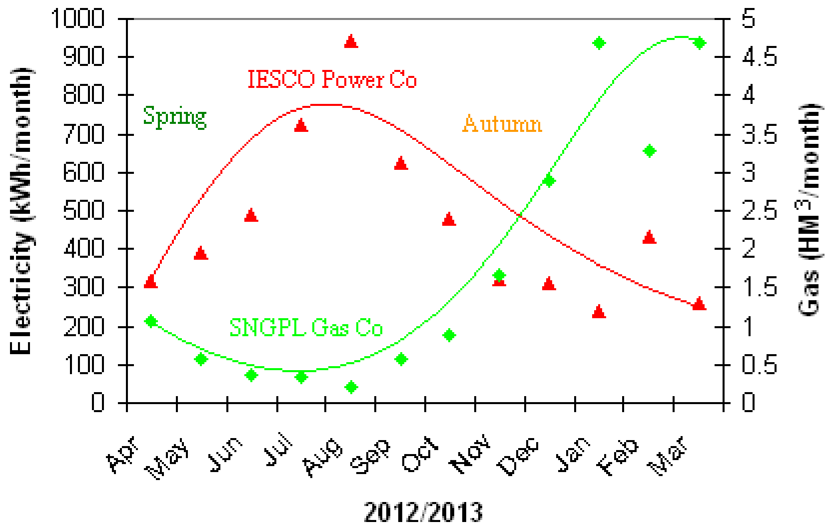


Fig.4 Power and gas consumptions for cooling and heating a home

Normal homes in Pakistan are made of mud, bricks and clay cements. Stone tiles, white cement slabs and various types of shingles are under investigation for overlaying on roofs to reflect excessive sunlight in summer. Private company (Sober) manufactures white cement tiles with polyurethane, white cement and sand as major ingredients is focused in this study for thermal performance. Manufacturer of Munawar Air Conditioning (MAT) tiles in Pakistan claims that he has replaced 30,000 air conditioners by installing white cement tiles in last 16 years. If one air conditioner uses 2kW power then it is equals 6 MW power conservation [28]. A simple solar shingle may be fabricated by mixing one kg of white cement in two kg of sand. If suitable metal oxides are also admixed then thermal performance of even I inch thick slab may increase by 8 to 10%. Solar shingles may be overlaid on rooftop and crevices among tiles may be grouted using slurry of same ratio. Energy conservation measures taken by Government of Pakistan have triggered research on white cement tiles in 1980s [29]. First white cement tile was fabricated for rooftop covering in 1996 [28]. This study conducts thermal performance study of white cement tiles having 1cm polyurethane add on the underside of the solar tile.

5. Solar Tiles Performance Study

To conduct thermal performance study of white cement tiles six models of flat and slanted rooftops were evaluated. Model A, B and C are shown in Fig.5.

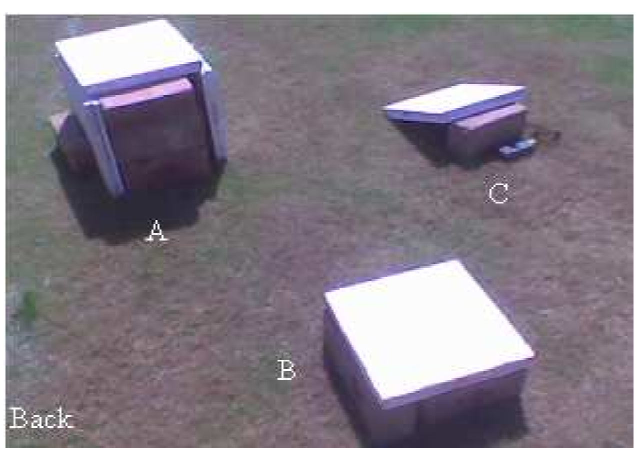


Fig.5 A, B and C type roof structures

Outdoor and indoor air temperatures near surfaces were measured using digital thermocouple probe (model I.269846tm902 K type) and digital LCD display thermometer (model) 2040W. Temperature probes were direct under sun when taking measurements. Indoor and outdoor temperature differences are shown in Table 2.

Table 2 Indoor/outdoor temperatures of type A, B and C structures.

Model	**Time**	**Inside T (°C)**	**Outside T (°C)**	**ΔT (°C)**
	10:52am 11:55am 01:30pm	25 23 24	30 37 39	5 15 15
	10:52am 11:28am 01:00pm	20 20 29	34 39 41	14 19 12
	11:05am 12:25am 01:42pm	22 25 24	29 39 39	7 14 15

Experimental measurements showed A and B type structures exhibit more indoor and outdoor temperature differences compared to C type structure. The differences were lower in forenoon, highest at noon and between above in afternoon as shown in Fig.6.

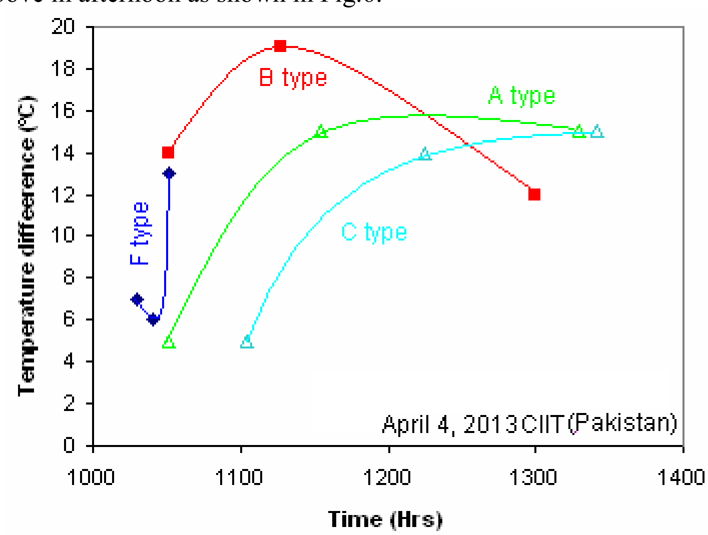


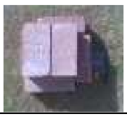
Fig.6 Indoor and outdoor temperature difference

A comparative study was undertaken on two D and E type structures to determine the relative thermal performance of white cement tiles over fired clay bricks. D and E type structures are shown in Fig.7.

Fig.7 D and E type structures

Structure D differs from structure B in terms of all cement tiles compared to bricks on back of structure B not facing direct sunlight. Structure D made by white cement tiles exhibited more stable temperature difference compared to simple fired clay bricks E type structure as shown in Table 3.

Table 3 Indoor/outdoor temperatures of type D (cement) and E (bricks) structures

Model	Time	Inside T (°C)	Outside T (°C)	ΔT (°C)
	10:25am	23	36	13
	12:30pm	25	38	13
	01:46pm	26	40	14
	02:50pm	23	38	15
	03:40pm	24	37	13
	10:35am	16	33	17
	12:00pm	25	37	12
	01:05pm	32	40	8
	02:15pm	30	39	9
	3:20pm	29	38	9

White cement tiles structure maintained more constant temperature difference in afternoon when fired clay bricks temperature difference declined as shown in Fig.8.

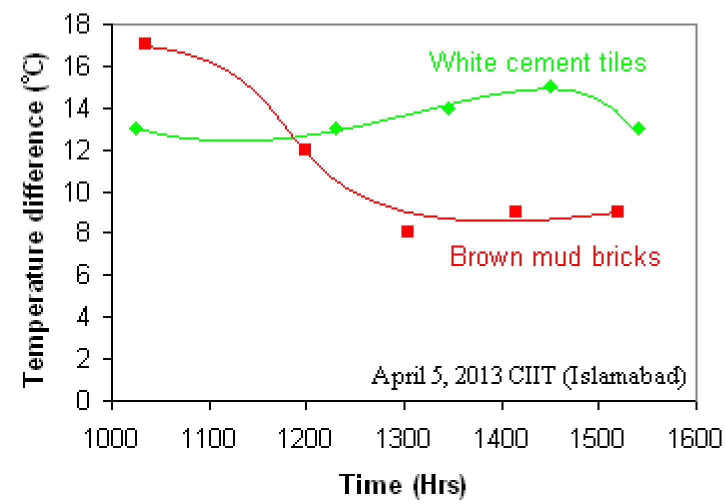


Fig.8 Comparative sun shielding study of tiles and bricks

Structure F (extended structure B) was chosen to determine effect of size on outdoor and indoor temperatures. F type structure is shown in Fig.9

Fig.9 Type F (=extended B) type structure

Indoor and outdoor temperature differences of structure F are shown in Table 4.

Table 4 Indoor and outdoor temperature differences of structure F

Model	Time	Inside T (°C)	Outside T (°C)	ΔT (°C)
 F	10:55 am	28	32	4
	11:30 am	28	43	15
	12:15 pm	30	42	12
	01:15 pm	32	41	9
	02:00 pm	**29**	**45**	**16**
	02:35 pm	31	44	13

Indoor temperature was found to stay stable bellow 31±1°C as shown in Fig.10

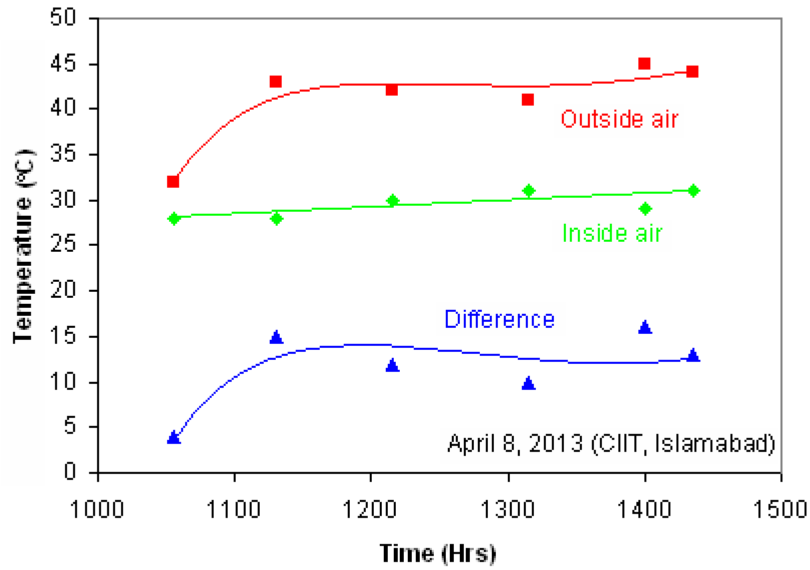


Fig.10 Indoor outdoor temperature differences of type F structure.

Experiments conducted on small scale structures A to F were repeated on a large commercial building covered by white cement tiles as shown in Fig.11.

Fig.11Far view, Jhangir Plaza, Blue Area, Islamabad

Table 5 Indoor/outdoor temperatures of tiles fitted large building

Model	Time	Outside T (°C)	Inside T (°C)	ΔT (°C)
	11:30 am	37	29	8
	12:05 pm	39	26	13
	12:40 pm	40	26	14
	01:00 pm	39	25	14
	02:05 pm	40	25	15
	02:40 pm	41	26	15

Indoor temperature was found to stay stable bellow 30°C as shown in Fig.12

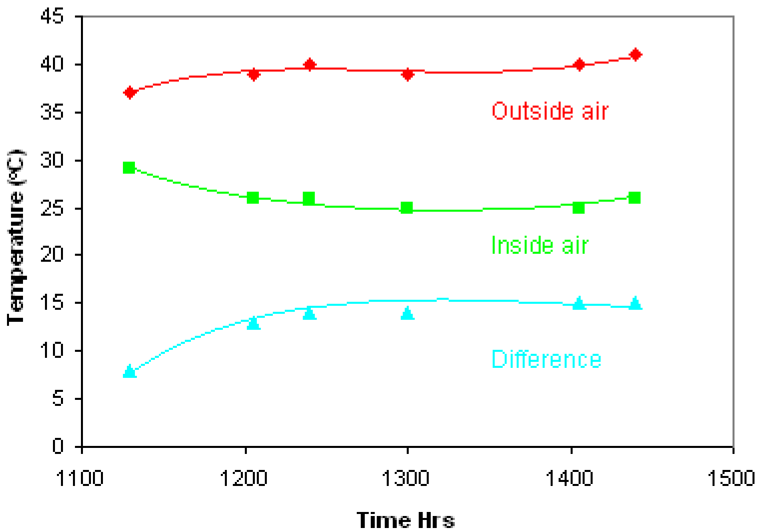


Fig.12 Indoor/outdoor temperature difference of tiles fitted building

5. Natural Heat Energy Balance

Sun is the ultimate source of energy on earth empowering. We receive nearly 74PW energy from sun and 44.6TW energy from earth. Sun generates energy using nuclear fusion reactions but earth receives 30TW from radioactive decay in subsurface and 8TW from planetary accretion. Earth is cooling gradually at a rate of 6 to 7TW every moment. Earth generates its magnetic field from convective vortices of molten metals around iron and nickel core. Flow of ionized liquid metals creates currents to demonstrate dynamo action. When earth will cool down it will loose the geomagnetism like mercury and venous planets. Earth's surface receives sunlight at rate of 1368W/m^2 globally. Total solar irradiance (TSI) S from 150 to 4000nm wavelengths falls in ultraviolet (5%), visible (43%) and infrared (52%) parts of electromagnetic spectrum. High frequency gamma rays, x-rays and deep ultraviolet radiations are absorbed by ozone layer in atmosphere. Some high frequency radiations, Cherenkov Effect, produce colorful aurora lights on sky near poles. Earth intercepts sunlight corresponding to its surface area πR^2, where R (=6371km) is earth's radius. To maintain the net heat balance earth emits infrared radiations, in response to sunlight, ranging from 3.5 to 50μm wavelengths. Solar irradiance is highest 550nm but earth irradiance peaks at 10μm.

Sunlight absorbed by earth may be given by

$$S_a = \pi R^2 (1-a) S \qquad (17)$$

Infrared heat flux emitted by earth is given by

$$S_e = 4\pi R^2 \sigma T_e^4 \qquad (18)$$

where σ is Stefan Boltzmann constant. In order to maintain global thermal equilibrium solar radiations falling on planet earth must balance its terrestrial radiations. If $S_a = S_e$ then equilibrium temperature (T_e) is given by

$$T_e = \left(S(1-\alpha)/4\sigma\right)^{1/4} \qquad (19)$$

Calculated values of natural earth temperature T_e corresponds to -18°C (=255K) which increases to average +14°C by an order of 32°C through optimum green house effect. Human body is at 37°C therefore we continuously emit energy peaking at 9.35μm. One way of energy conservation is to cover up our bodies in chilly weathers to protect the heat loss. A comparison of celestial (sun) and terrestrial (earth) emissions in biosphere is shown Fig.13.

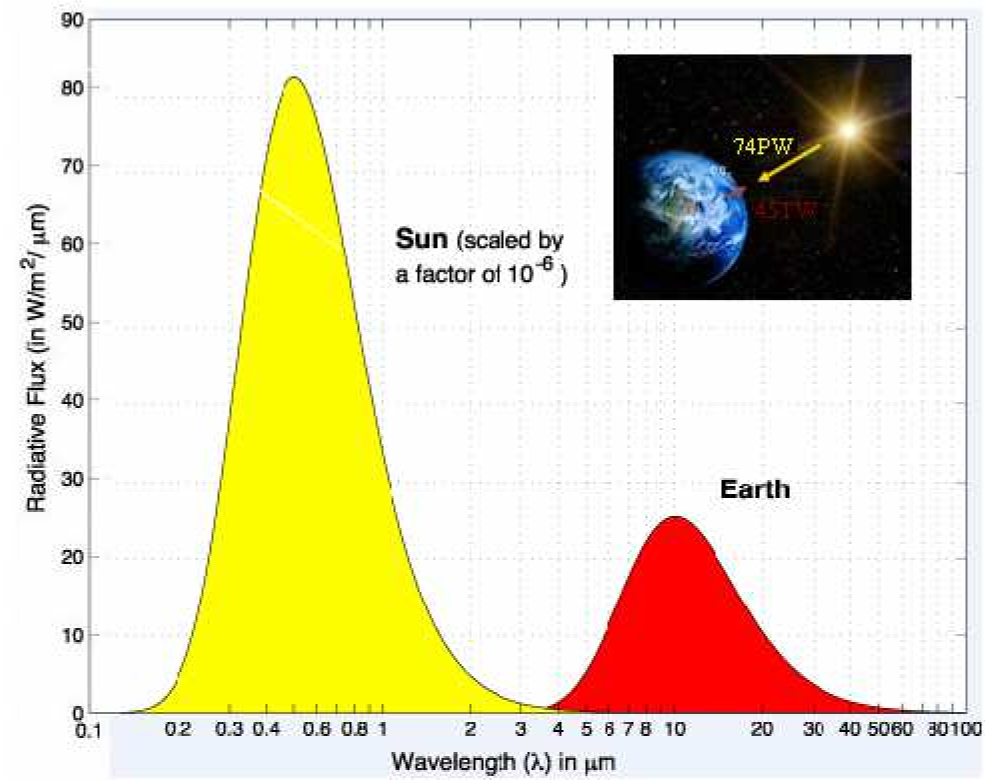


Fig.13 Sun (UV to NIR) and earth (NIR to FIR) emission spectra [30]

Sun and earth can feed up to 50 billions people but they can not fulfill human desires. Earth and human bodies consists of about 71 and 72% of water. Human body gets food energy from earth and radiative heat energy from sun. To maintain human body energy balance our bodies emits infrared energy peaking at 9.35μm. Human brain, heart, and stomach use 20-30, 10-15 and 25-30 watts of energy. An average person uses about over 100 W energy. Human energy demands may be estimated by simple mathematics.

Human food energy demand estimation:

Daily food intake = 2000 to 3000 kcal (≈2500 kcal)

Daily food intake = $\dfrac{kcal \times J / kcal}{Time(\text{sec})} = \dfrac{2500 \times 4.2}{86{,}400} = 125W$

Energy (Intake) = Watts ×Hrs =125×24 = 3 kWh

Solar absorption (Pa) = $\varepsilon a\ \sigma a\ Ah\ T4 = 0.95\times5.67\times10^{-8}\times1.5\times3104$ = 747 W

IR emissions (Pe) = $\varepsilon e\ \sigma e\ Ah\ T4 = 0.97\times5.67\times10^{-8}\times1.5\times3104$ = 762 W

Energy balance = IR Emissions - Sunlight Absorption = 25W

Human body uses = 125 - 25 = **100 Watts**

Life continuity power and energy demands for all people

Human food energy demand = $125 \times 7.2\times10^{9}$ ≈ 1.0 TW

Animals energy demand = 1.0 TW (Suppose equivalent)

Life continuity energy demand = 2.0 TW

Machines/comforts use = 14±0.5 TW
Life & machines demand = 16 ±0.5 TW (≈ **17 TW**)

To fulfill our energy demands we consume fossil fuels at rate of about 1000 barrels/sec. To meet energy demand we produce oil at a rate of 85 MBPD. About 85% of energy demand is met by fossil fuels and 15% by renewable energy resources such as hydro, nuclear, solar, wind, geothermal, ocean wave and woods.

Atypical calculation may be used to estimate earth population holding capacity.

Calories intake based earth population holding capacity may estimated by
A person's daily food intake = 2500 kcal
Worldwide daily food intake = 2500 x7.1×10^9 = 17×10^{12} kcal
Soil production capacity = 3200 kcal/m2/Yr
Earth land area (not sea) = 14x10^{12} m^2 (Fig.14)
Earth's production capacity = 14x10^{12}×3200 = 4.5×10^{16} kcal/Yr
Earth's production capacity = 4.5×10^{16}/365=1.2×10^{14} kcal/day
Earth feeding capacity = 1.2×10^{14}/2500
Earth feeding capacity = 49×109 persons

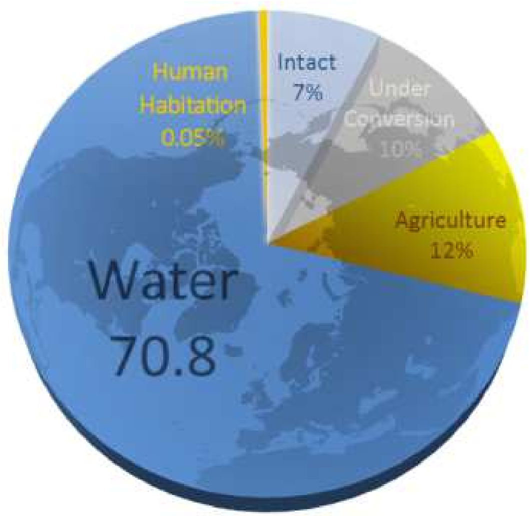


Fig.14 Arable land on earth [31]

Corn intake based earth population holding capacity may given by

Soil production capacity = 627gC/m^2/Yr
Total arable land (Fig.14) = 14×10^{12} m^2
Earth's corn capacity = 14×10^{12} ×627/1000
Earth's corn capacity = 8.8×10^{12} KgC/yr
A person's annual need = 182kgC/Yr
Earth feeding capacity = 8.8×10^{12}/182
Earth feeding capacity = 48×10^9 persons

Some researchers believe earth can not afford to accommodate more than 6.5 billion persons which limit has already exceeded whilst others believe earth can accommodate one trillion persons that sounds too high figure. My calculations are based on simple data but procedure to estimate is noteworthy.

6. Conclusions

This thermal performance study of a white cement natural air conditioning tile proves it helps maintaining indoor temperature down to 30°C when outside temperature rises to 40°C. Prior experience of users reveals they use one air conditioner instead of two before installing white cement tiles. Outside and inside air temperature measurements have shown the tiles restrict inside temperature to be 28±1°C in large building when outside air temperatures vary from 37 to 44°C. Outside and inside temperature differences were found to be 13±5°C. Inside and outside air temperatures of fired clay bricks rooftops were found to be 8-12°C when rooftop air temperature varied from 33 to 40°C. White cement tiles rooftop was found to reduce 5 to 6°C temperature more than equivalent fired bricks rooftops and 5 to 7°C more than equivalent grey cement rooftop buildings. A newly manufactured one inch thick white cement tile without polyurethane for summer exhibits even superior thermal performance.

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