International Journal of Environmental Trends (IJENT)
http://dergipark.gov.tr/ijent

International Journal of Environmental Trends (IJENT)

2022; 6 (1),1-9
ISSN: 2602-4160
Turkish JournalPark ACADEMIC

Research Article

Cool Concrete Facades Produced From Waste Materials

M.K. Gokay*[1] and K. Dogan[2]

[1] Technical University of Konya, Dept. of Mining Engineering, Turkey (*ORCIDNumber:0000-0003-3792-9414)*

[2] Technical University of Konya, Dept. of Mining Engineering, Turkey (*ORCIDNumber:0000-0001-9417-928X)*

Abstract

Human comfort inside or outside of the houses has been related also with surrounding temperature. Concrete masses used in urban areas influence surrounding air temperature due to their heat storage properties. Due to surrounding air temperature they absorb or supply heat energy through conductions, convention or radiation manners. Sun heated solid masses in cities mainly; roads, roofs, buildings' external walls, parking lots etc. have therefore influenced urban air temperatures. Heat energy originated due to radiation waves of sun have been accumulated on surfaces of those solid materials and then excess heat is ready to be transferred to surrounding environments (solids, liquids, gasses). That is, excess heat accumulated on concrete facades or concrete structural elements cause temperature increase around them until their temperatures have been levelled. This is favourable in winter (cold weather) for inside comfort of houses, but, it is disturbing in summer (hot weather) times. Small concrete facade samples had been prepared in this study to define their differences in heat energy storage capacities. Cool facade test samples were studied by preparing them by using raw materials; acidic & basic tuffs, fine waste materials from marble & travertine dimensioning facilities, cement factory fine size wastes, and fly ashes of power plant to observe their heat accumulation characteristics.

Received
04 April 2022

Accepted
01 June 2022

Keywords
Concrete facades
Insulation plates
Heat deposition
Inorganic waste materials
Recycling

Atık Malzemelerden Üretilen Düşük Isı Depolama Kapasiteli Yalıtım Plakaları

Özet

İnsanların yaşadıkları ev içinde ve dışındaki yaşam konforları çevresel hava sıcaklık seviyesiyle ilgilidir. Yerleşim yerlerinde kullanılan hertürlü beton yapı elemanları, kendi ısıl özelliklerinden dolayı çevre sıcaklığını etkilerler. Beton elemanlar, içinde bulunduğu çevresel hava sıcaklığına bağlı olarak, iletim, konveksiyon veya ışıma (radyasyon) yoluyla ısı enerjisi toplarlar veya yayarlar. Yerleşim yerlerinde, güneşin ısıttığı yollar, çatılar, binalar, dış duvar yüzeyleri, otopark alanları vb. iyice ısınarak (ısı enerjisi toplayarak), çevrelerindeki hava sıcaklığını artırırlar. Güneşin ışımasına bağlı olarak, yerleşim yerlerindeki katı yüzeylerde toplanmaya başlayan ısı enerjisi çevresel şartlara bağlı olarak, hemen etrafta bulunan katı, sıvı ve gazlara transfer olmaya hazırdır. Bir başka deyişle, yapılarda kullanılan beton kaplama plakaları üzerinde biriken ve çevresine göre yüksek değerlikli ısı enerjisi, çevresindeki ısı seviyelerine göre, ısı yayılımı yaparak çevresini ısıtacaktır. Bu ısı transfer işlemi, kış aylarında (soğuk hava şartları), evlerin iç konforu için tercih edilebilirken, yaz aylarında (sıcak hava şartlarında) rahatsız edici bir ortam oluşturur. Bu çalışmada, beton kaplama plakalarının farklı ısı depolama özelliklerini anlamak için inorganik atık malzemelerden küçük boyutlu plakalar dökülmüştür. Isı depolama özelliği düşük olan beton kaplama plakalarının araştırılması için; asidik & bazik tüfler, mermer & traverten boyutlandırma tesis atıkları, çimento atık tozları, termik santral uçucu külleri kullanılmıştır.

Anahtar Kelimeler
Beton kaplama plakaları
İzolasyon plakaları
Isı depolanması
İnorganik atık malzemeler
Geri dönüşüm

[1] Corresponding Author
Email: mkgokay@ktun.edu.tr

INTRODUCTION

Heat insulation or heat conductivity properties of solid materials are effective decision parameters in building designs. In order to sustain comfortable living spaces (which have suitable and levelled inner temperatures), heat exchange properties of constructions' structural elements (walls, ceilings, floors, stairs, windows, doors, roof etc.) are important. Heat radiated from sun is effective on earth surface in different gradients. Daily sunshine time and surrounding air temperatures are main influences on local climatic conditions. It has been long experienced also that surface-covers of land in the form of pavements, roads, houses, paved walking paths around us have influenced surrounding air temperature. It has also been known that urban areas have higher air temperatures with respect to countryside [1]. These locations may predominantly have higher surrounding urban air temperatures due to lack of summer blazes as well. If solid or liquid masses on earth surface have temperatures higher than surrounding air temperature, these objects behave as heating agents for surrounding air mass. In opposite conditions, air mass surrounding the objects is main heating medium. Urban areas which have high cost of indoor air-conditioning have been analysed for their summer and winter temperatures. Municipalities in recent times would like to decrease paved areas (covers of soil lands) to decrease urban air temperature in summer times. Soil covers (as roads and paved pedestrian walkways) and covers of constructions (outskirts, outside walls and roofs of houses & apartments, etc.) have their continuous effects on urban air temperature. In order to reduce the temperature in urban areas, researches had been performed and some municipalities had applied pilot scale projects as well. In Los Angeles (US) for example; certain parts of streets had been covered by special plasters [2]; similarly, cool asphalt cover applications had also been carried out in Qatar [3]. Researches reveal that there are some promising solutions to decrease urban air temperatures. Seasonal temperature differentiations have been measured in certain cities and locations [4, 5] which have high urban temperatures with respect to surrounding areas. These works presented that local areas (or regions) which have discriminately high air temperature are called as "hot-island" in city plans [6, 7]. Roads, concrete covered local areas, paved pedestrian walkways, roofs, walls, and paved parking areas around private houses etc. have enough solid materials which behave like heat storage mediums. In order to maintain sustainable human comforts in urban areas and eliminate hot-island formation, solid surfaces formed due to urban structures have started to be questioned in last decade. In hot weather conditions; covering the surfaces with cool materials is one of the methods offered to control human comforts in urban areas. In order to decrease urban air temperature at hot weather conditions, some cities employ applications including; shading their streets and pavements, recommending cool roof and wall covers (insulation covers, plates, facades), interlocking (permeable) concrete pavements [8, 9] and expanding green areas (parks) in city limits. Accordingly, cool insulation panel and facade researches have gradually expanded to include different design and production alternatives which concentrated on; facade models (shapes, textures, dimensions), raw materials, coatings, overlays, etc. [10, 11, 12]. For example, "Albedo" property of insulation panels and facades is very important for sun wave reflection if they are used for outskirt lining of the constructions. Differentiating raw material types and mixtures and evaluating their influences on facades' heat energy storage (and insulation) characteristics have logically been main research steps [8, 13, 14] in this field. Aksamija, (2015) wrote correspondingly that "material selection is an important factor in designing sustainable facades" [15]. Energy required and waste rates in production of any raw materials of concrete should also be considered deeply for modern, sustainable societies. In this respect low density waste materials which have high albedo properties can purposely be used to produce lightweight facades with higher albedo values. Usage of inorganic waste materials in facade production has not limited with natural stone industry wastes. Construction industry itself can produce waste materials when there is demolishing operation which can partly be recycled by producing facades and insulation panels, [16]. Mechanical properties of concrete produced by using marble and limestone wastes had been studied earlier by Binici et al. [17].

They modified concrete raw material content by substituting 5%, 10% and 15% marble and limestone wastes (powders) instead of fine sand aggregates. Marble and travertine waste materials are grey and whitish in colour and they are abundantly available in Konya as well. Thus marble and travertine wastes were decided to be considered for the prototype concrete facade preparation in this study. Due to volcanic material availability near Konya city, acidic and alkaline tuffs materials were also selected as types of raw materials for this study together with fly ash materials and cement factory fine sized wastes.

METHODS TO OBTAIN LOW HEAT STORAGE CAPACITY FOR FACADES

Thermodynamic knowledge points that if heating of facades has been realized under sun radiation without any internal material phase changes, this fact is also being called "sensible heat storage" [18, 19]. Heat energy amount stored at facade plates depends on their temperature changes. This can be defined by general heat energy evaluation [19] as follows; $E = m \int c.\ dT$, it can also be expressed in the form of; $\Delta E=m.c.(T2\text{-}T1)$, Where; E: Heat energy, ΔE: Heat energy differences (stored), m: Mass of the material, c: Specific heat capacity, ΔT or (T2-T1): Temperature differences which have been occurred at the material. Concrete facades' surface (which have put under sun radiation at outskirts of buildings to protect them), temperatures have gradually been raised depended on the facades' design parameters. There are studies about the shapes, dimensions, textures, aesthetics, models and facade-mechanisms in architectural point of views [20, 21]. There are also works about raw materials of concrete facades [10, 16]. Facades can be produced in different shapes with/without individual interlocking slabs/plates. These plates have several 3-Dimensional interlocking models for their customers' aesthetic considerations. It is important to point that, bigger the surface area of them which is exposed to sunshine, higher the opportunity to obtain sun radiation. Masses of the concrete facades are also important design parameters to regulate gained heat energy. Raw materials (binder-cement types, aggregates, additives and water) in concrete mortars directly influence final concrete facades' properties. Bigger mass values of the concrete blocks, plates and facades means mainly higher heat deposition capacity.

PREPARATION OF CONCRETE FACADE PROTOTYPES

Different concrete mortars are mixed to mould diverse concrete products like panels, facades and pavement blocks etc. Concrete aggregates have mainly been crushed and produced in limestone quarries in Turkey. This can also be changed in certain limit by substituting limestone aggregates with suitable inorganic wastes. Natural stone industry wastes are mainly $CaCO_3$ materials and their colour usually; white, whitish or beige. In order to decrease these wastes' environmental impact, reuse of them had been performed here to produce concrete facade samples. Waste materials handled from other industries, (cement factory, asphalt facility and coal operated power plant), had also been used to produce low density, concrete facade test samples. Main concerns in this study were also producing different prototypes (concrete test facades, plates) from these waste materials to compare their heat storage capacities. Insulation plate products in construction industry are regulated with standards. In addition to the features required through these standards, if a concrete facade absorbs less heat energy from the sun, it is more favourable for hot weather climates. Moreover, if the same facade has low heat conductivity (means high insulation capacity), it can also be approved for a candidate of facade to be used in cold climates as well. In order to prepare prototype concrete facades, selected raw materials were mixed to obtain light coloured concrete facades. They were prepared through the moulds which had 20x150x150 mm in dimensions. Concrete mortars which had been prepared by truly mixing of selected (Table 1) fine, (particles < 0.50 mm) aggregates (75% by weight) mixed with binder (25% by weight, [22]) and water. Certain amounts of the prepared concrete mortars were separated to mould cubical (50x50x50 mm) unconfined compressive strength (UCS) test samples. Five cubical UCS test samples were moulded for each concrete mortar mixes. When the prototypes and cubical UCS samples had been settled, they had been removed from their moulds. Then they were kept in laboratory environment (at room temperature, *20°C)* with supplying required amount of moisture. These were the steps which could possibly be planned to follow at a concrete facade production line in a factory building. Physical and mechanical properties of the prepared cubical specimens had then been measured (Table 2) for the prepared prototype concrete facades at designated 7th and 21st days of concrete curing periods. Table 2 has also especial UCS values of the prototypes which were tested after 20 cycles of thaw and freezes.

Table 1. Concrete prototype facade test specimen labels and their contents.

Samples	Aggregates	Samples	Aggregates
P1	Acidic tuffs (fine size), (Konya region, yellowish beige),	**P5**	Cement factory wastes (fine size, powders),
P2	Marble plant wastes (cutting and polishing wastes, fine sized, whitish powder),	**P6**	Travertine plant wastes (cutting and polishing wastes, fine size, whitish beige powder),
P3	Basic, alkaline, tuffs (Karapinar-Konya region, blackish),	**P7**	Fly ashes, (Coal operated "Power plant" wastes),
P4	Calcined fine sized limestone powders,	**P8**	Travertine rock plate, slab. *(Massive rock facade, It is a "control plate" of the other 7 prototypes).*

Table 2. Physical & mechanical properties of the concrete facade prototypes, (values obtained from 50x50x50 mm sized test samples).

No	UCS (7^{th} days, MPa)	UCS (21^{st} days, MPa)	UCS (after 20 thaw & freeze cycles, MPa)	Dry weight (gr)	Saturated weight (gr)	Dry Density γ (kg/m^3)	Porosity ε (%)
P1	5.44±0.03	6.09±0.04	10.38±0.04	157.31	195.10	1258.48	30.23
P2	11.20±0.04	13.27±0.04	16.41±0.03	247.26	270.19	1978.08	18.34
P3	8.88±0.05	10.13±0.03	11.43±0.02	237.59	258.68	1900.72	16.85
P4	17.36±0.03	21.94±0.18	26.40±0.21	238.64	263.37	1909.12	19.78
P5	3.57±0.03	5.69±0.02	7.86±0.02	210.21	248.29	1681.69	30.46
P6	14.51±0.03	17.52±0.02	21.39±0.05	240.07	264.63	1920.56	19.65
P7	7.70±0.03	9.47±0.02	10.68±0.03	211.83	245.10	1694.64	26.62
P8	Travertine rock: 26.90±1.56		24.60±0.48	301.67	339.24	2413.36	30.06

HEAT STORAGE CHARACTERIZATION OF THE FACADE PROTOTYPES

In order to understand heat storage characteristics of the prepared prototypes, test samples, they were put under direct sun shine and their surface temperature changes had been measured every hour for almost 3 days of test duration. At the beginning, 8 test samples which were small sized (20x150x150 mm) concrete facades were put orderly on a table (Fig. 1) side by side via 3 wooden tiny sticks *(diameter: 9mm, length: 10mm)* underneath them. Thus, the facade samples were not touched to the table surface; they were kept 9 mm above the table surface by means of wooden sticks. Therefore, heat deposited over the samples had very low opportunity to move, conduct, towards the table surface, (heat transfers by conduction were limited). Thus, tested facades had obtained heat energy from the sun by radiation and their inner temperatures were raised accordingly. Temperature differences between surrounding air and the test samples were the main causes of heat conventions occurred between them. It was obvious also that heat energy transferred from the surfaces of the samples into their inner parts

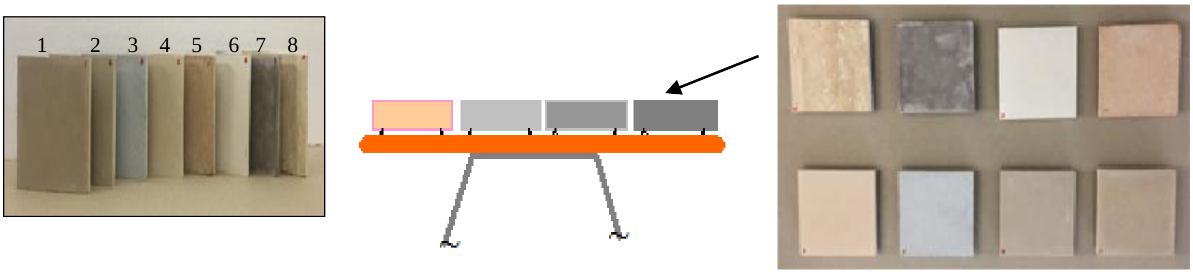

Figure 1. Test samples were put on table through three small wooden sticks underneath.

(internal conduction) was also influencing factors for their heat storage properties. Thus, increasing test samples' surface temperature (facades' top surfaces, 150x150 mm in dimension) forced heat energy transferring towards the inner, colder, parts of the samples. At this point, test samples' specific heat capacity values, "c", played important roles. Heat energy formed at the test samples' surfaces were also depended on the samples densities and porosities. During the test, heat energy amounts stored at the concrete facade prototypes had continuously been changed, thus these amounts were dynamic in character. Prototype facades' heat absorption test was started on Nov.8th 2019 at 11:40 o'clock and finished on Nov.11th 2019 at 07:00 o'clock at windless location (fairly enough, calm weather condition) in Konya. It was observed that maximum (22^{o}C) and minimum (3^{o}C) daily air temperatures had gradually been decreased to 21^{o}C and 2^{o}C degrees respectively during 3 days of the test. Measured peak surface temperatures of the facades can be listed in descending order; {(P7=highest), P8, P2, P3, P5, P1, P4, (P6=Lowest)} for "2^{cd} testing day", (Nov.9th 2019). Prototype concrete facades' surface temperatures had been obtained by infrared thermometer and they were indications of their stored heat energy situations. The differences among these energy levels characterize the facades' heat storage positions. Day time surface temperatures were measured maximum around 48.4 ^{o}C (at P7 surface) for the tested prototype concrete facades, this value was higher (double) than maximum air temperature around the tested facades (21^{o}C). Since the heat energy deposited (or lost in opposite conditions) in each of the tested concrete facade samples can be calculated by $\Delta E_i = c_i.[m_i.(T2_i - T1_i)]$, then a D_i factor can also be defined as a part of the equation as $D_i = [m_i.(T2_i - T1_i)]$. Thus, heat energy gained/lost for a tested concrete facade sample is then equal to $\Delta E_{Pi} = c_{Pi}.D_{Pi}$. In order to sense the effects of facade masses and facades' surface temperature differentiations together on stored heat energy values, D_{Pi} values were calculated separately for each tested prototype facades. Then bar graph (Fig. 2) was prepared to present "D_{Pi}." value changes at each tested facade along the 2^{cd} testing day of measurement. Bars coincided with the level of heat energy gained or lost by the test facades. That means; when D_{Pi} value of a prototype concrete facade was multiplied by specific heat capacity, "c_{Pi} ", heat energy, ΔE_{Pi}, added to (or subtracting from) the corresponding prototype facade was determined. Cumulative $D_{Pi} = m_{Pi}.(T2_{Pi} - T1_{Pi})$ value differentiations can also be observed through Figure 3 for 2^{cd} testing day.

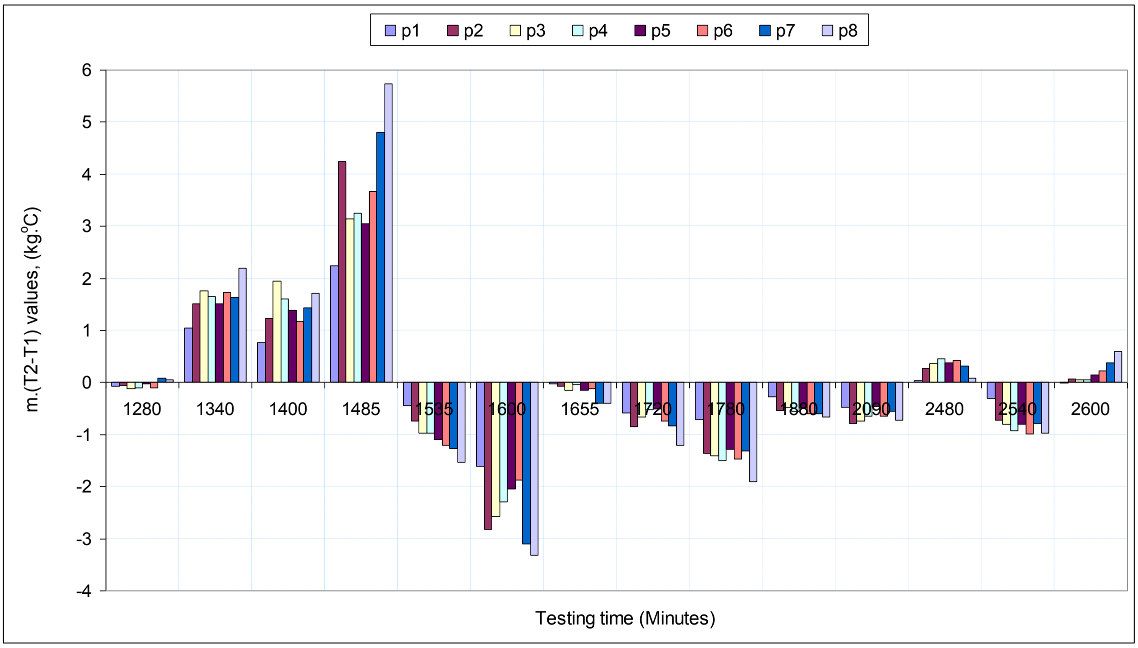

Figure 2. In heat energy calculation, $D_{Pi}=m_{Pi}.(T2_{Pi}-T1_{Pi})$ values for 2cd testing day, (Nov.9th 2019).

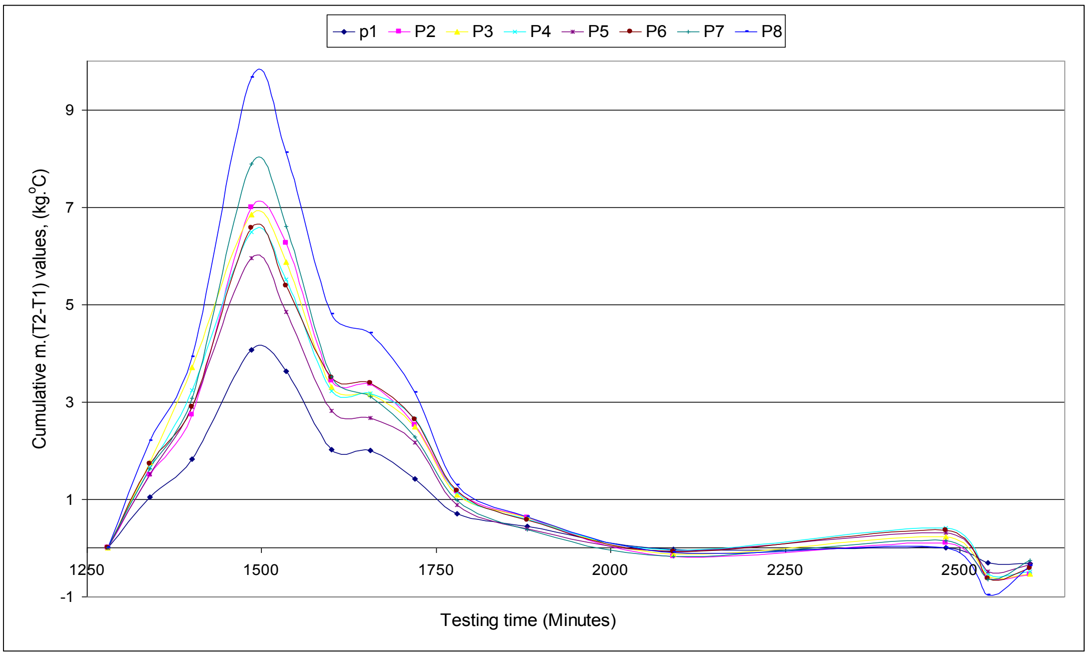

Figure 3. Cumulative $D_{Pi}=m_{Pi}.(T2_{Pi}-T1_{Pi})$ value graph for 2cd testing day. Peak values of "D_{Pi}" can be listed in descending order; (P8=highest), P7, P2, P3, P6, P4, P5, (P1=Lowest).

Increases in urban air temperatures in summer times have recently reached record high levels in each year. While urban area limits have gradually been expanded, earth crust covered by roads, pavements, constructions, industrial sites, industrial plants, car parks, etc. have been enlarged also. These locations with their surface covering materials; asphalt types, concrete paves, natural stone blocks or concrete plates (slabs) etc. have dynamic influences on surrounding air temperatures. Increases in local air temperatures at certain urban locations can reach 2-3 degrees in Celsius which is enough to call them "hot-island" of that local region. Researches on cool urban city plans, cool soil covering methodologies and cool materials have been increased in recent times to decrease hot-island formation. Raw materials constitute of pedestrian pave blocks and insulation plates, facades, have also specially considered in these studies. Reflective & permeable roads and pavements, suitable building insulations facades have found local applications in certain countries. Especially for insulation facade cases, high albedo characteristics of raw materials are played vital role on final decisions about their heat storage characteristics.

RESULTS AND DISCUSSIONS

In this study 7 concrete facade prototypes were prepared by using different raw materials. These facades' heat energy storage capacities had then been analysed. There was also one extra travertine rock facade (it was a "control facade" which had the same dimensions) to compare the test results with actual natural rock facade conditions. Prototype facades' strength (UCS) values and mechanical resistance to thaw-freeze were also determined (Table 2) by laboratory tests. Test results pointed that tested prototype facades can be used as actual concrete cover plates, facade, for buildings. When their UCS values which were obtained after 21st day of setting, curing, are listed in descending order, following list can be obtained; P8 (highest value: 26.90 MPa), P4 (21.94 MPa), P6 (17.52 MPa), P2 (13.27 MPa), P3 (10.13 MPa), P7 (9.47 MPa), P1 (6.09 MPa) and P5 (lowest value: 5.69 MPa). Defined limits of uniaxial compressive strength (UCS) for insulation plates (at Turkish Standard, TS825), were given as 0.30 MPa (*UCS values at 10% stain level, ε=(Δ sample length / sample length).100)* for "reverse terrace roof insulation" and "earth contact curtain wall insulation" [23]. Thus, the UCS results obtained for tested 7 prototype concrete facades here (including 1 extra travertine facade, P8), were higher than supplied 0.30 MPa UCS limits (at the breakage, before 10% strain level). Heat energy deposited at the prototype concrete facades were differentiating and the data revealed that ΔE_{Pi} values of test samples were depended on facades' masses, specific heat capacities, duration of heating, and surrounding air temperature fluctuations. Heat energy gain/lost situations for the tested prototype concrete facades were evaluated with their material properties after their surface temperature changes were obtained for the test duration. Peak surface temperatures obtained from the facade samples can be listed in descending order as; *{P7=highest), P8, P2, P3, P5, P1, P4, (P6=Lowest)}* for 2^{cd} testing-day (Nov.9th 2019). The list here pointed that sun radiation had caused less temperature differentiation for the facade numbered P6. Since the mass is important in heat absorption capacity of the materials; by including the tested facades' mass quantities, $D_{Pi}=m_{Pi}.(T2_{Pi}-T1_{Pi})$, $\{where: \Delta E_i=c_i.[m_i.(T2_i-T1_i)], \Delta E_i=c_i.D_{Pi})\}$, were calculated. According to related evaluations, cumulative D_{Pi} values were plotted for 2^{cd} testing day, (Fig. 3) and peak values of D_{Pi} can be listed in descending order as; *{(P8=highest), P7, P2, P3, P6, P4, P5, (P1=Lowest)}*. The results showed that, the facade numbered P1 had lowest cumulative D_{Pi} *values* among the tested 8 facade types (7 prototypes facades and 1 travertine facade). Therefore, tested P1 facade sample could be selected as *likely candidate* of "cool concrete facade" among the 7 tested prototype concrete facades, if specific heat capacity, "c_{Pi} ", of all the tested facades were almost similar value. It is import to notice here that heat absorption level of the tested facades is equal to $\Delta E_i=c_i.D_{Pi}$. Therefore, facade sample which have smaller c_{Pi} value has advantages in the evaluations, decisions.

CONCLUSIONS

Producing lightweight panels, slabs or facades which have also smaller specific heat capacities, (by using different available raw materials) are kept engineers busy on researching in this area of interest. Access to raw lightweight earth materials, their mining & marketing costs, living standards of societies, traditional & modern construction procedures have usually influenced slab & facade usages in different countries. Consequently, it is logical to point out that insulation panels, slabs or facades which are designed to protect constructions (buildings) by covering them in different engineered manners, should have primarily planned to be produced according to predefined energy conservation standards. Cool urban city plans for hot-weather conditions have progressively required cool concrete slabs and facades. Low levels in heat storage capacities of these products are then constantly researched to be achieved. Because they are possibly the ones which have inferior impacts on surrounding air temperature increases in urban areas as slabs & facades. In this article, 7 different facade samples produced as prototypes from waste materials were tested. In the tests, the heat storage capabilities of these plates within a certain time period were parametrically analyzed and examined as numerical quantities. The optimum plate concept and material components were evaluated from the findings. Information and results presented in the article contain findings in terms of examining the effects on the thermal performance of concrete plates, facades, to be used in finishing applications in buildings. It is necessary to point here also that these products should have also enough quality values to compensate standardized "fire-resistance" precautions. In addition, they have to be tested for their chemical durability values in different environments (climatic conditions). Raw materials used in production of these panels, slabs and facades should definitely be tested and evaluated also for their influences on human health, local environments and related features in societies.

REFERENCES

[1] P. Osmond and E. Sharifi, Guide to urban cooling strategies, Low Carbon Living CRC., Australian Government, Department of Industry, Innovation and Science, Business Cooperative Research Centres Programme, 2017, p72, Australia.

[2] M. Taleghani, D. Sailor and G. Ban-Weiss, Micrometeorological simulations to predict the impacts of heat mitigation strategies on pedestrian thermal comfort in a Los Angeles neighbourhood, *Environmental Research Letters*, 2016, 11, 024003, doi:10.1088/1748-9326/11/2/024003.

[3] Media Hub, Ashghal completes the works of cool pavement paint, Media Hub, Press Releases, Aug, 19th 2019, Internet page, www.ashghal.gov.qa/en/MediaHub/News.

[4] M. Santamouris, N. Gaitani, A. Spanou, M. Saliari, K. Giannopoulou, K. Vasilakopoulou and T. Kardomateas, Using cool paving materials to improve microclimate of urban areas, Design realization and results of the Flisvos Project, *Building and Environment*, 2012, 53, 128-136.

[5] J.M. Huang, R. Ooka, A. Okada, T. Omori and H. Huang, The effects of urban heat island mitigation strategies on the outdoor thermal environment in central Tokyo - A numerical simulation, *The Seventh Asia-Pacific Conf. on Wind Engineering*, Nov.8-12th 2009, Taipei, Taiwan.

[6] J. Roesler and S. Sen, Impact of pavements on the urban heat island, University of Illinois at Urbana-Champaign, Centre for Highway Pavement Preservation, CHPP, US Department of Transportation-Research and Innovative Technology Administration, RITA, 2016, p99.

[7] HARC, Dallas urban heat island, Report summary, Dallas sustainable skylines initiative, Houston Advanced Research Centre, HARC, 2009, Texas, US.

[8] H. E. Gilbert, P. J. Rosado, G. Ban-Weiss, J. T. Harvey, H. Li, B. H. Mandel, D. Millstein, A. Mohegh, A. Saboori and R. M. Levinson, Energy and environmental consequences of a cool pavement campaign, *Energy and Buildings*, 2017, 157, 53–77.

[9] A. Jamshidi, K. Kurumisawa, G. White, T. Nishizawa, T. Igarashi, T. Nawa and J. Mao, State-of-the-art of interlocking concrete block pavement technology in Japan as a post-modern pavement, *Construction and Building Materials*, 2019, 200, 713–755.

[10] R. Alyousef, O. Benjeddou, C. Soussi, M. A. Khadimallah and M. Jedidi, Experimental Study of New Insulation Lightweight Concrete Block Floor Based on Perlite Aggregate, Natural Sand, and Sand Obtained from Marble Waste, *Advances in Materials Science and Engineering*, V2019, Article ID 8160461, 2019, p14, doi.org/10.1155/2019/8160461.

[11] P. Johansson, Vacuum Insulation Panels in Buildings, Literature review, Report in Building Physics, Department of Civil and Environmental Engineering, Division of Building Technology, Building Physics, Chalmers University of Technology, Gothenburg, Sweden, 2012, p37.

[12] T. Herzog, R. Krippner and W. Lang, Facade construction manual, Second Edition, DETAIL Business Information GmbH, Munich, 2017, www.detail-online.com, ISBN: 978-3-95553-369-4 (Print), p37.

[13] J. Chen, Z. Zhou, J. Wu, S. Hou and M. Liu, Field and laboratory measurement of albedo and heat transfer for pavement materials, *Construction and Building Materials*, 2000, 202, 46–57. doi.org/10.1016/j.conbuildmat.2019.01.028.

[14] K. Gunawardena, T. Kershaw and K. Steemers,. Simulation pathway for estimating heat island influence on urban/suburban building space-conditioning loads and response to facade material changes, *Building and Environment*, 2019, 150, 195-205, doi:10.1016/ j.buildenv.2019.01.006.

[15] A. Aksamija, High-performance building envelopes: Design methods for energy efficient facades, Proceedings of the BEST4 Conference, 2015, www.brikbase.org/ research-format/proceedings?page=10, Retrieved in Nov. 2020.

[16] I. B. Pecur, M. Bagaric and B. Milovanovic, Development and Application of a Prefabricated Facade Panel Containing Recycled Construction and Demolition Waste, *Journal of Facade Design & Engineering*, 2020, 8, 2, 121-125.

[17] H. Binici, T. Shah, O. Aksogan, H. Kaplan, Durability of concrete made with granite and marble as recycle aggregates, *J. Mater. Process. Technology*, 2008, 208, 299–308.

[18] A. M. Waked, Solar energy storage in rocks, *Solar & Wind Techno*., 1986, 3, 1, 27-31.

[19] O. E. Ataer, Energy storage systems, Storage of thermal energy, Encyclopaedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO. Eolss Publishers, Oxford. Unesco-EOLSS Sample Chapter, http://www.eolss.net, Retrieved on: Nov.20th, 2019.

[20] A. Aksamija, Design methods for sustainable, high-performance building facades, *Advances in Building Energy Research*, 2015, doi.org/10.1080/17512549.2015.1083885.

[21] D. Sung, A new look at building facades as infrastructure, *Engineering*, 2016, 2, 63–68, doi.org/10.1016/J.ENG.2016.01.008.

[22] Yanmaz Kimya, Binder mixture, Personal communication, Yanmaz Chemicals Ltd. Co., 2019, Konya-Turkey, www.yanmazkimya.com, https://listofcompany.com/tr/company/yanmaz-kimya-san-tic.

[23] TSE825, Thermal insulation requirement for buildings, Turkish Standard, 2019, ICS91.120.10., TSE-825, Turkish Standard Institute, (TSE), Ankara, Turkey.