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EXPERIMENTAL AND THEORETICAL INVESTIGATIONS ON THERMOPHYSICAL PROPERTIES OF CONCRETE PRODUCED FROM DIFFERENT AGGREGATES

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HASAN OKTAY

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Experimental and theoretical investigations on thermophysical properties of concrete produced from different aggregates

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Supervisor

Assoc. Prof. Dr. Recep YUMRUTAŞ

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Hasan OKTAY

ABSTRACT

EXPERIMENTAL AND THEORETICAL INVESTIGATIONS ON THERMOPHYSICAL PROPERTIES OF CONCRETE PRODUCED FROM DIFFERENT AGGREGATES

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In this study, experimental and theoretical investigations are performed for obtaining new concrete types with relatively high strength, low density and good thermal properties for energy efficient buildings. For this purpose, different types of concrete samples were prepared with a constant water-cement ratio, and normal aggregates replaced by pumice, expanded perlite and rubber aggregates at different volume fractions such as 10%, 20%, 30%, 40% and 50% of the total aggregate volume. In totally, 108 samples with different materials and their compositions were produced. Compressive strength tests were all conducted and the hot disk method was used to establish thermal property values of concrete samples.

In order to determine the most suitable concrete samples, heat flows through the produced and commonly used concrete samples are calculated using a program developed in MATLAB. Calculation method for the heat flow is based on solution of transient heat transfer problem for the multilayer structures. The program is executed to calculate hourly heat gain values for these samples over a period of 24 h during design day for Gaziantep, Turkey. The results showed that the maximum reduction in heat gain values are obtained for EPC50 wall with thicknesses between 10 cm and 30 cm, which are 46.14 and 71.15 percent, corresponding to conventional concrete, respectively.

Keywords: Concrete, pumice, perlite, rubber, heat gain, energy efficient building

ÖZ

FARKLI AGREGALARDAN ÜRETİLEN BETONUN ÖZELLİKLERİNİN DENEYSEL VE TEORİK OLARAK İNCELENMESİ

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Tez Yöneticisi: Doç. Dr. Recep YUMRUTAŞ
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125 sayfa

Bu çalışmada, enerji verimli binalar için nispeten yüksek mukavemet, düşük yoğunluklu ve ısı yalıtımı olan yeni beton tipleri elde etmek için deneysel ve teorik bir çalışma gerçekleştirilmiştir. Bundan dolayı, sabit su-çimento oranında, normal agrega yerine hacimce %10, %20, %30, %40 ve %50 oranlarında pomza agregası, genleştirilmiş perlit aggregası ve lastik aggregası kullanılarak çeşitli beton numuneleri hazırlanmıştır. Farklı malzeme ve farklı bileşimlerde toplam 108 beton numunesi üretilmiştir. Üretilen tüm numunelerin basınç testleri yapılmış ve ısıl özellikleri sıcak disk yöntemi ile belirlenmiştir.

En uygun beton numunesini belirlemek için, yaygın olarak kullanılan ve üretilen beton numunelerinden geçen ısı geliştirilen bir MATLAB programı ile hesaplanmıştır. Isı geçişi değerleri çok katmanlı yapılarda geçici rejim ısı transferi probleminin çözümü kullanılarak yapılmıştır. Isı kazancını hesaplamak için, bilgisayar programı Gaziantep'te tasarım günü için 24 saat boyunca üretilen ve yaygın olarak kullanılan beton numuneleri için çalıştırılmıştır. Yapılan çalışmalar sonucunda, kalınlığı 10 cm ile 30 cm arasında değişen duvarların ısı kazanç değerleri karşılaştırıldığında en yüksek düşüş mevcut beton duvara göre EPC50 duvarda yüzde 46.14 ve 71.15 arasında değiştiği görülmüştür.

Anahtar Kelimeler: Beton, pomza, perlit, lastik, ısı kazancı, enerji verimli bina

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NOMENCLATURE

c	specific heat of roof or wall materials
E	equation of time
G_{on}	extraterrestrial radiation measured on the plane normal to the radiation on the *n*th day of the year
G_{sc}	Solar constant
hi	inside combined heat transfer coefficient
ho	outside combined heat transfer coefficient
i	complex argument
I_b	beam radiation
I_d	diffuse radiation
I_o	extraterrestrial radiation on a surface
I_T	hourly solar radiation on a tilted surface
k	thermal conductivity of roof or wall materials
k_T	the hourly clearness index
L_n	thickness of wall or roof material
n	number of day
q_k	complex Fourier coefficient of dimensionless solar heat gain
Rb	ratio of beam radiation on the tilted surface to that on a horizontal surface
t	time
T	temperature of roof or wall

To	outside air temperature
Ti	interior design dry bulb temperature
Tn	complex Fourier coefficient of temperature
$\dot{Q}$	heat transfer rate (W)
w	water

Greeks

α	thermal diffusivity of roof or wall material
α_s	absorbtance of exterior surface of wall or roof
β	Tilt angle
δ	declination angle
γ	azimuth angle
ω	hour angle
Φ	Latitude
ρ	density of roof and wall material
ρ_g	ground reflectance
θ	incidence angle
θ_z	zenith angle
τ, τ_n	dimensionless time

Subscripts

o	outside
i	inside

Abbreviations

AAC	Autoclaved Aerated Concrete
ACI	American Concrete Institute
AEC	air-entrained concrete

ASTM	American Society for Testing and Materials
EPA	expanded perlite aggregate
EPC	expanded perlite concrete
LWA	lightweight aggregate
LWC	lightweight concrete
NC	normal concrete
RA	rubber aggregate
RC	rubberized concrete
PA	pumice aggregate
PC	pumice concrete
XPS	extrude polystyrene

CHAPTER 1

INTRODUCTION

Great amount of total energy usage in the World has been consumed by heating and cooling systems. It is mandatory to minimize consumption of energy which affects source of energy, economic and environmental values. Because, using the energy redundantly causes reduction of energy sources, increasing of energy cost and negative impacts on economy of countries [1].

Building sector has an important role in global energy consumption in the world. In Turkey; the amount of energy consumption of buildings is approximately 37% that is a very large amount in total energy consumption [2]. It is known that the rate of energy consumption is depending on population growth, industrial process, urbanization and etc. Population growth leads to construction of more buildings, which rises to energy usage. Annual population growth rate in Turkey was 1.45% at the end of 2009 [3]. Besides, Turkey has to import nearly 75% of the energy demand from other countries because of the limited indigenous energy resources, therefore energy saving is very important issue in the country [4].

As a main part for energy loss, building structures have important roles in decreasing or increasing of the energy used for cooling load due to heat gain through these structures. If these structures having appropriate thermal properties are selected, and accurate calculation of the cooling load is performed, then cooling load due to heat gain may decrease, and suitable HVAC system may be selected. Hence, types of the walls, columns, beams, roofs, and calculation of the heat gain from these structures are very significant. Since, the capacities of the HVAC systems depend on types of these structures. As a result, estimations of the heat gain from building structures in the cooling season should be performed accurately.

Concrete building structures, the most economical building material that is used as one of the most versatile and universal. Concrete is used in construction twice as much as the total of all other building materials, including steel, wood, plastic etc. [5]. For providing energy saving, it is necessary to minimize energy consumption of buildings by improving the thermal characteristics of concrete structures. Besides, concrete is known for its compression strength that is a significant property in the construction and the design; hence these structures also need to have suitable mechanical properties.

Lightweight concrete (LWC) can be defined as a type concrete that provides additional features and reduces the weight of the concrete with expanding and porous component. It is lighter than conventional concrete varying with a density of 300 kg/m^3 to 1840 kg/m^3 [6]. Lightweight concrete has many and varied applications: multistory building frames and floors, curtain walls, shell roofs, folded plates, bridges, pre-stressed and pre-cast elements of all types and others.

Depending on its application, LWC can be classified as structural lightweight concrete and compacted lightweight concrete. The first is largely used for two purposes which are for cast in-situ roofs, walls and precast concrete blocks or panels. It is required to have sufficient strength and low density, in order to obtain low shrinkage during drying to avoid cracking and better thermal insulation. Structurally, lightweight concrete which can be used with steel reinforcement due to having a good connection between the concrete and steel should provide sufficient corrosion protection of steel. It is mainly compacted as conventional concrete with a dense aggregate [7].

This study is aimed to obtain new concrete types with relatively high strength, low density and good thermal properties by improving the properties of conventional concrete for energy efficient buildings.

CHAPTER 2

LITERATURE SURVEY

2.1. Introduction

LWC has been used successfully for structural purposes for many years. For structural application of LWC, the density is often more important than the strength. A decreased density for the same strength level reduces the self-weight, foundation size and construction costs [8].

The use of lightweight aggregate (LWA) with low thermal conductivity in the production of lightweight concrete blocks can provide an alternative cost-effective solution. LWA can be processed natural material, processed by-product or unprocessed material. With large number of voids in the aggregate, LWC possesses a relatively higher thermal insulating efficiency than the normal concrete. Therefore, lightweight concrete has superior properties such as lightness in weight, and good thermal insulation, but has a disadvantage of low mechanical properties which makes them suitable only as non-load bearing walls [9].

An important way to obtain more energy efficient buildings is to improve the thermal insulation properties. Reduction of the heat loss in buildings decreases the consumption of energy, thus, reduces the cost of heating and cooling. As a result of the lower use of energy, improvements in thermal insulation also affect sustainability. Due to its higher porosity, lightweight concrete is a suitable material for thermal insulation of structures [10-12].

2.2. Effect of mechanical properties on LWC

LWC has lower density and higher thermal insulation capacity than normal weight concrete about to six times. LWC used for insulation purposes may provide strength as low as 0.5 MPa and a density of less than 1450 kg/m^3. According to BS 6073: Part 1, the minimum strength grades are pointed as 2.8 MPa for all blocks, 3.5 MPa for facing blocks. Strength requirements for building blocks are most commonly set at 2.5 MPa for filler block and 5.0 MPa for load bearing blocks. For special purposes, a heavy duty bearing block with specified 7.5 MPa compressive strength is produced. Insulating masonry block elements are usually made with low strength natural aggregates such as pumice. These aggregates have an average compressive strength of 3.5 MPa, but this value can be increased up to 7.0 MPa. The average density of a masonry block is 978 kg/m^3 and thermal conductivity of these blocks is 0.20 W/mK [13].

Topcu et al. [14] replaced natural fine and aggregates by rubber fine grains and coarse crumb rubber. They detected that the compressive strength of the concrete was more decreased by adding the coarse rubber crumbs than by adding rubber fine grains. This showed that coarse rubber aggregates (RA) indicates as adverse impact on compressive strength than fine rubber grains.

The effect of rubber content within the range of 5–50% as the replacement for sand volume and water/cement (w/c) ratio (0.45–0.55) on the density and compressive strength of concrete blocks was investigated. All the mixtures were proportioned with a fixed aggregate/cement ratio of 5.6. A total of 50% of the total aggregate was fine aggregate. The density and compressive strength of rubberized concrete blocks is affected differently depending on the rubber content and w/c ratio. If the rubber content increases in the mixture, a systematic reduction in density and compressive strength takes place. It is recommended that the rubber substitution used in concrete blocks should not exceed 10% volume for structural and 40% volume for non-structural applications [15].

Absorption capacity of the LWAs affects the properties of the concrete. It was found that there is a reduction in strength when the LWC is made using dry LWA; because, there will be an exchange of water and air between the paste and the aggregate depend on setting period. Air bubbles form around the rim of the transition zone between the paste and LWA. Hence, air is evacuated from the LWA that causes loss of strength. This is overcome by mixing concrete, while aggregates blotted and air bubbles behave like conventional air bubbles, as if they were created using the air-entraining admixture [16]. Furthermore, Lo et al. [17] examined the effect of pre-wetting on the mechanical properties of the concrete. According to test results, the compressive strength reaches its maximum value when the LWA pre-wetted for 30 minutes. Besides, it was observed that the slumps of the fresh LWC mixes with the aggregate without pre-wetting and pre-wetted 60 min were lower than the samples pre-wetted for 30 min.

Khatib and Bayomy [18] carried out, that the use of RA in concrete mixes had a bad effect on workability. It was found that almost zero slump of fresh concrete was provided with rubber cumulative increase to 40%.

2.3. Effect of thermal properties on LWC

There are lots of studies about the effect of thermal properties on LWC. In these studies, it was found that both the aggregate weight percentage (%wt) content influence the thermo-physical properties of concrete and the type of aggregate [19].

In a study, the effects of expanded perlite aggregates (EPA) on the high strength concrete properties were studied. Time depended dry and wet curing effects on the thermal conductivity were compared. Five different concrete mix designs with the same mix proportions and different EPA replacements of aggregate were used: 0% (control), 7.5%, 15%, 22.5% and 30% EPA. The effects of EPA replacement and curing conditions upon concrete properties were examined. It was reported that compressive strength, thermal conductivity, ultrasound pulse velocity and oven dry density properties of high-strength concrete containing EPA were decreased with increasing of EPA [20].

In a different study, the effects of pumice aggregates (PA) on the thermal properties of concrete were studied. Different concrete mix designs with different PA replacements of aggregate with a ratio of 25%, 50%, 75%, and 100% were used. The test results showed that the addition of PA reduced the thermal conductivity and the density of concretes up to 46% and 40%, respectively. Moreover, increasing the cement dosage in concrete mixtures increased both density and thermal conductivity of the concrete [21].

Gündüz [22] Experimental test results showed the pumice concrete up to 25:1 aggregate/cement (A/C) ratio has sufficient strength and adequate density to be accepted as load-bearing block applications. Further, higher than 25:1 A/C ratio has sufficient strength, adequate density and the thermal conductivity to be accepted as non-load bearing infill blocks for insulation purposes. The properties, which increase in value and indicate the increasing quality with lower A/C ratios (high cement contents), are compressive strength, modulus of elasticity and density. Properties, which decrease in value, with higher A/C ratios are water absorption, wetting expansion, drying shrinkage and thermal conductivity. It was experienced that lowering the A/C ratios increases strength quality of pumice concrete. But, increase of the A/C ratio increases the thermal insulation property. Basically, the research showed that non-structural lightweight concrete can be produced by the use of fine, medium and coarse PA mixes without using any additions or admixtures.

Benazzouk et al. [23] conducted an investigation about the effects of waste rubber particles on the thermal properties of concrete were studied. Different concrete mix designs with different rubber particle replacements of aggregate with a ratio of 10%, 20%, 30%, 40% and 50% were used. It was found that that the addition of rubber particles reduced the thermal conductivity and density of samples. Also, they reported that the thermal insulating effect of rubber particles is most attractive and indicates a high and promising potential for development.

Physical, mechanical and thermal performances of rubberized concrete blocks have been investigated in various studies. Experimental studies have shown that the bricks with a high content of crumb rubber with conventional sand aggregate showed a high energy absorption capacity drastically reduced density and offered a smooth surface as compared with current concrete bricks. The improvements insulation characteristics vary from 5 to 11% depending on the amount of rubber crumb used [24].

Milon et al. [25] presented a study to specify the thermal properties of concrete produced with two different types of coarse aggregates which are burnt clay brick-chips and stone chips. The experimental investigations revealed that concrete containing burnt clay brick-chips indicates greater specific heat but lesser thermal diffusivity than concrete with stone-chips and also thermal diffusivity increased with increasing density. Also, it was reported that thermal conductivity of both types of concrete is directly proportional to its thermal diffusivity.

2.4. Effect of silica fume on properties of LWC

Microsilica (Silica fume) which has a great influence on properties of LWC is a by-product material which results in reduction of high purity quartz with coal in an electric furnace in the production of silicon or ferrosilicon alloy. There are many studies on the effect of silica fume on the properties of LWC. Guneyisi et al. [26] reported that the addition of the silica fume into the concrete matrix reduced the rate of strength loss but improved the mechanical properties of the rubberized concretes. It was reported that rubberized concretes with compressive strength of 16–32 MPa might be produced with a rubber content of as high as 25% by total aggregate volume.

In a different study, it was conducted that silica fume causes an increase in the specific heat and a reduction in the thermal conductivity of cement paste [27]. Alshamsi et al. [28] reported that addition of silica fume to concrete mixtures causes to lower workability.

Demirboğa [29] studied the effect of silica fume on the thermal properties of LWC. It was found that the addition of 7.5 and 15% microsilica in a concrete matrix to reduce the thermal conductivity and density by 5 and 14%, respectively.

2.5. Heat gain and cooling load calculation method and its applications

The cooling load of buildings comprises a large fraction of the overall energy consumption in summer season. In many buildings, heat gain from the external walls and roofs constitutes a major portion of the total cooling load, since they are exposed to the climatic conditions such as convection and solar heat flux. Therefore, estimation of the heat gain to a space through the external walls and roofs is the first essential step in the calculation of cooling load and selection of air-conditioning system components [30,31]. However, accurate estimation of the heat gain into the conditioned space is quite complicated and time consuming as it is highly transient in nature due to thermal storage effects of the building mass and ever changing external conditions, and furthermore, dependence of the heat gain on location, shape, and orientation of the buildings complicates the problem [32].

There are many methods for estimating the heat transfer characteristics of building structures. The problem is essentially reduced to solving the Fourier heat-conduction equation in a composite structure subject to time-dependent boundary conditions. Ozisik [33] described various analytical methods for solution of one-dimensional problems such as the separation of variables, orthogonal expansion technique, Green's function, Laplace transform and integral methods. Thakur [34] presented periodic solutions, in terms of Fourier series, of the heat conduction equation in inhomogeneous materials for which the thermal properties exhibit spatial variations. A numeric-analytical approach using complex algebra of analyzing linear periodic heating and cooling problems in laminates was described by Chen and Lin [35] extended the hybrid application of the Laplace transform technique and the finite-element method to include non-linear radiation boundary conditions.

The solar energy affects interior environment and energy requirements of buildings. A fraction of the incident solar flux is collected and stored in the structural thermal mass of the building envelope, and influences essentially dynamic thermal characteristics of the building and the indoor environment especially during the cooling season [36]. The determination of the dynamic thermal characteristics of building structures has recently received great interest. Several studies related with the characteristics of building structures have been conducted [37]. In another study, Ulgen [38] examined experimentally and analytically the thermal response of various wall formations under the effect of solar radiation. Furthermore, Yumrutaş et al. [31] developed a theoretical methodology based on periodic solution of one dimensional transient heat transfer problem for the building structures in order to determine TETD values for three types of walls and flat roofs commonly used. They found out that higher solar radiation and ambient air temperatures give higher TETD values, corresponding to higher heat gains and higher energy consumption to maintain a space at a given temperature.

CHAPTER 3

THE PROPERTIES OF CONCRETE

3.1. Introduction

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together [39]. In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

Figure 3.1. Concrete components are combined to form concrete [40]

Since the cement paste is a plastic material when the cement and water are first mixed, the mixture of the concrete making materials is also plastic when first mixed. Since cement paste gains the rigidity and hardness as time passes, the plastic concrete mixture also gains rigidity and hardness in time. Therefore, by placing the plastic concrete mixture into a mold having the dimensions and required shape, a rock like material having the desired shape and dimensions is obtained when the concrete hardness.

Concrete is a material that literally forms the basis of our modern society. Scarcely any aspect of our daily lives does not depend directly or indirectly on concrete. The popularity and wide use of concrete as a construction material derives from its advantages over other construction materials. Some of these advantages can be listed as follows:

- Concrete has the ability to be cast to any desired shape since it is in a plastic condition when the materials are mixed and hardens as time passes.
- Concrete is durable because it does not easily lose its quality as does steel, which corrodes, and as does timber, which decays with time.
- Concrete is economical: a) because of the abundance and relatively low price of the aggregates which constitute about three fourths of its volume, b)because semi-skilled workers can largely be employed and relatively unsophisticated equipment used in concrete work, c)because of the low maintenance cost.
- Concrete is an efficient material as compared to metals and other construction materials. Aggregates, which constitute the greatest part of concrete volume, are abundant and cheap as mentioned.
- Concrete has satisfactorily high compressive strength.
- Concrete has fairly high fire resistance as compared to that of metals and timbers.
- Concrete has aesthetic properties since concrete elements of any shape and color can be produced easily by the use of admixtures.
- In order to obtain energy-efficient building, modern concrete wall systems utilize both insulation and thermal mass [41].

Concretes are grouped in to three according to their bulk densities:

1. Heavy concrete: The bulk density varies from 3200 kg/m^3-4000 kg/m^3 and this kind of concrete mainly used in nuclear reactors.

2. Normal concrete: The bulk density bulk density varies from 2400 kg/m^3-2600 kg/m^3.

3. Lightweight concrete: The bulk density is less than 2000 kg/m^3.

Lightweight concretes can be divided into structural lightweight concretes and ultra-lightweight concretes for non-structural purposes. Figure 3.2 shows the typical ranges of densities of concretes made with various LWAs

Low density concretes, these very light nonstructural concretes, are employed chiefly for insulation purposes. With low densities, seldom exceeding 800 kg/m^3, thermal conductivity is low. Compressive strengths ranging from about 1.0 MPa to 7.0 MPa are characteristics.

Moderate strength concretes, require a fair degree of compressive strength, and thus they fall about midway between the structural and low-density concretes. These are sometimes designed as “fill” concretes. Compressive strengths are approximately 7.0 MPa to 17.0 MPa and insulation characteristics are intermediate.

Structural concretes contain aggregates that fall on the other end of the scale and that are generally made with expanded shales, clays, slates, slags, and pumice. Minimum compressive strength, by definition, is 17.0 MPa and most structural LWAs are capable of producing concretes with compressive strengths in excess of 35.0 MPa and also, with many of these; concretes can be made with strengths considerably greater than 40.0 MPa. Because, the densities of structural lightweight concretes are considerably greater than those of low density concretes, insulation efficiency is lower. However, thermal conductivity values for structural lightweight concrete are substantially better than normal weight concrete [42].

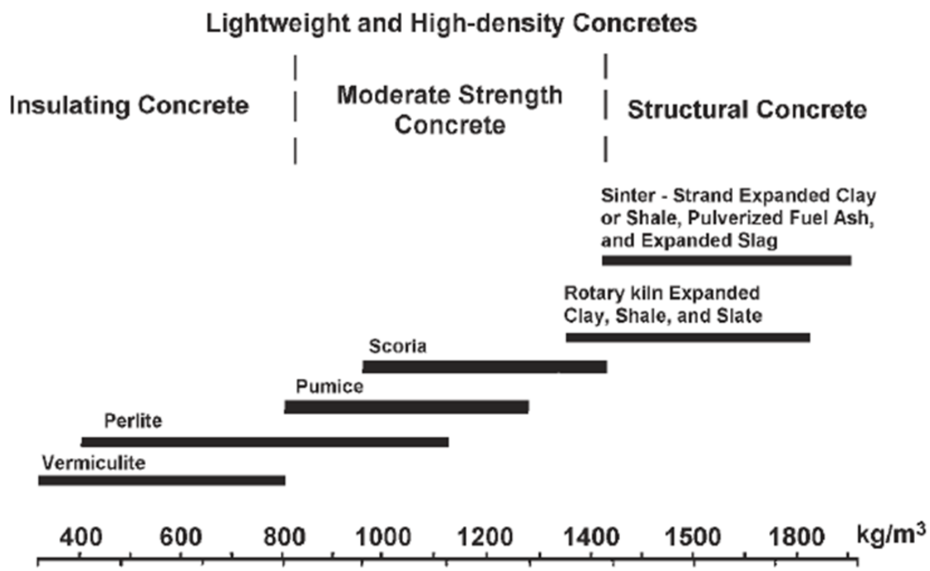

Figure 3.2. Typical ranges of densities of concretes made with various LWAs [43]

In accordance with ACI 213 [44], the structural LWC is a concrete, LWA produced air-dried weight in 28 days, usually in the range from 1440 to1850 kg/m^3 and a compressive strength of 17.2 MPa. However, ACI 213 [44], as the definition goes, this definition is not a specification. Qualification requirements may vary, from time to time until the unit weight of up to 1900 kg/m^3.

The main advantages of LWC are given as follows:

- It reduces the weight of the structure that may cause to a reduction in size of the supporting base and column size.
- It enhances the inherent fire resistance of buildings.
- LWC with a low thermal conductivity can be obtained by creating air bubbles or voids in concrete. This provides high thermal insulation of buildings.

The use of lightweight concrete is increased, and the research and development going on around the world to develop high-performance structural LWC.

3.2. The Special Types of Concretes

With the advent of a new generation of concrete admixtures and aggregates, combined with a much better understanding of the fundamental mechanisms governing concrete rheology, strength, cracking, and durability, we can now largely make concretes to provide the precise properties required for a particular project.

3.2.1. Rubberized concrete

Rubberized concrete may be defined as concrete reclaimed from the demolition of old structures or pavements that has been processed to produce aggregates suitable for use in new concrete. The processing (as with many natural aggregates) generally involves: crushing; removal of contaminant materials such as reinforcing steel, remnants of formwork, gypsum board, and other foreign materials; grading; and washing. The resulting coarse aggregate is then suitable for use in concrete. The fine aggregate, however, generally contains a considerable amount of old cement paste and mortar. This tends to increase the drying shrinkage and creep properties of the new concrete, as well as leading to problems with mix stability and strength. Generally, the strength of the source of the recycled aggregate has relatively little impact on the strength of the resulting concrete. While the compressive strength of RA concrete may be as much as 8 MPa lower than that of natural aggregate concrete at the same w/c ratio, this difference can easily be made up by a small reduction in w/c ratio; other engineering properties are not much affected.

Most publications in the field of rubberized concrete dealt with this subject as an environmental issue to use and recycle waste rubber tires. Rubber concrete could be regarded as a special concrete manufactured due to its enhanced toughness and ductility properties that are required in many applications. Early investigations on the usage of waste rubber tires in concrete or mortar mixtures had been very encouraging. Therefore it was decided to produce rubberized concrete with optimized mechanical properties.

3.2.2. Air-entrained concrete

Air-entrained concrete is ordinary concrete that contains controlled amounts of air in the form of microscopic bubbles which extremely small. They range in size from a few thousandths of an inch in diameter to a few hundredths. There are literally billions of these air bubbles in a single cubic foot of air-entrained concrete, and their presence dramatically changes the nature of both the fresh and hardened concrete. The primary benefit of entrained air in hardened concrete however is the resistance it offers to freeze-thaw damage and scaling caused by de-icing salts or chemicals. Most concrete contains some moisture which expands during freezing temperatures. Without room for this expansion, large forces develop that can rupture the surface causing what is commonly called surface scaling. The small, entrained air bubbles serve as reservoirs or expansion chambers to relieve these pressures Intentionally entrained air bubbles are extremely small in size, between 10 to 1000 µm in diameter, while entrapped voids are usually 1000 µm (1 mm) or larger. The majority of the entrained air voids in normal concrete are between 10 µm and 100 µm in diameter. As shown in Figure 3.3, the bubbles are not interconnected; they are well dispersed and randomly distributed. Non-air entrained concrete with a 25-mm (1-in.) maximum-size aggregate has an air content of approximately 11⁄2%. This same mixture air entrained for severe frost exposure would require a total air content of about 6%, made up of both the coarser "entrapped" air voids and the finer "entrained" air voids. As for climate, air-entrained concrete is recommended and used considerably in southern climates [40].

3.3. Concrete making materials

3.3.1. Cement

Cement is a generic term that can apply to all binders. There is a wide variety of cements that are used to some extent in the construction and building industries, or to solve special problems. The chemical composition of these cements can be quite diverse, but by far the greatest amount of concrete used today is made with Portland cements.

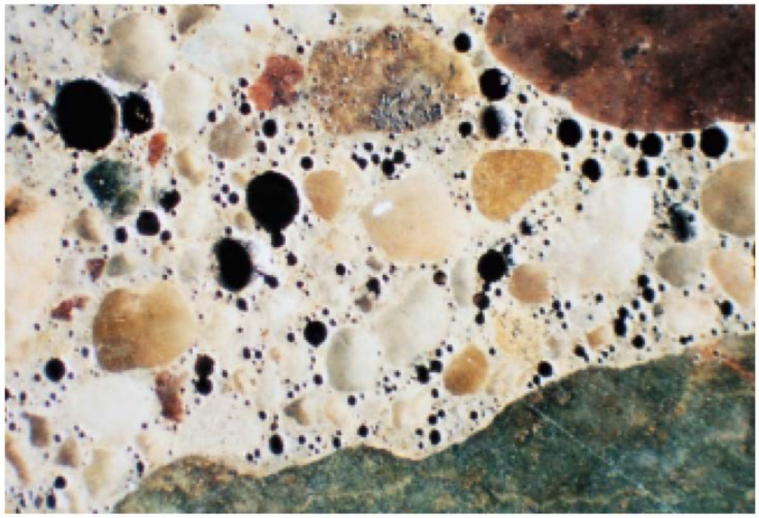

Figure 3.3. A section of air-entrained concrete [40]

Portland cement is a hydraulic binder produced by pulverizing a small amount of gypsum along with the Portland cement clinker that is obtained by burning an appropriate combination of calcareous and clayey materials.

The mixture of cement and water is called “cement paste”. The function of the cement paste in a concrete is to cover the surfaces of the aggregate particles, to fill the spaces between the particles and produce a compact mass by binding the aggregates particles.

3.3.2. Water

Water is a key ingredient in the manufacture of concrete. A large amount of concrete is made using water supplies. However, good quality concrete can be made with water which would not pass normal standards for drinking water.

Mixing water can cause problems by introducing impurities that have a detrimental impact on concrete quality. In spite of the fact that satisfactory strength development is of primary concern, impurities contained in the mix water may also affect drying shrinkage, setting times, or durability or they may cause efflorescence. Water should be avoided if it includes large amounts of dissolved solids, or appreciable amounts of organic materials [40].

3.3.3. Aggregates

Aggregates generally occupy 70 to 80 % of the volume of concrete therefore they have an important effect on its properties. They are granular materials obtained from the most part from natural rock and sands. Moreover, synthetic materials such as expanded clay and or slag shale are used to some extent, mostly in lightweight concrete [39]. In terms of their size, aggregates are mostly divided into two groups as coarse and fine. Coarse aggregate is used to describe particles larger than 4 mm, while fine aggregates are particles equal to or smaller than 4 mm.

Aggregates are classified according to their source:

1. Natural Aggregates: Natural aggregates are obtained from native deposits with no change in their natural state during production other than crushing, grading or washing. Sand, gravel, pumice, perlite, crushed stone are examples of natural aggregates.

2. Synthetic Aggregates: Most lightweight concretes today are made either with natural materials specially processed to provide LWAs, or with synthetic materials. Wide varieties of materials come under the general heading of solid wastes. These range from municipal and household garbage, or building rubble, through unwanted industrial byproducts such as slag and fly ash or discarded or unused materials such as mine tailings [39]. Recycled tire rubbers can be categorized under municipal wastes. Blast-furnace slag is typical example of a

by-product aggregate; expanded perlite, expanded vermiculite, burned clay and fly ash aggregate are example of aggregates produced by heat treatment.

Aggregates are essential in making concrete into an engineering material. They give concrete its necessary property of volumetric stability. They have an enormous effect on reducing moisture-related deformations (e.g. shrinkage) of concrete, a fact that renders pure paste and rich mortars very difficult to work with. Also, they restrain creep of the paste, giving acceptable long-term deformation properties. Moreover, aggregates are generally the more durable and stable of the materials incorporated into concrete mixtures, and thus provide durability. Besides, aggregates themselves may exhibit a lack of durability, but this tends to be the exception. Hence, aggregates help to produce an engineering material in two important ways: They reduce the cost and they fulfill the basic requirements of successful engineering, in order to produce a product that is fit-for-purpose in the most economical way [45].

With regard to their specific gravity or unit weight, concrete aggregates are classified as:

1. Normal Weight Aggregates: Specific gravities of normal weight aggregates vary between 2.4 and 2.8.

2. Lightweight Aggregates: Aggregates with a specific gravity of less than 2.4 are called lightweight aggregates.

3. Heavyweight Aggregates: Aggregates with a specific gravity more than 2.8 are called heavyweight aggregates [46].

Concrete aggregates are required to meet minimum standards of cleanliness, strength, and durability, and to be substantially free of deleterious substances. Materials that are soft, very flaky, too porous, or that can react detrimentally in concrete should be excluded. For this reason, thorough testing and examination, including petrographic examination, should be carried out before new or untried sources of aggregate are used. A further goal of characterization, not yet fully achieved, is to provide measurable properties which can be related to the aggregate performance in concrete. Different aggregate types may interact differently with the matrix, and these differences may be technically important depending on the magnitude of the influence. On occasions, improvements in strength induced by use of different aggregates may be economically important, by permitting significant reductions in cement content.

Pumice, scoria, and tuff are porous, glassy materials derived from igneous rocks. They differ primarily in their pore structure. Pumice contains a network of interconnected tube-like voids; scoria tends to contain more spherical voids; and tuff (formed from the cementing together of volcanic ash) has an irregular pore structure. These materials may be crushed and screened to obtain the desired gradation. Such materials were, of course, the first used to make lightweight concrete. For instance, the Pantheon in Rome, built in the second century, was constructed in part of concrete containing pumice to reduce the weight of the great dome. The Pantheon is still in use today, which attests to the potential durability of lightweight concrete.

Perlite is a volcanic glass that contains about 2–6 per cent water within its structure. When it is heated quickly to about 1800 C, the water dissociates itself from the mineral structure; the steam that results causes a cellular structure to develop within the material. This leads to a very low density. This material is widely used, primarily for insulation purposes, and to protect steel from the effects of fire. RA have used in low strength flowable concretes for fill applications. It leads to concretes with more flexibility and better thermal insulating properties. However, it is unlikely to be suitable for ordinary structural concrete [46].

Waste tires which can be used for preventing impact damage, and as a pavement making material have hardness and elasticity properties superior to those of rubber, good resistance to weathering due to their low specific gravity which is lower than most construction materials [47]. The Typical shape and size of RA are shown in Figure 3.4.

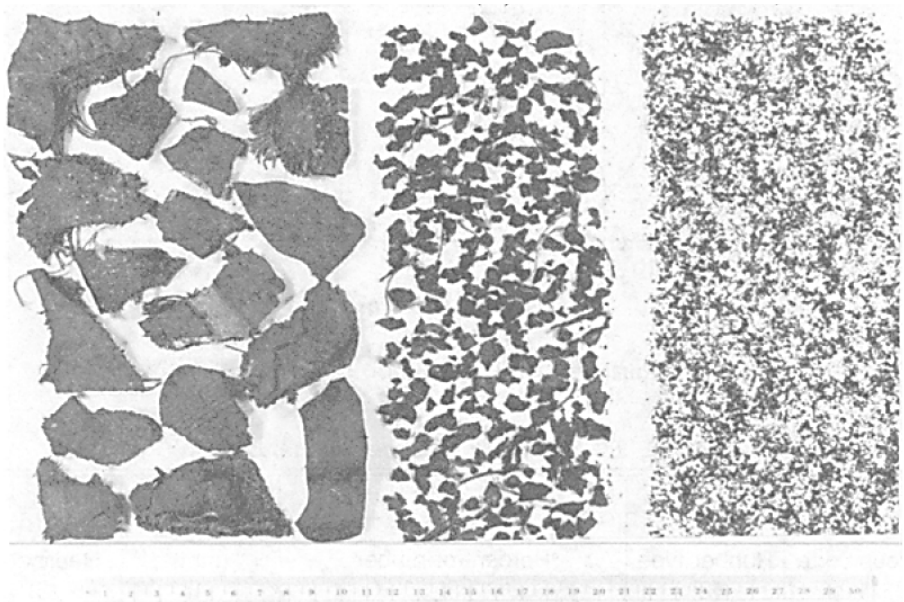

Figure 3.4. Typical shape and size of RA [48]

3.3.3.1. Physical properties of aggregates

Each of the properties of the LWAs may have some bearing on the properties of hardened and plastic concrete. However, those properties of lightweight concrete, in common with those of normal weight concrete, are greatly influenced by the quality of the cement paste. Specific properties of aggregates which may affect the properties of concrete as follows:

3.3.3.1.1. Porosity

Most conventional dense mineral aggregate particles have a measurable porosity and they are able to absorb water. Porosity, *p*, is the internal pore volume as a proportion of the total volume of a solid,

$$p = \frac{V_p}{V_T} \tag{1.1}$$

where V_p, is the volume of internal pores and V_T , is the total volume of the solid.

The significance of aggregate porosity lies in its effects on aggregate density and thus concrete density which is indirectly related to concrete strength and stiffness. Besides, porous aggregates will have lower density, elastic modulus, and strength, extreme cases being lightweight and highly porous aggregates that require special mix proportioning and handling procedures. They may increase the permeability of the concrete to ions and fluids, particularly if their pore system is interconnected [46].

3.3.3.1.2. Absorption and moisture state

Aggregates that are porous can absorb water. Absorption is thus governed by porosity. For the pores of an aggregate particle to fill with water, the pores must be interconnected and open to the surface so that water from the exterior can penetrate the solid. Absorption is expressed as the ratio of the increase in mass of an oven-dried sample after saturation to the mass of the saturated-surface-dry sample, in per cent. Aggregate particles can assume different moisture states: oven dried, in which evaporable water is driven off at 100–110 °C; air dry, when aggregates dry to hygral equilibrium with the surrounding air and some moisture is retained by the aggregates; and saturated-surface-dry (SSD), which is the condition when the aggregate particles themselves are saturated, but also there is no free or excess moisture on the surface. The condition of saturated particles with free surface moisture (‘wet’) can also occur. Figure 3.5 illustrates these different moisture states. The moisture state will affect aggregate density and therefore density is measured at some standard or specified moisture state [46].

Figure 3.5. Moisture states of aggregates [46]

Aggregate porosity and absorption will govern its water content ω, defined by

$$w = \frac{M_W}{M_D} \tag{1.2}$$

where

M_W is the total mass of evaporable water in the aggregate (including absorbed and free surface water)

M_D is the mass of (oven-dried) solids.

Water content is determined gravimetrically by heating a sample of aggregate to 100–110 °C and measuring the amount of water driven off. Equation (1.2) can be expressed in other forms to define particular parameters for aggregates:

$$\text{Absorption capacity} = \frac{M_{SSD} - M_D}{M_D} \times 100\% \tag{1.3}$$

which represents the maximum amount of water the aggregate can absorb.

M_{SSD} = Mass of SSD aggregate

M_D = Mass of oven-dry aggregate

3.3.3.1.3. Density

Density ρ of a solid is defined as the ratio of its mass to the volume it occupies, that is

$$\rho = \frac{M_S}{V_S} \tag{1.4}$$

where M_S and V_S are the mass and volume of the solid, respectively.

The density of aggregates is used as the basis for classifying them into 'normal weight', 'lightweight', or 'heavyweight' aggregates. Hence, there are several measures of density that must be considered.

3.3.3.1.3.1. Absolute density

This is the density of a solid excluding the internal enclosed pores, which is it is the density of the solid material only. This is not normally used in concrete technology, since it involves pulverizing the material to eliminate the enclosed impermeable pores.

3.3.3.1.3.2. Relative density (Specific gravity)

The term ‘relative density’ is preferred to ‘specific gravity’ which is sometimes used to denote the same property. The relative density of a solid is its density divided by the standard density of water (1000 kg/m^3). It is a relative measure of density, useful since it is independent of the units used for absolute density. In concrete technology, the relative density frequently refers to the ratio of apparent density to density of water. Normal aggregates have relative densities that vary from about 2.2 to 3.0. The specific gravity of coarse LWAs is range about 1/3 to 2/3 of that for normal weight aggregates [46].

3.3.3.1.3.3. Bulk density

This is the density of the material in bulk granular form, which is the mass of aggregate particles occupying a certain volume:

$$\rho_{bulk} = \frac{M_T}{V_T} \qquad (1.5)$$

where

M_T is the total mass of the granular sample (the mass of solids)

V_T is the total volume occupied by the sample.

Table 3.1. indicates that bulk densities of aggregates can vary from very low values of less than 100 kg/m^3 for insulating aggregates to values in excess of 4500 kg/m^3 for heavyweight aggregates.

Table 3.1. Classification of aggregates in terms of bulk density. [46]

Classification	Range of bulk density (kg/m^3)	Compaction mode
Insulating	96-196	Dry loose
Lightweight for masonry	880-1120	Dry loose
Lightweight for concrete	880-1120	Dry loose
Air-cooled slag	>1120	Compacted
Normal weight	1200-1760	Compacted
Heavyweight	1760-4640	Compacted

3.3.3.1.4. Unit weight

The concept of unit weight also applies to an assemblage of aggregate particles, which is to the bulk material. The unit weight γ of a bulk material is the bulk density expressed in weight (i.e. force) units, thus

$$\gamma = \rho_{bulk} g \qquad (1.5)$$

'Bulk density' is frequently taken in the literature to be equivalent to 'unit weight' although this is not strictly correct [46].

3.3.3.1.5. Particle shape

Particle shape refers not only to the basic shape of aggregate particles, but also to other measures such as angularity, flakiness. Particle shape can be quantified and classified by measuring the dimensions of particles, which is length, width, and thickness. This is easier to do for coarse than fine particles.

Synthetic aggregates such as crushed metallurgical slags can also have very poor particle shapes. On the other hand, natural gravels will tend to be more spherical and have rounder edges due to wear.

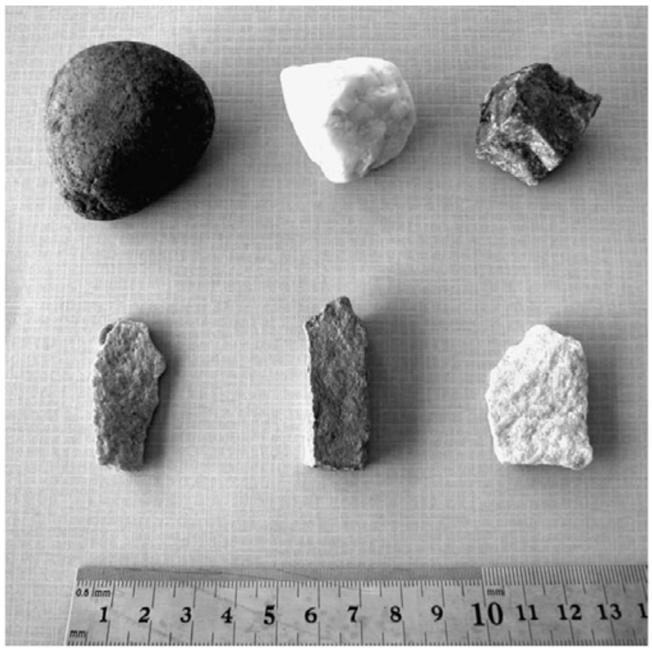

Figure 3.6. Illustrations of particle shapes. Shapes are, clockwise from top left: Rounded, Irregular, Angular, Flaky, Elongated, Flaky and Elongated. [46]

The closer to spherical and rounded the aggregate particles are, the more desirable it is for concrete from the perspective of workability and low water requirement. Flaky and elongated aggregates can trap bleed water underneath particles as well as increase the water requirement. Figure 3.6 provides a series of photographs illustrating particle shapes.

Shape, particularly for fine aggregates, is a significant property since it has a strong influence on the plastic properties of concrete Rounded, less angular particles are able to roll or slide over each other in the plastic mix with less resistance compared with flaky and angular particles. Poorly shaped particles also tend to induce aggregate interlock in the mix, resisting energy (compactive effort). Shape also affects the void content and packing density of aggregates, with lower compacted densities and higher void contents resulting from poorly shaped particles.

3.3.3.1.6. Particle surface texture

Surface texture is another significant property affecting the performance of aggregates in plastic and hardened concrete. Surface texture depends on hardness, grain size, pore structure, and texture of the parent rock, as well as the amount of wear on the particle that might have either smoothed or roughened it.

Rough surface texture increases the total surface area of an aggregate and increases the internal friction between aggregate particles during compaction. These impacts tend to increase mix-water requirements; since the former requires more water to wet the aggregate surface while the latter promotes ‘harshness’ in a mix. On the other hand, rougher textures can provide to better bonding between aggregates and paste and can enhance the mechanical properties of concrete [46].

3.3.3.1.7. Grading

Grading refers to the particle size distribution and is a characteristic of aggregates in their granular form. Aggregate grading is very important in relation to the plastic properties of concrete. Well-graded and well-shaped aggregates give workable mixes that are readily transported, placed, and compacted. Cohesive mixes are entrenched provided sufficient fine material is present, and particularly in low cement content mixes this requires an aggregate grading with an adequate amount of ‘fines’. Besides, it is also necessary to stress that good concrete can be made even with poorly graded or poorly shaped aggregates, provided the mix properties can be matched with the concreting operation and the structural application. Grading and its effects on plastic concrete is significant not least since the hardened properties of concrete cannot be fully realized if the concrete is unworkable and difficult to compact.

Grading of aggregates manages the amount of voids that must be filled by paste as well as the surface area of aggregates that needs to be coated with paste.

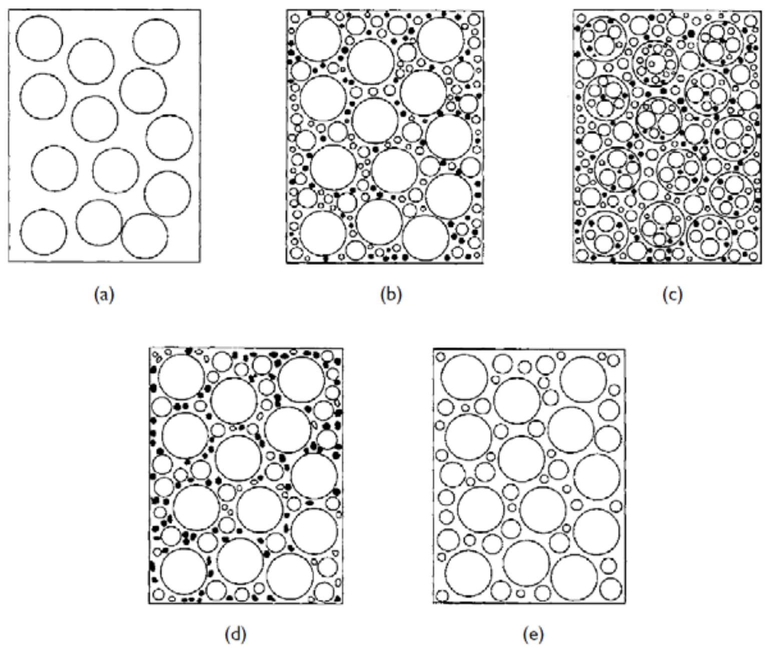

Figure 3.7. Schematic representations of aggregate gradations (a) uniform size; (b) continuous (c) replacement of small sizes by large sizes; (d) gap-graded (e) no-fines [46]

Several types of grading are common for concrete aggregates, illustrated in Figure 3.7. Uniform or single-sized aggregates (Figure 3.7a) include large volumes of voids between the particles, whereas continuous grading (Figure 3.7b) in which a range of sizes is present decreases the void space and reduces the paste requirements. Using a larger maximum aggregate (Figure 3.7c) can also decrease the void space. Occasionally, gap-graded (Figure 3.7d) or no-fines gradings (Figure 3.7e) are used as well. Grading of aggregates is not a ‘property’ as such. However the combined effects of particle shape, grading and surface texture largely govern the plastic properties of concrete and none of these properties can be considered in isolation of the others.

In general, it is an advantage to have as large a maximum aggregate size in a concrete mix as possible, because this reduces the total surface area per unit volume of aggregate which the paste has to cover. This will also reduce the water requirement of the mix. High strength concretes usually have a restriction on maximum aggregate size, typically 19 mm. The range of particle sizes in aggregate is illustrated in Figure 3.8.

Figure 3.8. Range of particle sizes found in aggregate for use in concrete. [40]

3.3.3.1.8. Fineness modulus

This dimensionless parameter is used as a single number to characterize and measure a grading and is effectively a evaluating of the average particle size (or more strictly, the logarithmic average particle size). It is a parameter of the particle size distribution which is obtained by adding together the cumulative percentages of material retained on each of the standard sieves and dividing the sum by 100. As a rule, gradings having the same fineness modulus will require a similar quantity of water to produce a mix of the same consistency. However, the water requirement depends not only on the average particle size as given by the fineness modulus, but more especially on the percentage of finer material (<300μm) in the grading. Fineness modulus calculations apply equally to stone as to sand samples, although fineness moduli are usually only computed for sands, for which they can be used as a measure of sand fineness or coarseness as suggested in Table 3.2.

Table 3.2. Categorization of fineness of concrete sands, using fineness modulus [46]

Fineness modulus	Sand fineness
<1.0	Very fine
1.0-2.0	Fine
2.0-2.9	Medium
2.9-3.5	Coarse
>3.5	Very coarse

3.3.3.1.9. Strength

The strength of aggregate particles varies with type and source and is measurable only in a qualitative way. Some particles may be strong and hard, and others weak and friable. There is no reliable correlation between aggregate strength and concrete strength and lower particle strength would not preclude use of an aggregate in structural concrete. Aggregate compressive strengths range from 65 to 270 MPa [39].

3.3.4. Admixtures for concrete

Additives fine materials which are added to obtain the specific properties of the machinery and concrete mortar. Another, no less important, the purpose of use of mineral additives in cement concrete benefits include economic and environmentally safe disposal of industrial and other waste. Unlike chemical additives are used in relatively large as a replacement for the cement and/or fine aggregate in the concrete [40].

3.3.4.1. Mineral admixtures

Mineral admixtures are classified into three general types:

1. Those which are pozzolanic or mainly pozzolanic with some additional cementitious properties.
2. Those which are cementitious
3. Others

The name “pozzolan” is a corruption of Pozzuoli that contains siliceous and aluminous and no cementitious materials but chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. A town in the Bay of Naples was the source of a highly prized deposit of weathered ash from Mount Vesuvius. The name is now applied to any reactive aluminosilicate material, of either natural or industrial origin [40]

Volcanic ashes, volcanic tuffs (trusses), volcanic glasses, pumicites, calcined clays or shales, diatomaceous earths, fly ashes (the fine ashes obtained from the burning of pulverized coal in power plants for generating electricity), condensed silica fumes and rice husk ashes are the commonly known materials that exhibits pozzolanic characteristics [40].

Microsilica is a by-product material which is used as a pozzolan which is a result of the reduction of high-purity quartz with coal in an electric furnace in the production of silicon or ferrosilicon alloy. Microsilica rises as oxidized fumes from the furnace 2000 °C. Upon cooling, it is condensed and collected in a huge cloth bags. Condensed silica fume is then treated to remove impurities and to control the particle size. Condensed silica fume substantially silica (usually 85%) as a non-crystalline (amorphous) form. It is very well with particles smaller than 1 micron in diameter and having an average diameter of about 0.1 microns, about 100 times smaller than the average number of particles of cement. The relative density of microsilica as a rule, in the range of from 2.20 to 2.5, and Portland cement has a specific gravity of about 3.15. Bulk density (unit weight uncompacted) microsilica varies from 130 to 430 kg/m^3. Microsilica is sold in powder form, but more commonly available in liquid form. Silica fume used in an amount of from 5% to 10% by weight of total cementitious material. It is used in cases where a high degree of impermeability needed in high-strength concrete. [40]

3.3.4.2. Chemical admixtures

Admixtures are those ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing. Admixtures can be classified by function as follows:

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers
9. Alkali-silica reactivity inhibitors
10. Coloring admixtures
11. Miscellaneous admixtures such as workability, bonding, dampproofing, permeability reducing, grouting, gas-forming, antiwashout, foaming, and pumping admixtures.

Concrete should be workable, finishable, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by resorting to admixtures (except air-entraining admixtures when needed).

The major reasons for using admixtures are:

- To reduce the cost of concrete construction
- To achieve certain properties in concrete more effectively than by other means
- To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions
- To overcome certain emergencies during concreting operations

Despite these considerations, it should be borne in mind that no admixture of any type or amount can be considered a substitute for good concreting practice. The effectiveness of an admixture depends upon factors such as type, brand, and amount of cementing materials; water content; aggregate shape, gradation, and proportions; mixing time; slump; and temperature of the concrete.

Air-entraining admixtures are used to purposely introduce and stabilize microscopic air bubbles in concrete. Air entrainment will dramatically improve the durability of concrete exposed to cycles of freezing and thawing. Entrained air greatly improves concrete’s resistance to surface scaling caused by chemical deicers. Furthermore, the workability of fresh concrete is improved significantly, and segregation and bleeding are reduced or eliminated.

Water-reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water-cement ratio, reduce cement content, or increase slump. Typical water reducers reduce the water content by approximately 5% to 10%. Adding a water-reducing admixture to concrete without reducing the water content can produce a mixture with a higher slump. The rate of slump loss, however, is not reduced and in most cases is increased. Rapid slump loss results in reduced workability and less time to place concrete. An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is reduced. For concretes of equal cement content, air content, and slump, the 28-day strength of a water-reduced concrete containing a water reducer can be 10% to 25% greater than concrete without the admixture [40].

3.4. Mechanical properties of concrete

3.4.1. Workability

Easy placement, consolidation, and finishing with the newly mixed concrete and the extent to which it is opposed segregation called workability. Factors affecting the workability of concrete are: (1) the amount and characteristics of cementitious materials (2) the consistency of concrete mixture, (3) the method and duration of transport (precipitate) and (4) Sorting, surface texture and form fine and coarse aggregates (5) a water content, (6) entrained air, (7) and admixtures of concrete and ambient air temperature. A uniform grading of aggregate particles and the existing entrained air provide considerably improvement the control of workability and segregation.

Aggregates influence workability in two principal ways: (1) by influencing the rheological properties due to particle shape, size, and grading, and (2) by governing the mix-water requirement for a given workability. The grading of fine aggregate has a more crucial influence on workability than that of the coarse aggregate. While aggregate grading (and other particle characteristics) may influence workability, the converse is also true: desired aggregate grading is a function of the workability of the mix, which itself is related to the practical application.

The slump test is the oldest and still the most widely used workability test. It employs a mold in the shape of a truncated cone, 300-mm high, and 200 mm in diameter at the base and 100mm in diameter at the top, into which the concrete is compacted by rodding. The difference in height of fresh concrete before and after removal of the mold is measured, and called as slump of the concrete. The test is limited to ordinary fresh concrete, generally within the slump range of 20–180 mm, which covers low to high workability in terms of construction requirements. It is not suitable for non-cohesive mixes such as lean and no-fines mixes. The slump test is extensively used as a means of rapid and continual checking of uniformity of fresh concrete supply. It is not a measure of workability as such. Its major disadvantages are that it has no basis in fundamental rheology and is operator sensitive. However, there is hardly a well-run construction site in the world where the slump test may not be seen in regular operation.

The increasing the size or percentage of RA reduced the workability of the mixture. This causes subsequently a decrease in the slump values in mixture. The presence of air improves the workability of concrete. It is particularly effective in low cement mixture, which might otherwise be very serious and difficult to handle. Thanks to the improved performance of captured content of the air, water and sand can be significantly reduced. Air entrained concrete requires lower water than normal with non-air entrained concrete. On the other hand, high air content can make the mixture more sticky and difficult to complete. [40]

3.4.2. Strength

Compressive strength levels required by the construction industry for the usual design strengths of cast-in-place, pre-cast or prestressed concrete can be obtained economically with the structural LWAs in use today. Design strengths of 20.0 MPa to 35.0 MPa are common. In precast and prestressing plants design strengths of 35.0 MPa are usual.

All aggregates have strength ceilings and with LWAs the strength ceiling generally can be increased at the same cement content by reducing the maximum size of the coarse aggregate. The compressive strength of LWC is usually related to cement content at a given slump rather than water-cement ratio. Water reducing or plasticizing admixtures are frequently used with lightweight concrete mixtures to increase workability and facilitate placing and finishing [40].

3.4.3. Density (Unit weight)

Weight reduction for concrete of structural quality is the primary advantage of lightweight concrete. Depending upon the source of material structural grade lightweight concrete can be obtained in a dry weight range of 1440 kg/m^3 to 1840 kg/m^3.

The density of concrete depends upon the moisture and cement content, mix proportions, grading of the aggregates, method of compaction, curing conditions, mineral and chemical admixtures, w/c ratio, etc [40].

RA leads to a decrease in the concrete density by replacement of natural aggregates. [49]. The bulk density of the mixture containing normal aggregates decreases with the increasing proportion of the rubber content due to the low specific weight of the rubber particles. Also, increasing the rubber content increases the amount of air that leads to reduce the density.

3.4.4. Water absorption

Water absorption of the aggregates immensely affects the properties of the concrete. There is a higher air content in concrete mixtures containing LWA when compared to natural aggregates. Even without any air-entrainment admixtures being introduced, it has been conducted that the air content is significant.

Water absorption increases with increasing of rubber content due to higher air content of rubber concrete mixtures. The nature of the nonpolar rubber entraps air in its gear surface texture. When a non-polar RA is mixed with concrete mix, it can draw air as it repels water. [49]

3.4.5. Thermal properties of concrete

The thermal properties of a system are defined as those properties, which measure the response of the system to thermal and mechanical stimuli. These include both the thermodynamic properties which describe the change of the system between initial and final equilibrium states and the transport properties which define the flow of heat or material resulting from a steady departure from equilibrium. For building heat-transfer processes, the important thermo-physical properties are thermal conductivity, specific heat and density. Thermal properties of a concrete are strongly affected by the corresponding thermal properties of the aggregates and by the aggregate volume concentration. Concretes with desired thermal conductivity therefore need to be designed with the aggregate properties and proportions [50-52].

3.4.5.1 Thermal conductivity

Thermal conductivity (k) is defined as the rate of heat flow through a body of unit thickness and unit area, with a unit temperature difference between two surfaces (units typically of W/mK). The distance of heat transfer is defined as Δx, the rate of heat transferred through the material is Q, which is perpendicular to area A with a distance (Δx) from temperature T_1 to temperature T_2, when $T_1 > T_2$ [53].

$$k = \frac{Q\Delta x}{A(T_2 - T_1)} \tag{1.6}$$

The thermal conductivity of concrete depends largely on the thermal conductivity of the aggregate, which in turn depends on rock and mineral type. Quartz has a relatively high conductivity while feldspars exhibit the opposite trend. Thus, quartzitic aggregates have high values of thermal conductivity (>3.0 W/mK), while basic igneous rocks and some limestones exhibit lower values (<1.5 W/mK). Porosity of an aggregate is also important in two respects: if the pores are air-filled, thermal conductivity is reduced since air is a good insulator; if the pores are water-filled, the opposite occurs due to the high thermal conductivity of water. Therefore, the moisture content of an aggregate has a large influence on thermal conductivity. Conductivity of concrete is influenced by its porosity and moisture content, which includes the corresponding aggregate properties. Consequently, if concrete with a high degree of insulation is desired, aggregates of high porosity yet relatively low absorption should be used. These requirements are most easily met with closed-cell artificial aggregates [50].

3.4.5.2. Specific heat

Specific heat (*c)* is the amount of heat required to raise the temperature of a unit mass of material by one unit of temperature (units of J/kg K).

$$Q = m \times c \times (T_2 - T_1) \tag{1.7}$$

Specific heat of concrete is usually governed by heat units. Concrete high specific heat is helpful to raise the temperature stability of the structure. For conventional concrete common range between 840 and 1170 J/kgK largely depends on the types of aggregate, moisture content and the density of the concrete. [51]

3.4.5.3. Thermal diffusivity

Thermal diffusivity is described as the thermal conductivity divided by the specific heat and density (units of m^2/s); it is a physical material property that determines the time rate of change of temperature at any point within a body. As with thermal conductivity, the thermal diffusivity of a normal weight aggregate depends mainly on its quartz content. Likewise, specific heat is governed by mineral content [54].

$$\alpha = \frac{\lambda}{\rho C_P} \tag{1.8}$$

As with thermal conductivity, the thermal diffusivity of a normal weight aggregate depends largely on its quartz content. Likewise, specific heat is governed by mineral content [52,54]. Depending on the type of aggregate used in concrete, the thermal diffusivity of typical conventional concrete is in the range of 5.5×10^{-7} and 15.5×10^{-7} m^2/s [51]. Thermal properties of some building materials are given in Table 3.3.

Table 3.3. Thermal properties of some building materials [55].

	Thermal conductivity k (W/mK)	Specific heat c (kJ/kgK)	Thermal diffusivity α (m^2/s)
Briquette	0.920	0.840	6.84 × 10−7
Brick	0.690	0.840	5.20 × 10−7
Blokbims	0.230	0.835	3.57 × 10−7
AAC	0.150	1.047	3.58 × 10−7
Concrete	1.370	0.880	7.50 × 10−7
Plaster	0.700	0.840	2.99 × 10−7
XPS	0.034	1.280	12.1 × 10−7

CHAPTER 4

THERMAL BALANCE OF BUILDING STRUCTURE

4.1. Introduction

Human beings only sense well and comfortable within a narrow range of thermal conditions. Only at a few places on earth does the natural climate provide comfort for human beings. In most areas the climate conditions are comfortable only for a limited time per day and for a limited time period per year. A building is an enclosure that protects against external conditions. It should provide a comfortable environment on the inside. The first major system of a building that we consider is the building structure which includes walls, floors, ceilings, and external parts of a building. Commonly these parts are referred to as the building envelope. The building envelope may not seem to be that important or may not appear to be a system. But, the way a building is pitted against the elements has a direct impact on the operation of other systems in the building and can result in very definite savings. Heat loss is a very significant factor in the operation of a building. The amount of heat that is lost from a building into the outside air influences the amount of heating, cooling, and ventilation required in a building. The heat loss depends on the type of building structure which includes doors, windows, walls, floors, and ceilings. The climate of an area is also important in determining heat loss [56].

Prior to the design of the heating, an estimate must be made of the maximum probable heat loss of each room or space to be heated. There are two kinds of heat losses: (1) the heat transmitted through the walls, ceiling, floor, glass, or other surface, and (2) the heat required to warm outdoor air entering the space. The sum of the heat losses is referred to as the heating load. The heating load is the amount of heat energy that would need to be added to a space to maintain the temperature in an acceptable range.

4.2. Heat gain and cooling load

It is important to differentiate between heat gain, cooling load, and heat extraction rate. Heat gain is the rate at which energy is transferred to or generated within a space. It has two components, sensible heat and latent heat, which must be computed and tabulated separately. Heat gains usually occur in the following forms:

1. Solar radiation through openings.
2. Heat conduction through boundaries with convection and radiation from the inner surfaces into the space.
3. Sensible heat convection and radiation from internal objects.
4. Ventilation (outside air) and infiltration air.
5. Latent heat gains generated within the space [57].

A major difference between heat loss and heat gain is that most heat loss usually occurs at night, and the greatest heat gain usually occurs during the day. Air infiltration into buildings in the summer is ordinarily much less than in the winter. This is due to the smaller temperature difference between inside and outside air and the lower wind speed in the summer in most areas [56].

The cooling load is the rate at which energy must be removed from a space to maintain the temperature and humidity at the design values. The cooling load will generally differ from the heat gain because the radiation from the inside surface of walls and interior objects as well as the solar radiation coming directly into the space through openings does not heat the air within the space directly. This radiant energy is mostly absorbed by floors, interior walls, and furniture, which are then cooled primarily by convection as they attain temperatures higher than that of the room air. Only when the room air receives the energy by convection does this energy become part of the cooling load. Figure 4.1 illustrates the phenomenon. The heat storage and heat transfer characteristics of the structure and interior objects determine the thermal lag and therefore the relationship between heat gain and cooling load. For this reason the thermal mass (product of mass and specific heat) of the structure and its contents must be considered in such cases. The reduction in peak cooling load because of the thermal lag can be quite important in sizing the cooling equipment [57].

Figure 4.1. Schematic of Load Transfer. [56]

The heat extraction rate is the rate at which energy is removed from the space by the cooling and dehumidifying equipment. This rate is equal to the cooling load when the space conditions are constant and the equipment is operating. However, that is rarely the case for a number of reasons, including the fact that some fluctuation in room temperature is necessary for the control system to operate. Because the cooling load is also below the peak or design value most of the time, intermittent or variable operation of the cooling equipment is required.

The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, doors etc.) and heat generated by occupants, equipment, and lights as seen in Figure 4.2. External loads are formed because of heat gains in the conditioned space from external sources through the building envelope or building shell and the partition walls.

Sources of external loads include the following cooling loads:

- Heat gain entering from the exterior walls and roofs
- Solar heat gain transmitted through the fenestrations
- Conductive heat gain coming through the fenestrations
- Heat gain entering from the partition walls and interior doors
- Infiltration of outdoor air into the conditioned space

Internal Loads are formed by the release of sensible and latent heat from the heat sources inside the conditioned space. These sources contribute internal cooling loads:

- People
- Electric lights
- Equipment and appliances

The percentage of external versus internal load varies with building type, site climate, and building design. The total cooling load on any building consists of both sensible as well as latent load components. The sensible load affects the dry bulb temperature, while the latent load affects the moisture content of the conditioned space.

Buildings may be classified as externally loaded and internally loaded as shown in Figure 4.3. In externally loaded buildings the cooling load on the building is mainly due to heat transfer between the surroundings and the internal conditioned space. Since the surrounding conditions are highly variable in any given day, the cooling load of an externally loaded building varies widely. In internally loaded buildings the cooling load is mainly due to internal heat generating sources such as occupants, lights or appliances.

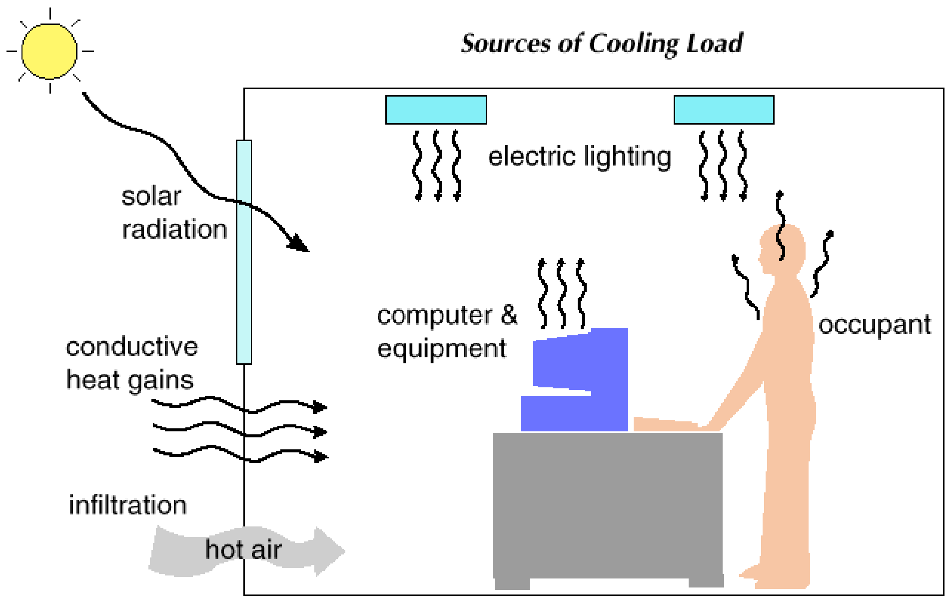

Figure 4.2. The sources of cooling load [58]

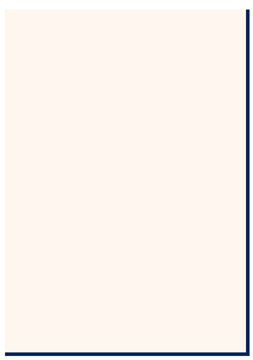

Figure 4.3. External and internal loads [58]

In general the heat generation due to internal heat sources may remain fairly constant, and since the heat transfer from the variable surroundings is much less compared to the internal heat sources, the cooling load of an internally loaded building remains fairly constant. Obviously from energy efficiency and economics points of view, the system design strategy for an externally loaded building should be different from an internally loaded building. Hence, prior knowledge of whether the building is externally loaded or internally loaded is essential for effective system design [58-60].

4.3. Cooling load calculation methods

For calculating the cooling load in building, there are several methods which can be classified as exact, numerical and transfer function methods.

The first method is exact method which is called balance (HB) is rigorous hence it requires the use of computers, but it is also direct and can be used easily for parametric studies. The exact method to calculate the space cooling load is to use heat balance equations to determine the temperature of the interior surfaces of the building structure at time t simultaneously and then to calculate the space sensible cooling load, which is equal to the sum of the convective heat transfer from these surfaces, latent cooling loads, and the cooling load due to infiltrated air at time t. The heat balance method is direct and clear in load calculation methodology. Using the heat balance method, the assumption of linear supposition is not required, and the changing of certain parameters, such as the surface convective heat-transfer coefficient, can be modeled as required. If moisture transfer should be included in the cool-down period in nighttime shutdown mode in a location where the outdoor climate is hot and humid in summer, then the heat balance method will give comparatively more accurate results. However, the heat balance method demands laborious work, more computing time, complicated computer programs, and experienced users [61].

The second method is called the radiant time series (RTS) method which is simpler to apply than heat balance method since, there is no zone heat balance and the storage and release of structure energy are approximated with predetermined zone response instead. The cooling load is found directly but the zone air temperature assumed constant. Design cooling loads are based on the assumption of steady periodic conditions. Thus, the heat gain for a particular component at a particular hour is the same as 24h prior, which is the same as 48h prior etc. RTS method is exactly the same as previous simplified methods (TFM and TETD/TA). Important areas that are different include the computation of conductive heat gain, the splitting of all heat gains into radiant and convective portions, and the conversion of radiant heat gains into cooling loads ASHRAE. Radiant time factor and conduction time factors are to important factors derived from heat balance model. Radiant time factors reflect the percentage of an earlier radiant heat gain that becomes cooling load during the current hour. Likewise, conduction time factors reflect the percentage of an earlier heat gain at the exterior of a wall or roof that becomes heat gain at the inside during current hour [62].

In order to calculate the cooling loads in buildings, several methods have been developed based on the concept of transfer functions, namely, transfer function method (TFM), total equivalent temperature difference method (TETD) time averaging method (TA), cooling load temperature difference (CLTD) solar cooling load (SCL) cooling load factor (CLF) and [63].

TFM is less rigorous and quite convenient from the point of view of computation. The method of transfer function is a simplification of the heat balance method, however; TFM software is user-friendly saving of computing time. In TFM; firstly, the inner surface temperature and heat gain or loss of heat from the outer walls, roofs and floors have been calculated using response factors or coefficients of the conduction transfer function, as well as solar and internal heat sources are calculated directly part of an hour. Secondly, the number of the coefficients of the transfer function is used to convert heat gain for cooling loads or heating loads of heat loss. Second, room transfer function coefficients are used to convert the heat gains to cooling loads, or the heat losses to heating loads. Today, it is the most widely used computer-aided load calculation method in HVAC&R consulting firms. However, since the cooling load calculations depend on the value of transfer function coefficients as well as the characteristics of the space, the TFM is limited. In addition, the transfer function is only available for certain representative of the walls and roofs, and for others, they must be obtained either from experiments or by using the HB. [64].

CLTD is a theoretical temperature difference that accounts for the combined effects of inside and outside air temp difference, daily temp range, solar radiation and heat storage in the construction assembly/building mass. It is affected by orientation, tilt, month, day, hour, latitude, etc. CLTD factors are used for adjustment to conductive heat gains from walls, roof, floor and glass.

CLF accounts for the fact that all the radiant energy that enters the conditioned space at a particular time does not become a part of the cooling load instantly. The CLF values for various surfaces have been calculated as functions of solar time and orientation and are available in the form of tables in ASHRAE Handbooks. CLF factors are used for adjustment to heat gains from internal loads such as lights, occupancy, power appliances. SCL factors are used for adjustment to transmission heat gains from glass. The limitations of the TFM are also carried through to the CLTD/SCL/CLF results. Furthermore, the grouping of CLTD/SCL/CLF may cause additional errors [62].

The TETD/ TA method is also a member of the TFM family and is developed primarily for manual calculation. TETD/TA is simpler in the conversion of heat gains to cooling loads. However, the time-averaging calculation procedure is subjective. it is more an art than a rigorous scientific method. Also the TETD/TA method inherits the limitations that a TFM possesses if the TFM is used to calculate the TETD [62,65].

4.3.1. Reliability and accuracy of various calculation methods

For each cooling load calculation method, there are several benefits/limitations which feature each method. Simplicity and accuracy are two contradicting objectives to be fulfilled. If a method could be considered to be simple, its accuracy would be a matter of question, and vice versa.

While modern methods emphasize on improving the procedure of calculating solar and conduction heat gains, there are also other main sources coming from internal heat gains (people, lighting and equipment).

For strictly manual cooling load calculation method, the most practical to use is the CLTD/SCL/CLF method as described in the 1997 ASHRAE Fundamentals. This method, although not optimum, will yield the most conservative results based on peak load values to be used in sizing equipment. It should be noted that the results obtained from using the CLTD/CLF method depend largely on the characteristics of the space being considered and how they vary from the model used to generate the CLTD/CLF data shown on the various tables. Engineering judgment is required in the interpretation of the custom tables and applying appropriate correction factors [62].

4.3.2. Cooling load calculation software

Today, most of the load calculations are performed by personal computers. Among the widely adopted load calculation and energy analysis software, only Building Load Analysis and System Thermodynamics (BLAST) developed by the University of Illinois adopts the heat balance method.

All the others are based on the transfer function or weighting factors method. Load calculation software can also be divided into two categories. The first includes those developed by government or public institutions, such as the Department of Energy (DOE-2.0), National Bureau of Standards Load Program (NBSLP), and BLAST, which are “white box,” or transparent to the user, and called public domain software. The second category consists of those programs developed by the private sector, such as TRACE 600, developed by The Trane Company; HAP E20-II, developed by Carrier Corporation; and HCC (loads) and ESP (energy), developed by Automatic Procedures for Engineering Consultants Inc. (APEC). The private-sector- developed software programs were based on the published literature of government, research, and public institutions such as ASHRAE. The most widely used, reliable, user-friendly, and continuously supported load and energy calculation programs in design are TRACE 600, HAP E20-II, and DOE-2.1E. BLAST is the most elaborate load calculation program developed in the United States and is usually considered a research tool. Most HVAC&R designers do care about the accuracy of the computational results of the software; however, the priority is the user friendly inputs and outputs [62].

4.4. Design information

To calculate the space cooling load, detailed building information, location, site and weather data, internal design information and operating schedules are required. Information regarding the outdoor design conditions and desired indoor conditions are the starting point for the load calculation and is discussed below.

4.4.1. Outdoor design conditions

ASHRAE Handbook 1997 Fundamentals [59] list tables of climate conditions for the US, Canada and other International locations. Design condition is used to calculate maximum heat gain and maximum heat loss of the building. For comfort conditions, the temperature and humidity provided for annual percentile values of 0.4, 1 and 2 during summer months and annual percentile values of 99.6 and 99 during winter months. The 0.4, 1 and 2 % design condition means that the outside summer temperature and coincident air moisture content will be exceeded only 0.4, 1 and 2 % of hours from June to September (these summer months) i.e. 0.4, 1 and 2 % of the time in a year, the outdoor air temperature will be above the design condition. Note, in energy use calculations, hour-by-hour outdoor climate data of a design day should be adopted instead of summer and winter design values.

4.4.2. Indoor design conditions

The indoor design conditions are directly related to human comfort. Current comfort standards specify a “comfort zone”. These standards representing the optimal range and combinations of thermal factors (air temperature, radiant temperature, air velocity, humidity) and personal factors (clothing and activity level) with which at least 80% of the building occupants are expected to express satisfaction which are detailed in ASHRAE Standard 55-1992 [66,67].

4.4.3. Building characteristics

To calculate space heat gain, the following information on building envelope is required: Architectural plans; sections and elevations for estimating building dimensions/area/volume

- Building orientation (N, S, E, W, NE, SE, SW, NW, etc), location etc
- External/Internal shading, ground reflectance etc.
- Materials of construction for external walls, roofs, windows, doors, internal walls, partitions, ceiling, insulating materials and thick nesses, external wall and roof colors - select and/or compute U-values for walls, roof, windows, doors, partitions, etc. Check if the structure is insulated and/or exposed to high wind.
- Amount of glass, type and shading on windows

4.4.4. Operating schedules

Obtain the schedule of occupants, lighting, equipment, appliances, and processes that contribute to the internal loads and determine whether air conditioning equipment will be operated continuously or intermittently (such as, shut down during off periods, night set-back, and weekend shutdown). Gather the following information:

- Lighting requirements, types of lighting fixtures
- Appliances requirements such as computers, printers, fax machines, water coolers, refrigerators, microwave, miscellaneous electrical panels, cables etc
- Heat released by the HVAC equipment.
- Number of occupants, time of building occupancy and type of building occupancy

4.4.5. Considerations & assumptions

Design cooling load takes into account all the loads experienced by a building under a specific set of assumed conditions. The assumptions behind design cooling load are as follows:

- Weather conditions are selected from a long-term statistical database. The conditions will not necessary represent any actual year, but are representative of the location of the building. ASHRAE has tabulated such data.
- The solar loads on the building are assumed to be those that would occur on a clear day in the month chosen for the calculations.
- The building occupancy is assumed to be at full design capacity.
- The ventilation rates are either assumed on air changes or based on maximum occupancy expected.
- All building equipment and appliances are considered to be operating at a reasonably representative capacity.
- Lights and appliances are assumed to be operating as expected for a typical day of design occupancy.
- Latent as well as sensible loads are considered.

- Heat flow is analyzed assuming dynamic conditions, which means that heat storage in building envelope and interior materials is considered.
- The latent heat gain is assumed to become cooling load instantly, whereas the sensible heat gain is partially delayed depending on the characteristics of the conditioned space. According to the ASHRAE regulations, the sensible heat gain from people is assumed 30% convection (instant cooling load) and 70% radiative (delayed portion).
- Peak load calculations evaluate the maximum load to size and select the refrigeration equipment. The energy analysis program compares the total energy use in a certain period with various alternatives in order to determine the optimum one.
- Space (zone) cooling load is used to calculate the supply volume flow rate and to determine the size of the air system, ducts, terminals, and diffusers. The coil load is used to determine the size of the cooling coil and the refrigeration system. Space cooling load is a component of the cooling coil load.
- The heat transfer due to ventilation is not a load on the building but a load on the system [62].

CHAPTER 5

EXPERIMENTAL STUDY

5.1. Introduction

In this study, experimental and theoretical investigations are performed for acquiring new concrete types with relatively high strength, low density and good thermal properties for energy efficient buildings.

The materials used to produce concrete mixtures were normal aggregate, RA, PA, EPA, cement, air-entrained admixture and silica fume. Normal aggregates were replaced by PA, EPA and RA at different volume fractions such as 10%, 20%, 30%, 40%, and 50% of the total aggregate volume. A total of 17 fresh mixtures were prepared with a constant water-cement ratio of 0.48 and cement content of 350 kg/m^3. In order to investigate the influence of silica fume on the properties of concretes, it is used as an amount of 10% by weight of cement in this study. Besides, a control mix with no replacement of the aggregate was produced to make a comparative analysis. All mixes contained 0.5%-1.5% of superplasticizer by weight of cement. Also, 0.3% of air-entraining admixture by weight of cement was used in all mixes except control mix. After the mixture preparation**,** fresh concrete properties (bulk density and slump) were specified.

In totally, 102 pieces 100x100x100 mm cubic sample were produced and cured water at room temperature of 20 ± 2 °C. The compressive strength tests were performed at the age of 28 days, and the hot disk method was used to establish thermal property values of concretes. The other properties such as thermal conductivity, specific heat…etc. were all conducted at the age of 35 days. All measurements are compared, and results are presented in figures and discussed. Experimental studies on both aggregate and concrete were determined according to TSE and ASTM International standards.

In order to determine the most suitable concrete samples, heat flows through the produced and commonly used concrete samples are calculated using a program developed in MATLAB. Calculation method for the heat flow is based on solution of transient heat transfer problem for the multilayer structures. The program is executed to calculate hourly heat gain values for these samples over a period of 24 h during design day for Gaziantep, Turkey. The results obtained from the numerical calculations for the produced and commonly used concretes are given in figures and compared in this study.

5.2. Materials

5.2.1. Aggregate

Sieve analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round meshes starting with the largest. It is used to determine the grading, fineness modulus, an index to the fineness, coarseness and uniformity of aggregates. The quality of concrete to be produced is very much influenced by the properties of its aggregates. Aggregate grain size distribution or gradation is one among these properties and should be given due consideration [39].

Accordance with TS 802 [68], the gradation of aggregates was selected to be ideal region depending on the maximum grain size. In order to produce of LWC, in the experiments, the maximum particle size and fineness modulus for natural sand and river gravel named as fine and coarse aggregates were selected as 4 mm, 16 mm and 2.35 and 5.51, respectively. Due to the fact that the gradation of aggregates has a significant impact on the property of the concrete composition, in this study a single and a uniform grain size was used. Sieve analyses of aggregates were performed according to TS 130 and TS 706 [69,70] is shown in Figure 5.1.

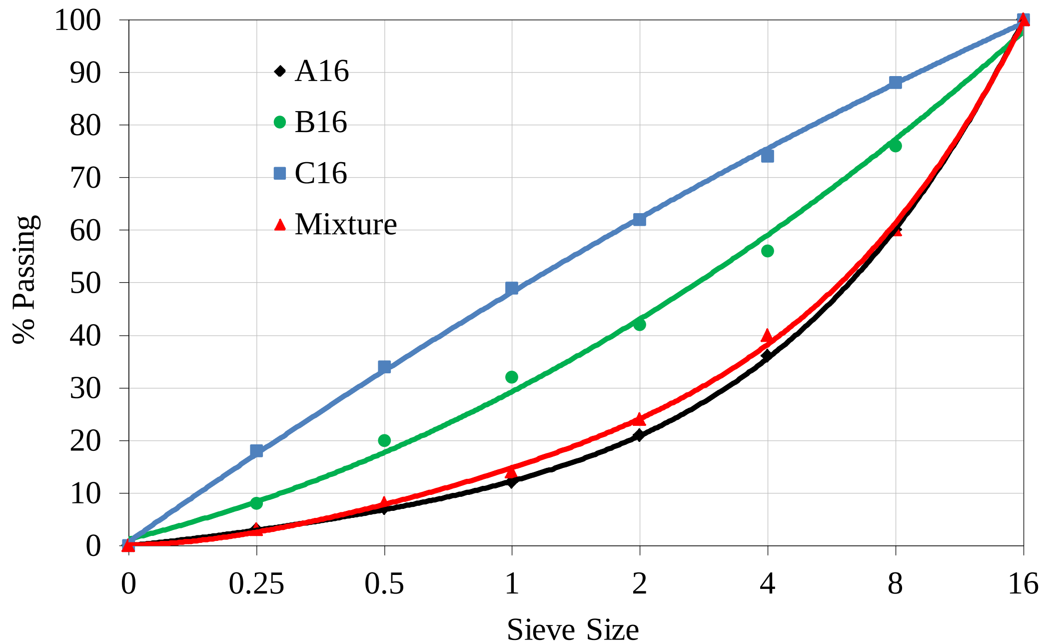

Figure 5.1. Sieve analyses of aggregates

Table 5.1. Chemical composition of EPA and PA

Chemical content	PA (%)	EPA (%)
SiO2	59	71-75
Al2O3	16.6	12-16
Fe2O3	4.8	-
CaO	1.8	0.2-0.5
Na2O	5.2	2.9-4
K2O	5.4	-

Both natural sand and gravel were obtained from Batman River, and PA was obtained from Isparta, Turkey. PA was obtained from a quarry in three different sizes of 0-4 mm, 4-8 mm, 8-16 mm and EPA was obtained from İnper Perlit Company expanded perlite in Gaziantep, Turkey. The chemical composition of EPA and PA is shown in Table 5.1.

The source of the RA was recycled tires which were collected from the small tire industrial in Batman, Turkey. For uniformity of the concrete production and convenience, medium truck tire was selected as a type of tire. In this study, used Crumb rubber (Figure 5.2) which consists of particles ranging in size from 4.75 mm to 0.075 mm is generated from the waste section of the tire without steel fibers with a cracker mill process. Physical properties of the aggregates used in this study are listed in Table 5.2.

Figure 5.2. Waste tire rubber replaced with fine aggregate.

Table 5.2. Physical properties of aggregates used in this study

Aggragate type	Sieve size (mm)	SSD Bulk Density (g/cm3)	Absorption capacity (%)
Gravel	8-16	2.69	0.76
	4-8	2.68	0.82
	2-4	2.66	0.93
Sand	0-2	2.61	1.26
PA	8-16	1.06	29.49
	4-8	1.09	22.99
	2-4	1.32	16.71
	0-2	1.65	10.87
EPA	4-8	0.42	179.31
	2-4	0.42	195.36
	0-2	0.37	228.45
RA	4-8	1.00	-
	2-4	0.94	-
	0-2	0.69	-

5.2.2. Cement

An ordinary Portland cement with a specific gravity of 3.15 g/cm^3 was used in this study (Portland cement CEM, I 42.5R). The physical and chemical properties of the cement are given in Table 5.3.

Table 5.3 The physical and chemical properties of the cement

Chemical compositions (%)	Cement	
CaO	64.02	
SiO_2	20.31	
Al_2O_3	5.64	
Fe_2O_3	3.27	
MgO	1.64	
SO_3	2.86	
K_2O	0.8	
Na_2O	0.87	
Physical properties		
Loss on ignition	0.9	
Blaine fineness (cm^2/g)	3489	
Specific Density (g/cm^3)	3.11	
Setting Time (h:min)	Initial	Final
	2:30	3:30
Compressive strength (MPa)	7 days	28 days
	38.8	45.78

5.2.3. Water and admixtures

The quality of the water plays an important role in concrete production. Impurities in the water may prevent setting of the cement, may adversely affect the strength of concrete or cause stains on the surface, and could also lead to corrosion of the reinforcement. For these reasons, the availability of water for mixing and curing targets should be considered. In this research, tap water supplied by Batman water and sewerage authority at room temperature was used in all mixes.

A superplasticizer (SEFAR CONFLUIMIX 780) of Polycarboxylic ether dissolved in water was used in dosage between 0.5% -1.5% by weight of total cementitious material as an admixture during mixing of fresh concrete. Micro Air 200 is oil alcohol and ammonium salt based air-entraining admixture that forms permanent, small and optimum separated air bubbles by entraining controlled air into concrete in accordance with ASTM C260 [71]. The used dosage is 0.3% by weight of total cementitious material. The properties of superplasticizer and air-entraining admixture are given in Table 5.4.

Table 5.4. The properties of superplasticizer and air-entraining admixture

Additive	Superplasticizer	Air-entraining admixture
Density (g/cm^3), 20°C	1.10 - 1.14	1.00 - 1.02
Chloride Content%	< 0.1	< 0.1
Alkaline Content %	< 3	< 10
Color	Brown	Amber
Chemical Composition	Polycarboxylic ether	Oil Alcohol and Ammonium Salt

5.2.3.1. Microsilica (silica fume)

Microsilica (silica fume) is a densified or undensified admixture which consists primarily very fine amorphous SiO_2 particles and meets ASTM C-1240 standards. Microsilica is used in construction, construction chemicals and refractory industries. Silica fume was obtained from Dostkimya Company in Istanbul, Turkey. The physical and chemical properties of the silica fume are given in Table 5.5. It was used in dosage is 10% by weight of total cementitious material.

Table 5.5 The physical and chemical properties of the silica fume

Chemical compositions (%)	Silica fume
SiO_2	85-95
Fe_2O_3	0.5-1
Al_2O_3	1-3
MgO	1-2
CaO	0.8-1.2
C	0.5-1
S	0.1-0.3
Physical properties	
Loss on ignition	0.5-1
Blaine fineness (cm^2/g)	3489
Specific Density (g/cm^3)	2.2

5.3. Concrete mixture composition, mixing proportioning and sample preparation

Concrete mix is defined as the proper selection and dosing of components for the production of concrete with pre-defined characteristics in the fresh and hardened states.

After the amount of cement, silica fume content, water-cement ratio, and a fine in the total population were determined as a percentage of the intended use of the concrete in the structure, dosing mixture in terms of weights design party was determined. Densities were accurately determined for each material used in order to share the mixed absolute method of volume. Cement and silica fume have a specific gravity 3.11, and 2.2, respectively. Bulk specific gravity in saturated surface dry state was used for a fraction of fine and coarse aggregate. The dosage of the specific volume of the absolute method includes the calculation of the amount of each ingredient and its contribution to the creation of 1 m^3 of concrete. The volume is then converted to the calculated weights, which then becomes the basis for the actual production of concrete. For cementitious materials and water, by weight to volume conversion is performed by dividing body weight (kg) per unit weight of material and then dividing the density of water (1 g/cm^3 at 4 ° C). Conversion of volume to weight was achieved simply by taking a known volume (m3) component and multiplying by the specific weight ingredient and then multiplying by the density. Volume to weight conversions for aggregates was accomplished by the same series of calculations. The target air content was established at 2% for control concrete and at 6% for air-entrained concretes by the special provision.

Figure 5.3. Concrete mixing proportioning and sample preparation

The mixture proportions of concrete studied (Figure 5.3) given with their abbreviated names and description shown in Table 5.6 that consists of structural LWC with cementitious material content of 350 kg/m^3 and w/c ratio was 0.48. Normal aggregates were replaced by PA, EPA and RA at different volume fractions such as 10%, 20%, 30%, 40%, and 50% of the total aggregate volume.

Table 5.6. Mix proportions for 1m^3 of concrete

Types of Concrete		**NC**	**AEC**	**EPC**					**PC**					**RC**				
LWA ratios (%)		**0**	**0**	**10**	**20**	**30**	**40**	**50**	**10**	**20**	**30**	**40**	**50**	**10**	**20**	**30**	**40**	**50**
w/c ratio		0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Cement (kg)		350	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
Water (kg)		168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168
Silica Fume (kg)			35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Superplasticizer (kg)		5.3	5.3	5.3	5.3	1.8	1.8		5.3	5.3	1.8	1.8		5.3	5.3	5.3	5.3	5.3
Air-entraining admixture (kg)			1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1				1.1	1.1	1.1	1.1	1.1
Normal aggregate (kg)	**0-2 mm**	434.8	406.2	237.0	67.7				237.0	67.7				406.2	237.0	67.7		
	2-4 mm	295.4	275.9	275.9	275.9	173.3			275.9	275.9	173.3			275.9	275.9	172.5		
	4-8 mm	372.5	348.0	348.0	348.0	349.6	349.6	175.2	348.0	348.0	349.6	349.6	175.2	348.0	348.0	348.0	348.0	174.0
	8-16 mm	746.2	697.1	697.1	697.1	700.4	700.4	702.1	697.1	697.1	700.4	700.4	702.1	697.1	697.1	697.1	697.1	697.1
EPA (kg)	**0-2 mm**			24.1	48.2	58.1	58.1	58.2										
	2-4 mm					16.3	43.5	43.6										
	4-8 mm							27.3										
PA (kg)	**0-2 mm**								107.2	214.5	258.6	258.6	259.2					
	2-4 mm										51.6	137.5	137.8					
	4-8 mm												71.1					
RA (kg)	**0-2 mm**													44.6	89.1	107.0	107.0	107.0
	2-4 mm															36.5	97.3	97.3
	4-8 mm																	64.9

Due to the fact that the having high absorption capacity of EPA and PA, Initial stages of mixing without pre-wetting can cause loss of slump, these aggregates were pre-wetted for 30 min. In order to provide the desired consistency: 1.5% of accelerator superplasticizer was used in the mixtures containing 0%, 10% and 20% EPA and PA, and 0.5% of accelerator superplasticizer was used in the mixtures containing 30% and 40% these aggregates by weight of cement. Since the desired consistency of the fresh concrete was achieved, no superplasticizer was used in the mixture containing 50% EPA and PA.

The mixtures were produced as NC, AEC, PC, EPC and RC which denote the normal concrete, air-entrained concrete, pumice concrete, EPA concrete and rubberized concrete, respectively. The numbers (10, 20, 30, 40 and 50) following show the percentage of replacement.

The concrete mixes were prepared in a laboratory in the following order:

- Firstly, PA and EPA were pre-wetted for 30 min.
- Secondly, one third of water and LWA.
- Thirdly, cement, silica fume, admixtures mixed with remaining water.
- Finally, stirring was continued until a uniform concrete was produced.

Figure 5.4. Cubic samples 100 x 100 x 100 mm

Figure 5.5. Vibrating Table

Cubic samples of 100 x 100 x 100 mm (Figure 5.4) were cast from fresh concrete mixtures. The compaction of mixtures was obtained by vibration as shown in Figure 5.5. All test samples were removed for 24 hours from the mold and cured at a temperature of 20 ± 2 ° C for 28 days. Samples were then placed at room temperature until the day of testing laboratory. (ASTM C330-99)

5.4. Tests performed on LWC

5.4.1. Slump

Slump is a most important factor in achieving a good floor surface with LWC. A lower slump, offers adequate workability and also provides cohesiveness and "body" there by preventing the lighter coarse particles from working up though the mortar to surface. In addition to "surface" segregation, excess slump will cause unnecessary finishing delays.

The slump test of fresh concrete was conducted in accordance with ASTM C143 [72]. The slump test was carried out using the apparatus shown in Figure 5.6 below.

Figure 5.6. Slump Test

5.4.2. Density

Density of fresh concrete is determined according to ASTM C138 [73] through calculation of the net weight of concrete per kilogram and subtracting the weight of the total weight of the least; volumetric weight calculated by dividing the net weight of measure used.

5.4.3. Compressive strength

The compression test was carried out in accordance with ASTM C39 [74] at a loading rate of 0.24 MPa/s on 100 x 100 x 100 mm cube specimens by a testing machine with a capacity up to 1112 kN. The compressive strengths of mixtures were performed at 28 days of age. In experiments, three mixtures were prepared for each group to specify the compressive strength of LWCs and the arithmetic mean of results was used (Figure 5.7).

Figure 5.7. Compressive Strength Test

5.4.4. Water absorption (Absorption capacity)

Water absorption test is done using samples obtained after 28 days using the method described in ASTM C 948. [75] The purpose of this test is to specify the ability of specific water absorption.

The absorbent capacity is determined by finding the weight of the surfactant after the dry sample is soaked for 24 hours and then finding the weight after the sample was dried in an oven, as shown in Figure 5.8.

The percentage of water absorption of the samples is calculated using the following equations:

Water absorption = $(X - X_1) / X_1$, (%)

X = mass of SSD sample, kg

X_1 = the net oven-dry mass of the sample, kg

Figure 5.8. Hardened concrete samples in oven

5.4.5. Thermal conductivity, specific heat and thermal diffusivity

The thermal conductivity, specific heat and thermal diffusivity test were performed on air dried samples at the age of 35 days according to EN 12667 [76]. The samples were dried in an oven at 105 ° C until the weight loss of no more than 1% at 24 h (ASTM C 332). The specimens' surfaces were sandpapered before measuring their thermal properties. ISOMET 2104 is a portable device for the direct measurement of the thermal conductivity coefficient, specific heat capacity, and thermal diffusivity coefficient. For measurements one can used needle probes (for loose and soft materials) or surface probes with a memory and known calibration constants. ISOMET 2104 is controlled by a microprocessor which can optimize the conditions of the measured process. The measurement is based on the analysis of the time dependence of the thermal response of a tested material on the impulses of heat flux. A heat flux is induced by electrical resistance heater in the probe which is in a direct contact with the tested sample. The measurement time is about 8-16 minutes. Figure 5.9 below shows the thermal property measurement device used in this study. Values of device ranges for the measured parameters are in Table 5.7.

Figure 5.9. Thermal property measurement device used in this study.

Table 5.7. Values of device range for measuring parameters

Measurement Accuracy	Measurement Range	Accuracy
Thermal conductivity coefficient	0.015–6 W/mK	5 % of reading + 0.001 W/mK
Specific heat capacity	$4 \times 10^4 - 4 \times 10^6$ J/m^3K	15 % of reading + 1.103 J/m^3K
Operating temperature	From -20 – +70 °C	1°C

CHAPTER 6

THEORETICAL MODEL

6.1. Introduction

Complex finite Fourier transform (CFFT) is an analytical technique and it allows the transformation of the problem into a form that leads to a periodic solution. This technique maybe used for various problems in which a periodic solution is desired. Being an analytical method, the CFFT is proposed as an alternative to other analytical and numerical methods.

Theoretical model is composed of solution of transient heat transfer problem for multilayered wall and flat roofs, estimation of solar radiation flux on the wall surfaces and heat flow through these structures. In the calculations, measured values of temperatures and solar radiation on horizontal surface are used. Procedures for each component of the theoretical model developed by Yumrutaş et al. [30,31] are summarized in this chapter.

6.2. Formulation of transient heat transfer problem

Heat transfer from a building wall or roof to room changes with ambient air temperature and solar radiation flux on the outer surface of the wall during a day. It is important to calculate the temperature distribution in the wall depending on temperature and solar radiation. It is necessary to solve the transient heat transfer problem to obtain this temperature distribution. Schematic view of a multilayer wall or flat roof, consisting of a finite number of layers is shown in Figure 6.1.

Figure 6.1. Schematic view of a multilayer wall or flat roof

The mathematical model is formulated according to the following assumptions:

- There is good contact between the layers with an interface resistance is negligible.
- The changes in thermophysical properties are negligible.
- There is no heat generation in each layer of walls or roofs.
- The convection coefficients are constant depending on the direction of heat flow.

The transfer of heat in the building of walls and flat roofs is given as the following partial differential equations, boundary and matching conditions:

$$\frac{\partial^2 T_n}{\partial x^2_n} = \frac{1}{\alpha_n}\frac{\partial T_n}{\partial t} \qquad 1 \le n \le N \tag{6.1}$$

$$h_i(T_i - T_1) = -k_1\frac{\partial T_1}{\partial x_1} \qquad \text{at } x_1 = 0 \tag{6.2}$$

$$-k_{n-1}\frac{\partial T_{n-1}}{\partial x_{n-1}}(x_{n-1} = L_{n-1}) = -k_n\frac{\partial T_n}{\partial x_n}(x_n = 0) \qquad 2 \le n \le N \tag{6.3}$$

$$T(x_{n-1} = L_{n-1}) = T(x_n = 0) \qquad \text{for } 2 \le n \le N \tag{6.4}$$

$$-k_N\frac{\partial T_N}{\partial x_N} = h_o\left[T_N - T_o(t)\right] - \alpha_s I_T(t) \qquad \text{at } x_N = L_N \tag{6.5}$$

where α_n is the thermal diffusivity , n refers to the layer, i.e. n=1, 2,…,N, α_s is the absorptance of the surface, k is the thermal conductivity, and also h_i and h_o are the combined convection heat transfer coefficients at the inner and outer surfaces, respectively. The transient heat transfer problem consisting of Equations (6.1)–(6.5) will be put into dimensionless form by introducing the following dimensionless variables:

$$z_n = \frac{x_n}{L_n}, \quad b_i = \frac{h_i L_1}{k_1}, \quad b_o = \frac{h_o L_n}{k_n}, \quad \tau_n = \frac{\alpha_n t}{L_n^2}$$

$$S_{n-1,n} = \frac{k_{n-1}L_n}{k_n L_{n-1}}, \quad I_T(\tau) = \frac{\alpha_s L_n}{k_n} I_T(t), \quad \tau_{np} = \frac{\alpha_n p}{L_n^2} \tag{6.6}$$

$$t = h - 12, \quad p = 24h. , \quad \frac{\tau_n}{\tau_{np}} = \frac{t}{p} = \frac{h-12}{24} = \tau$$

The resulting dimensionless formulation is:

$$\frac{\partial^2 T_n}{\partial z_n^2} = \frac{\partial T_n}{\partial \tau_n} \qquad 1 \le n \le N \qquad (6.7)$$

The dimensionless boundary conditions:

$$\left(T_i - T_1\right) b_i = -\frac{\partial T_1}{\partial z_1} \qquad \text{at } z_1=0 \qquad (6.8)$$

$$S_{n-1,n} \frac{\partial T_{(n-1)}}{\partial z_{n-1}} (z_{n-1} = 1) = \frac{\partial T_n}{\partial z_n} (z_n = 0) \qquad 2 \le n \le N \qquad (6.9)$$

$$T_{n-1}(z_{n-1} = 1) = T_n (z_n = 0) \qquad 2 \le n \le N \qquad (6.10)$$

$$-\frac{\partial T_n}{\partial z_n} = b_o [T_n - T_o(\tau_n)] - I_T\left(\tau_n\right) \qquad \text{at } z_n=1 \qquad (6.11)$$

Equations (6.7)(6.11) will be solved to obtain periodic solution by an application of the following CFFT:

$$T_n (z_n, \tau_n) = \sum_{j=-\infty}^{\infty} T_{nj} (z_n) e^{i\omega_{nj}\tau_n} \qquad (6.12)$$

or

$$T_n(z_n, \tau_n) = T_{n0}(z_n) + \sum_{j=1}^{\infty}\left[T_{nj}(z_n)e^{i\omega_{nj}\tau_n} + T_{-nj}(z_n)e^{-i\omega_{nj}\tau_n}\right] \tag{6.13}$$

where

$$\omega_j = 2\pi j, \text{ and } \omega_{nj} = \frac{\omega_j}{\tau_{np}} = \frac{2\pi j}{\tau_{np}} \tag{6.14}$$

$$T_{nj}(z_n) = \frac{1}{\tau_{np}}\int_{-\tau_{np}/2}^{\tau_{np}/2} T_n(z_n, \tau_n)e^{-i\omega_{nj}\tau_n}d\tau_n \tag{6.15}$$

The general solution is:

$$T_{n0}(z_n) = A_n z_n + B_n \qquad \text{for} \qquad j=0 \tag{6.16}$$

$$T_{nj}(z_n) = C_{nj}\sinh(\gamma_{nj}z_n) + D_{nj}\cosh(\gamma_{nj}z_n) \qquad \text{for} \qquad j\neq 0 \tag{6.17}$$

where

$$\gamma_{nj} = \sqrt{i\omega_{nj}} = (1+i)\sqrt{\omega_{nj}/2} \tag{6.18}$$

Heat gain the rate of heat from the wall in the space can be calculated from the temperature distribution on the inner wall surface or a flat roof.

$$\dot{Q}_c = h_i\left[T_n(0,\tau) - T_i\right] \tag{6.19}$$

$$T_n(0,\tau_n) = \sum_{j=-\infty}^{\infty} T_{nj}(z_n) e^{i\omega_{nj}\tau_n} \qquad \text{at } z_n=0 \qquad (6.20)$$

where $T_n(0,\tau_n)$ is the inside surface temperature of the wall or flat roof, and also the temperature distribution at the outside surface of the wall or flat roof can be obtained

$$T_n(1,\tau_n) = \sum_{j=-\infty}^{\infty} T_{nj}(1) e^{i\omega_{nj}\tau_n} \qquad \text{at } z_n=1 \qquad (6.30)$$

6.3. Solar radiation flux

Boundary condition of Equations (6.5) and (6.11) given in definition of conduction heat transfer problem depends on time dependent solar radiation flux and convection heat transfer. That is, heat flow through the walls or roofs is a function of solar radiation. Since solar radiation is essential in calculating cooling load, the equations needed to find solar heat gain should be given for a wall surface. For that reason, the hourly total solar radiation incident on the wall surfaces is calculated by using the equations and the hourly measured solar data on a horizontal surface. This is because local meteorological stations measure only solar radiation on the horizontal surface. In this study, hourly mean values of solar radiation data for Gaziantep measured between 1997 and 2007 are used to calculate the hourly solar radiation flux on the wall surface. The calculation procedure is broadly presented by Duffie and Beckman [77]. The necessary definitions and equations for calculating the solar radiation flux on the surfaces are summarized below.

6.3.1. Definitions of terms

6.3.1.1. The Solar constant

The solar constant, $G_{sc,}$ is the energy from the sun, per unit time, which value of G_{sc} of 1353 W/m^2 (4.921 MJ/m^2hr) is used in this study.

6.3.1.2. Extraterrestrial radiation

It is the total energy in the extraterrestrial solar indicated by equation:

$$G_{on} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \tag{6.31}$$

where G_{on} is the extraterrestrial radiation, measured on the plane normal to the radiation on the nth day of the year.

6.3.1.3. Solar time

Solar time is based on the apparent angular motion of the sun across the sky, that is the difference between solar time and standard time;

$$\text{Solar Time - Standard Time} = 4(L_{st} - L_{loc}) + E \tag{6.32}$$

where L_{st} is the standard meridian for the local time zone and L_{loc} is the longitude of the location. The equation of time E (in minutes) is determined from Equation (6.32).

$$E = 229.2(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B) \tag{6.33}$$

where B is,

$$B = (n-1)\frac{360}{365} \tag{6.34}$$

6.3.1.4. Direction of beam radiation

The geometric relationships between the plane of any particular orientation relative to Earth at any time (whether that plane fixed or moving relative to the earth), and the incident solar radiation beam, i.e. the position of the sun relative to this plane can be described in terms of several angles. Angles follow:

- **Latitude (*ϕ*)** is the angular location north or south of the equator. It changes -90° to 90° where north is positive.
- **Declination *(δ)*** is the angular position of the sun at solar noon with respect to the plane of the equator. It changes -23.45° to 23.45°.where north is positive.
- **Slope *(β)*** is the angle between the planes of the surface and the horizontal. It changes 0 to 90°.
- **Surface azimuth angle *(γ)*** is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian. It changes -180° to 180°.where south is zero, east is negative, and west is positive.
- **Hour angle *(ω)*** is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour, afternoon positive, morning negative.

- **Angle of incidence *(θ)*** is the angle between the beam radiation on a surface and the normal to that surface.
- Additional angles determined that describe the position of the sun in the sky:
- **Zenith angle *(θ_z)*** is the angle between the vertical and the line to the sun.
- **Solar altitude angle *(α_s)*** is the angle between the horizontal and the line to the sun.
- **Solar azimuth angle *(γ_s)* *is*** the angular displacement from south of the projection of beam radiation on the horizontal plane. Displacements east of south are negative and west of south are positive. The position of the sun relative to this plane in terms of several angles is shown in Figure 6.2.

The declination δ can be found from the equation:

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right) \tag{6.35}$$

where *n* is the day of the year.

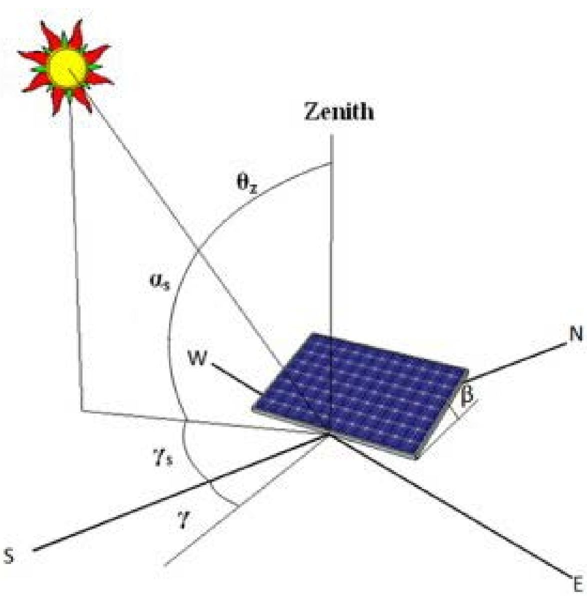

Figure 6.2. The position of the sun relative to this plane in terms of several angles

There are many good relationships between these angles. Equations with respect to the angle of incidence of the radiation beam on the surface, θ is the angle to the other

$$\begin{aligned}\text{Cos}\ \theta &= \sin\delta\ \sin\varphi\ \cos\beta - \sin\delta\cos\varphi\sin\beta\cos\gamma + \cos\delta\cos\varphi\cos\beta\cos\omega \\ &+ \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} \tag{6.36}$$

For β=0 and the Equation (6.36) becomes as:

$$\text{Cos}\theta_z = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta \tag{6.37}$$

6.3.2. Calculation of solar radiation on the tilted and horizontal surface

The hourly average clearness index k_T is the ratio of hourly radiation on a horizontal surface to hourly extraterrestrial radiation, which is given as,

$$k_T = \frac{I}{I_o} \tag{6.38}$$

To calculate the extraterrestrial radiation on a horizontal surface for a period between hour angles ω_1 and ω_2 which define an hour (where ω_2 is the larger),

$$\begin{aligned}I_o &= 12.\frac{3600}{\pi}G_{SC}.\left[1+0,033.\cos\left(360.\frac{n}{365}\right)\right].\Big(\cos(\varphi).\cos(\delta).\left[\sin(\omega_2)-\sin(\omega_1)\right] \\ &+ 2.\pi\left(\frac{\omega_2-\omega_1}{360}\right).\sin(\varphi).\sin(\delta)\Big)\end{aligned} \tag{6.39}$$

The ratio of hourly diffuse radiation on a horizontal plane to that of total hourly radiation on horizontal plane is correlated for different range of clearness index. This correlation has been widely used and is represented by the following equations:

$$\frac{I_d}{I} = \begin{cases} 1.0 - 0.249k_T & \text{for } k_T < 0 \\ 1.557 - 1.84k_T & \text{for } 0.35 < k_T < 0.75 \\ 0.177 & \text{for } k_T > 0.75 \end{cases} \tag{6.40}$$

Beam radiation is,

$$I_b = I - I_d \tag{6.41}$$

The radiation on the tilted surface was considered to include three components; beam, isotropic diffuse, and solar radiation diffusely reflected from the ground. A surface tilted at slope I_T from the total solar radiation on the tilted surface for an hour as the sum of three terms:

$$I_T(t) = I_b(t)R_b + I_d(t)\left(\frac{1+\cos\beta}{2}\right) + I(t)\rho_g\left(\frac{1-\cos\beta}{2}\right) \tag{6.42}$$

where ground reflectance ρ_g is usually taken as 0.2 .

$$R_b = \frac{G_{b,T}}{G_b} = \frac{G_{b,n}\cos\theta}{G_{b,n}\cos\theta_z} = \frac{\cos\theta}{\cos\theta_z} \tag{6.43}$$

The geometric factor *Rb*, the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time, can be calculated exactly by appropriate use of Equation 6.43. Where $cos\theta$ and $\cos\theta_z$ are both determined from equations derived from Equation (6.36) and (6.37) [77].

6.4. Climatic data

The climatic conditions used in the application should be known in order to find temperature and heat gain variations for the structures. Inside design air temperature is considered to be 25°C. Combined heat transfer coefficients on the inner and outer surfaces are assumed to be 9°C and 22 W/m^2, respectively. Data for hourly solar radiation flux on a horizontal surface measured by the meteorological station located in the city of Gaziantep (37.1^o N), in July 23, 2007 are used. Cooling energy consumption of a building can be significantly reduced by limiting solar heat gain through envelope, which depends on the absorptivity (color) of external surface as it determines the amount of absorbed solar radiation. Many works in the literature have revealed that exterior surface color of building has significant effect on the thermal performance of the building envelop [78,79]. However, there is little information on the effect of the envelop color on the space cooling load of a large space building in hot and humid area. There are usually four different envelop color used in building envelope. The solar absorptivities given in Equation (6.5) for each color are listed in the Figure 6.3 [80]. The hourly measured values ambient temperature and the flow of heat radiation on a horizontal surface are shown in Figure 6.4. It is clear that, the values indicate the solar radiation heat flux values on a clear sky day. The hourly solar radiation flux on the wall and roof is calculated by using isotropic sky model presented before. Calculation procedure for the solar radiation flux on a wall is proofed.

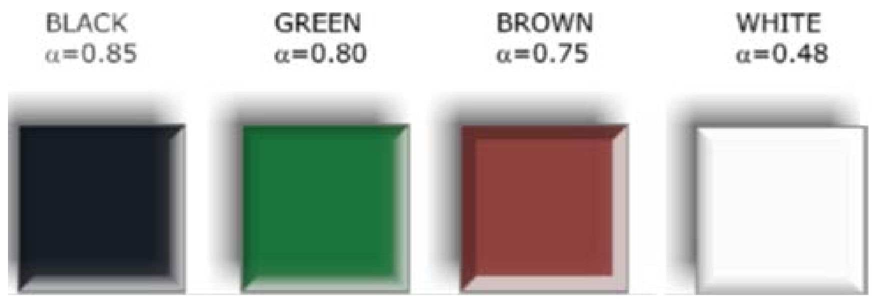

Figure 6.3 Sample for various envelope colors [80]

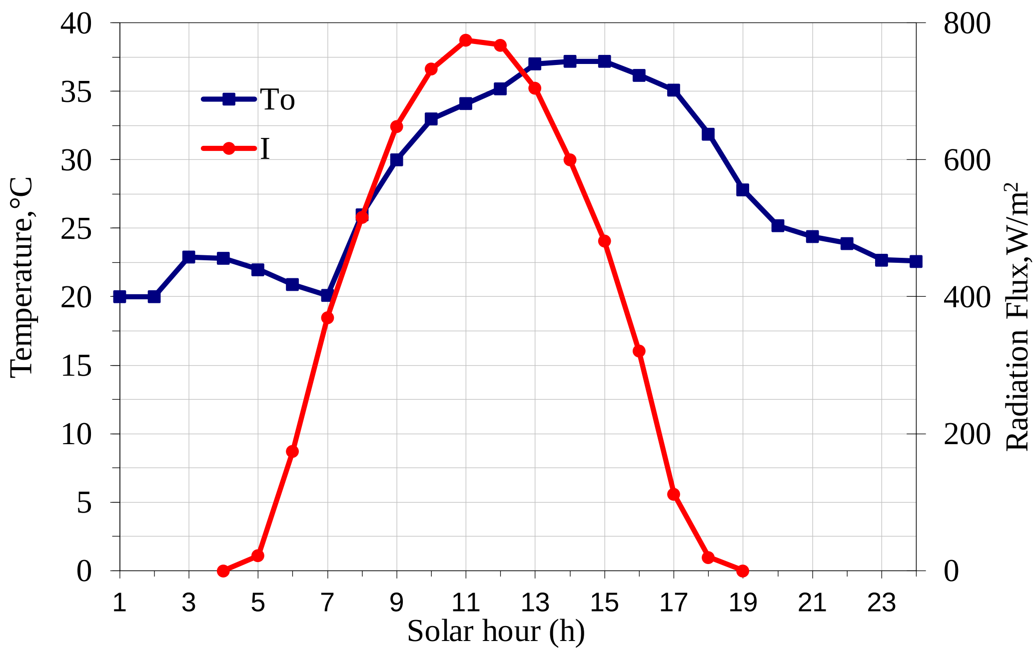

Figure 6.4. Mean hourly values of outside air temperature, and solar radiation flux on a horizontal surface for July 23, 2007.

CHAPTER 7

THE COMPUTER PROGRAM

7.1. Introduction

A computer program is developed in MATLAB. All the input parameters of the program are given below in detail.

In the previous chapters various formulas and methods, for calculating hourly solar radiation flux on a wall and roof surface and hourly cooling load of a building, are discussed in detail. To make the computation friendly and time effective a computer program is developed using MATLAB. The computer program is developed to carry out the numerical calculations based on the analytical model developed. The model is applied for daily periodic operation, which is generally done in cooling load calculations. The wall and the roof of a building are considered in the calculations to demonstrate the use of the analytical model. The solution was used to find calculating the hourly incident solar radiation on horizontal and tilted surfaces, cooling load of a space due to walls or flat roofs, and also temperature variations in these structures for daily periodic operation. The program uses as input the parameters which are hourly solar radiation flux on the horizontal surface, thermophysical properties of the wall or roof materials, combined convection heat transfer coefficient for both sides of inside and outside air, hourly outside air temperature and inside design air temperature.

MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and FORTRAN [81].

The details of these programs with their algorithm developed will be discussed in this chapter. For the calculating the hourly solar radiation on tilted surface for different orientation is shown in Figure 7.1. In a similar manner, algorithm for the hourly inner and outer surface temperature of wall and roof is shown in Figure 7.2

To make the programs developed user-friendly type GUI (graphic user interface) is developed. So any person without knowing the detail of the program can run and have the hourly cooling load of the building.

Based on the above three algorithms, three programs are developed as shown in appendix. Each program is associated with graphical interface that deals with various inputs.

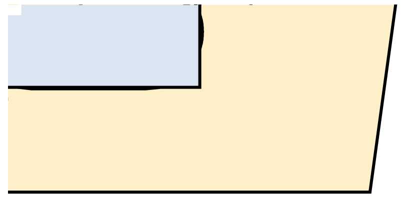

Figure 7.1. Algorithm for calculation of solar radiation flux on horizontal and tilted surfaces

I-number of hours per day

Figure 7.2. Algorithm for calculation of the hourly inner and outer surface temperature of wall and roof and heat gain through wall and roof

Tiw-the hourly inner surface temperature of wall and roof
Qc-the hourly heat gain through wall and roof

7.2. The GUI

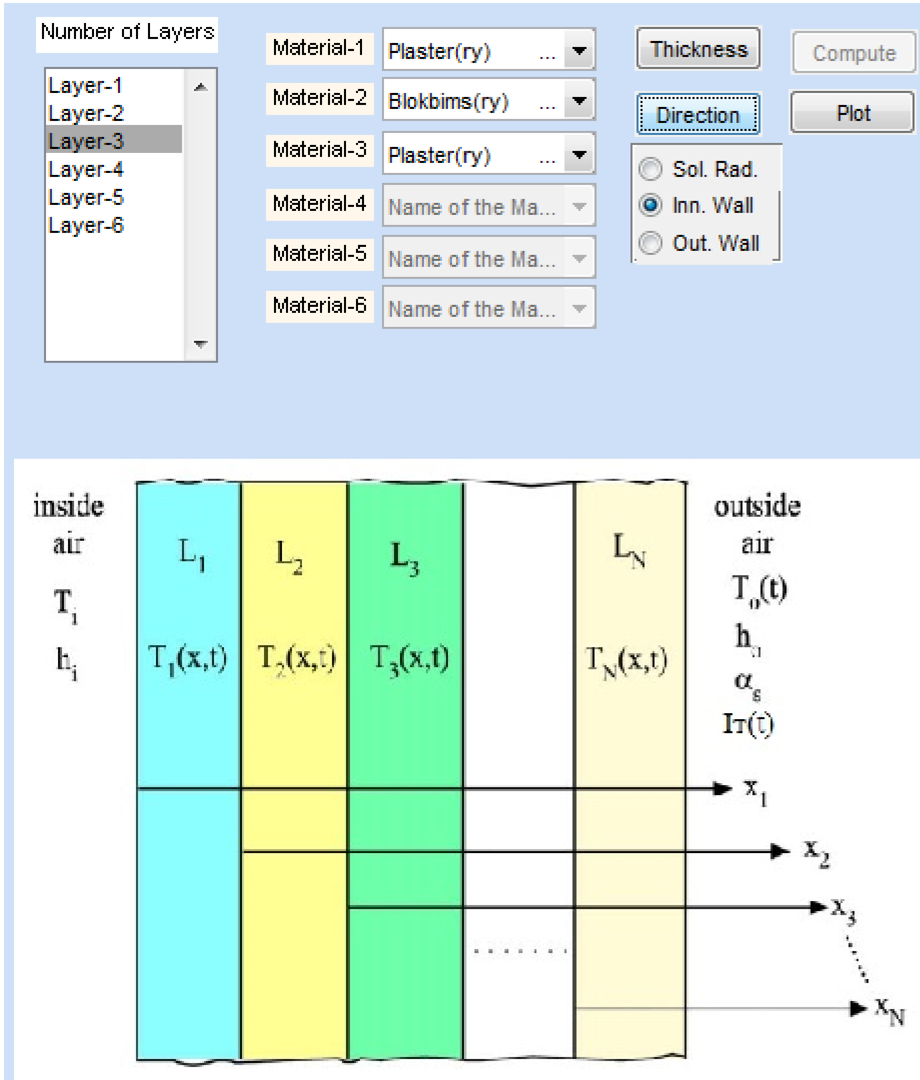

Figure 7.3. General input module of GUI interface

There are three main GUI programs developed. The first model is designed as "general input module", Figure 7.3. It contains one list box, four push buttons which are 'thickness, 'direction', 'compute', and "plot', six popup menus, and one uipanel. The list box provides the user to select the desired number of wall or roof layers in a building. The maximum six wall or roof layers can be selected by the user for a building. The popup menus, which are enabled after selection of wall or roof layers, are especially designed for accepting thermal properties of the construction materials layer by layer in their order. After the selection of the 'thickness' button, a new GUI interface menu appears on screen which enables the user to define the thickness of each selected layer as shown in Figure 7.4**.**

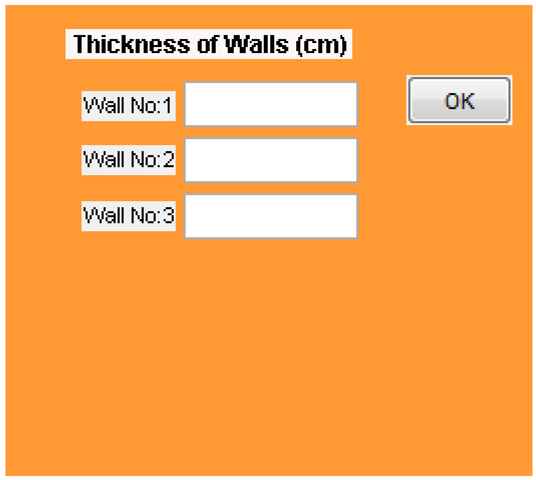

Figure 7.4. Thickness selection module of GUI interface

If the user selects 'direction' button, a new GUI interface menu appears on screen, Figure 7.5. This module is designed in such a way that it accepts inputs and selections that are necessary for defining the orientation and surface properties of the wall or roof.

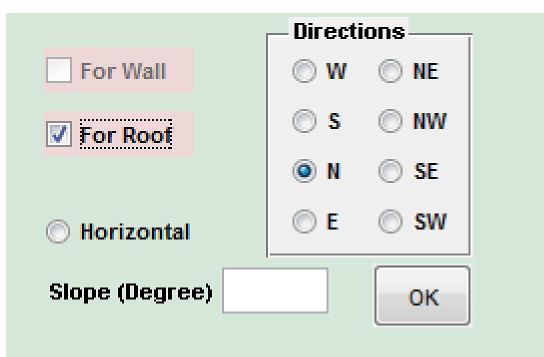

Figure 7.5. The selection module of GUI interface; orientation and surface properties of the wall or roof

Uipanel provides functionality as a container for controls. It contains three radio buttons, ‘solar radiation’, ‘inner wall’, and ‘outer wall’. This module enables the user to choose which computation will be performed. After the selection of the ‘compute’ button, the hourly incident solar radiation on horizontal and tilted surfaces for different orientation, inner and outer surface temperature of wall and roof will be calculated. And finally, selecting ‘plot’ button enables to generate 2-D plot of the calculations mentioned before.

CHAPTER 8

TEST RESULTS AND DISCUSSIONS

8.1. Introduction

This section consists of two parts: First part describes the results of the tests carried out to investigate the various properties of the pumice, air-entrained, expanded perlite and rubberized concrete mixes prepared in contrast with the control mixes. In the succeeding parts, the experimental results for workability, density, compressive strength, thermal conductivity, specific heat and thermal diffusivity tests are presented.

In the second part; theoretical studies are presented for finding time dependent temperature variation in multilayer building walls and flat roofs and heat flow through the structures, and also for comparing the evaluated temperatures and heat flow with these values obtained by measurement. The measured values for hourly outside air temperatures and nodal temperatures for each layer of flat roof are presented, and heat gains through the structures are calculated by using the measured temperatures. Hourly temperature values and heat gain for the same structures are computed by using the computer program based on the theoretical model in order to compare with those measured values. All the measurements and calculations are given by figures and discussed in this section. Analysis and discussions are also made on the findings.

8.2. Fresh concrete properties

8.2.1. Slump and fresh density

The slump and fresh density values of fresh concretes are tabulated in Table 8.1. It was observed that the workability of rubberized concrete showed a decrease in slump and fresh density with the increase of volume waste tire rubber content of total aggregate volume. Although, the rubber contained mixtures had 1.5% of accelerator superplasticizer and 0.3% air-entraining admixture, the slump was 1.8 cm at rubber contents of 50% by total aggregate volume and the concrete was not workable by hand. This is also due to silica fume (10% as partial replacement of cement) resulted in significant reductions in porosity in mixtures. In contrast, it was noted that the slump values showed a tendency to increase with the increase of percentages of EPA and PA in all samples as shown in Figure 8.1. The reason for this is that the work done by density is lower in the case of lighter PA and EPA. Because of lower aggregate density, structural low-density concrete does not slump as much as normal density concrete with the same workability. By the way due to the fact that air bubbles in air-entrained concrete causes workability to increase, slump increased. The small reduction in slump values was due to reduction of the amount of superplasticizer in the mixtures. The maximum and minimum slump and density values of fresh concrete samples were 25 mm, 220 mm and 2372.07 kg/m^3, 1525.59 kg/m^3, respectively.

Table 8.1 Properties in fresh state

Types of Concrete	Slump (mm)	Fresh Density (kg/m^3)
NC	40	2372.07
AEC	100	2251.50
EPC (10%	203	2106.31
EPC (20%)	220	1961.13
EPC (30%)	193	1818.55
EPC (40%)	213	1672.47
EPC (50%)	193	1525.59
PC (10%)	183	2189.48
PC (20%)	206	2127.45
PC (30%)	176	2031.06
PC (40%)	203	1966.98
PC (50%)	166	1864.52
RC (10%)	45	2126.80
RC (20%)	32	2002.11
RC (30%)	25	1885.25

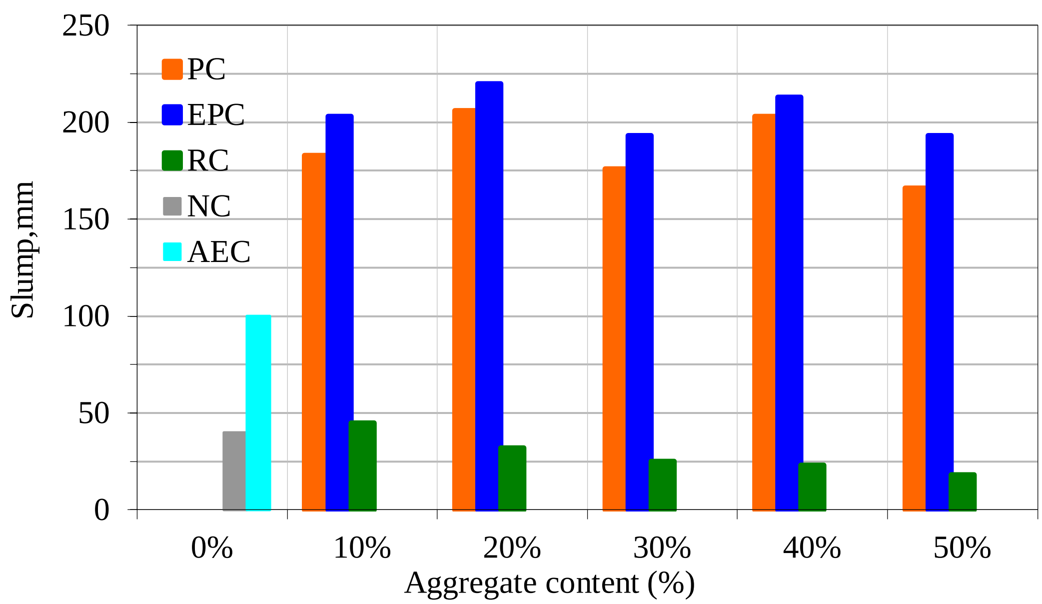

Figure 8.1. Slump values of EPA, PA and RA mixtures

8.3. Hardened concrete properties

The different tests that have been carried out to establish the hardened properties of the concrete samples produced were; determination of bulk density, compressive strength, absorption capacity, thermal conductivity, specific heat and thermal diffusivity tests. The mechanical tests were carried out on air-dry specimens. However, since the moisture content during testing may affect the results obtained, the thermal conductivity, specific heat and thermal diffusivity tests was made on oven-dried specimens. The results are tabulated in Table 8.2 below.

Table 8.2. Mechanical and Thermal properties of hardened concrete samples

Types of Concrete	Comp. Strength (MPa)	Density (kg/m^3)		Absorp. Capacity (%)	Thermal Con. (W/mK)	Specific Heat (J/kgK)	Thermal Diffusivity (m^2/s)
		Air-dry	Oven-dried				
NC	51.85	2446.16	2345.09	4.31	1.960	709.07	11.8×10^{-7}
AEC	48.11	2372.92	2288.86	3.67	1.910	712.14	11.7×10^{-7}
EPC (10%)	31.21	2267.65	2139.09	6.01	1.510	725.48	9.73×10^{-7}
EPC (20%)	19.02	2069.20	1885.52	9.74	1.215	779.63	8.27×10^{-7}
EPC (30%)	10.01	1781.53	1550.07	14.93	0.701	906.45	4.99×10^{-7}
EPC (40%)	9.15	1757.50	1496.26	17.46	0.503	925.86	3.63×10^{-7}
EPC (50%)	4.88	1440.28	1168.63	23.25	0.363	966.95	3.21 x10-7
PC (10%)	33.46	2117.68	2001.78	5.79	1.535	772.42	9.93×10^{-7}
PC (20%)	23.39	2016.54	1851.02	8.94	1.345	818.52	8.88×10^{-7}
PC (30%)	13.07	1782.11	1559.95	14.24	0.759	903.87	5.38×10^{-7}
PC (40%)	9.90	1642.70	1400.72	17.28	0.543	949.51	4.08×10^{-7}
PC (50%)	9.51	1602.75	1332.73	20.26	0.407	991.80	3.08×10^{-7}
RC (10%)	42.04	2336.18	2249.48	3.85	1.720	721.83	10.6×10^{-7}
RC (20%)	30.41	2262.40	2148.07	5.32	1.435	737.70	9.06×10^{-7}

8.3.1. Compressive strength, density and absorption capacity

The 28-day compressive strength and the oven-dried concrete density varied from 4.53 MPa to 51.85 MPa and 1168.63 kg/m^3 to 2345.09 kg/m^3, respectively. It was observed from the Figure 8.1 that compressive strength decreased with increasing EPA and PA ratios. Reductions at 28-day were 39.80, 63.33, 80.69, 82.35 and 90.58, and 35.46, 54.89, 74.80, 80.90 and 81.66 percent for 10%, 20%, 30%, 40% and 50% EPA and PA, respectively. This was owing to the porous and weak structures of EPA and PA. Substantial reductions in the compressive strength of EPA were higher than PA. It can be attributed to the lower density of EPA, grading of the aggregate and their moisture content and compaction of the concrete.

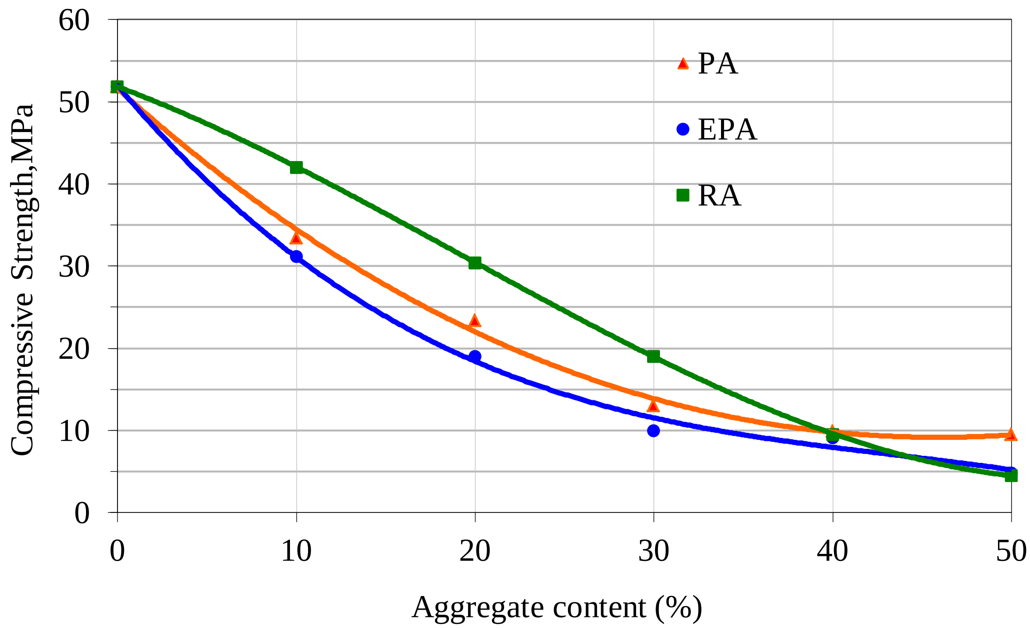

Figure 8.2. Effect of EPA, PA and RA content on the compressive strength.

For rubberized concrete, the results show that the addition of RA resulted in a significant reduction in concrete compressive strength compared with the control concrete as shown in Figure 8.2. This reduction increased with increasing percentage of RA. Losses in compressive strength of 18.91%, 41.35%, 63.28%, 81.65% and 91.26% were observed when 10%, 20%, 30%, 40% and 50% of the normal aggregate was replaced by an equivalent volume of RA, respectively. The reason for the greatest reductions could be attributed both to a reduction of quantity of the solid load carrying material and to the lack of adhesion at the boundaries of the RA. In rubberized concrete, crack formation is different from plain concrete because bond strength between rubber and cement paste is poor than that of between aggregate and cement paste. Therefore, initial cracks were formed around RA and cement paste in rubberized concrete.

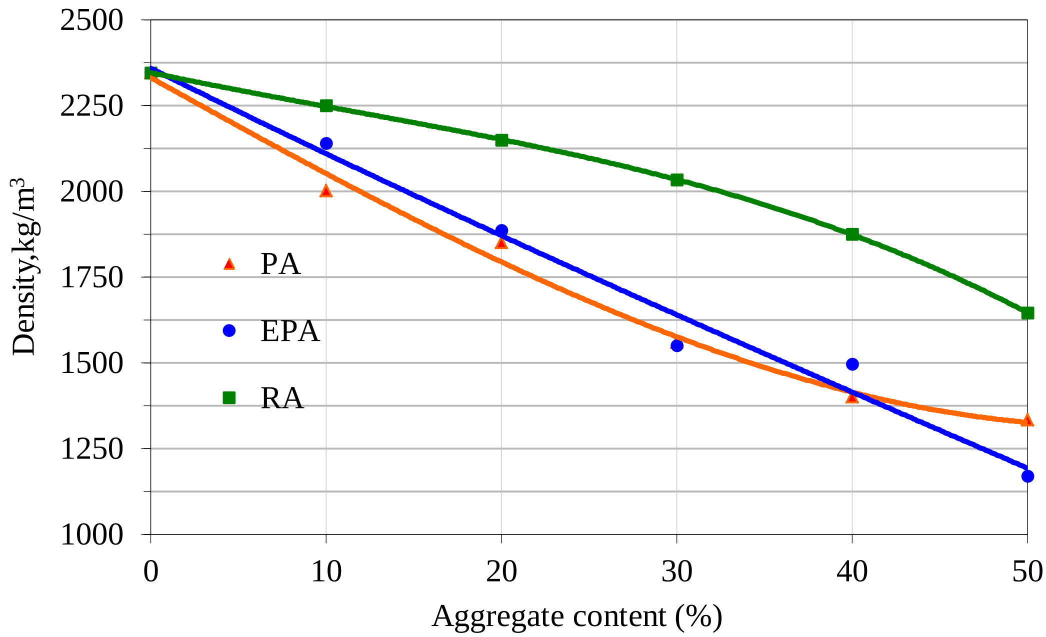

Figure 8.3. Effect of EPA, PA and RA content on density.

Figure 8.3 shows that the normal concrete produced only with the normal aggregate has an oven-dried density of 2345.09 kg/m^3 and its cube compressive strength is 51.85 MPa. Air-entrainment admixture causes more reduction in compressive strength. However, the loss in compressive strength was only 7.21% for air-entrained concrete. This reduction in the strength is very small due to the high reactivity of silica fume and its famous micro filler effect. The oven-dried density decreased with increasing EPA, RA and PA ratios. From the results, it was found out those reductions of densities up to 29.85 %, 43.17%, and 50.17%, were observed when 50 % by volume of the normal aggregate was replaced by RA, PA and EPAs in sample, respectively. Such a reduction in the specific weight (bulk density) can have significant advantages in performance structures. The weight concrete design reduces stress in structural elements, and with the stresses caused by seismic loading also depends on the weight of the structure, reducing the weight of the structure is advantageous from the point of earthquake resistance. The forces acting on the basis of structure is also reduced [82]. Significant reduction in density is a measure of the presence of larger and a higher amount of open cells to the surface.

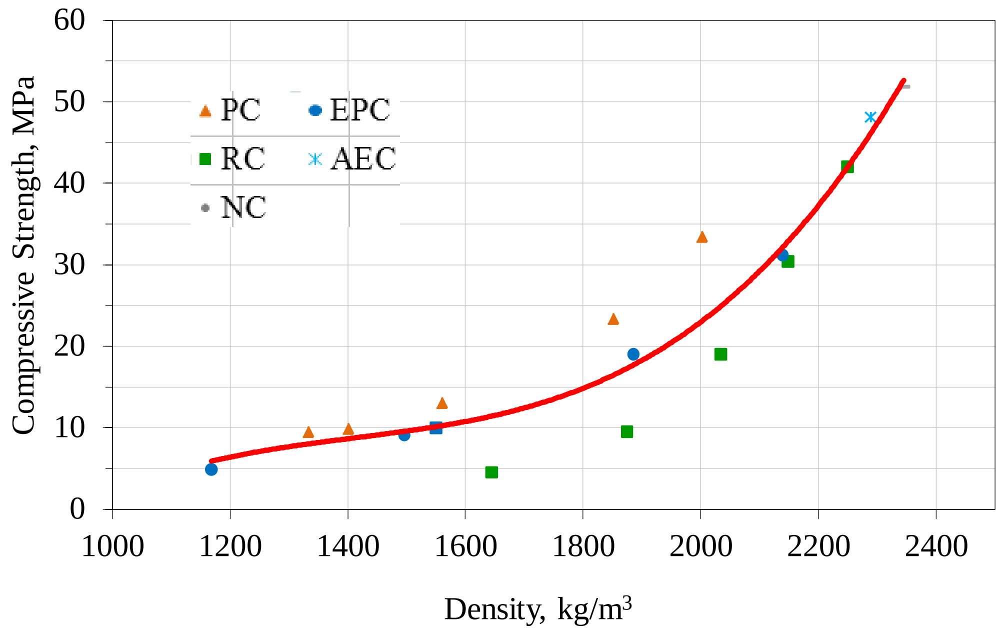

Figure 8.4. Relationship between compressive strength and density.

As can be seen from the figure, the compressive strength is significantly reduced with the proportion of concrete. When the ratio is shown in Figure 8.4 is studied in more detail the relationship between compressive strength and density can be divided into two parts, one part between density of about 1600 kg/m^3 or higher, and the other for mixtures having a density below 1600 kg/m^3 . Since the slope of the curve is steeper for the densities of more than 1600 kg/m^3, we can conclude that when the natural aggregate is replaced with LWA, the compressive strength is more affected by the substitution rate to 40%. In addition, the replacement rates, although the force continues to fall, the rate of loss of strength below.

One of the important parameters is the water absorption capacity of the concrete. Basically the desired state is in the same degree as the reduction of water absorption of the lightweight concrete due to the high porosity of the aggregates. The tests show that the water absorption was found to vary between 3.85% and 23.25%, ranging from an aggregate relationship (Table 3).

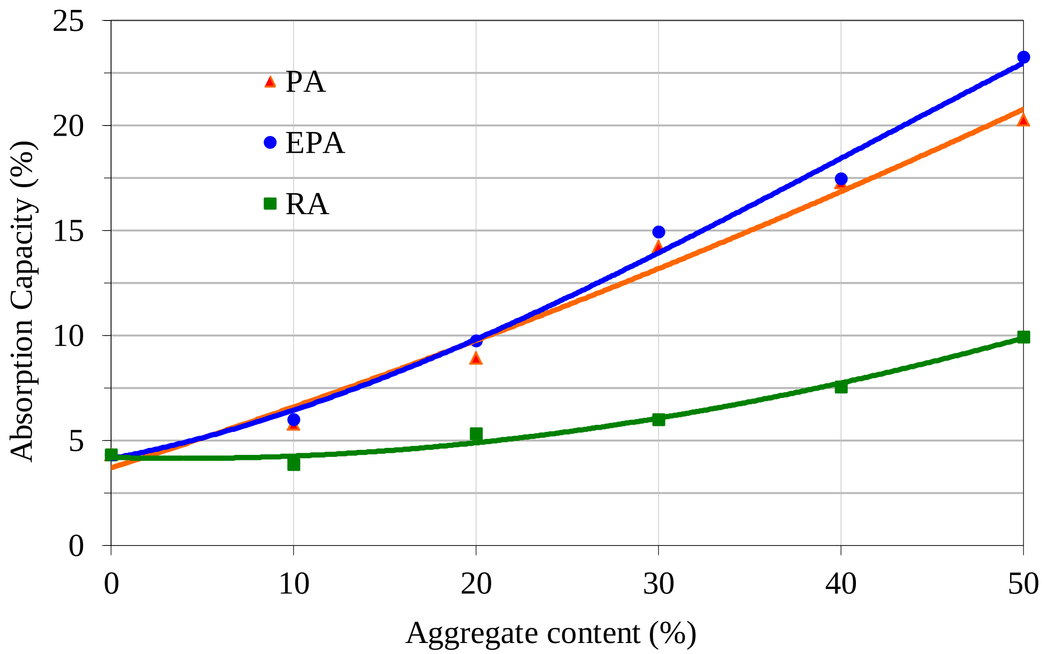

Figure 8.5. Effect of EPA, PA and RA content on the water absorption.

Increasing the total water absorption ratio increases as shown in Figure 8.5. The water absorption increases with decreasing density, and the maximum water absorption occurred in the EPA concrete. The EPA is a porous aggregate, and as mentioned above, the EPA water absorption up to 230%, water absorption greatly promoted lightweight concrete. Incidentally, natural sand was replaced by PA as a more porous structure, thereby a higher water absorption, and as shown in the table for PA containing more than 20%, water absorption rate increased more significantly. The water absorption also increased with increasing the RA content (%), and absorption capacity of 50% RA was nearly three times higher than 10% RA.

8.3.2. Thermal conductivity, specific heat and thermal diffusivity

As shown in Figure 8.6, the absorption determined by the porosity, which is one of the factors affecting the thermal conductivity and thermal diffusivity of the concrete and to reduce closed pores due to the low thermal conductivity of air.

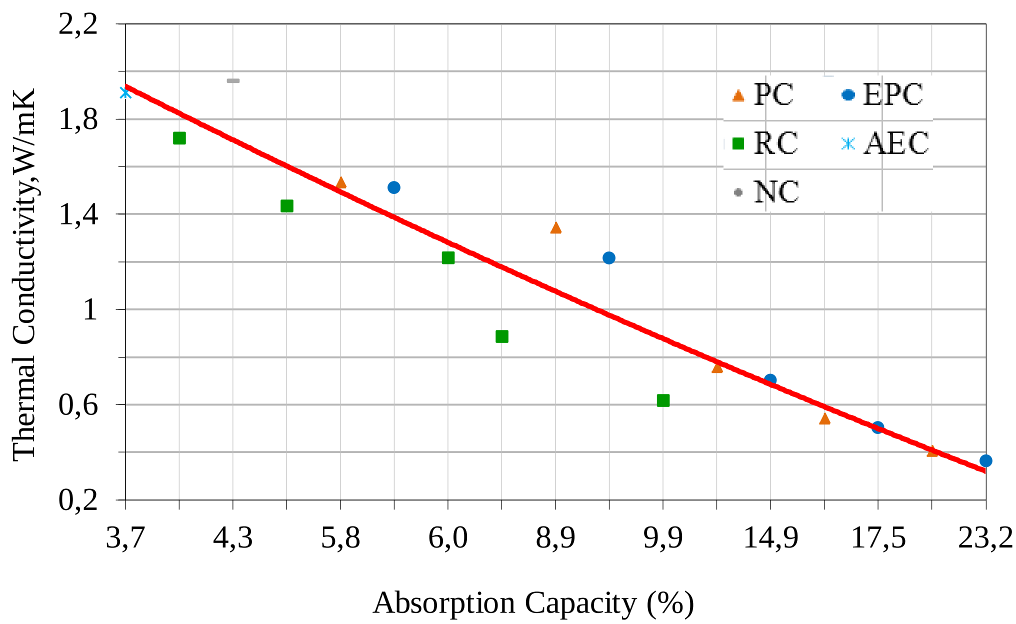

Figure 8.6. Relationship between thermal conductivity and water absorption.

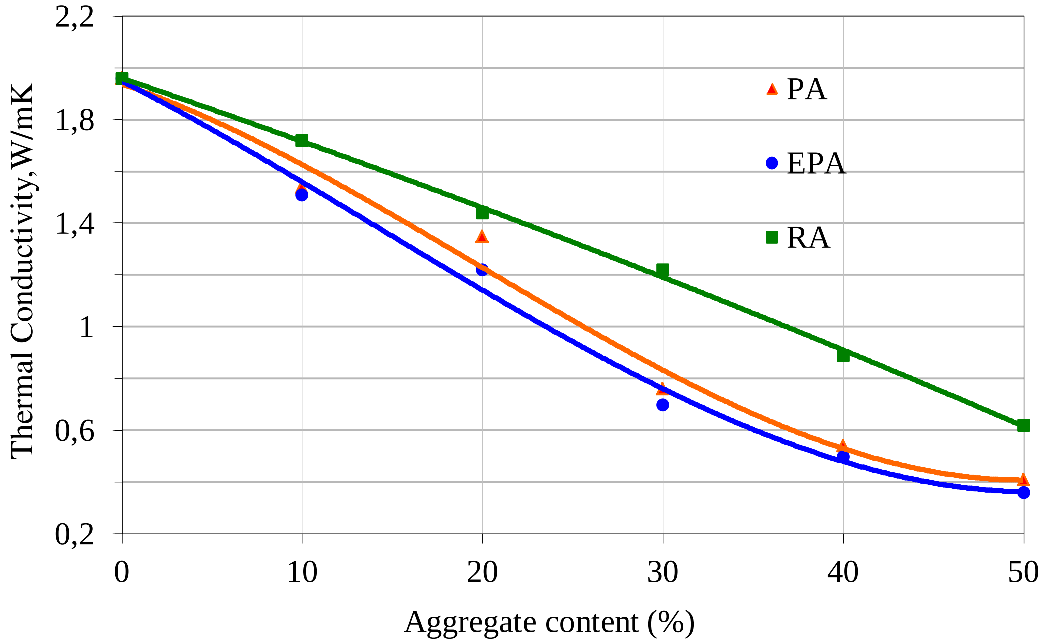

Figure 8.7. Effect of EPA, PA and RA content on the thermal conductivity.

Replacing normal aggregate with LWAs increases the overall porosity of concrete which affects the conductivity. Air entrainment can also reduce the thermal conductivity of all the mixes. Also, silica fume (10% by weight of cement) decreased density cement slurry and cement slurry reducing heat occurs due to decrease density. Replacing normal aggregate by the EPA and PA reduced the thermal conductivity, resulting in porous PA and perlite. As shown in Figure 8.7 that the maximum reduction in thermal conductivity of concrete occurred at the EPA (50%). For 10%, 20%, 30%, 40% and 50% EPA replacement, the reductions in thermal conductivity were 22.96, 38.01, 64.23, 74.36 and 81.48 percent, respectively. For 10%, 20%, 30%, 40% and 50% PA replacement, the reductions were 21.68, 31.38, 61.28, 72.30 and 79.23 percent, respectively, compared to the corresponding control specimens. This is because the density decreased with increasing EPA and PA content. The variation with respect to rubber particle volume content is also displayed in Figure 8.6. It was observed that the addition of rubber particles into the cement matrix reduces the thermal conductivity of the composite. Values decreased from 1.96, for the control specimen, to 0.62 W/mK for a specimen containing 50% rubber particles. This corresponds to a decrease of 68.52%. The reduction in thermal conductivity of composite is due to the insulating effect of rubber particle, which has a lower thermal conductivity compared to that of cement matrix. This may be a non-polar nature of the rubber particles and their tendency to entrap air in rough surfaces. The increases in air content with increasing rubber particles reduce the thermal bridges in the matrix and improve the composite material.

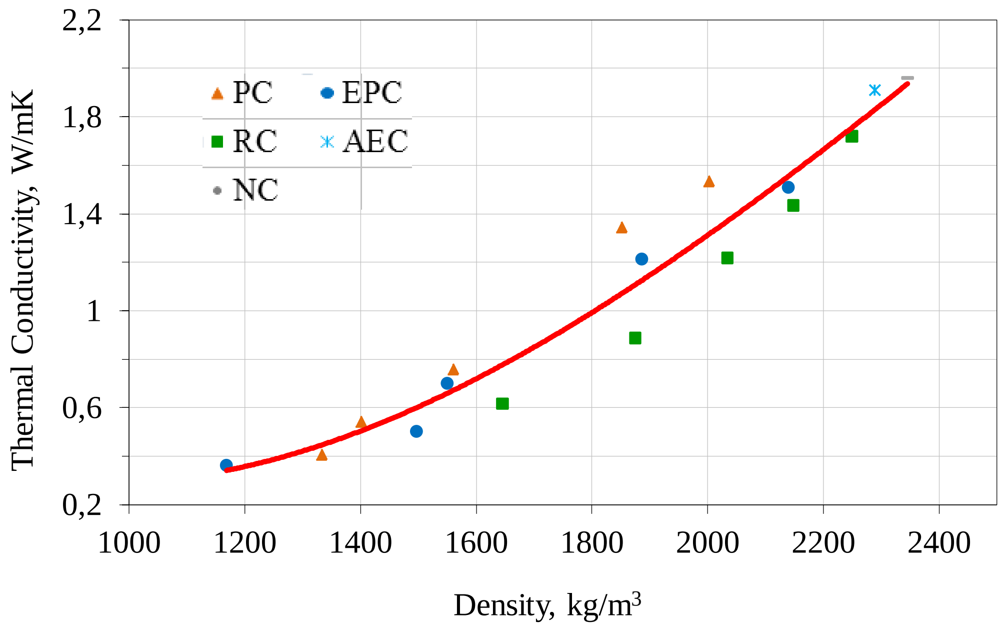

Figure 8.8. Relationship between thermal conductivity and density.

The reduction in density of concrete by means of these aggregates is probably related to the increasing of porosity, also the thermal conductivity decreased due to the density decreasing of concrete as seen in Figure 8.8, which results in an increase void content. Besides, it could be noticed that most reduction in conductivity occurred concrete specimens with EPA. This may due to resulting in significantly increased apparent porosity, but also to the lowest thermal conductivity of EPA themselves.

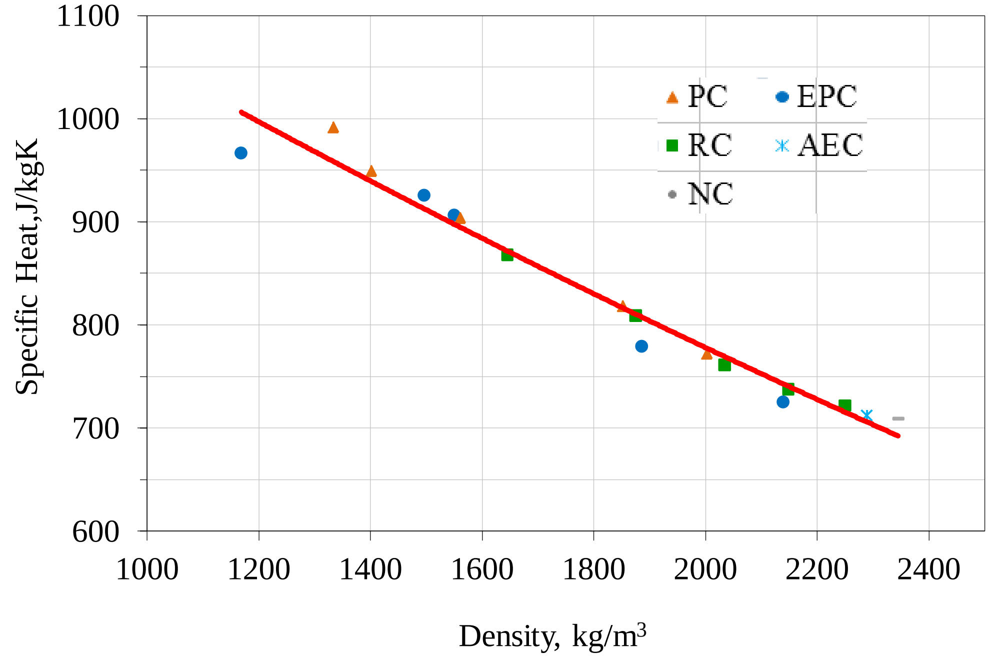

Figure 8.9. Relationship between specific heat and density.

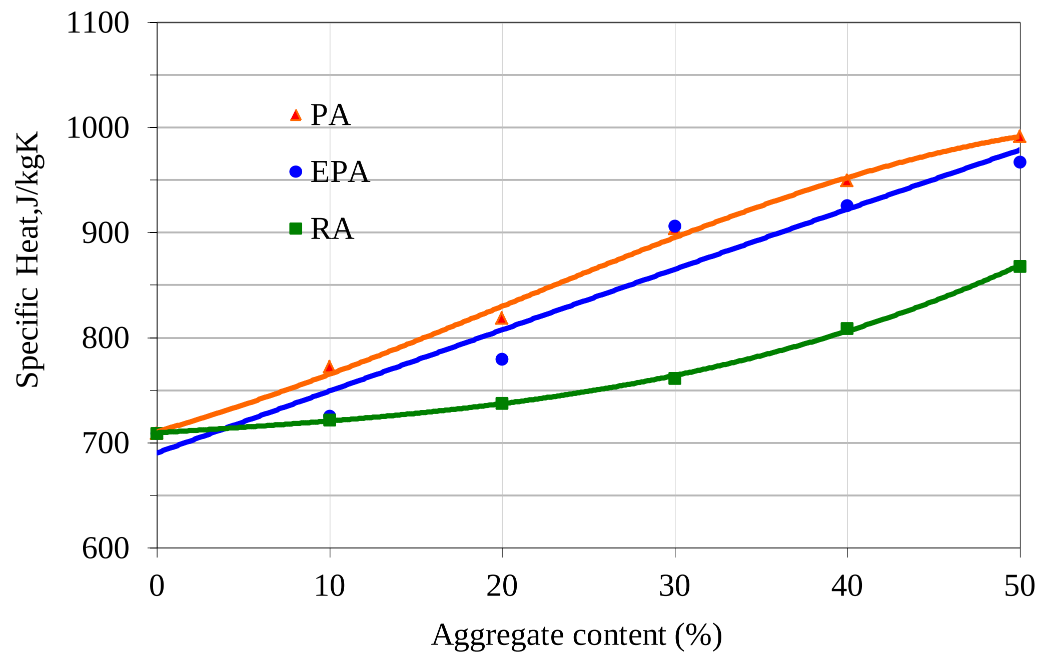

Figure 8.10. Effect of EPA, PA and RA content on the specific heat.

It can be observed from the Figure 8.9 that the type of concrete which have lower density shows greater specific heat and the higher density concrete have lower specific heat. From this figure, it could be concluded that the specific heat is inversely proportional to the density of concrete. As seen in Figure 8.10, values increased from 709.07, for the control specimen, to 868.16, 966.95 and 991.80 J/kgK for specimens containing 50% RA, EPA and PA, respectively. The specific heat of aggregates depends on not only density, but also aggregate type. It can be decided that the specific heat of PA samples increased further with increasing PA content.

The thermal diffusivity is proportional to the thermal conductivity and inversely proportional to the density and the specific heat. However, because of the comparative invariance of the latter property among typical insulating materials, the diffusivity is almost proportional to the ratio of conductivity to density. Although the conductivity of non-metallic materials decreases generally as the gross density decreases, their ratio, and hence the diffusivity, is found to pass through a minimum, so that materials with the lowest conductivities do not necessarily have low diffusivities [83].

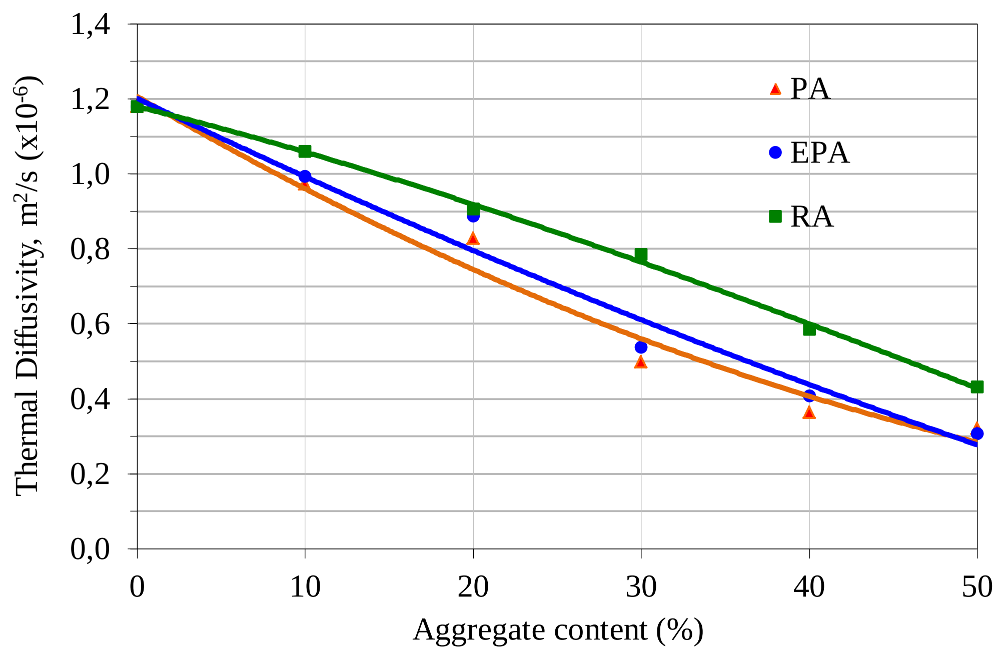

Figure 8.11. Effect of EPA, PA and RA content on the thermal diffusivity.

EPA, PA and RA in mixtures reduced the thermal diffusivity as a result of the total porosity of concrete increased. As shown in Figure 8.11 that the reductions in thermal diffusivity of the concretes were; 17.45, 29.88, 57.67, 69.23 percent and 72.75, 15.78, 24.69, 54.33, 65.36 percent and 73.88, 10.13, 23.17, 33.31, 50.38 and 63.35 percent when 10%, 20%, 30%, 40% and 50% by volume of the normal aggregate was replaced by EPA, PA and RA, respectively. The maximum reduction in the thermal diffusivity of concrete occurred at the PA (50%) which has higher thermal conductivity than EPA (50%).

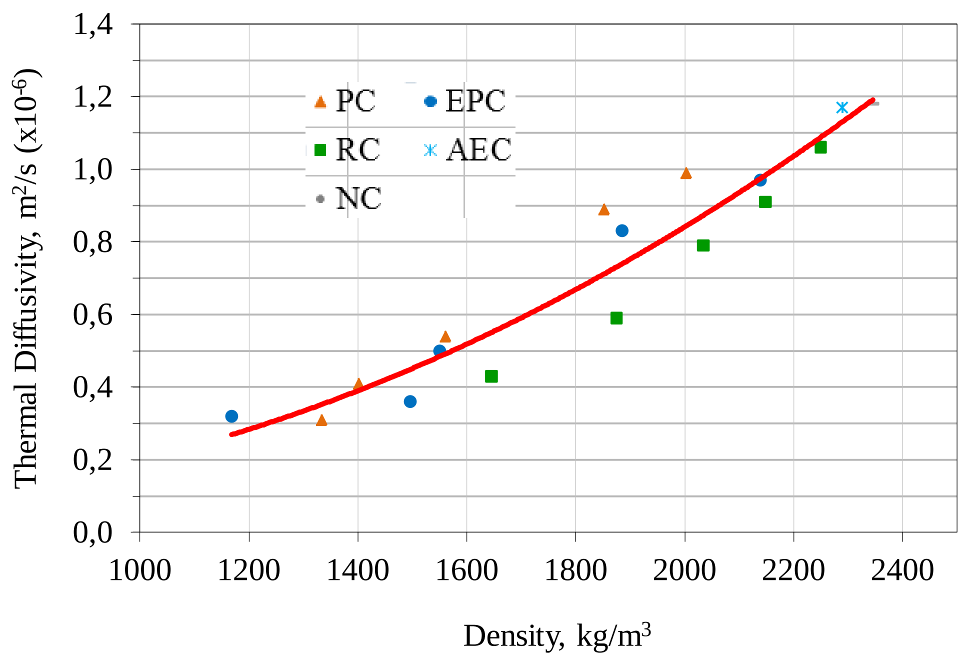

Figure 8.12. Relationship between thermal diffusivity and density.

The relationship between thermal conductivity and density is displayed in Figure 8.12. This figure shows a linear relationship between thermal diffusivity and density as the density increases with the increasing amount of thermal diffusivity. Moreover, the values of density and thermal diffusivity have a great affinity on the thermal conductivity of concrete. Thermal diffusivity increases with increasing thermal conductivity.

8.4. Thermal performance results of multilayer wall and roof

In this part of the periodic solution of the problem is performed using a set of finite Fourier transform (CFFT), which is an analytical method. Computer program MATLAB prepared was performed using a microcomputer for various values of the input system. These parameters are hourly ambient temperature and solar radiation on a horizontal surface is measured meteorological stations, thermal and physical properties (thickness, number of layers, the density, specific heat, thermal conductivity and diffusion) of the roof and walls of the building. Schematic representation of the walls and roofs and their dimensions are given in Figure 8.13.

Figure 8.13. Schematic representation of the walls and roofs and their dimensions

The space heat gain is the main part of the cooling load and the inner surface temperature is related to thermal comfort of the occupants of a building due to the radiation exchange between the occupants and the wall surfaces. The analysis includes the calculation of hourly values of space heat gains and inner surface temperatures for the wall and the roof. Thermal properties of construction materials obtained in Table 3.3 and Table 8.2 are presented before. The data hourly outdoor temperature and solar radiation on a horizontal surface obtained in Figure 6.4, as previously discussed. In order to find heat gain values for the structures, hourly mean measured values of outside air temperatures and solar radiation flux on horizontal surface, and calculated values of solar radiation flux by using measured values on horizontal surface for the North, South, East and West directions are shown in Figure 8.13 for the city of Gaziantep.

Figure 8.14 shows that the values of the solar radiation for all surfaces treated as symmetrical, but they are not completely symmetrical. This is especially noticeable in the East and West directions. Daily solar radiation for all surfaces in the tables are as symmetric values in ASHRAE [66], wherein clear-sky model is used to calculate solar radiation on tilted surfaces. Besides, it is observed that diffuse radiation values for the West direction are higher than those for East direction.

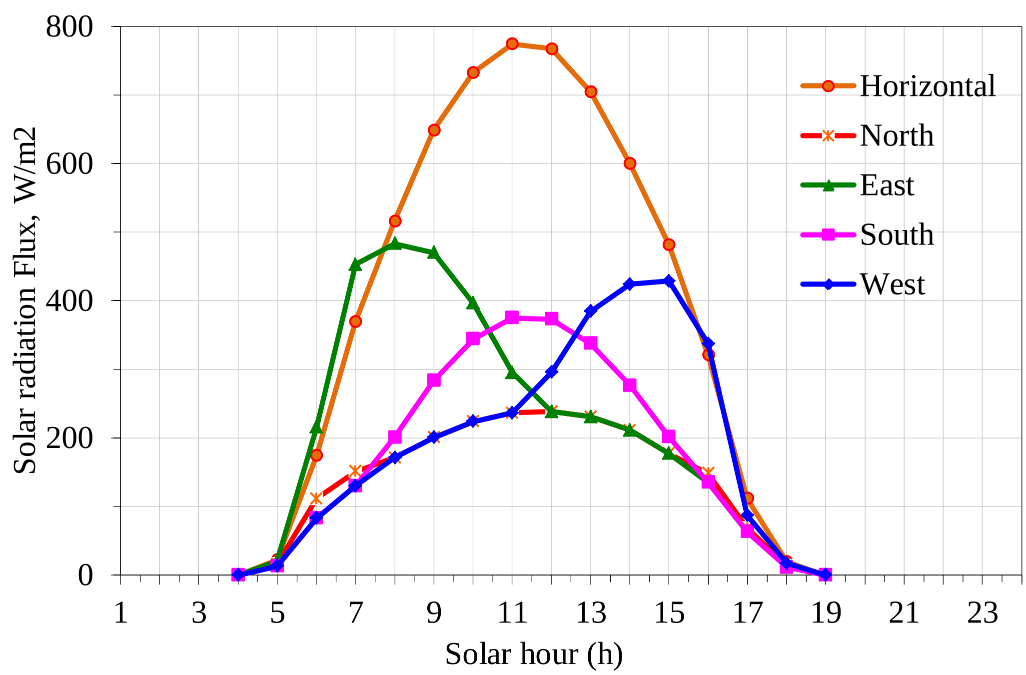

Figure 8.14. Mean values of hourly incident solar radiation flux on horizontal and for four main directions.

Heat gain values of EPC50 wall due to East, West and South directions is shown in Figure 8.15 which is depicted for determining the highest heat gain through the wall. The lowest heat gain values are obtained at the hour between 9 and 10 and the highest heat gain take place at times between 20 and 21 for all directions. The lowest daily mean value of heat gain is obtained for the north wall with a value of 1.624 W/m^2 and the highest mean value of heat gain is obtained for the west wall with a value of 17.846 W/m^2. Effects of solar radiation flux and heat gain on the west wall are clearly seen in these figures. It is necessary to calculate the cooling load due to heat gain for the West direction, and to minimize wall surface area directed due to West when a building will be constructed.

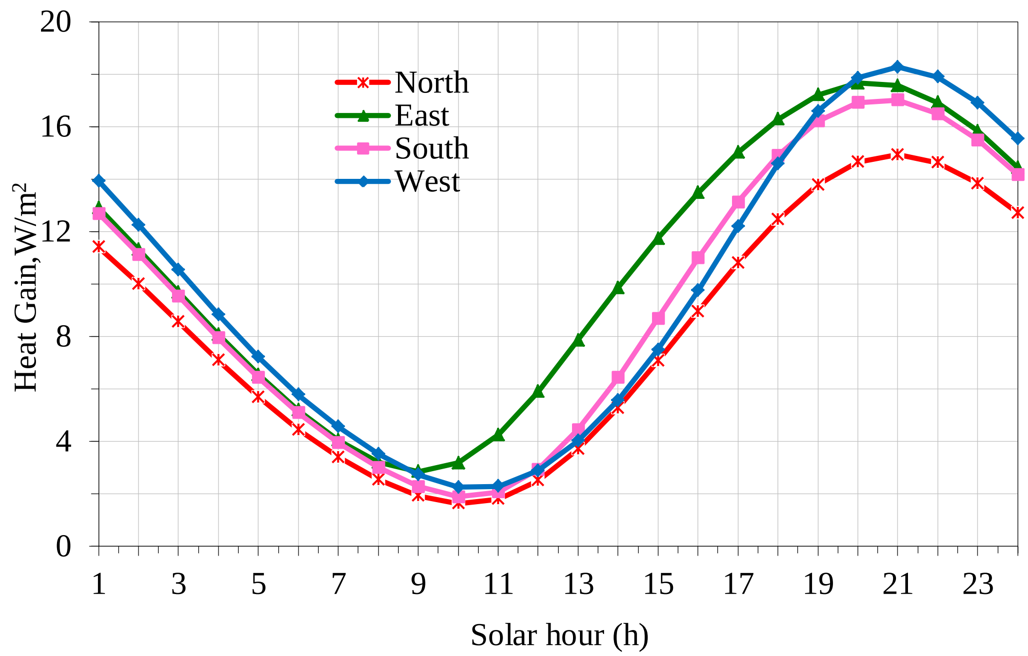

Figure 8.15. Heat gain values of green colored EPC50 wall due to main directions.

Figure 8.16 shows daily variation of heat gain values of different colored walls due to south direction. The heat gain values obtained from the highest to the lowest one are black, green, brown, and white surfaces, respectively. It is seen from the figure that absorptivity of the wall has profound effect on heat gain values. The absorbtivity of the walls depend on the colors of the walls. The absorbtivity of dark surfaces are higher than that of the light surfaces. The dark surfaces absorb more solar radiation than the light surfaces.

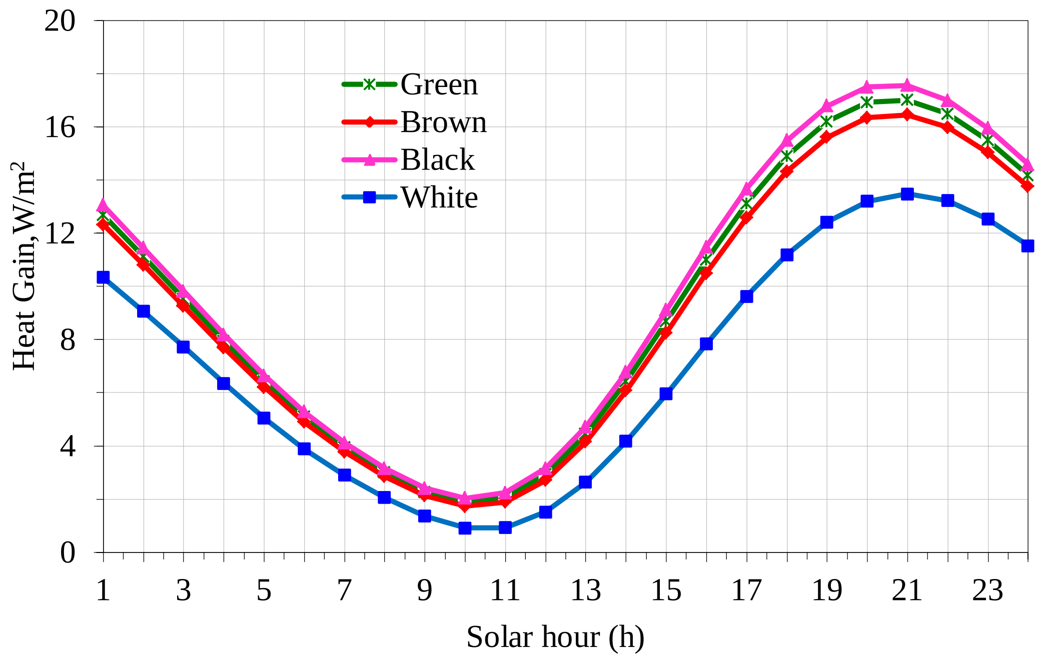

Figure 8.16. Daily variation of heat gain values of different colored walls due to south direction.

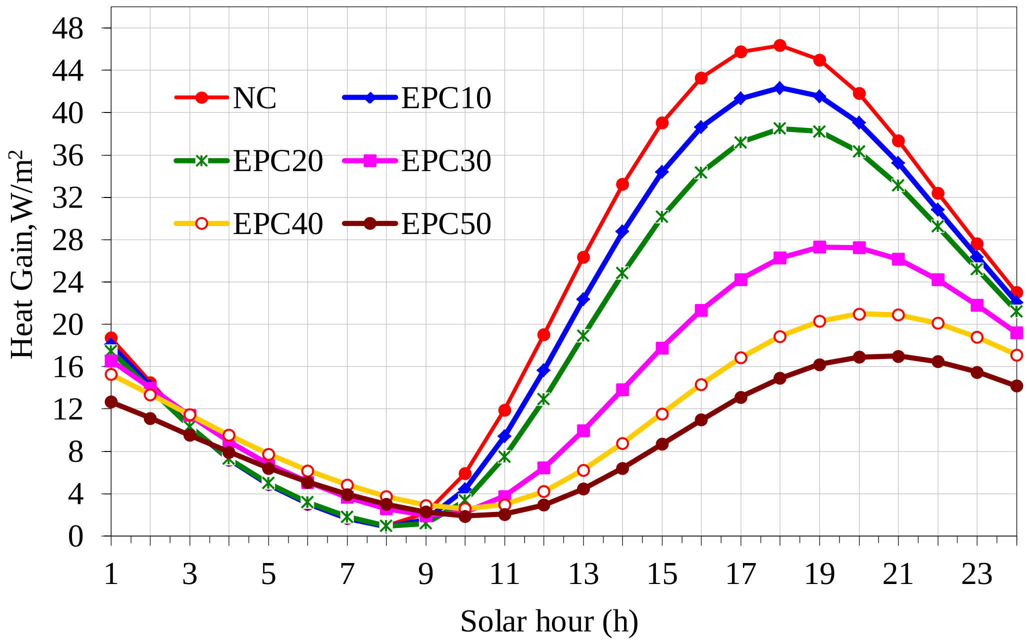

Figure 8.17. Daily variation of heat gain values of green colored NC and EPC walls with different EPA ratios due to south direction.

Daily variations of heat gain values of the NC and EPC walls and roofs with different EPA ratios are shown in Figure 8.17 and 8.18, respectively. NC construction wall and roof have the highest amplitude of the heat gain value and this is followed by EPC10, EPC20, EPC30, EPC40 and EPC50, respectively. The highest heat gain value is obtained for the EPC50 and NC wall with values of 1.885 W/m^2 and 46.364 W/m^2, and the highest heat gain value is obtained for the EPC50 and NC roof with values of 57.24W/m^2 and 128.98 W/m^2, respectively.

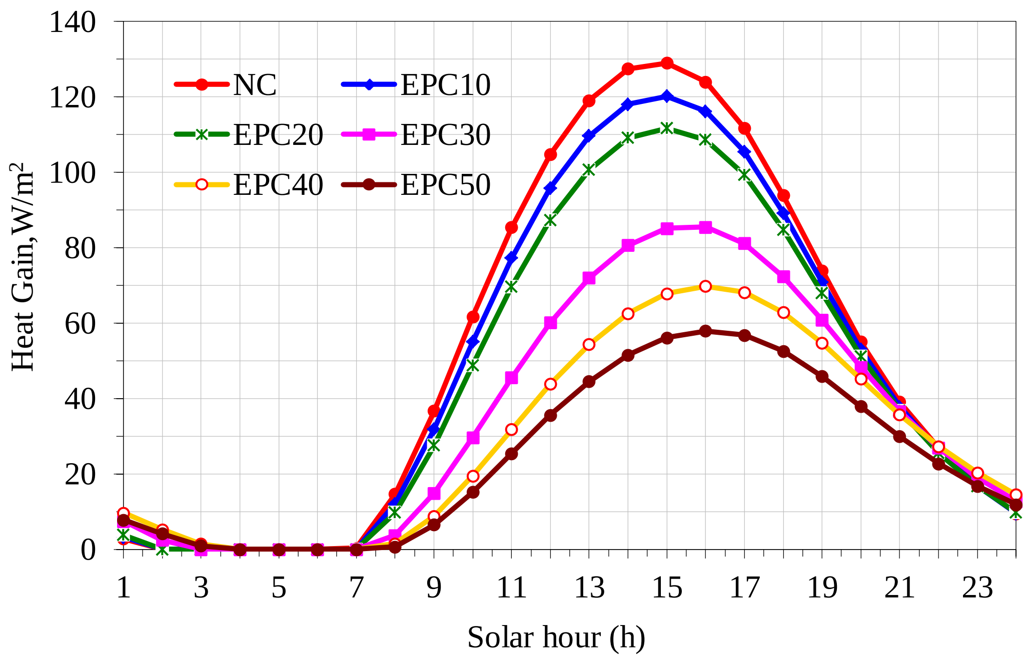

Figure 8.18. Daily variation of heat gain values of green colored NC and EPC roofs with different EPA ratios.

Figure 8.19 and 8.20 shows NC construction wall and roof have the highest amplitude of the heat gain value and this is followed by PC10, PC20, PC30, PC40 and PC50, respectively. The highest heat gain value is obtained for the PC50 wall and roof with values of 17.735W/m^2 and 60.495W/m^2, respectively.

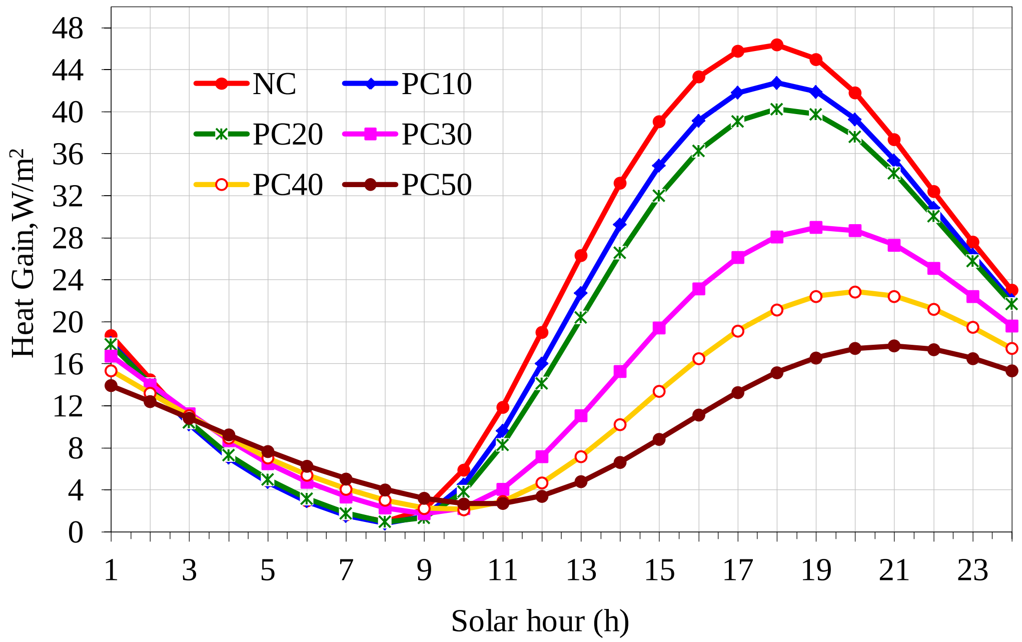

Figure 8.19. Daily variation of heat gain values of green colored NC and PC walls with different PA ratios due to south direction.

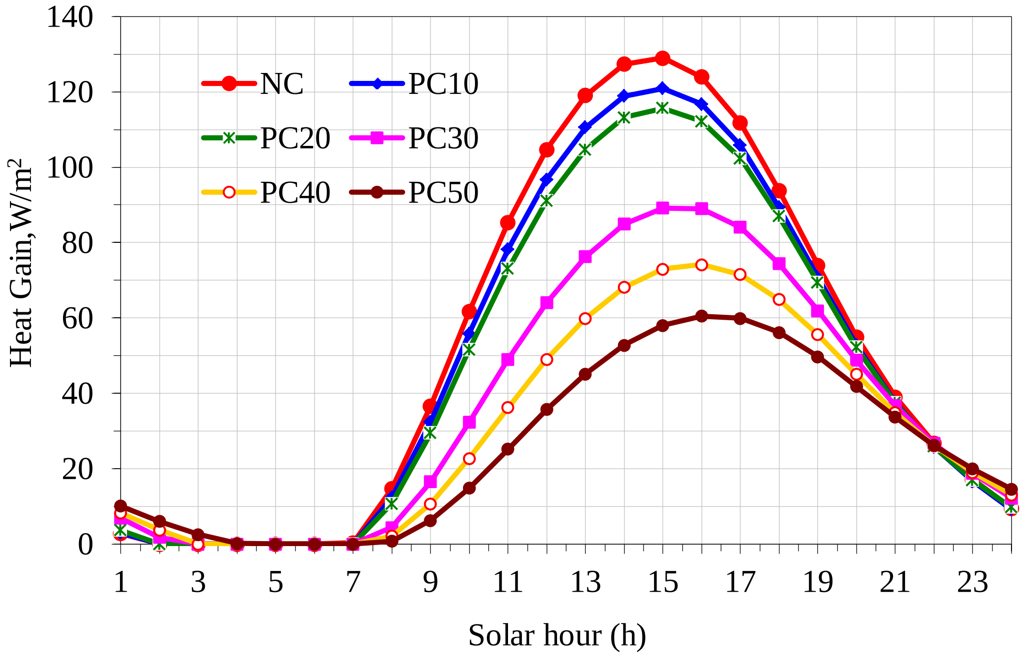

Figure 8.20. Daily variation of heat gain values of green colored NC and PC roofs with different PA ratios.

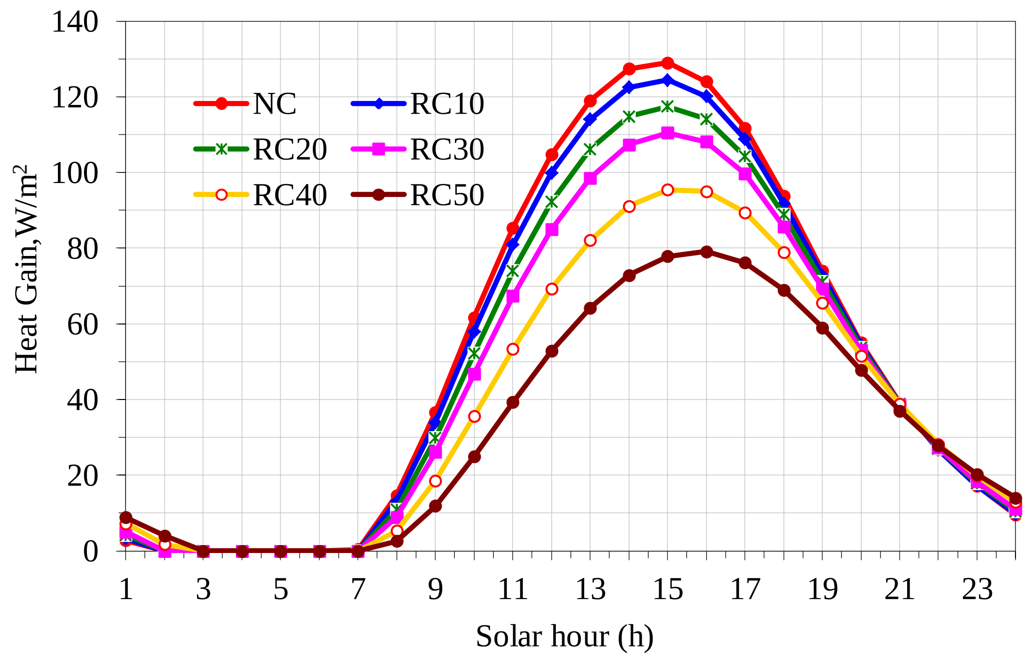

Figure 8.21. Daily variation of heat gain values of green colored NC and RC roofs with different RA ratios.

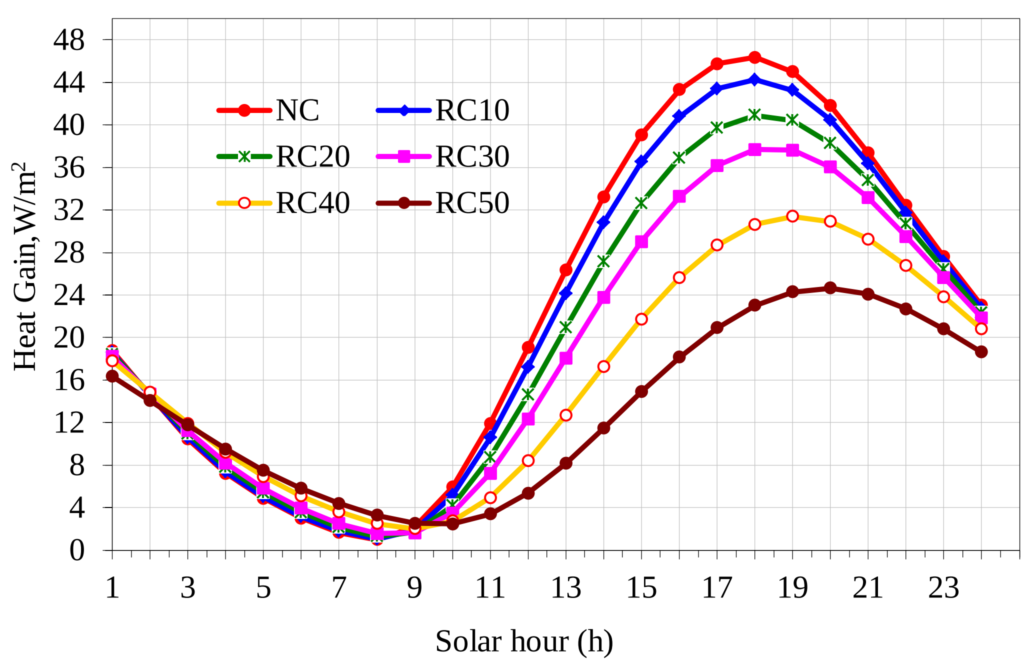

Figure 8.22. Daily variation of heat gain values of green colored NC and RC walls with different RA ratios due to south direction.

As shown in Figure 8.21 and 8.22, NC construction wall and roof have the highest amplitude of the heat gain value and this is followed by RC10, RC20, RC30, RC40 and RC50, respectively. The highest heat gain value is obtained for the RC50 wall and roof with values of 24.646 W/m^2 and 79.084 W/m^2, respectively.

Results of daily heat gain and temperature values for the interior surface of roofs and the south-facing walls are shown in Figure 8.23 and Figure 8.24, respectively. It is seen from these figures that the largest inner surface temperature and daily temperature amplitude, and also heat gain occur for the wall and roof constructed with NC, which has the highest thermal diffusivity and conductivity. It is observed that thermal diffusivity and conductivity of the materials have significant effect on thermal behavior of the structures. The largest outer surface temperature and the smallest amplitude of inner temperature and heat gain occur for the wall constructed with EPC50 which has the lowest thermal conductivity.

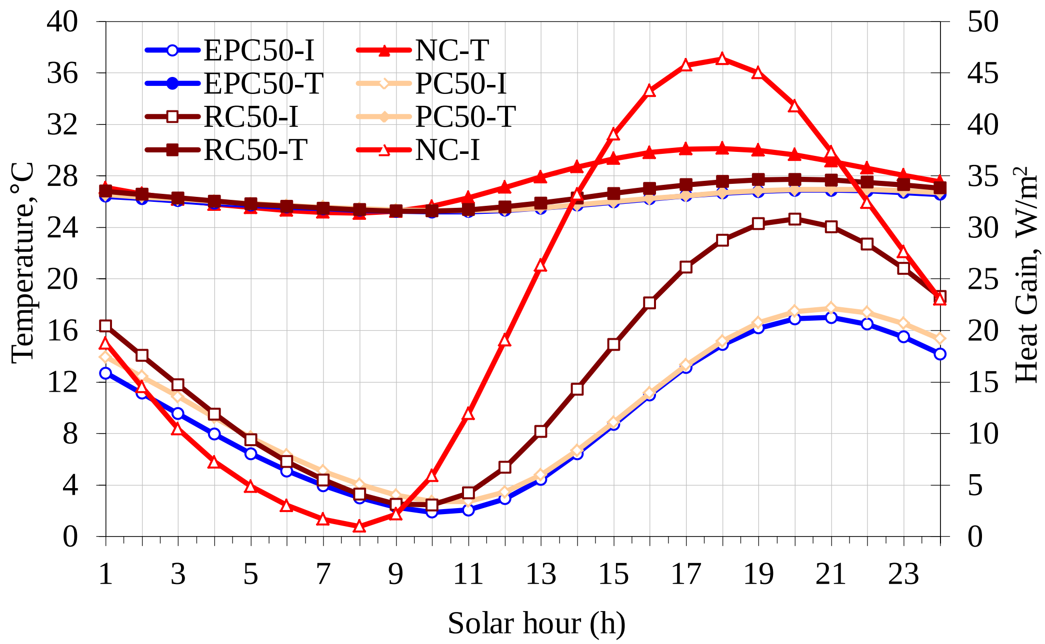

Figure 8.23. Variation of heat gains, and inner surface temperatures for south-facing wall constructions.

These values for PC50 or EPC50 are closer to each other. It is seen from the Figure 8.22 and Figure 8.23 that PC50 or EPC50 are suitable building wall material. Because their utilization leads to lower heat gain as compared to NC and RC50. As a result, the usage of walls having lower thermal diffusivity and conductivity leads to stable room temperature or comfortable condition in the room even when outside air temperature is high.

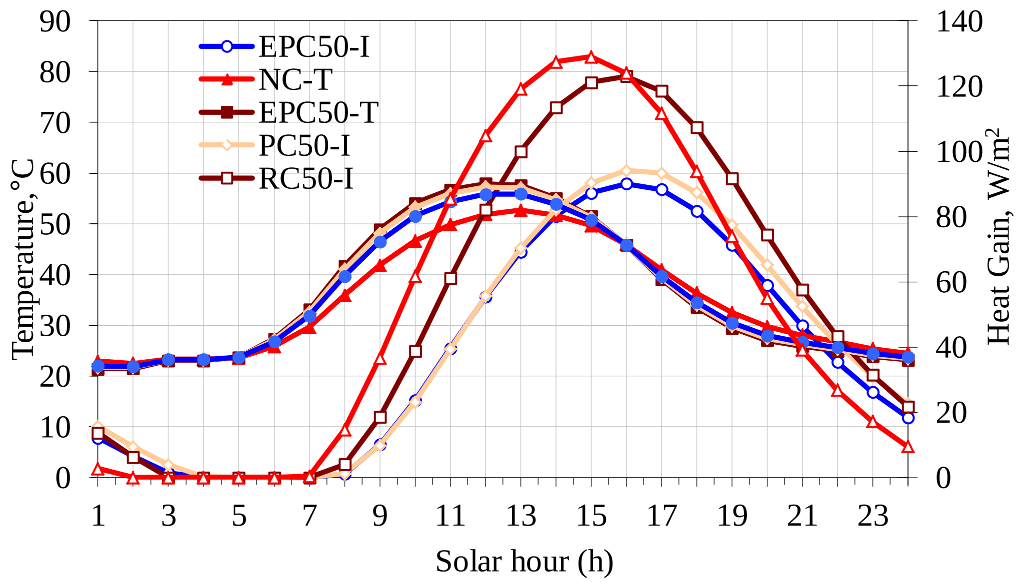

Figure 8.24. Variation of heat gains, and outer surface temperatures for roof constructions.

Daily variation of heat gain values of green colored structural lightweight concrete constructions due to south direction is presented in Figure 8.25. NC construction wall and roof have the highest amplitude of the heat gain value and this is followed by AEC, RC10, PC10, RC20, PC20, EPC20 and RC30, respectively. It is seen from the Figure 8.25 that the largest heat gain occur for the structural concrete constructed with NC , which has the highest compressive strength but also highest thermal diffusivity and conductivity. These values for NC or AEC are closer to each other.

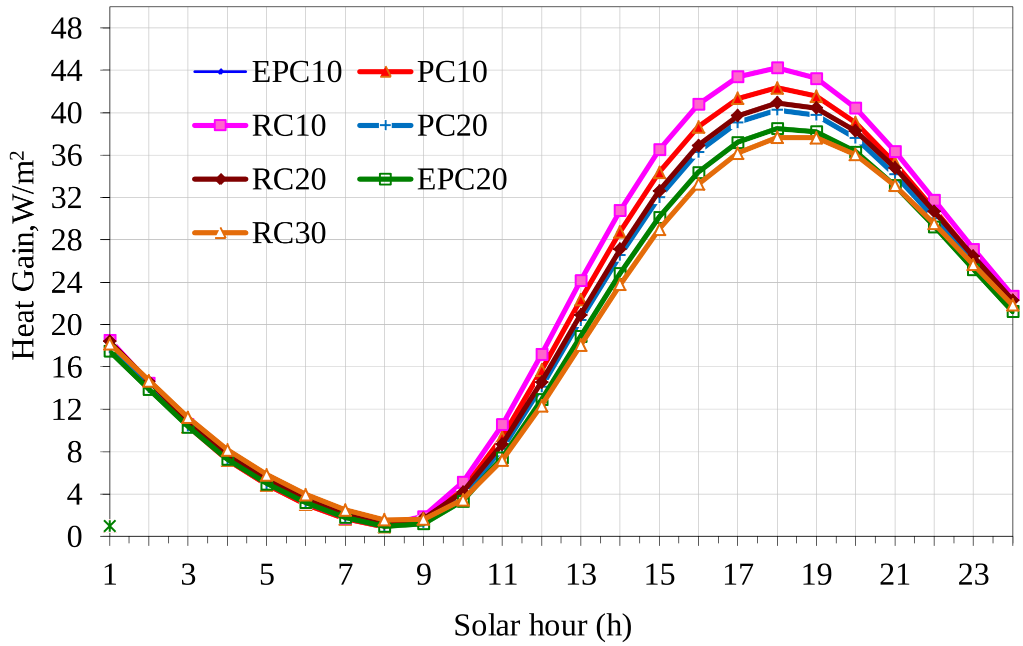

Figure 8.25. Variation of heat gain values of green colored structural lightweight concrete constructions due to south direction.

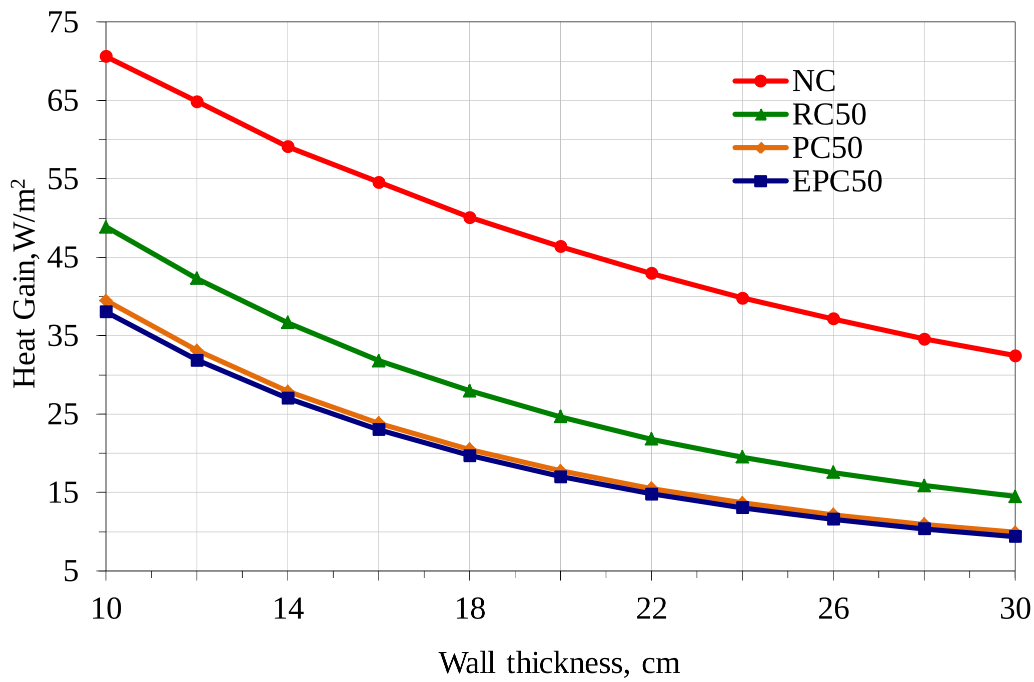

Figure 8.26. Variation of the highest heat gains with thickness for wall constructions.

It is observed that the smallest amplitude of heat gain occur for the structural concrete constructed with RC30. It is observed that cooling load due to wall and roof decreases more when the structural concrete constructed with RC30 or EPC20. The heat gain values for PC20 or RC50 are closer to each other. It is seen from the Figure 8.25 that RC30 or EPC20 are more suitable structural building material.

Figure 8.26 is depicted for comparing the highest heat gain with respect to wall thickness for walls of NC, RC50, PC50 and EPC50. Time of the highest heat gain occurs in different hours depending on thermophysical properties and heat storage capabilities of the wall material. The heat gain for each wall and differences in values of heat gain of the walls decrease as the wall thickness increases. As the highest heat gain occurs for the NC, the lowest heat gain takes place for the EPC50.

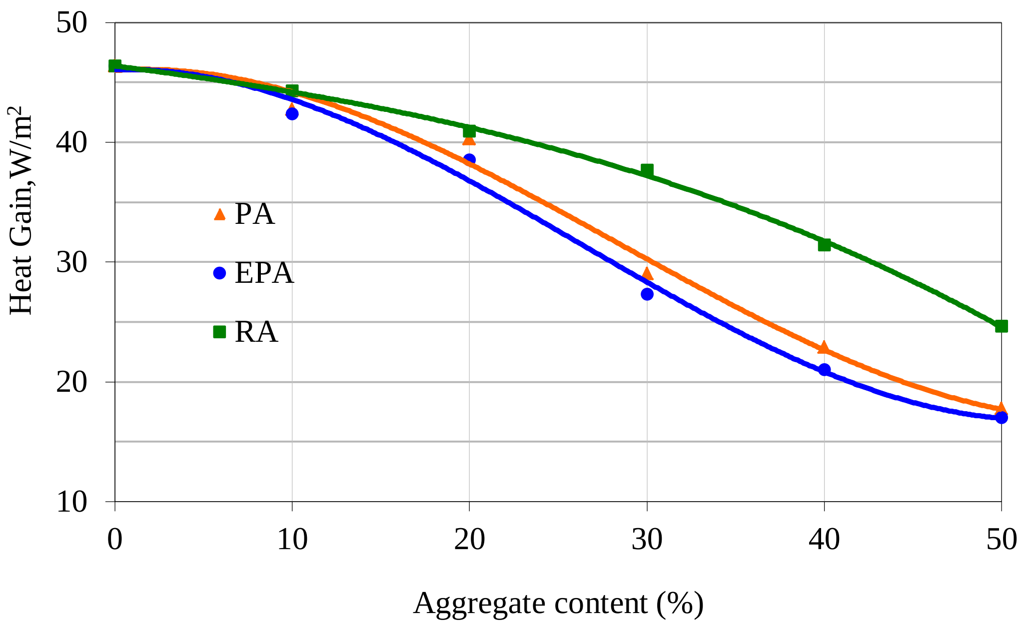

Figure 8.27. Variation of the highest heat gains with LWA content for south-facing wall constructions.

Figure 8.26 gives an idea about which one of thickness for the walls constructed with NC or RC50 corresponds to the PC50 or EPC50. At this time, it is shown that how much wall heat gain is necessary for a wall thickness and each of the structures. It is observed from the figure that heat gain through the EPC50 wall with 10 cm thickness corresponds 13.5 cm of RC50 and 26 cm of NC walls. Also, amount of gain through the PC50 wall with a thickness of 12 cm will be equal to the same heat gain through EPC50, RC50 and NC with thickness of 11.5 cm, 15.5 cm and 30 cm, respectively. It is concluded from the figure that EPC50 gives approximate results with those of the PC50. When these wall constructions are used in building wall constructions in Turkey, they provide stable temperature in the rooms and comfortable condition for the people living in the buildings. Also, there will be a reduction in the size of air conditioner, initial and operation costs of the conditioner and building construction will be decreased.

Figure 8.27 shows variation of the highest heat gains with EPA, PA and RA content for south-facing wall constructions and Figure 8.28 displays variation of the highest heat gains with thermal diffusivity for south-facing wall constructions. It was noted these figures strictly closer to Figure 8.6, Figure 8.7 and 8.11 and it can be observed these figures that thermal diffusivity and thermal conductivity are the dominant properties due to thermal comfort in building envelope. The lowest heat gain is obtained for the EPC50 (EPA with 50% aggregate content) wall with value of 17 W/m^2.

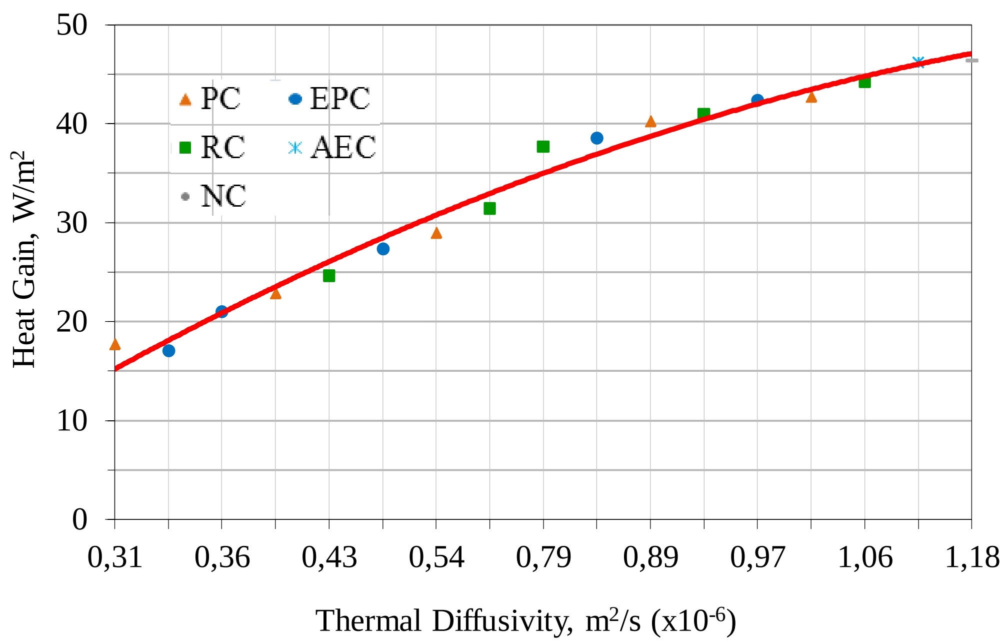

Figure 8.28. Variation of the highest heat gains with thermal diffusivity for south-facing wall constructions.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from the experimental and theoretical results:

1. It is known that the thermal properties of the concrete, associated with its density. Density is the most important parameter that a direct relationship exists between the density, specific heat, thermal conductivity, and thermal diffusivity of the material. By reducing the density of the concrete, low thermal conductivity and thermal diffusivity but higher specific heat can be achieved. Thus, by creating voids or air bubbles in concrete, LWC can be produced for insulation.

2. A low density and thermal diffusivity, coupled with the ability to apply to any desired shape provides lightweight concrete is a very suitable material for use as construction material.

3. Reduction in thermal conductivity may be due to the effect of air entrapment rubber particles, resulting in greatly increased porosity, but also lower thermal conductivity of rubber particles.

4. Despite the corresponding decrease in bulk density of LWCs, the higher specific heat of LWCs gives a general decline in the thermal diffusivity.

5. Compressive strength decreases with increasing the amount of LWA. Lightweight concretes can be divided into different groups depending on the bulk density and compressive strength mentioned before. The LWC which are EPA10, EPA20, PA10, PA20, RA10, RA20 and RA30 have a higher

compressive strength than 17.3MPa and can be called as a lightweight structural concrete.

6. Compressive strength of concrete is reduced due to replacing normal aggregate with the porous EPA and PA. Besides, air entrainment contributed to the low strength concrete.

7. Because of the density of LWCs are lower than the density of NC, the dead weight of the structure will be reduced by using LWCs in construction.

8. It should be noted that all of the mixture obtained in this research are the same w/c ratio of 0.48 and higher strength but also higher density can be obtained by reducing of the w/c ratio.

9. Both water absorption and efficiency increases with EPA and PA amount. However, there is decrease in workability with a higher amount of RA.

10. Silica fume causes reduction in density (unit weight), thermal conductivity, and workability resulting from low water absorption values, but increased in the specific heat of the concrete. This is because it has a lower thermal conductivity and specific gravity as compared with cement.

11. Thermal properties of the wall or roof materials have a profound impact on the enhancement the heat gain and surface temperature values. In particular, thermal conductivity is a key and materials with high thermal conductivity give large amplitude of heat gain value.

12. Thermal conductivity and diffusivity have significant impact on the heat gain through the walls and flat roof. In all types of roofs and walls, the lowest heat gain value detected for the EPC50, but the highest heat gain value detected for the NC. In addition, the lowest daily amplitude and inner surface temperature occurred in PC50 and EPC50 walls.

13. Because solar radiation flux is higher in the west and ambient temperature is higher in afternoon compared to the other directions, the highest the value of heat gain is detected in the West direction.

14. Heat gain values of the EPC50 are close to the values of PC50 in both wall and roof constructions.

15. The absorptivity value of dark surfaces are greater than that of the light surfaces that causes higher heat gain value; because, the dark surfaces absorb more solar radiation.

16. Absorptivity of surfaces, meteorological values, thermophysical properties and directions of the walls have important effect on the cooling load in buildings. The air condition system capacity will be increased as the cooling load increases. When the capacity increases, the need for energy and maintenance costs of the system will increase. It is desirable to use the lowest power when comfort conditions could be achieved.

17. The use of RA from recycled tires provides reduction of the environmental threats caused by waste tires, introduction of an alternative source to aggregates in concrete.

Future studies should be continued in the following areas as part of the extension of this research:

1. The texture and shape of aggregate affects the properties of hardened concrete. Crushed stone aggregate have a higher surface-to-volume ratio and better bond characteristics than that of gravel. Hence, it can be satisfied higher compressive strength if crushed stone is used in concrete mixture.

2. The test results in this study are based on results taken after 28th days of standard curing of the test samples. The long-term effects of EPC, PC and RC needs to be studied to find out the relevant properties associated with the age of the concrete.

3. Preferably, for optimal thermal properties which are as low as possible heat conductivity and diffusivity value received for a particular mixture provided with higher LWA content that minimum strength is satisfied.

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APPENDIX A

Table A: Solar Radiation on Horizontal Plane and Ambient Air Temperature Data for Gaziantep

GAZİANTEP (37.01) July 23					
Hour	T_o °C	I_T W/m^2	Hour	T_o °C	I_T W/m^2
1	20	0.0	13	37	60.6
2	20	0.0	14	37.2	51.6
3	22.9	0.0	15	37.2	41.4
4	22.8	0.0	16	36.2	27.6
5	22	1.9	17	35.1	9.6
6	20.9	15.0	18	31.9	1.68
7	20.1	31.8	19	27.8	0.0
8	26	44.4	20	25.2	0.0
9	30	55.8	21	24.4	0.0
10	33	63.0	22	23.9	0.0
11	34.1	66.6	23	22.7	0.0
12	35.2	66.0	24	22.6	0.0