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Effect of structural lightweight aggregates in mitigating thermal bridging in buildings

[1]M.PRIYAMVADHA Assistant Professor priyam.sri.157@gmail.com
[2]R Jaipal Assistant Professor jaipalcivil.jntu@gmail.com
Department of Civil Engineering,
Pallavi Engineering College Hyderabad, Telangana 501505

ABSTRACT

An effort is underway in the EU member states to encourage energy efficiency improvements in buildings and fulfill the increasing demand for indoor comfort while also decreasing the energy consumption for space heating and cooling. NWC construction may be replaced with SLWAC construction to improve indoor air quality and reduce energy usage. A structure's energy efficiency may be improved through SLWAC in the end. Concrete mixtures made from SLWAC and NWC have their thermal characteristics examined. With the use of two-dimensional heat transfer software Term and a building energy modeling program Energy Plus, a case study was conducted to examine how SLWAC influences thermal bridge heat losses and energy consumption. It has been shown that SLWAC may enhance building energy efficiency, making it a viable option to NWC.

1.Introduction

Due to technical advancement and rising living standards, the quality of buildings has substantially increased in recent decades. In order to fulfill today's comfort standards, a building's design must take a number of factors into account.

In most cases, the only way to maintain a comfortable inside temperature is to use air conditioning, which accounts for a significant portion of the energy used by buildings.[1].

40 percent of EU energy use was accounted for by buildings in 2010. (EU) [2,3] (about 30% in Portugal [4]), Residential constructions accounted for over two-thirds of all building energy usage, according to a new report. There was a wide variation in the amount of electricity utilized in EU residential buildings in 2009, mostly due to climatic variances.

Space heating accounts for 60–80 percent of total household energy use [5]. For the most part, these requirements are being met by repairing the country's deteriorating and poor construction. A similar situation should exist in other countries. It is critical to examine this problem from the standpoint of both new construction and historic preservation. Improving a building's thermal envelope and installing energy-efficient equipment are just a few of the methods to cut down on traditional energy use while also helping the environment. Another option is to integrate renewable energy sources.

"In recent years, EU member states have been pressed to adopt the EU Directives on the Energy Performance of Buildings (EPBD). It is a newer version of the original, like Directive 2002/91/EC [7] and the more recent Directive 2010/31/EU [3]." Buildings in the EU can be made more environmentally friendly, as both writers note, and they provide ideas on how to do so.

Buildings and building units must meet minimal requirements for energy efficiency, This must be defined by each member state [3]. That all heat transmission mechanisms and other factors (e.g., heating and air-conditioning systems) are thoroughly examined, passive heating and cooling components) be taken into consideration when assessing compliance with standards (such as shading control).

For the energy efficiency of a building, the envelope is one of the most critical components. As a result, a thorough investigation of conduction heat losses through the building envelope is necessary to identify probable causes of poor thermal behavior and to make the most appropriate design and construction choices.

Thermal bridges and other components of the building envelope are critical to the transfer of heat. Wall/floor/ceiling connections, for example, might introduce thermal bridges into the building envelope because of their varying thermal conductivities, the thickness of the fabric they use, or the difference in temperature between the interior and the exterior [8,9]. As a general rule, thermal bridges modify the flow of heat and the temperature within a building. [8]. Heat loss via thermal bridges may account for up to 30 percent of a building's overall energy consumption in the EU, according to research [10,11]. Similar findings were found by Theodosius and Papadopoulos [12].

Concretized structural elements, such as columns and beams, are a major contributor to thermal bridges because of their high thermal conductivity compared to the surrounding building materials' low one. Lightweight aggregate concrete may make a huge difference in this situation. Due to its decreased density, lightweight aggregate concrete (LAC) is possible to minimize the permanent load as well as the thermal conductivity of structural parts. structural lightweight aggregate concrete (SLWAC) may minimize thermal bridging in place of non-woven fabric concrete (NWC) by reducing global heat loss via building envelopes or by minimizing corrective insulation systems needed to achieve traditional criteria for thermal insulation.

LWA (lightweight aggregates with a porous structure) has a lower thermal conductivity than NWC, which is why SLWAC has a better thermal insulation capability.

NWC has a thermal conductivity between 0.1.4 and 2.9 W/m K, whereas SLWAC has a thermal conductivity between 0.58 and 1.86 W/m K with an average density of 1850 kg/m3. One substance, NWC, is not the same as another. As opposed to these findings, data from ITE50 indicates that the thermal conductivity of SLWAC at 1400–1800 kg/m3 and NWC at 2000–2600 kg/m3 may range from 0.85 to 1.05 W mm K and 1.65 to 2.0 W mm K, respectively. Comparing SLWAC to NWC, Thermal conductivity is reduced by 50–70% as a consequence.

Thermal conductivities of SLWAC were found to be 40–53 percent lower than those of NWC when the W/B ratios were changed. Each one-tenth of a percent increase in total porosity is equivalent to, thermal conductivity decreases by 0.6 percent.

Thermal bridge effects and energy requirements can be used in new constructions in an efficient manner, requiring less resources for the same end result (construction of an adequate building with certain load capacity), thus contributing to the overall costs and encouraging environmental and economical sustainability. In buildings incorporating SLWAC components, no signs of thermal bridges or energy efficiency studies could be seen at all.

Them 7.3 and Energy Plus 7 free source software tools are used in this case study to investigate the potential of SLWAC to minimize thermal bridging effects and energy usage. Research on the thermophysical properties of several SLWAC variants was used to arrive at this conclusion. The study's methodology may be seen in Figure 1, which you can see here.

Too far, these LWA-concrete combinations have not been extensively employed in building construction. As a result, they're being used in a unique way: as a structural and thermal insulation material. Because of these factors, material properties that can be tested experimentally are important. As shown in Fig. 1, characteristics of various concrete mixes are first acquired using an experimental programmer, before being employed in the Them and Energy- plus modelling systems. Based on the energy efficiency of these materials, it is hoped that this method would provide more precise and realistic results.

2.Experimental program

2.1 Materials,compositionsandproduction

For this study, four kinds of coarse light-weight aggregate (LWA) specimens were created, including two Portuguese expanded clay aggregates (known as Leca and Argex) and one British sintered fly ash (Lytag) aggregate, all of which were used in the production of the specimens (commercial name Stalite). Aggregates made from crushed limestone, fine and coarse, were used as normal weight aggregates in the study of NWC specimens (NWA). It was determined that while comparing Argex (70 percent) with the two crushed limestone fractions (34 percent fine and 66 percent coarse gravel), specific proportions were specified between the two. Both the SLWAC and the NWC specimens were constructed with fine aggregates composed of 70% coarse and 30% fine normal weight sand. As seen in Table 1, these aggre-gates have a number of common properties, which have extremely different porosities.

In order to create the five concrete combinations, the method outlined by Bogus and Gomes was followed (four LWA and one NWA). Coarse aggregate was used at 350 L/m3, with 400 kg/m3 of CEM I (according to EN197-1), and fine aggregate at 310 L/m3.

The concrete was made utilizing a bottom discharge vertical shaft mixer. Presoaking LWA for 24 hours and drying them with absorbent towels ensured that the concrete's workability and effective water content could be better controlled. For two minutes, the sand and half of the water were mixed together before the binder and the remainder of the water were added. After another minute, the superplasticizer was diluted with 10% water and gently added to the mixture. Seven minutes totaled the mixing process. The aggregates in Agree-produced concrete were first dried before being mixed. LWA water absorption was evaluated before to mixing in order to account for total mix water corrections, as advised by the techniqueBogusetal.

2.2 Testmethodsandmeasuredproperties

In accordance with EN12390-3, A drying oven at 100 °C was used for the dry density and thermal characteristics testing after 28 days of water cure. Dry thermal properties specimens were stored in the lab for one day at a temperature of around 20 degrees Celsius to minimize moisture exchange during the testing.

EN12390-7 was used to conduct the dry density testing, and a modified transient pulse technique was used to conduct the thermal performance tests.

Applied Precision Enterprise's ISOMET 2114 portable hand-held heat transfer analyzer was used to conduct the thermal testing. ISOMET 2114 is a hard-material surface measurement probe that uses a modified transient pulse approach to evaluate thermal characteristics (MTPS). When a heat pulse is supplied to the specimens in thermal equilibrium, the temperature is measured in degrees Celsius and W/m K, respectively. As a result of the preceding, thermal diffusivity (a), measured in m2/s, is added in the list of properties.

There is a 10% to 15% + 1103 J/m3 K measurement error for plier, although the measurement error for 0.7 to 6 W/m K is between 1 and 1 percent for plier. Using this method, Oktay et al. and Real et al. examined the heat conductivity of this and other concrete mixes. Following ITE50, the thermal conductivity coefficient for CE-designated objects is calculated using an average temperature of 10 degrees Celsius. For the purposes of conductivity testing, ISO/FDIS 10456 [32] recommends setting the temperature to 10°C. It should be noted that this standard should only be used for procedures that remain stationary.

3.“Thermalconductivity,specificheatcapacityandthermaldiffusivity”

One of the most essential aspects of concrete's thermal performance is its thermal conductivity, which includes properties like specific heat capacity and heat transfer coefficients. For a material to have good thermal conductivity, it must be able to transmit heat in the direction corresponding to its surface under steady-state circumstances, the quantity of heat that may be transported through a given thickness of a given substance. It is a measure of a material's ability to transmit heat while it is stationary. The exterior building envelope should be restricted in thermal conductivity to prevent poor thermal performance.

Cp = cq/q, or specific heat capacity, is a measurement ofrise in temperature in a unit mass (or Kelvin). When calculating a material's thermal mass, one consideration is the material's specific heat capacity. Using materials with a high thermal mass may help maintain a steady interior temperature without using excessive amounts of energy.For char-based materials, thermal diffusivity (a) is a unique feature.

Acting as a heat conductor for erratic heat flow As a function of volumetric heat capacity and thermal conductivity, a = k/cq In other words, it evaluates how well a substance can transmit heat in relation to how well it can store heat. Low thermal diffusivity, together with high volumetric heat capacity, make for a suitable insulator in non-steady-state applications.Table 2 displays the results of the tests performed on the oven-dried specimens for the different characteristics described above.

Table 2 first example, SLWAC cubes have a compressive strength range of 26.1–49.9 MPa, and a second case range of 1541–1811 kg/m3. This range is defined by EN206-1 to include density classes LC20/22-2 through LC40/42-44, respectively. Structural concrete may be produced by adhering to the prescribed LWA.Using lightweight particles considerably enhanced the thermal insulation of the concrete, according to Table 2. A SLWAC specific heat of 0.94–1.21 W/m K thermal conductivity (k) was attained.the thermal diffusivity (a) to be in the range of0.6210^{-6}–0.7310^{-6} m^2/s. ISOMET 2114 measurements showed a 39–53 percent decrease inWhen compared to NWC, SLWAC has a lower thermal diffusivity and a higher thermal conductivity, as well as an increased specific heat capacity of 26–35 percent. “Despite the fact thatTable1

Table1: Despite Fact

Property	Lightweightaggregates					Normalweightaggregates			
	Leca	Argex2-4	Argex3-8F	Lytag	Stalite	Finegravel	Coarsegravel	Finesand	Coarsesand
Drydensity(kg/m^3)	1076	669	597	1338	1483	2646	2683	2605	2617
Drybulkdensity(kg/m^3)	624	377	330	750	760	1309	1346	1569	1708
Absorptionat24h(%)	15.8	21.4	19.3	17.9	3.6	0.7	0.4	0.2	0.3
Granulometricfraction(d_i/D_i)[a]	4/11.2	4/8	4/11.2	4/11.2	8/16	0/8	4/11.2	0/1	0/4
Totalporosity(%)	58.9	73.1	76.1	47	43.1	–	–	–	–

[a]$d_i$and$D_i$aretheminimumandmaximumdimensionsoftheaggregatewithinthebaseseriesaccordingtoEN12620.

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3.1 Energyperformance

Energy Plus 7.1 SLWAC's impact on building energy performance is modelled in Section 4.1 using an open source Energy performance in Lisbon model. Temperature setpoints of 18 and 25 degrees Celsius were used in the numerical simulation for Lisbon for the heating and cooling phases of the experiment. From October 31 to May 11 and June 1 to September 30 respectively, average outside temperatures of 12.5°C and 21.6°C were chosen for the heating and cooling phases.

Fig. 9 In this paper, we report on the findings of our investigation into the two apartment scenarios studied (middle and top floor) and the concrete materials studied (columns, beams, and floor slabs). NWC and SLWAC showed lower heating and cooling energy consumption on the intermediate level than on top, as predicted. This is due to the top floor's increased outside surface area, which results in higher thermal gains and losses and, as a result, higher heating electricity consumption. The energy requirements for heating and cooling on the intermediate level were on average 30% and 71% lower than on the top floor.

Fig. 9That's not all: SLWAC components use less heating energy, regardless of where the apartment is located, compared to NWC elements. For SLWAC and NWC, the energy savings range from 6–11% based on the 0.9–1.3 kWh/m2 year difference. Even more interesting, it was observed that apartments with NWC and SLWAC components had just a 0.2 kWh/m2 year difference in cooling energy consumption, compared to apartments with NWC and NWC components (2 percent energy savings). As a consequence, an apartment with SLWAC components had lower annual energy usage than an apartment with NWC components.

SLWAC's reduced thermal conductivity means less heating energy is required, whereas cooling energy consumption is essentially unaffected by NWC (Fig. 9). The thermal bridging effect is minimal in Lisbon during the cooling season because of the city's reliance on solar gains rather than heat losses from buildings' exteriors.In Fig. 920 percent of the total heating energy was attributable to ther-mal bridges, according to calculations.

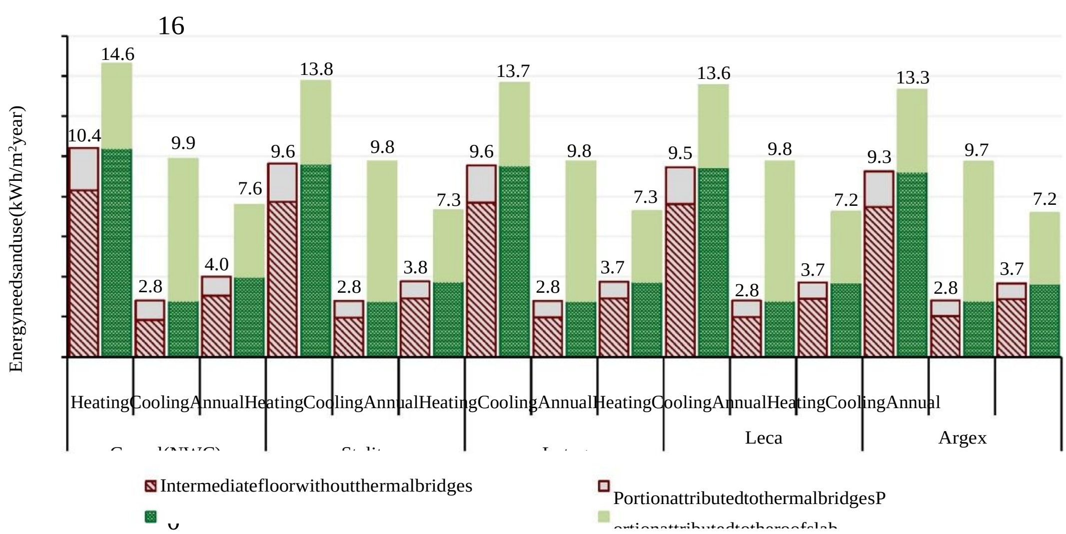

Figure:9.Apartments in Lisbon on the upper and middle levels, As well as the roof slab and thermal bridges, each space has variable heating and cooling energy needs and annual energy use.

4.Conclusions

Studies on the efficiency of SLWAC in residential structures were carried out for the purpose of this article.Laboratory experiments were used to examine the thermal characteristics of four different SLWAC kinds. Therefore, the dry thermal conductivity, diffusivity, and specific heat capacity of lightweight concrete are all lower when compared to those of heavyweight concrete. Thus, all of SLWAC's thermal insulation performance was superior to that of NWC. When compared to NWC, the thermal conductivity of SLWAC was found to be reduced by 39–53 percent, the specific heat capacity increased by 26–35 percent, and the thermal diffusivity was found to be reduced by 38–47 percent.

Therm 7.3 and EnergyPlus 7.1 A concrete-framed building with apartments on the third and fourth levels was utilised as a case study. It was shown that SLWAC might lessen the thermal bridging impact in this particular case study. As measured by EnergyPlus, thermal bridges accounted for 11–19 percent less energy in the case of SLWAC vs NWC components in a Lisbon intermediate-level apartment.

EnergyPlus studies also indicated that SLWAC may reduce heating energy consumption wherever it is installed in Europe, regardless of the weather outside. Apartments with SLWAC components used 15% more heating energy than those with NWC elements, whereas the cooling energy demands did not vary significantly between the two types of concrete. Because it decreases the permanent load and hence the thermal bridging effect and energy requirements, SLWAC outperforms NWC in terms of resource consumption in a new building, helping to lower total costs while also encouraging environmental and economic sustainability.

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