Sustainable applications of asphalt mixes with reclaimed asphalt pavement (RAP) materials: innovative and new building brick

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Abstract
This paper presents an experimental study to evaluate the effect of various percentages of RAP on the properties of asphalt mixtures. Moreover, the thermal characteristics of using asphalt mixes with RAP in asphalt concrete blocks for sustainable application in building construction was also studied. For this issue, four mixtures, which were the combination of different ratios of RAP materials viz, 0%, 30%, 60%, 90% and virgin aggregates, were studied in this research. A comprehensive experimental program was conducted to find out the highest ratio of RAP in asphalt mixes that retains an acceptable level of physical and mechanical properties. This revealed that 90% RAP has such an acceptable level. Finally, the thermal characteristics of asphalt concrete blocks for walls in building construction were analytically investigated using TAS EDSL. This software was initially validated by building a real model of walls with asphalt concrete blocks where temperature and humidity measurements were taken through data loggers for both the indoor and outdoor spaces. A comparative study was conducted to find out the energy efficient behaviour of this material in four different climate conditions. It was concluded that the asphalt concrete mixes with 90% RAP are beneficial materials for use as a thermal mass in building construction and it is suitable only for cold weathers.

Keywords: Reclaimed Asphalt Pavilion (RAP); Mixture design; sustainable buildings; Thermal Mass; application of RAP in buildings

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1 INTRODUCTION
The maintenance and rehabilitation processes for asphalt pavement revealed huge quantities of materials known as Reclaimed Asphalt Pavements (RAPs). For example, in the US, the Federal Highway Administration [1], reported that about 90 million metric tons of asphalt pavements are removed each year. On the other hand, the demand for sustainable and environmentally friendly materials has increased substantially. Recently, the pavement construction technology should be emphasized towards green technologies. Therefore, the use of RAP in the construction of new pavements has increased since it is a logical conservation of the natural resources for pavement materials. Not only that, it also contributes to reducing the cost of pavement construction. Moreover, reusing RAP materials will have a positive environmental impact since these materials are considered to be solid waste pollutants.

RAP used for aggregate substitution in asphalt concrete mixes and also used as asphalt cement supplement in hot/cold asphalt mixes. Moreover, it can be used for base/subbase and stabilized base courses or as an embankment or fill materials [2]. Statistics reported by the European Asphalt Pavement Association (EAPA) showed that 47% of the available RAP was used in hot or warm mix asphalt applications, while 22 million tonnes were used in other applications or stockpiled [3]. Moreover, in the US, a survey by the National Asphalt Pavement Association
(NAPA) estimated that a total of 71.8 million tonnes of RAP was accepted in 2011, 84% of which was used in asphalt applications [4]. It should be pointed out that there are no reported studies in the literature that show the use of RAP in building construction, for example, for blocks for walls or any other applications.

An extensive literature review was conducted on the use of RAP in pavement applications. It was found the percentage of RAP used in asphalt mixes reached up to 80% in some cases [5]. Most of the reported studies used a range of 20% to 50% like [6, 7]. In general, conflicting results were found regarding the effect of incorporating RAP into asphalt mixes in terms of properties and performance. For example, some reported studies showed the performance properties of mixes increased with the use of a certain percentage of RAP such as [8, 9], while other studies indicated that there were no significant changes in the performance of asphalt mixes which incorporated certain percentages of RAP [10]. Moreover, recycled asphalt mixes showed good resistance to moisture damage at low RAP content and the increase of RAP content has no significant effect in resistance to moisture damage as reported by [11]. On the other hand, other studies showed that resistance to moisture damage significantly decreases with the presence of RAP [12]. The stiffness of asphalt mixes with RAP was also investigated by some researchers like [9]. They found that the stiffness of asphalt mixes increases with the presence of RAP while stiffness decreased with RAP. Also, tensile strength increases with the use of RAP according to [9]. The fatigue life of asphalt mixes also exhibited conflicting results in the literature. Some studies revealed its increase with RAP like [13]. Rutting of asphalt mixes with RAP was also investigated, for example by [14] who evaluated rutting on mixes with 20% RAP. They reported that mixes with RAP exhibited lower rutting depths than virgin mixes.

Moreover, RAP can be used in paved and unpaved roadways as a granular base material. Parking areas, bicycle paths, gravel road rehabilitation, shoulders are other applications for RAP, [1]. The literature indicates that 100% RAP does not produce a base course of high quality due to its significant rate dependency and high deformation and creep [15]. Some researchers obtained high-quality base courses through blending RAP with virgin aggregates. Others used stabilizing RAP with chemical additives such as cement, lime, fly ash, etc as described by [16].

Health hazards of using of RAP materials in the construction was also surveyed through literature. Most of the reported studies investigated the hazards and safety precautions of using petroleum asphalts in the construction industry. This is due to the direct exposure of human and environment to fumes emitted through the use of petroleum asphalt. The industry of asphalt and its applications includes many stages starting from the asphalt production in the refinery processes, handling and transportation of asphalt cement, production, handling, transportation and placement of hot-mix asphalt concrete in various applications. All of these operations require heating the asphalt cement up-to certain temperature depending upon the stage, but this will lead to emission of such fumes. In concern with asphalt fumes composition, it should be highlighted that the way in which asphalts are handled during paving and roofing operations probably influence the composition of asphalt fumes and vapours. Previous studies like [17] revealed that the most marked increase in fumes formation was recorded when asphalt temperatures reached 146°C (295°F) and continued to increase to 175°C (347°F). RAP materials required reheating to temperature less 146°C (295°F) for moulding and compaction [18]. Outlined a procedure for inclusion of RAP into the hot-mix asphalt process through separate feed systems that heat the material by convection leading to much lower fumes rather than the use of virgin materials.

Many researchers and recognized authorities quantified the health hazards of asphalt (bitumen) on both human and the environment [19]. Published a report on 2004 under the joint sponsorship of the United Nations Environment Program, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Program for the Sound Management of Chemicals. This report cited the geometric mean of personal exposures for total particulates (TP) and benzene-soluble particulates (BSP) with various types of asphalt industries. TP values were ranging from 0.18 mg/m³ at asphalt refineries to 0.78 mg/m³ at asphalt mix plants while; BSP recorded an average value of 0.2 mg/m³. SHRP, 1993 is another comprehensive report that discussed the effects on human health identified through clinical and epidemiological reports and animal toxicological studies related to asphalt hazards. Another study conducted by [20] concluded that the mutagenicity of bitumen and asphalt fumes increased with the inclusion of inorganic additive like Coal Fly Ash (CFA), did not change the mutagenicity of the fumes, whereas the organic additive like waste plastics, increased the mutagenicity of the laboratory emissions significantly. It should be reported that National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) are another health authorities addressed statistics and standards for the asphalt fumes hazards.

Another important issue is related to the asphalt asbestos which was an important component in many construction projects between the 1960s and early 1980s. Asbestos fibres are water resistance, fireproof, inexpensive and easy to work with. Therefore, it was used frequently, in asphalt until 1980th. Since then, its use with asphalt had been stopped due to the deadly health consequences of using asbestos in construction. All health organizations have addressed the asbestos hazards in specific standards for example OSHA launched a specific standard for toxic and hazardous substances that are showing the problems with using asbestos in construction [21].

On the other hand, when searching for other applications for RAP, a literature survey was conducted on different available building materials to investigate the suitability of RAP materials in such applications. Many traditional materials that have been produced from natural materials were used as building materials such as clay, sand, stone, gravel, cement, bricks,
blocks, tiles, timber and steel. All these materials can damage the environment due to their continuous exploitation [22]. Moreover, different building materials have different response to climatic conditions due to their inherent properties. The thermal properties of building components such as walls, ceilings and floors together determine the energy consumption patterns and comfort conditions in an enclosed space [23].

Temperature and humidity measurements were analysed by Soofia [23]. They conducted such measurements within buildings constructed from a variety of traditional and modern materials. They concluded that the mud brick and straw bale buildings required minimum energy in production, compared to contemporary building materials. They are also more appropriate and affordable, while the main disadvantage lies in their higher maintenance requirements. Hanan [24] has examined a typical Saudi residential building as a case study. They considered energy conservation measures like improving the thermal insulation of the external walls and roofs. They identified many shortcomings common to the current design of Saudi dwellings and they put forward a number of strategies which should help towards the development of a more sustainable residential sector in Saudi Arabia. Among these strategies is the search for sustainable alternatives for building materials.

To address this issue, the current study was targeted at the investigation of sustainable applications of RAP materials in building construction especially in the construction of asphalt bricks for the walls of buildings. Therefore, a comprehensive experimental program was conducted for the evaluation of asphalt mixtures containing various RAP ratios. RAP contents of 0%, 30%, 60% and 90% were added to virgin materials to study the effect of various RAP contents and sources on the mixture properties. Moreover, the suitability for using asphalt concrete mixes incorporating RAP for bricks to be used in building construction was also investigated. Finally, the thermal characteristics of asphalt concrete blocks for walls in building construction were analytically investigated using the software, TAS EDSL. Through this a comparative study was conducted to find out the energy efficient behaviour of this material in four different climatic conditions.

2 MATERIALS CONSIDERATION

Virgin aggregates were collected from the Aljazeera company crusher in Taif, KSA. The type of aggregate was crushed basalt. Coarse aggregates of Maximum Nominal Size (MNS) 19 mm as well as quarry dust were collected from the crusher. The properties of collected natural aggregates are given in Table 1. Asphalt binder 60/70 penetration grade was acquired from the Aljazeera asphalt mix plant in Al-Hadaa Road in Taif, KSA. Table 2 summarizes the physical properties of this asphalt according to AASHTO specifications as well as the specifications of the Saudi Ministry of Municipal and Rural Affairs for construction of urban roads- Part-7. RAP was taken from Taif to Alhaweyah road. The specimen of the recycling asphalt pavement was taken by milling road about five centimetres by milling machine. Using extraction equipment, the specimen has a 5.54% of bitumen content. The gradation of the recycling aggregates is shown in Figure 1.

It is known that densely graded aggregates for the asphalt mixes offer greater area of load transfer. Moreover, the gradation that results in maximum density would offer high stability to the final mix. Therefore, theoretical gradation was used to arrive at the target gradation of the desired specifications. This generally takes the following form [25].

\[ P = 100(d/D)^n \]  

\[ P = \% \text{ Passing} \]
\[ d = \text{Size of sieve opening} \]
\[ D = \text{Largest size in gradation} \]

Four dense graded mixtures of hot mix asphalt incorporating recycled asphalt pavement percentages of 0%, 30%, 60% and

| Property | Ref. Standards Designation | Course Aggregate (CA) (19/4.75 mm) | Fine Aggregate (FA) (4.75/0.075 mm) | Mineral Filler (MF) Passing #200 |
|----------|---------------------------|----------------------------------|----------------------------------|-------------------------------|
| Specific gravity (Bulk) | AASHTO T-85 | 2.61 | 2.82 | 2.88 |
| % Absorption | AASHTO T-85 | 1.88 | 1.94 | N.A |
| Los Angeles Abrasion | AASHTO T-96 | 19.0% | N.A | N.A |
| % Passing # 200 | – | N.A | N.A | 97% |

N.A (Not Applicable).

| Criteria | Ref. Standards Designation | Spec. Limit | Results |
|----------|---------------------------|-------------|---------|
| Penetration (25°C, 0.1 mm) | AASHTO T-49 | 60–70 | 62 |
| Viscosity at (135°C, Centi stock) | AASHTO T-201 | 200 (min.) | 316 |
| Flash Point (°C) | AASHTO T-48 | 232 (min.) | 271 |
| Ductility (25°C, cm) | AASHTO T-51 | 100 (min.) | 124 |
| Specific Gravity (Bulk) | AASHTO T-228 | – | 1.05 |
90% were designed based on the specifications of the Saudi Ministry of Municipal and Rural Affairs for the construction of urban roads- Part-7. The four mixes were designated as M0, M30, M60 and M90 representing the incorporated RAP ratio. The upper and lower limits of desired gradation were chosen as type-C of the specified specifications which is used for local roads with low traffic volumes as presented in Table 3.

3 EXPERIMENTAL TESTING PROGRAM

3.1 Marshal test
A mixed design was performed using the Marshal method by preparing and compacting 15 different samples with asphalt content varying in 0.5% increments (3 samples for each asphalt content) according to the AASHTO T-245 test method. This test was conducted to find out the Optimum Asphalt Content (OAC) and the corresponding properties like stability, flow, Air Voids (AV), Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA) and unit weight. Marshal graphs were plotted for each property and, also, the trend with RAP ratio was also determined.

3.2 Indirect tensile strength test
The problems associated with cracking have motivated the pavement engineers to study the tensile properties of asphalt mixes. For this concern, the indirect tensile strength test (IDT) was used to determine the tensile properties of asphalt mixes which can further be related to the cracking properties of the pavement. Marshal specimens were loaded at a constant rate by a compressive load acting parallel to and along the vertical diametrical plane of the specimen through two opposite loading strips to evaluate the tensile characteristics of asphalt mixes. Through this loading configuration, a uniform tensile stress will be developed perpendicular to the direction of the applied load and along the vertical diametrical plane. This will cause a failure of the tested specimen by splitting along the vertical diameter. The peak load was recorded and divided by appropriate geometrical factors to obtain the split tensile strength using Equation (2) [13].

\[
\text{ITS} = \frac{2000 \times P}{\pi \times H \times D}
\]

where:
- ITS = The indirect tensile strength (kPa)
- P = The maximum load to failure (N)
- H = The specimen thickness (mm)
- D = The specimen diameter (mm)

This test was conducted for all investigated mixes to find out their tensile properties to help in selecting the optimum RAP ratio to be added to the virgin materials of asphalt mixes.

3.3 Loss of stability test
The resistance of asphalt mixes to moisture damage has to be evaluated to measure the durability of these mixes especially with RAP incorporation. This was achieved for all investigated mixes by conducting a loss of stability test which is a simplified version of AASHTO-T165. The specimens of all investigated mixes were cured by immersion in water of 60°C for two different periods of time viz, 0.5 and 24 hrs. The reduced stability (compressive strength) was obtained for all investigated mixes to further judge the effect of RAP ratio on this criterion.
4 RESULTS AND DISCUSSIONS

The mechanical properties of different investigated asphalt mixes were determined through Marshal Tests. The effect of RAP content was studied and analysed based upon these properties as well as the indirect tensile strength and loss of stability. This will be illustrated in the following paragraphs. Air voids are an important factor that must be considered in the design of asphalt concrete mixes. The acceptable level ranges from 3% to 5%. Figure 2 shows the determined air voids for all investigated mixes. The increase in RAP content leads to an increase in air voids but all revealed air voids are within the acceptable limits even for 90% RAP content. On the other hand, as air voids increase with the increase in RAP content, unit weight of the mix decreases as shown in Figure 3. The flow of an asphalt mix is an indication of its resistance to permanent deformation. The results show that flow values decrease with the increase in RAP content, but all are within the permissible level as presented in Figure 4. On the other hand, stability decreases with the increase in RAP content from 0% to 60% but it suddenly increased at RAP content of 90% as given in Figure 5. This may be related to the existence of aggregate mass from the 90% RAP which exhibited more militancy, i.e., it becomes more solid under pressure. It should be pointed out that all achieved values of stability reached the minimum acceptable value.

Table 4 shows the voids in mineral aggregates (VMAs) for all investigated mixes, i.e. for various RAP contents. It was discovered that VMAs increase as the RAP content increases. The reason for that may be related to the prevention of new asphalt from occupying the pores of aggregates that occupied by the ineffective old asphalt. On the other hand, voids filled with asphalt (VFA) do not show a definite trend. VFA increased with RAP content of 30% and decreased with the increase of RAP content as shown in Table 4. It should be pointed out that both VMA and VFA values are within the permissible levels as per the Saudi Code of Practice.

With regard to indirect tensile strength, Figure 6 shows the variation of indirect tensile strength (ITS) with the variation of RAP content. It is clear that RAP incorporation in asphalt mixes enhanced the ITS values in comparison with the control mix (0% RAP). It should be pointed out that mixes containing 60% RAP achieved the highest values for ITS. The results for the loss of stability test are presented in Table 5; it is obvious that the increase in RAP materials in the asphalt mix leads to an increase in the loss of stability ratio. This is quite expected since VMAs increased with the RAP content and so resistance
to moisture damage decreased. It should be highlighted that the maximum loss of stability was achieved at RAP content of 90% but it was still within allowable limits. The revealed Marshal properties, indirect tensile strengths and loss of stability for all investigated mixes were considered for selection of the optimum RAP ratio to be considered for further applications. All properties met the targeted mix of type 4 C as per the Saudi Code of Practice which is positive in allowing flexibility in choosing suitable RAP content depending upon the targeted applications. For example, if RAP is to be used in an asphalt mix in roads with low traffic, an RAP content of 60% would be most suitable since its cost would be less. On the other hand, when searching for applications for asphalt mixes with RAP, a content of 90% RAP would be the best choice. Therefore, a RAP content of 90% was selected for further investigation in the present study.

The findings of hazard review conducted by [26] suggest that humans have not provided consistent evidence of carcino-genic effects in workers exposed to asphalt fumes during paving operations. Also, no animal studies have examined the carcino-genic potential of either field- or laboratory-generated samples of paving asphalt fume condensates. The results from epidemiologic studies conducted through this report showed uncertainty of exposure of workers of asphalt roofing to cancer. For the present study, the proposed RAP blocks were not raw asphalt, nor chemical materials. These materials were asbestos free therefore, the negative hazards of asbestos will not be predicted. On the other hand, the RAP materials required for preparing the blocks were reheated to temperature less 146°C (295°F) for moulding and compaction to have lower expected fumes than those expected with virgin materials by using the followed standards for such issue as recommended by [18]. In addition to the illustrated issues related to the expected health hazards with RAP blocks, the RAP blocks in the present study were proposed for use in the walls’ construction only that will be protected more with the finishing materials of such walls.

### Table 5. Loss of stability test results

| RAP content (%) | % Loss of stability |
|-----------------|---------------------|
| 0               | 9.8                 |
| 30              | 12.5                |
| 60              | 17.6                |
| 90              | 22.9                |

The thermal performance of asphalt concrete blocks for building construction is an essential factor for classifying the use of RAP in building construction as a sustainable alternative. To compare its environmental performance, temperature and humidity, measurements should be taken in a real wall of a building constructed using such material or it could be evaluated based on computer simulations. This had already been done by using the TAS EDSL computer code for such a scenario.

### 4.1 Validation of TAS EDSL and research methodology

TAS EDSL is considered one of the most powerful and accurate tools for predicting building energy performance; therefore, many researchers used it to conduct analysis of building energy efficiency such as [27–30]. The analysis through this software consists of three stages related to each other. The first stage includes the shape of the building and the choice of places and dimensions of the windows and doors and the introduction of the waypoints. The second stage includes entering the details of the thermal maps for the site of the building and materials used in construction and the choice of the number of days required to know the thermal distribution and entering each element issued such temperature (fridge or lap-top) or similar. The third stage provides results which may reveal number of curves representing energy levels inside and outside the analysed model. Figure 7 shows the Process and flow of TAS EDSL.

Since this research deals with a novel and innovative investigation, namely applying asphalt blocks to external building walls as a thermal mass technique, it has to carry out exceptional validation. In order to do this, a model of a building with complete components was designed and constructed. The building components were selected to simulate the actual conditions of real life which included four external walls constructed from asphalt concrete incorporating 90% RAP, reinforced concrete slab as a ceiling and a marble floor. The model dimensions were 70 cm×70 cm×40 cm as given in Figure 8. The asphalt blocks were designed and fully prepared in Taif University labs (Figure 17). It should be pointed out that four concrete columns were constructed in each corner and the model was covered with a 5 cm reinforced concrete slab in order to simulate the model in reality. The model was oriented towards the south. In addition, two data loggers were fixed inside the constructed model and another one was fixed outside for measurements of the indoor and outdoor temperatures.
The same model dimensions were built in TAS EDSL along with the same building material characteristics shown in Table 6. Since outdoor temperature will vary in terms of actual and predicted values derived from TAS EDSL’s database weather file, the actual outdoor temperature was recorded using different data loggers in order to replace the results with the predicted ones in TAS. The indoor and outdoor temperature measurements were recorded for 6 entire days. Figure 9 shows the outdoor and indoor air temperatures (OAT & IAT) derived from data loggers. Also, Figure 10 indicates the mismatch between the actual and predicted values.

Table 6. Material features of building envelope developed by TAS EDSL.

| Layers          | Thickness (cm) | Conductivity (W/m²°C) | Total U value (W/m²°C) |
|-----------------|----------------|-----------------------|------------------------|
| External wall   |                |                       |                        |
| Asphalt        | 10             | 0.60                  | 2.97                   |
| Ground         |                |                       |                        |
| Sand           | 25             | 0.52                  | 1.27                   |
| Slab           | 10             | 1.4                   |                        |
| Marble         | 5              | 0.5                   | 1.27                   |
| Roof           |                |                       |                        |
| Reinforced concrete | 5      | 0.41                  | 3.70                   |

Figure 8. Investigated model for TAS-validation. (a) is the 3D model, (b) is the plan side and (c) is a view of the actual model.

Figure 9. Outdoor and indoor air temperatures derived from data loggers.
between the actual recorded outdoor temperature and the predicted one which was derived from the TAS database. In conclusion, Figure 11 shows an acceptable accuracy between actual and predicted tools. This ensures a high level of accuracy with regard to obtained results. As a result, TAS EDSL can be utilized to carry out further investigations for this research.

4.2 Analytical study of the effectiveness of asphalt concrete mix blocks as a thermal mass

After validation of computer modelling, a new model design for a domestic building was developed to be used in the selected sites globally to study the effectiveness of Asphalt Concrete Mix Blocks (ACMBs) as a thermal mass in building construction. Figure 12 introduces a plan for the designed model for a domestic building.

Four different cities were selected with varying climatic conditions. The selected cities were Riyadh in KSA, Kuala Lumpur in Malaysia, Rome in Italy and Moscow in Russia. These selected sites represent different climatic conditions varying from in terms of hotter and colder weather and also varying in their summer and winter season conditions. Simulations were conducted for one day in winter and another in summer for all the four investigated cities. The predicted temperature of the four faces of the building in all geographical directions was collected as well as the outdoor air temperature. All of these results were compared and presented in Figures 13–16.

Based upon these figures, it should be noted that it was assumed that ACMBs are expected to work better in cooler regions. This is due to the physical characteristics of their material. For instance, in a hot and dry region like Riyadh (Figure 13), ACMBs were responsible in the rooms facing south and east for a rise of more than 6°C at peak times. This rise is in comparison with the outdoor temperature. However, for rooms facing north and east, the rise was in the acceptable range (1.5–2.0°C) which is enough to bring the indoor temperature closer to comfort level in winter. On the other hand, as the outdoor temperature in Riyadh rises significantly, ACMBs had a remarkable impact on all spaces within the building design; hence, this technique should be avoided in summer completely. Moreover, shading can be used for south and east facing zones as well as in summer in order to utilize the benefit of this mechanism.
Since tropical regions have an almost identical climate in both summer and winter, the pattern of the impact of ACMBs was almost the same seasonally. In addition to that, it can be seen that the ACMB method cannot be used in such regions. This is because of the limited outdoor temperature swing between daytime and night as in Kuala Lumpur (Figure 14). Tropical regions do not require any sort of thermal mass; they rather require natural ventilation in order to release excessive heat and moisture from indoors. In a moderate climate as in Rome (Figure 15), it was observed that an ACMB system is not appropriate due to the limited amount of solar radiation in winter which is not enough to bring the indoor air temperature to a more comfortable level while in summer the major amount of solar radiation was responsible for excessive increases in indoor temperature (Figure 15). This amount of solar radiation raised indoor temperatures by almost 10°C. Taking into account the previous discussion, it can be revealed that the ACMB technique is not recommended in tropical and moderate climates; however, it might be utilized in hot regions with some modifications to building design.

On the other hand, it seems that this technique works perfectly in colder regions like Moscow. This is due to the limited amount of solar radiation in both summer and winter. In winter, the ACMB system managed to bring the indoor temperature in all zone directions closer to above the freezing limit (Figure 16), particularly in south and east facing directions.
which are popular for their intensive amount of solar radiation. South and east facing directions which tend to be avoided in hot and moderate regions seem very promising in cold regions as can be seen in Figure 16. Owing to the direct solar gain on the outer surface of ACMBs on these walls, an increase of 5°C occurred. Considering the summer performance, although the amount of outdoor solar radiation is limited in this region, there was a massive rise in the indoor temperature. This is because of the low angle of solar radiation on the external walls which was responsible for a huge increase in the indoor temperature. As a result, direct solar gain should be avoided in summer especially in south and east directions (Figure 17).

5 CONCLUSION

The research has presented an experimental work in order to evaluate the impact of various percentages of RAP on asphalt mixtures. The physical characteristics of using the model with RAP in asphalt concrete blocks in building application were also investigated. This can be stated as a new method to be applied into sustainable building construction. The research used multi methods to ensure high quality of results. The following outcomes and recommendations can be stated out of the research:

- Adding RAP to asphalt mixes affects their mechanical properties but all of these properties were within the allowable specifications.
- The air voids increase with the increase of RAP content and, simultaneously, bulk specific gravity decreases.
- Stability of asphalt mixes decreases with the increase in RAP content up to 60%; however, it increases at 90% RAP content. This is due to an increase in flow values with the increase in RAP content.
- The new asphalt is prevented from occupying the pores of aggregates due to the presence of ineffective old asphalt. Therefore, VMAs increase with the increase in RAP content.
- The presence of RAP in an asphalt mix improves its indirect tensile strength where the highest value was achieved at 60% RAP content.
- Incorporation of RAP asphalt mixes revealed a reduction in its stability increasing with the increase in RAP content.
- For applications of RAP in asphalt mixes in low volume roads, RAP content of 60% looks to be the most suitable for such applications. However, for applications of RAP in asphalt mixes for buildings, a 90% RAP content is more suitable.
- ACMBs had a remarkable impact on all spaces within the building design; hence, this technique might be utilized in hot regions with some modifications to building design.
- The pattern of impact of ACMBs in tropical regions shows identical behaviour in summer and winter. This is because tropical regions do not require any sort of thermal mass; they rather require natural ventilation in order to release excessive heat and moisture from indoors.
- In moderate climates the ACMB system is not appropriate due to the limited amount of solar radiation in winter which

Figure 16. Indoor and outdoor temperatures in Moscow (winter and summer).

Figure 17. A) Preparation of Asphalt Blocks for Building the Verification Model. B) Extraction of Asphalt Blocks for Building the Verification Model. C) Conditioning of Asphalt Blocks. D) Prepared Asphalt Blocks for Building the Verification Model.
is not enough to bring the indoor air temperature up to a more comfortable level.
• The ACMB technique works perfectly in colder regions like Moscow. This is due to the limited amount of solar radiation in both summer and winter.
• Construction of walls with RAP blocks has to be further investigated in future to work as sandwich in between two concrete walls for more safety in terms of asphalt fumes emission with high temperatures and to search for better thermal comfort with sustainable alternatives. It is proposed to search this with thin layers (5 cm thick. each).

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