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# Effect of Using Roof Structure as a Solar Collector for Space Heating

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## ABSTRACT

*The conservative roof structure in Iraq was operated to collect solar radiation for housing space heating. This technique included painting the external roof surface with high absorptive paints and covering it by insulated glass 10 mm air space. An air gap of 10 cm was left between the roof surface and glass. By employed the roof as a solar collector called roof solar collector in the present work RSC and is used mainly for northern oriented spaces of the building. The suitable sun altitude angle and relatively high solar intensity in Iraq compared with European regions in winter months make RSC suitable for Iraqi residences. The test room measures 3.2 m x 3.1 m x 2.87 m in Baghdad city/Iraq (33° 19' N, 44° 25' E). The roof is constructed of 4 cm cement Shtyger as a roofing material, 5 cm soft sand, 5mm of felt and membrane, 10 cm h.w. concrete and 1 cm finish. Temperature measurements were done using LM 35 thermistors with data acquisitioned. The results obtained showed a reasonable increase in indoor temperature by using roof solar collector. The maximum averages indoor temperature using roof solar collector were reached the comfort level for all winter months while the minimum averages were slightly decreased below the comfort level. The monthly average energy saving using roof solar collector was reached 213kW/Hr.*

**Keywords**: Solar roof heating, Flat plate collector, Passive domestic heating, Concrete core condition

## INTRODUCTION

A great amount of energy consumption arises in buildings due to space heating, cooling. For this reason, it is important to decrease the energy consumption and its environmental risks. It is also important to use clean, limitless and emission free energy as energy source in order to provide energy effectiveness and conservation. Solar energy is one that utilized in residential applications for sustainability. A proper structure element needs to be modulated for utilizing solar energy in passive way and to decrease energy loss. By using passive solar devices in the architectural design, the energy demands of building can be reduced. Formerly, people have used thick walls and roofs of adobe or stone to capture the solar radiation during the daytime and release it slowly and evenly at night into the space [1]. A new trend in space heating for residential applications in Iraq by manipulation of the roof structure was investigated in the present work. This is accomplished by investing the roof structure to act as a solar collector. The heat stored in the roof structure is re-radiated into the space at night due to time lag. The solar thermal roofing was defined as solar collection equipment for the building roof such that the equipment performs the function of a roof and collects solar energy at the same time [2]. Solar roof concept was used by many workers with different concepts and arrangements. Roofs area can be invested for domestic air heating by using fins or corrugated surfaces as solar collectors [1]. Different modifications are applied to improve the heat transfer rate between the absorber plate and the air. V-grooved absorbers extended on roof are one of these modifications [2]. The horizontal corrugated V-groove absorber enhances the heat transfer characteristics of the absorber plate. A passive method was evaluated to use the solar radiation to induce outdoor air for residence in tropical regions for cooling load reduction. They indicated that solar radiation can be exploited in a low-cost way by adaptation of the constructive method [3]. Heat flow in a solar roof collector which is driven by natural convection was simulated using Boussinesq approximation by modeling air density variation. Four different air gap heights were used for simulation, namely 7 cm, 14cm, 21cm and 28 cm for a 2 m collector length[4].

The solar roof term was used for building integrated photovoltaic (BIPV), and roof structure is suitable to integrate PV into these buildings. This allows for a roof to produce electricity for the occupants of the building[5].

Another concept of solar roof called solar roof pond was described. It is often called a thermal storage roofs that are similar to storage wall. In this arrangement a waterbed (like bag) of water, exposed to sunlight that is collected, stored and distributed heat. The heat transmitted by free convection down through the ceiling to the space to be conditioned and gently warming it. Basically, solar roof pond is 20 to 30 cm deep. Roof pond is always flat, but in northern Europe buildings windows are often sloped to the south to capture the sun direct beams and to eliminate snow formation [6]. Many workers studied the different types of solar roof pond. They a recovered and uncovered with or without spraying, energy roof (water bags within roof), cool pool (open pond covered by tilted louvers), cool roof (with floating insulation), moveable pond with night water circulation (with embedded insulation), wet gunny bags (with a floating cloth) and ventilated solar roof pond [7].

During literature surveying of using the roof structure as a solar collector where the solar radiation is absorbed by the roof structure and re-radiated into the space has not been investigated yet. This is because that most European and US buildings are with roofs of low thermal mass. Moreover, the sun has with low altitude angle compared with that in Middle East region. However, the wall structure was used as a solar collector instead of roof in these regions. The technique proposed by Felix Trombe was used for passive heating in Europe and US buildings [8]. This is called Trombe wall. The trend of using roof structure as a solar collector (called roof solar collector RSC) in the present work is the same as the Trombe wall concept but for roof structure. Trombe wall is applicable for south oriented walls in houses of rural areas. The aim of this work is to exploit roof construction to act as a solar collector to decrease space heating load and energy consumption.

### The Working Principle of the Roof Solar Collector RSC

Roof solar collector, as an effective domestic passive solar heating system is exploited the roof structure to store solar radiation at daytime and released into the room during night. Its applications are simple and economical, are suitable for building of high roof thermal mass, and located in a relatively high altitude solar angle locations. A typical RSC involves a massive thermal roof with a clear outer glazing and a convective air gap in between. The massive thermal roof serves in harnessing and storing solar energy. Sunlight passing the glass is absorbed by the dark surface, stored in the roof and conducted slowly and evenly inward through the massive roof with a time lag. The stored heat loss to the

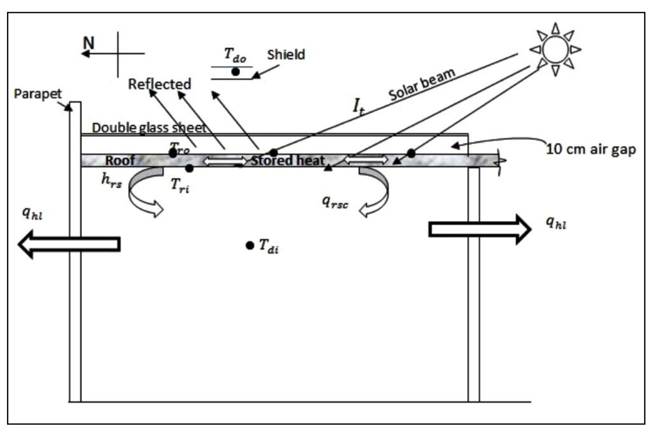


**Figure 1: A Sectional View of the Test Room with Roof Solar Collector and Temperature Measurement Locations**

surrounding during night is reduced by using double glass sheets [9]. Figure 1 shows the roof solar collector RSC concept and the heat transfer mechanism. Roof solar collector is applicable for spaces located at the north side of the building to avoid south parapet effect which is considered as a shade to the direct sun beam or used for buildings with exposed roof. RSC technique has a negative effect during summer time so, RSC should be removed by glass cover dismantling and paint removal or by covering RSC with white color sheet.

## Typical Roof Construction in Iraq

The conventional roofs in Iraq are horizontally oriented and differ in structure from region to another. While roofs are constructed from 10 cm adobe as a roofing material in south of Iraq, 4 cm cement Shtyger is the main roofing material in middle and north regions. The main roofing material is constructed from 10, 15 or 20 cm heavy weight concrete or 12 cm common brick. The thermal mass of the roof construction in Iraq is high enough to store and re-radiate solar energy. Table 1 shows the typical roof construction in Iraq and its overall coefficient of heat transfer and their thermal capacity [10].

## Experimental Work

The test room that used in the present work is a part of a residential building located at Baghdad city/Iraq (33° 19' N, 44° 25' E) and measured 3.2m x 3.1m x 2.87 m. The test room is occupied the north part of the second floor [11] of the building. Roof solar collector is applicable for the north oriented rooms to avoid the shadow effect created by the parapet structure. The roof is constructed of 4 cm cement Shtyger as a roofing material, 5 cm soft sand, 1 cm of felt and membrane, 10 cm h. w. concrete and 1 cm finish. The outer surface of the roof was painted dark black in order to get an absorbent surface. The paints used can be removed easily to perform the performance comparison with and without RSC. This was done by dust scattering on the paint. However, water type paint was used which can be removed easily. Double sheet glass with 10 mm air space are covered the roof with 10 cm air gap. The glass cover short wave absorbance, emmitance and transmittance are 0.065, 0.945 and 0.915 respectively. Walls are constructed of 24 cm common brick finished by 1 cm cement plaster on both sides. 4 mm single glass window 1.5 m x 1 m is located at the north wall of the room. The internal wooden door 2 m x 1 m is located at the west wall. Figure 2 shows a plan view of the test room.

Two persons were assumed to occupy the space doing light works. The number of air change due to infiltration was taken as 0.5 because only window located at one side of the room. The adjacent spaces were considered to be conditioned. Temperature measurements were achieved by using six thermostat type LM35 to measure the outdoor dry bulb temperature $T_{do}$, indoor dry bulb temperature $T_{di}$, roof external surface $T_{ro}$ and roof

**Table 1: Convectional Roof Construction in Iraq[10]**

| Roof structure | Mass per unit area kg k/m$^2$ | U-valueK W/m$^2$ | Thermal capacity kJ/m$^2$K |
|---|---|---|---|
| External air conductance 4 cm of cement Shtyger +5cm of sand +1 cm of felt and membrane +10 cm of high density concrete + internal air conductance | 531 | 1.81 | 449 |
| External air conductance +4 cm of cement Shtyger +5 cm of sand +1 cm of felt and membrane +15 cm of high density concrete + internal air conductance | 655 | 1.76 | 554 |
| External air conductance +4 cm of cement Shtyger +12 cm of sand +1 cm of felt and membrane +20 cm of high density concrete + internal air conductance | 768 | 1.69 | 723 |
| External air conductance +10 cm of adobe straw mixture +1 cm of felt and membrane +150 cm of high density concrete + internal air conductance | 1123 | 0.65 | 1330 |
| External air conductance +10 cm of adobe straw mixture +1 cm of felt and membrane +12 cm common brick + internal air conductance | 958 | 0.76 | 1046 |

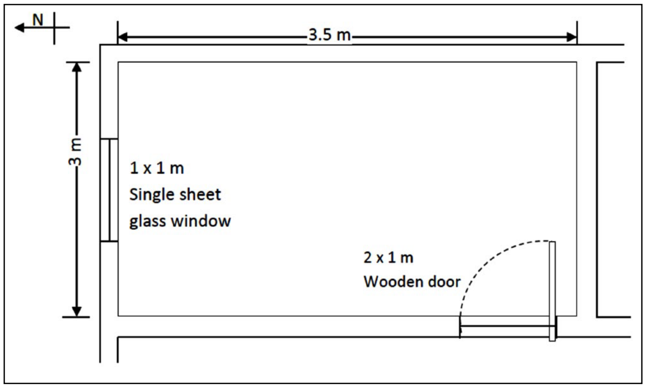


**Figure 2: A Plan View of the Test Room**

internal surface $T_{ri}$. There are three thermistors were used to measure the external roof surface while there is one thermostat for the other temperature measurements. A data logger type Labjack-UL3 was used. Thermostat readings were calibrated using two points method. Solar intensity incident on a horizontal surface was evaluated using tables in reference [11].

Figure 3 shows the solar intensity that incident on a horizontal surface in Baghdad city.

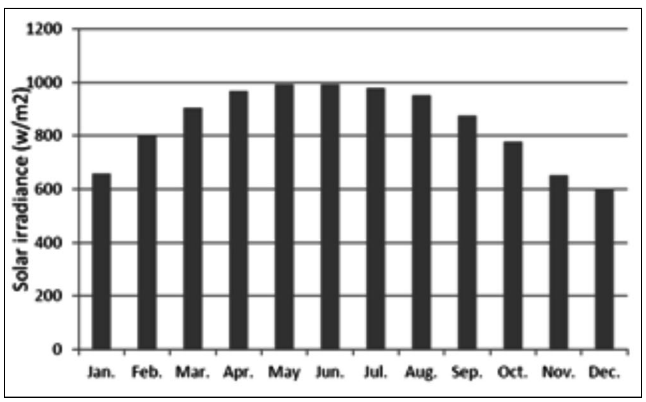


**Figure 3: Monthly Average Solar Intensity that Incident on A Horizontal Surface in Baghdad [11]**

Test room heating load was calculated using RTS method where periodic response factors PRF were determined using PRF/RTF Generator software. Figure 4 shows the hourly heating load on 4 January 2015 and the outdoor temperature while Figure 5 shows the sunshine duration for many cities in Iraq on 4 January [12]. Figure 6 shows a photograph of the test room roof covered by a glass sheets.

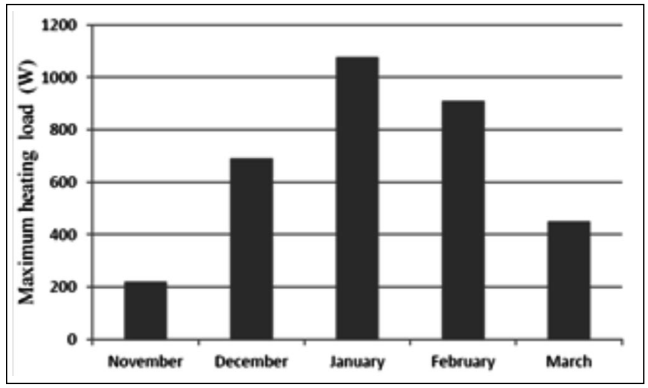


**Figure 4: Monthly Maximum Heating Load of the Test Room**

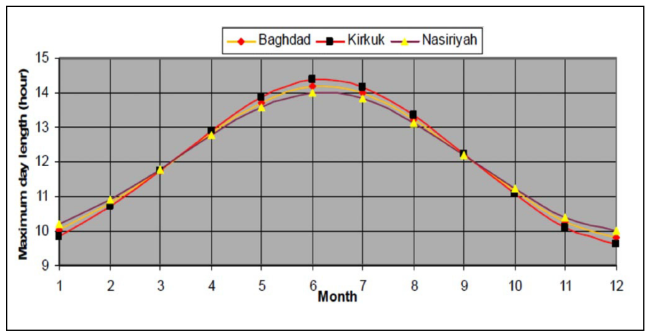


**Figure 5: Maximum Sunshine Duration in Hours for many Iraq Cities [12]**

**Figure 6: A Photograph from Test Room**

## MATHMATICAL ANALYSIS

The space heating load $q_{hl}$ represents the heat transmitted through the roof and external walls. The heat extracted from the space by the roof structure when acts as a solar collector $q_{rsc}$ is transmitted to the space by natural convection. Heating load can be calculated for any surfaces as;

$$q_{hl} = \sum_{s=1}^{n} \quad U_r A_r \ (T_{di} - T_{do}) \ \ldots.(1)$$

and, $q_{rsc} = h_{rs} A_r (T_{ri} - T_{di}) \quad \ldots.(2)$

Where

$T_{di}$ and $T_{do}$ are indoor and outdoor dry bulb temperatures respectively (°C),

$U_r$ is roof overall heat transfer coefficient (W/m$^2$. °C),

$h_{rs}$ is the heat transfer coefficient between the roof and space (W/m$^2$. °C),

$T_{ri}$ is the roof inner surface temperature and (°C),

$A_r$ is roof area ($m^2$).

The total solar irradiance $I_{th}$ that strike horizontal surface at any time is calculated as [13];

$I_{th} = I_{DN}$ (sin a + C) …… (3)

In addition, for horizontal solar collectors:

$\beta = 0$, Y=1 and $\cos\theta = \sin\alpha$

Where; β is the tilt angle of the roof, Y is the ratio of the sky diffuse on any surface to that of horizontal surface and θ is the angle of incidence.

Where, $I_{DN}$ is the direct normal solar intensity for day number $N$ and α is solar altitude.

$$I_{DN} = A/e^{\frac{B}{\sin\alpha}} \quad \ldots.. (4)$$

$$A = 1158[1 + 0.066 \cos\frac{360\ N}{370}] \quad \ldots. (5)$$

$$B = 0.175[1 - 0.2\cos(0.93N) - 0.0045(1 - \cos(1.86N)] \ \ldots (6)$$

$$C = 0.0965\left[1 - 0.42\cos\frac{360\ N}{370}\right] - 0.0075[1 - \cos(1.95N)] \ldots..(7)$$

Where C is a dimensionless value that represents the average ratio of diffuse to direct normal radiation.

Roof solar collector efficiency is calculated as;

$h_{rsc} = q_{rsc}/I_{th}.A_r$……(8)

Where, $A_r$ is the roof area (m$^2$).

Energy saving in kW.hr/day = $\sum_{j=1}^{24}(q_{rsc})j$ …… (9)

The daily energy required to maintain the space within comfort level (auxiliary energy) is calculated as the amount of the total heating load that exceeded the energy extracted from the space by RSC at that day. In equation form;

Auxiliary energy demand/day = $\sum_{j=1}^{24}(q_{hl})j - \sum_{j=1}^{24}(q_{rsc})j$ ….(10)

Space comfort condition was estimated considering clothing index in Iraq and activity level of occupants. Although ASHRAE [14] considered the comfort temperature within a space for residential applications is 20-23.5°C for clothing index of clo = 0.3-1.2, people clothing at Baghdad city is estimated at clo = 1.8. Therefore, heating indoor comfort conditions can be reduced to 18-22°C.

## RESULTS

Typical temperature measurements for 21 December were shown in Figure 7. The indoor temperature fluctuation was minimized compared with outdoor due to the [15,16] roof thermal storage.

From Figure 7, it was noted that the indoor temperature can be estimated according to the roof internal surface temperature as;

$T_{di} = T_{ri} - 5$, …….. (11)

This is applicable for other winter months.

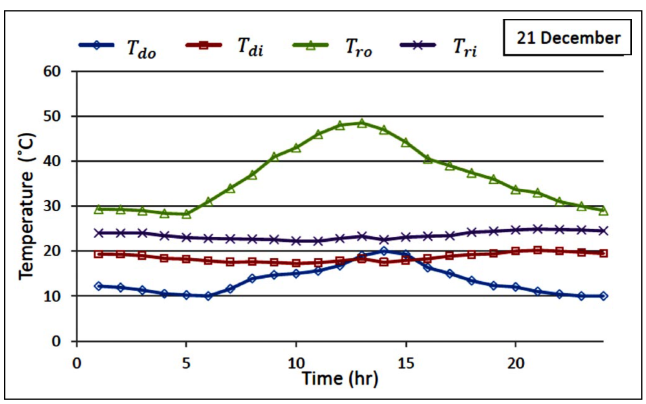


**Figure 7: Typical Temperature Sensors Measurements**

A comparison was made for the indoor temperature with and without RSC for 21 January and 23 January respectively. It was noted that there is a significant increase in indoor temperature with RSC as shown in Figure 8.

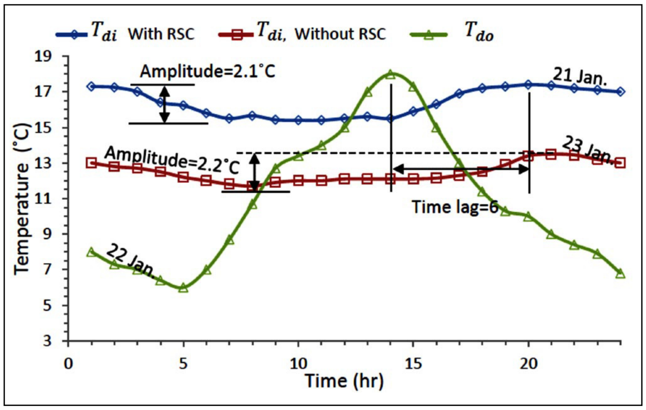


**Figure 8: Indoor Temperature with and without RSC Compared with Outdoor Temperature**

Moreover, the time lag of indoor temperature was 6 hours compared with outdoor temperature for both. Temperature amplitude of indoor temperature was noted decreased significantly compared with outdoor one. Amplitude attenuation ratio which is the ratio between temperature amplitude of outdoor to indoor temperatures found 0.83. The time lag and amplitude implementation ratio affected mainly by structure thermal storage. However, the indoor temperature doesn't reach the comfort level for most time due to the high heating load during January. Figure 9 shows the maximum and

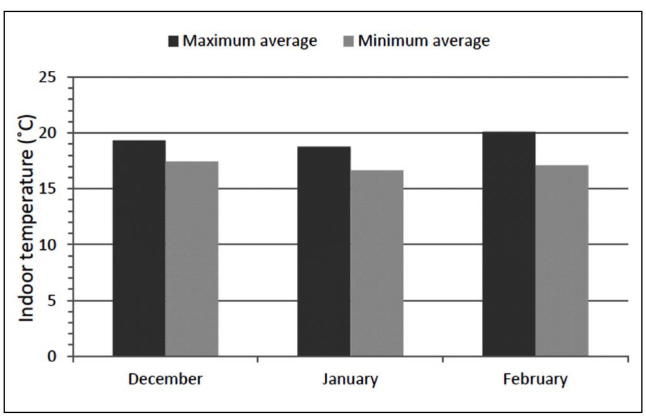


**Figure 9: Maximum and Minimum Monthly average Indoor Temperatures Using RSC**

minimum averages of the indoor temperature for winter months (December, January and February).

The maximum averages of the indoor temperature were within comfort level for all winter months while the minimum averages were slightly decreased below the comfort level.

The space heating load with and without RSC were shown in Figure 10.

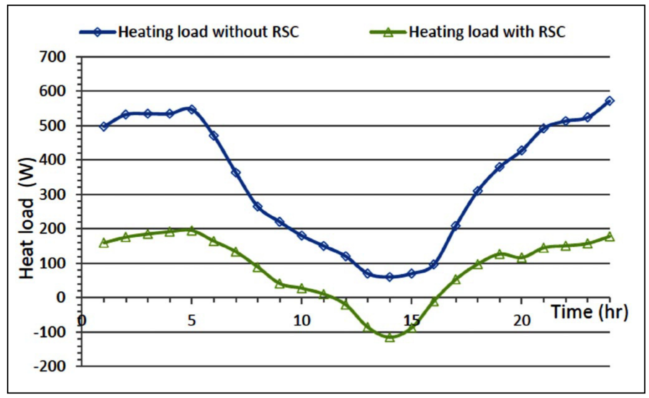


**Figure 10: Heating load with and without RSC**

Heating loads have minus sign during noon time because the indoor temperature is larger than outdoor temperature. There is a significant decrease in space heating load with RSC. The heat extracted from the space by the RSC can be increased further by using a ceiling fan to increase the heat transfer coefficient by convection. Space heating load with RSC can be removed using essential internal sources. A domestic refrigerator and laptop computer can complement the space heating load elimination with RSC. The contribution of RSC system in removing space heating load is called contribution percent CP that is defined as the ratio of the room total heat extraction to the total heating load for a defined period. The monthly average of CP for the RSC system and its energy savings during winter months are shown in Figure 11.

It is clear from Figure 11 that CP is high for December and February while it is relatively low for January. According to the definition of CP, this factor can be considered as the percentage of monthly energy savings

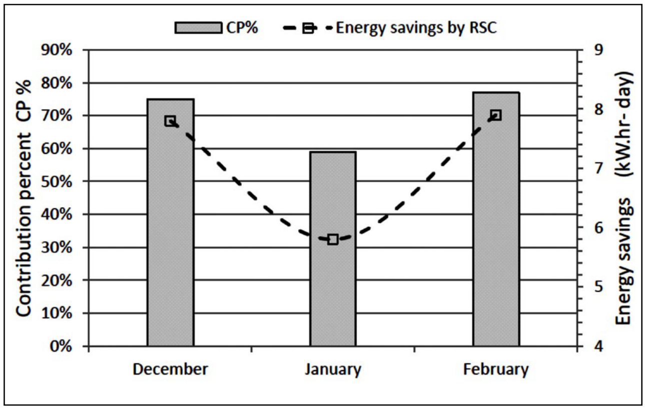


**Figure 11: Contribution Percent CP of RSC and RSC Monthly Average Energy Savings**

by RSC. Moreover, the monthly average energy saving with RSC is high for December and February and low for January. From Figure 11, it is obvious that the daily average energy saving is 7.1 kW.hr and consequently the monthly average energy saving is 213 kW/hr. The energy needed by the auxiliary energy source to reach comfort conditions with RSC can be calculated by the area under heating load with RSC curve in Figure 11. The daily average auxiliary energy demand with RSC found 2.95 kW/Hr and so the monthly average of auxiliary energy demand is 88.5 kW/Hr Also, the operation time of auxiliary unit used for complement heating load elimination is 12:00 a.m. – 11:30 a.m. and 4:00 p.m. – 12:00 p.m. according to Figure 11.

## CONCLUSIONS

The following conclusions can be inferred from the present work:

- The roof solar collector RSC can be used for residential space heating in Iraq.
- There was a significant increase in indoor temperature with RSC.
- There was a high percentage of contribution in decreasing the heating load with RSC.
- There was a considerable energy saving with RSC.
- A considerable amount of auxiliary energy should be used to complement elimination of heating load with RSC.

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