Several aspects of solar buildings towards sustainability: the massive wall, green energy, and early environmental education

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Abstract

In this study, several aspects of solar buildings and their importance to the environment is highlighted: 1) Energy savings and reduction of pollution, 2) Control of the external temperature variations, with the goal of reducing their effect on internal temperatures via massive walls, 3) Trombe wall performance, as compared to prism walls. Finally, educational activities about this topic designed for the kindergarten framework were developed and demonstrated. In order to increase awareness of the subject, educational activities suitable for kindergarten are developed and implemented.

Keywords: Environmental education, solar energy, kindergarten.

Resumen

En este estudio, se destacan varios aspectos de edificios solares y su importancia para el medio ambiente: 1) Ahorro de energía y reducción de la contaminación, 2) el control de las variaciones de la temperatura exterior, con el objetivo de reducir su efecto sobre la temperatura interna a través de enormes muros, 3) Rendimiento de muro Trombe, en comparación con las paredes del prisma. Por último, se han desarrollado y demostrado actividades educativas sobre este tema en un marco de referencia de jardín de niños. Con el fin de aumentar la conciencia sobre el tema, se desarrollan e implementan las actividades educativas adecuadas para el kindergarten.

Palabras clave: Educación ambiental, energía solar, jardín de niños.

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I. INTRODUCTION

Among the features that make solar buildings attractive are the heating system, by which a house is heated primarily by passive solar gain, as well as from the heat load generated by the people, everyday appliances, and electrical equipment inside it. The housing structure is designed to be so efficient that it captures all of these heat sources, significantly reducing the need for additional heat or cooling. Thus, the house uses about 90% less energy than the average home today and about 80% less energy than the average newly-built home. Solar buildings also include concrete countertops and floors, which increase the energy-storing thermal mass; solar shading on the windows, hyper-attention to energy use (making the house hyper-comfortable), and a massive wall, which stores solar energy and controls temperature variations in the house.

Green energy use (solar energy, wind energy, biomass, etc…) is a pillar of the green world. Energy resources and their utilization are closely linked to sustainable development. In attaining sustainable development, increasing the energy efficiency of processes utilizing sustainable energy resources plays an important role. Further, the utilization of renewable energy offers a wide range of exceptional benefits. A sustainable energy system may be regarded as a cost-efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks [1].

With the severe energy crisis in the modern world, the utilization of energy has become a vital issue, and the conservation of energy has acquired prime importance. One of the areas with the most unexploited opportunities for sustainable energy conservation is the in the construction industry, including various residential and office buildings. Among the different control tasks of energy distribution, air conditioning is one of the most important to humans [8]. The use of passive building concepts for achieving thermal comfort is a growing concern the world over for the area of building energy conservation. A major element of the passive house is the Trombe wall. It is used to reduce energy consumption in zones where heating is much more important than refrigeration [8].

Solar houses could be designed to minimize heating power in winter and cooling power in summer. This goal can be achieved by proper design of the house. The wall that faces the sun plays a major role in solar buildings. It may be designed in such a way [3] so as to collect, store and distribute solar energy in the form of heat in the winter, and reject solar heat in the summer. The differences between a passive solar home and a conventional home are in their design. Every passive solar building includes five different elements: the aperture (or collector), the absorber, thermal mass, distribution, and control. In addition, there are three basic types of solar design: direct gain, indirect gain (Trombe wall) and isolated gain; such designs differ in how the five elements are incorporated [3].

A low-energy technique for heat removal from the interior of a building, under summer conditions, is through the use of natural ventilation. Among others, Trombe walls use natural ventilation. They can be operated in several different modes, including: accumulating heat in the storage wall, regulating the temperature in order to maintain desired conditions inside the building, and ventilation [2].

A number of modifications have been made to the Trombe wall's original design in order to produce more advantages and reduce its disadvantages. The standard Trombe wall has the drawback of significant energy loss at night-time [9].

To improve the solar gain in passive buildings, the Trombe wall has been replaced by a rotating prism wall. The kinetics of rotating prism walls were first addressed by Faiman [4]. Its performance details were published in 1984 [5], and it was numerically modeled and validated in 1989 [6, 7]. The rotating prism wall was recently reconsidered in the design of passive buildings [9]. These studies show substantial improvements when compared to the Trombe wall.

In this study, the Trombe wall and the prism wall are reconsidered, and their solar gain is compared, assuming non-rotating conditions of the prism wall. In addition, an idea to increase awareness of the solar passive buildings among children is suggested and demonstrated at the Alzarafa kindergarten of the Alhuzayyel secondary school in the southern city of Rahat, Israel.

The outline of the paper is as follows: Section I consists of the introduction, and the massive wall is considered in Section II., Section III details the experimental methods and results, and kindergarten educational activities are discussed in section IV. Finally, Section V consists of the summary and conclusions.

II. THE MASSIVE WALL

A. The Trombe wall

The classical Trombe wall is designed to absorb solar energy at its outside face, which is located behind double glazed window, and radiate only a small portion of its thermal storage energy at its back to the interior space. A schematic diagram of a Trombe house is shown in Fig. 1.

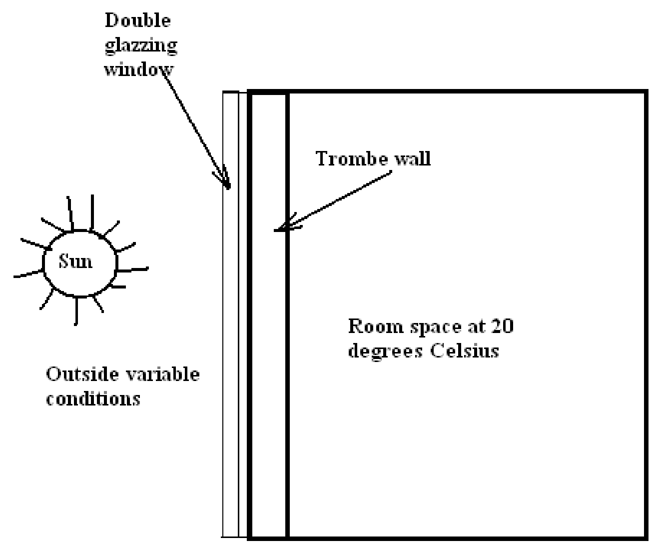


FIGURE 1. Schematic diagram of the Trombe wall.

In order to obtain the temperature distribution within the Trombe wall, the parabolic heat diffusion is solved under known boundary conditions.

The Trombe wall is considered a one-dimensional slab with width *l*. The heat conduction equation is formulated as follows:

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2}, \qquad 0 < x < l \tag{1}$$

where $\alpha = k/\rho c$ is the thermal diffusivity (m2/s), k is thermal conductivity of the wall material (W/m°C), the density (kg/m3), c the heat capacity (J/kg°C), (x, t) the temperature in the slab (K), t the time (s) and x the location inside the slab (m) in the south-to-north direction.

The boundary condition for x=0, at which solar radiation $q(t)$ (W/m^2) is absorbed by the exterior side of the wall, and heat is rejected to the ambient room according to the overall heat convection coefficient h_{out} (W/m^{2}C), is given by:

$$q(t) = -k\frac{\partial T(x=0,t)}{\partial x} + h_{out}(T(x=0,t) - T_{out}(t)) \cdot \tag{2}$$

In principle, the solar radiation has a sinusoidal shape from sunrise to sunset. During the winter, it is modeled as a step function, as follows:

$$q(t)=\begin{cases}500 & 0\le t<8h,\\ 0 & 8\le t<24h.\end{cases} \quad (3)$$

In a similar manner, the ambient temperature $T_{\text{out}}(t)$ (°C) is approximated by the stair function below:

$$T_{out}(t)=\begin{cases}10 & 0\le t<8h,\\ 5 & 8\le t<24h.\end{cases} \quad (4)$$

The boundary condition at the interior side of the Trombe wall at $x=l$ is described by:

$$-k\frac{\partial T(x=l,t)}{\partial x}+h_{in}(T(x=l,t)-T_{in}(t))=0\cdot \quad (5)$$

Here, the inner temperature $T_{\text{in}}(t)$ is generally constant, and is assumed to be fixed at 20°C. (It will be shown in the next section that this boundary condition leads to inner wall temperatures very close to the interior temperatures with the set of parameters chosen; this simplifies the boundary condition to the constant wall temperature).

Finally, to complete the definition of the problem, the initial distribution inside the Trombe wall $T(x, t=0)$ is assumed constant, with a value of 5°C.

By solving for the heat (put variable here), the heat diffusion makes it possible to calculate the energy flows at both surfaces of the wall. The total energy input gained from the sun at the outer surface is divided into two parts: the first part is rejected back to the ambient room and the second part is delivered into the room. The reflected energy to the ambient air outside the room, q_{out}, is given by:

$$q_{out}=\int_{t=0}^{24(h)}h_{out}A_{out}\left(T(x=0,t)-T_{out}(t)\right)dt\,. \quad (6)$$

A similar integration would produce the amount of energy delivered to the room, given by:

$$q_{in}=\int_{t=0}^{24(h)}h_{in}A_{in}\left(T(x=l,t)-T_{in}(t)\right)dt\,. \quad (7)$$

For a constant temperature of the inner wall, the energy delivered to the room is calculated by applying the conduction equation:

$$q_{in}=\int_{t=0}^{24(h)}-kA_{in}\frac{\partial T(x=l,t)}{\partial x}dt\cdot \quad (8)$$

The energy quantities are divided by the total energy absorbed at the outer surface to produce the fraction of energy rejected to the outside ambient air and the fraction of energy delivered to the room.

B. The non-rotating prism wall

In a similar manner, the massive wall is assumed to have an equilateral triangular cross-section with same volume. Thus, the Trombe wall, with a constant slab width of 0.3m, is replaced by four equilateral triangles, with sides of 0.7m each (see Fig. 2.a). Due to the symmetry of the structure, it is possible to consider the right half of the triangle, as depicted in Fig. 2.b.

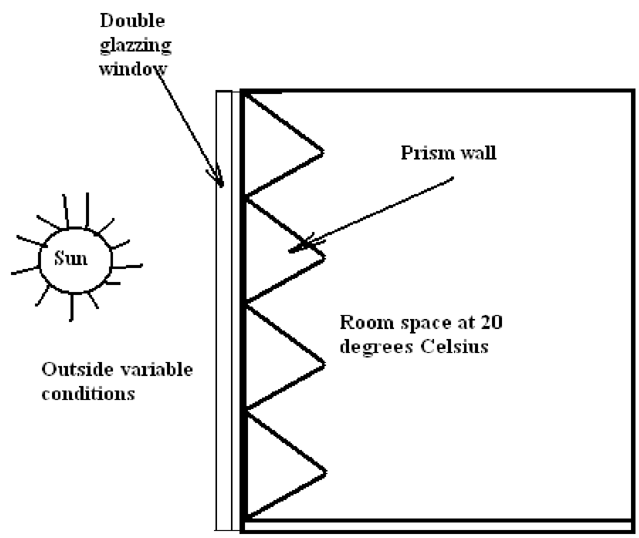


FIGURE 2a. Schematic diagram of the prism wall.

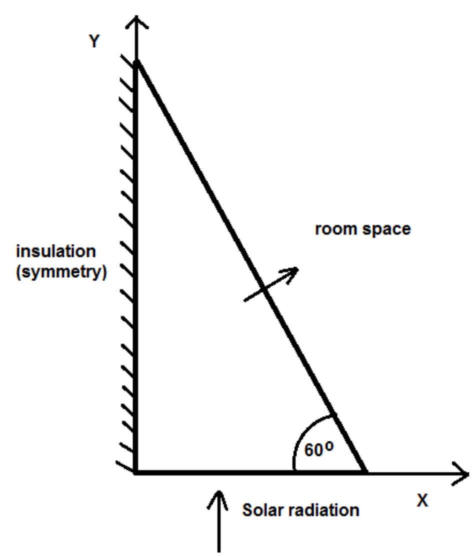


FIGURE 2b. Schematic diagram of a cross-section of the prism wall.

The heat conduction equation is two-dimensional, and is formulated as follows:

$$\frac{1}{\alpha}\frac{\partial T}{\partial t}=\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}, \quad 0<x<l/2, \quad 0\le y<\sqrt{3}(l/2-x). \quad (9)$$

The variables are the same as given by eq. (1), with slight modifications to their definitions. In this case, the temperature distribution $T(x, y, t)$ is in two-dimensional space, and y corresponds to the external-to-internal direction, while x runs along the lateral side (west to east).

The boundary conditions are modified accordingly, to fit the changes in the geometry. At the outer side of the wall, the heat balance equation leads to the boundary condition at y=0, which is given by:

$$q(t)=-k\frac{\partial T(x,y=0,t)}{\partial y}+h_{out}(T(x,y=0,t)-T_{out}(t)). \quad (10)$$

At x=0, the boundary condition is defined as zero flux, due to symmetry, as follows:

$$-k\frac{\partial T(x=0,y,t)}{\partial x}=0. \quad (11)$$

Finally, the boundary condition at the inner surface of the wall is similar to equation (5), but the flux leaving the wall is in the direction normal to the surface. This boundary condition is given by the following:

$$-k\frac{\partial T(x,y+\sqrt{3}x-\sqrt{3}l/2=0,t)}{\partial n}+ h_{out}(T(x,y+\sqrt{3}x-\sqrt{3}l/2=0,t)-T_{out}(t))=0. \quad (12)$$

For simplicity, this condition may be replaced by constant surface temperature equals the room temperature. This simplification is justified in the next section.

In order to calculate energy fractions, equations (6) – (8) were adopted, and the integration was performed as a summation at the appropriate boundaries.

III. METHODS AND RESULTS

A. Methods

In order to model the temperature distribution inside the massive wall, an analytic solution may be considered, which in principle could be found for simplified models and simplified boundary conditions. In such a model, the boundary conditions would be simplified and given by Newtonian heat transfer law. The boundary conditions include the thermal radiation heat transfer law, which incorporates nonlinearity into the model. Another complication consists of the geometry of prism's cross section of the wall. In this study, a numerical solution approach is followed; numerical methods are considered especially useful for problems without analytic solutions. However, numerical methods are used in cases in which when the price of calculation is very high. Thus, with the aid of a personal computer, an accurate numerical solution may be achieved within fraction of a second to few seconds, while producing an analytic solution may take several hours or days.

In order to solve the parabolic equations (1) and (6) with appropriate boundary conditions, a numerical scheme must be developed. One of the simplest numerical schemes is the forward difference scheme for the first order differential of temperature with respect to time, as well as central differences for the second order differential of the temperature with respect to space coordinates. The price for using such a simple scheme is the limitation on the time step. In this study, the space step is arbitrarily defined as one-tenth of the overall thickness. Accordingly, a time step of 144 s (more than ten times smaller than the condition for stability) is found to be sufficient for the production of accurate results. The calculation's accuracy may be checked for cases for which an analytic solution may be derived, and compared to the numerical solution. Details of the numerical scheme are discussed by Smith [6].

In this study, the governing equations were solved using Microsoft Excel (2007), specifically its macro capabilities, based on the Visual Basic Application language (VBA).

B. Results

The parameters of the model and the massive wall material were adopted from previous studies [7]. The thermal properties of the massive wall (in SI units) are: a thermal conductivity of 1.3, density of 1930 and heat capacity of 1000. The heat convection coefficient to the outside ambient air is 3.0, and the heat convection coefficient to the room is 8.0.

With aid of VBA, the governing equations were marched over time for ten days, in order to assure steady state operation. In the following subsection, the results are detailed for both types of massive wall tested: the Trombe wall, and the rotating prism wall.

B.1 The Trombe wall

Figure 3 shows the temperature distribution inside the Trombe wall. The graph clearly shows that the outer surface reaches a high temperature (approximately 70 °C) while the interior temperature remains at 20 °C. These values highlight the importance and usefulness of the massive wall in temperature regulation. Actually, the massive wall (Trombe wall) isolates the inside of the room from the ambient conditions.

The binary energy distribution is shown in Figure 4. Clearly, the amount of energy rejected is slightly higher than the fraction of energy delivered to the room.

B.2 The non-rotating prism wall

Figure 5 shows the distribution of the temperature along the symmetric line of the triangle, from the outside surface, with higher temperatures, to the inside surface, at room temperature.

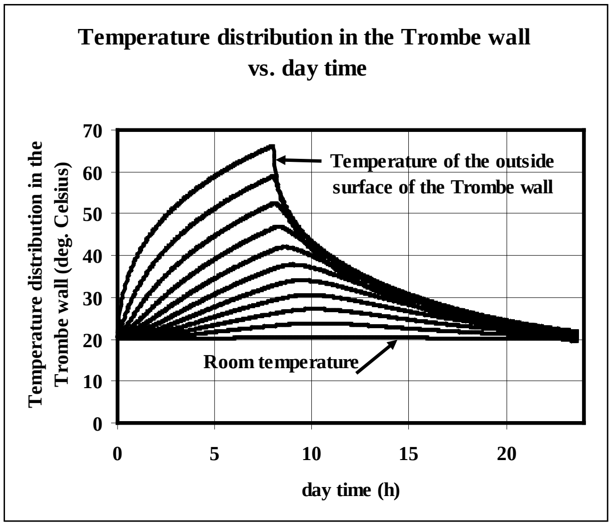


FIGURE 3. Temperature distribution inside the Trombe wall.

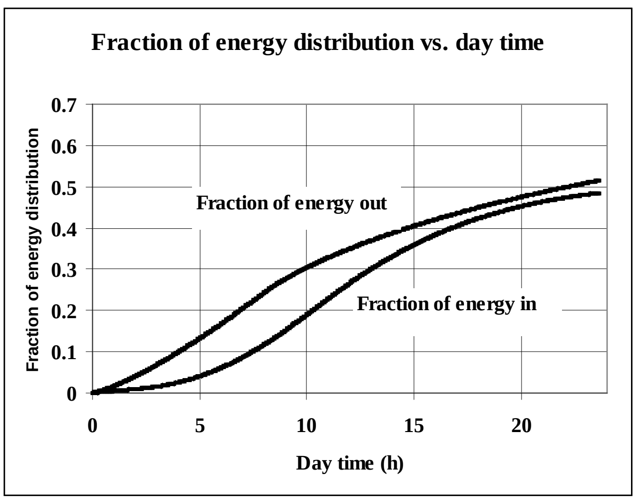


FIGURE 4. Fraction of energy distribution of the Trombe wall.

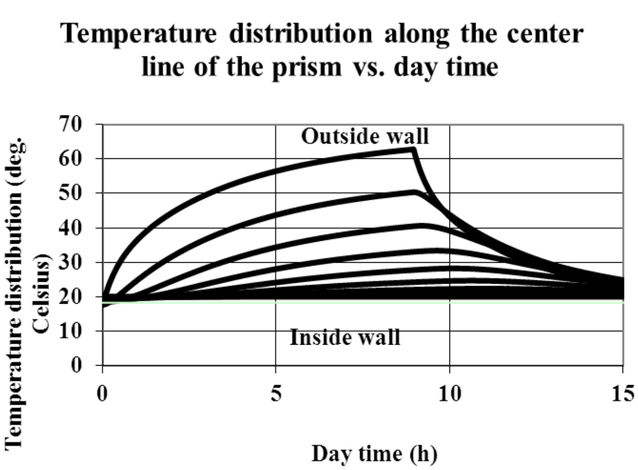
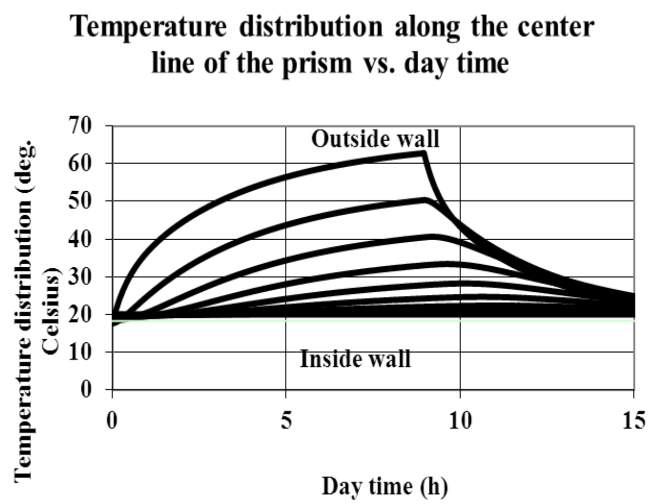


FIGURE 5. Temperature distribution along the center line of the non-rotating prism wall.

It may be observed that the non-rating prism wall's behavior is similar to that of the Trombe wall qualitatively, in terms of temperature regulation and smoothing. However, the results show a more favorable outcome for the prism wall with respect to the amount of energy delivered to the room. This fact may be observed by considering Figure 6.



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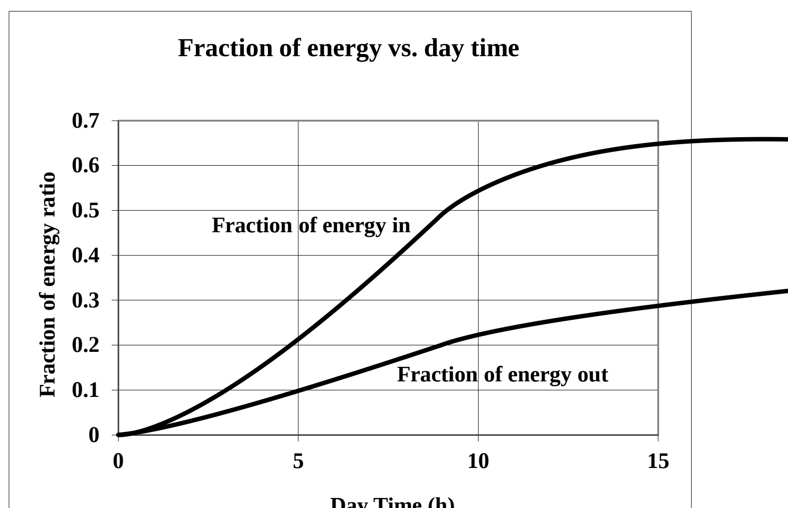

FIGURE 6. Fraction of energy distribution of the non-rotating prism wall.

IV. ACTIVITY FOR THE KINDERGARTEN

A. General Comments

In order to increase youngsters' awareness of the kindergarten, we have developed and implemented an activity on the topic for kindergarteners. It is important to stress that the process of the activity should be highlighted, rather than the final result. Solar passive buildings are currently among the most attractive candidates for attaining sustainability, due to the fact that housing is a basic human need. The suggested activity is constructed from three major steps: together, they might be called the triangle model, first proposed in the current work. The triangle model, which is suitable for activities in any area of interest and for participants of all ages, consists of the following steps: describe the phenomena, provide a possible suggestion or a solution and assign responsibility.

B. The Triangle Model

B.1 Step One: Describe the Phenomena

Step one begins with a brainstorming session. During this session, goals are defined and terms and ideas are collected from the group, in order to build the subsequent activity on basic knowledge shared by the participants. Specifically, in our case the brain storming session commenced with the issue of green energy and sustainability. The current knowledge about solar passive buildings was summarized, and possible directions of research and implementation were discussed.

B.2 Step Two: Provide a Possible Solution

The suggested solution could be the outcome of the first step described above – that is, it could arise during the brainstorming session. The process of the activity is defined in more detail, and it is divided to smaller steps towards achieving the proposed goal. For our study, which included building a model solar passive house, these steps included: spotting the location of the construction, collecting the materials for the construction, and starting the construction.

B.3 Step Three: Assign Responsibility

The first two steps are important to increase awareness of the topic, which aims to increase the participants' sense of self-confidence and taking responsibility toward their lives. As such, the participants are motivated to act with great pleasure and full responsibility, as individuals working together towards a final goal. Regarding the issue of sustainability in general, passive solar buildings in particular, both kinds of responsibility (individual and group) are important. Ideally, participants' sense of responsibility should be taken based on knowledge of the challenges and dangers faced by the human civilization. If responsibility towards these challenges is not developed, and the appropriate actions not taken, it is no surprise that disaster results. In the current study, step three consisted of (add description here, as you did for steps 1 and 2).

C. Demonstration in the Alzarafa kindergarten

This activity joined many other ongoing activities and initiatives conducted in the Alzarafa kindergarten for the past few years in the field of environmental education. Such activities covered the topics of pollution (sources, effects on health, ideas for reduction, etc.), agriculture, solar energy (the solar oven), and other activities of this kind.

During the brainstorming session, the kids showed great motivation to contribute to the discussion and were eager to take an active part in it. The activity at the kindergarten also attracted the attention of other classes nearby. The 8th grade students, for example, were interested to "see the green energy with their own eyes", though it is not actually visible – thus, their stop at the kindergarten was a learning opportunity for them. Overall, the activity created a positive atmosphere and effect on the surrounding community, including students, teachers, and parents not of the kindergarten.

After drawing the plan for activity, the kindergarteners started to collect materials for the construction of a model of a solar passive house, as shown in the pictures of Figure 7, below.

The pictures in Figure 7 are arranged in two columns, in chronological order: the first picture is at the top right, and continue downwards; the next column also begins at the top and should be viewed top to bottom. As can be seen from the last two pictures, one final step is missing, that of adding the structure's cover and glazing the south-facing wall.

V. SUMMARY AND CONCLUSIONS

In this study, the importance of green energy is briefly considered, and the important role of the massive wall in solar passive applications is highlighted. Scholarly research has shown that careful building designs may save electricity, which is produced at industrial power plants; thus, such a reduction in electricity may help reduce atmospheric pollution.

Mathematical models of the temperature distributions in the Trombe wall and the non-rotating prism wall were described via the parabolic heat diffusion equation, together with the appropriate boundary conditions. The two models were subject to similar conditions, with one crucial difference in their construction: the shape of the cross section.

It has been shown that qualitatively, both walls exhibit the same behavior in controlling the surrounding temperature, but quantitatively, the non-rotating prism wall showed superior behavior compared to that of the Trombe wall. These results were observed in previous studies, and were elaborated on in the current work, which considered the amount of energy delivered as a function of time of the day.

In addition, beyond the scientific research, building awareness of sustainability is crucial. Thus, in light of academia's responsibility to give back to society, an activity on the topic at the local kindergarten was developed and implemented, and described here. .

Throughout the activity, positive interactions were observed among the participants and the surrounding community.

FIGURE 7. Pictures of the kindergarten activity.

The feedback we gained, both from the local community and from other nearby schools, interested in also organizing such activities, hinted at the potential of such activities and of the triangle model, as well as the general public's receptiveness to them. It is important that children's abilities, curiosities, and physical abilities not be underestimated – in fact, often adults are those that put artificial obstacles in front of them. Overall, we believe early environmental education, starting at the kindergarten age, is crucial for creating a knowledgeable and responsible society, of the type that is receptive to widespread use of such advances as passive solar buildings.

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