Energy Conservation Measure in RDP House in South Africa

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Abstract. Thermal efficiency of a building is primarily affected by meteorological factors surrounding the building. The indoor temperature distribution of RDP (Reconstruction and Development Program) houses in South Africa is strongly affected by the outdoor weather conditions. This is due to the low quality (low R-value) materials used in constructing the house. According to TIASA (Thermal Insulation Association of South Africa) approximately 24% of heat is lost through walls in an un-insulated home. Therefore good thermal insulated walls can minimize the influence of the outdoor weather condition on the indoor temperature distribution of the building. In this study the effect of the walls on the heat flow dynamics was analyzed and ultimately the building thermal efficiency was evaluated. A RDP house was monitored for one year but for simplicity this paper will present results over one week only. A number of sensors were installed to monitor indoor and outdoor temperatures, wind speed and direction, and solar radiation. Indoor and outdoor surface wall were also monitored. A thermal lag of 2 hours and an average temperature difference of 5.29^{o}C were observed between the inner and outer four walls temperature of the house. The average percentage difference between the outdoor and indoor four walls temperature is 55% over the week. A graphical observation shows a linear relationship between the indoor temperature and solar radiation. From these observations it is indicated that the rate of heat transfer through the walls of the building is high. A detailed and conclusive report containing the thermal properties of the wall is presented in this paper.

1 Introduction

Energy efficient design is the most efficient way to conserve energy in a building. There are two major types of energy efficient walls; cavity and double skin walls. Construction of cavity walls require the erection of two thin walls separated by an air-gap and braced with metal ties (stainless steel). Double skin walls are similar to cavity walls but polystyrene or an insulation board is inserted between the walls, filling the air-gap. The air-gap and insulation board reduces the rate of heat transfer through the walls. [1]. Most houses in South Africa are still designed with single walls; this is the case with all low cost houses. The low cost housing provides for those on small incomes in South Africa is of poor quality, with inferior thermal performance characteristics. This has resulted in excessive energy consumption for space heating and emission of greenhouse gases such as CO_2 [2]. Recent statistic by IEA shows that, South Africa moved from the 18th largest national emitter of CO_2 in 2007 to the 15th position in 2009 [3]. This is attributed to the major impact of coal in electricity production in South Africa. The government of South Africa and other energy conservation organizations have taken various measures to solve this energy crisis. Eskom's Demand Side Management (DSM) plan was to reduce the growth in the country's electricity demands by encouraging people to use energy-efficient equipment, which reduces energy usage. The use of thermal insulation will reduce the energy required for electrical heating and cooling, thus supporting Eskom DSM [4]. TIASA is promoting and encouraging the use of thermal insulation in South Africa.

2 Methodology

The house used in this paper is located in Alice and falls under the Nkonkobe Municipality Eastern Cape. The house is occupied by a mother with her teenage daughter and a toddler. The building is oriented 16° east of north. Alice is -32° latitude and 26° longitude at an altitude of 493.10 m, in the sub-tropical climate zone. It is a rural settlement primarily occupied by senior citizens, children and low income earners. Figure 1 shows the actual picture and a floor plan of the house.

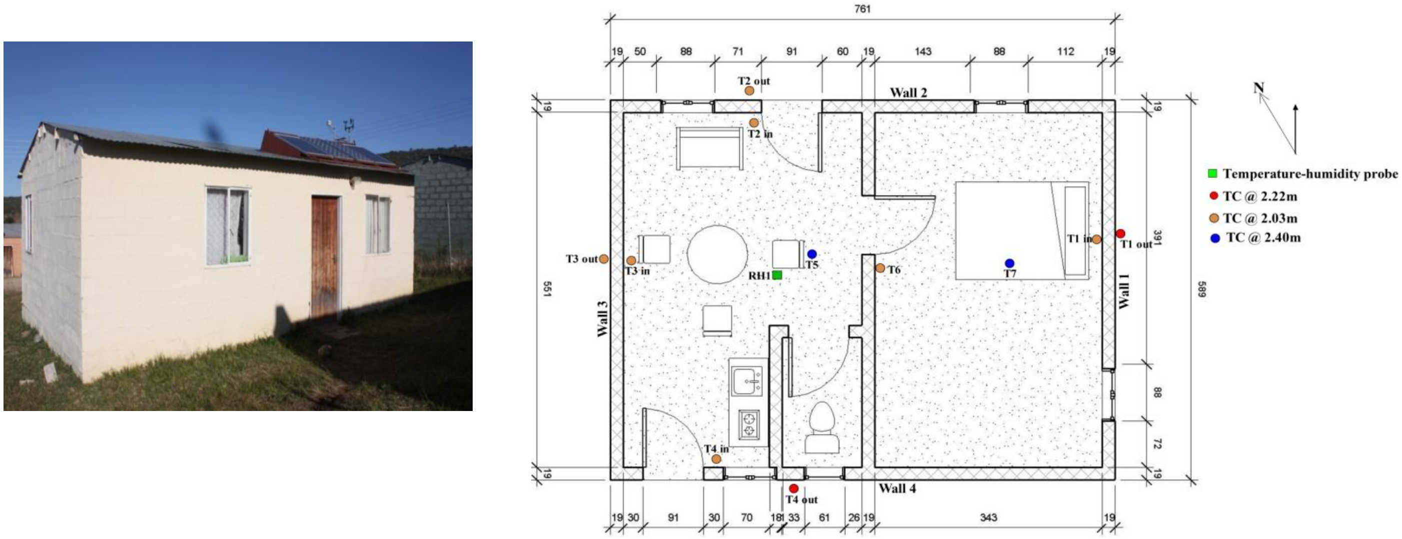

Figure 1: Low cost house and Floor plan

A total of eleven thermocouples, one wind anemometer / wind vane and one pyranometer were installed in the house for meteorological measurement. Wind anemometer / wind vane and pyranometer are located at the roof of the house. The thermocouples were placed on the indoor and outdoor walls of the house. Temperatures of all four walls were monitored both in and outside. These type K thermocouples are denoted T_{in} and T_{out} in the Figure 1.2, where T = 1, 2, 3, 4. Furthermore, temperature of the living area (n = 5), center wall (n = 6) and bedroom (n = 7) were also monitored. The thermocouples were mounted on the walls to ensure that the sentry terminals are in a direct contact with the walls. The sensors were placed at different height on the walls, in order to prevent the occupants of the house from interfering with them. Figure 2 below shows the schematic of the data acquisition system used in the study as well as the actual electronic components.

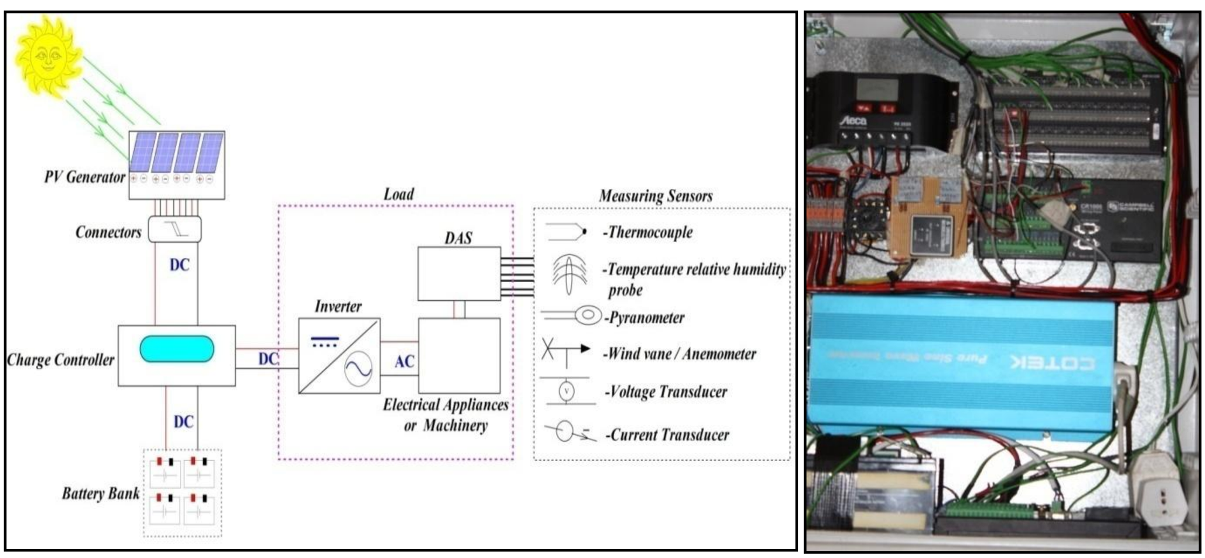

Figure 2: Project schematic and DAS

3 Meteorological Data Analysis

Meteorological factors are the major element that affects the thermal performance of a building. In this section of the paper some of these elements will be discussed and analyzed based on the data collected from the house.

3.1 Temperature

When two regions of different temperature are close to one another internal energy is transferred from one region to the other until they both have the same temperature [5]. On a sunny day, the sun heats up the external walls of a building by means of radiation. The heat in the external walls of the building is transferred to the inside walls of the building by conduction. The amount of heat and the time taken for the heat to transfer through the walls of the building depends on the solar irradiance at that particular time and the thermal properties of the wall. The heat on the inside walls is distributed in the house by convection. At night a reverse process takes place, the trapped heat drifts out of the house due to the cold air outside. The size of the house, number of occupants and activities (human factors) in the house also contribute to the thermal behavior of the house. Figure 3 shows the temperature distribution of the four external walls of the house. The four walls of the house are denoted as Wall 1, Wall 2, Wall 3, and Wall 4 from East to South respectively.

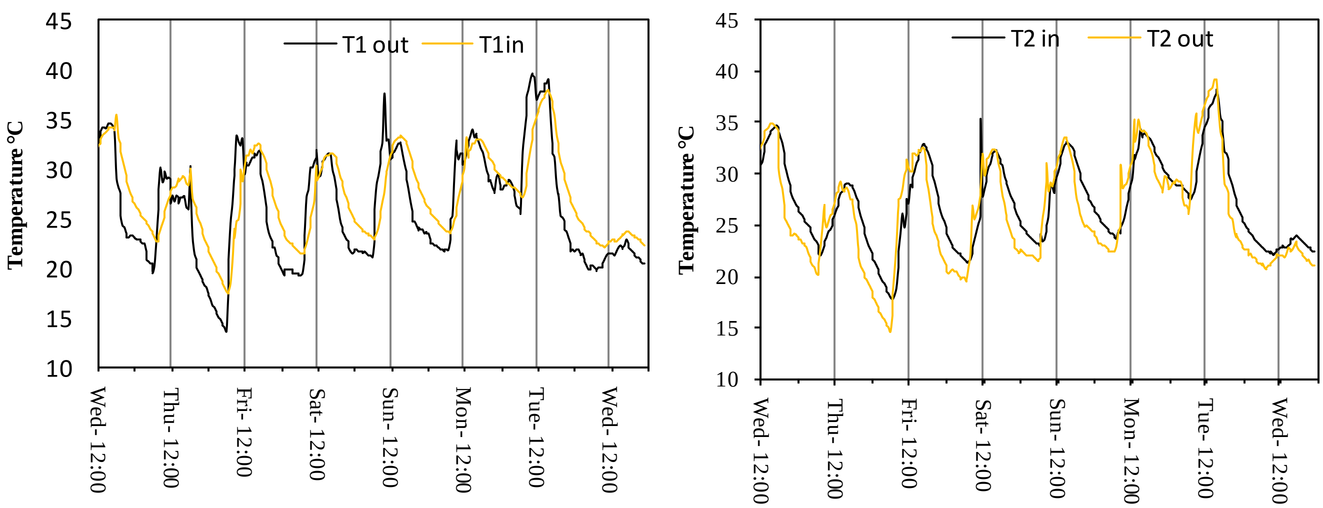

Figure 3(a): Wall 1 and Wall 2 temperature distribution

The morning sun rays concentrate on the east side of the building spreading across the Wall 2 and Wall 1 of the building. As observed from the graph the Wall 1 of the building gets more of the early morning sun. The Wall 1 (outdoor) attains its maximum temperature at about 10:30 after which the temperature gradually declines as the sun rays move towards the north. Wall 1 tends to contribute positively in terms of warming up the bedroom at the early hours of the morning. A thermal lag of 5 hours was observed between the indoor and outdoor wall temperature and an average thermal difference of 4.44°C, on Wall 1. The wild thermal lag of Wall 1 is caused by the increase of the indoor temperature of the house. This is caused by the indoor temperature. Wall 2 (outdoor) temperature at the time is still increasing and reaches its peak temperature at about 14:30. At midday the sun rays concentrate on the north side of the building spreading across Wall 3 and Wall 2. An observation performed on the building shows that at 13:22, Wall 4 and Wall 1 were completely shaded while Wall 2 was partially shaded. The shading on Wall 2 causes the low temperature of the wall and the time taken to attain maximum temperature, when compared to Wall 3. A thermal time lag of 2 hours was observed between the indoor and outdoor wall temperature of Wall 2 and an average thermal difference of 1.37°C.

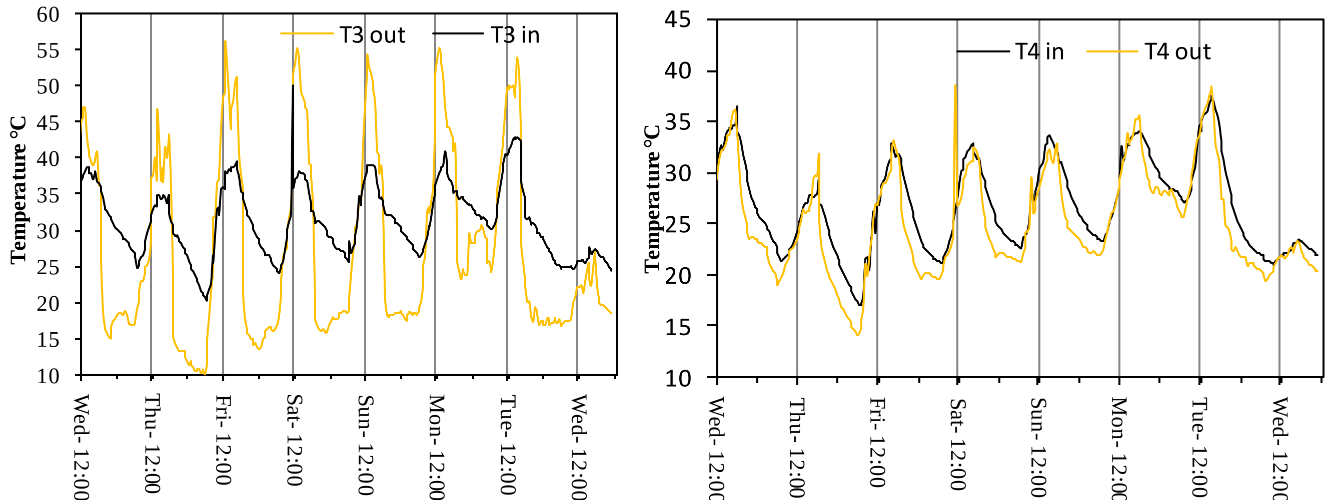

Figure 3(b): Wall 3 and Wall 4 indoor & outdoor wall temperature distribution

Wall 3 (outdoor) receives full midday sun rays generating a very high temperature on the wall during the day. Wall 3 attains its peak temperature at 13:00, as the sun sets Wall 3 temperature decreases. The sun rays move from the north and concentrate on the west spreading across Wall 4 and Wall 3. A thermal time lag of 2 hours was observed between the indoor and outdoor wall temperature of Wall 3 and an average thermal difference of 14.34°C. The temperature of Wall 3 is also influenced by the wind direction which will be discussed in a later section of this paper. Heat form Wall 2 and Wall 3 are transferred across the house by means of convection. This will be an advantage during the winter season but in summer, it will result in over heating in the house. As sure, a proper overhanging roof of 40 cm – 60 cm offset Wall 2 and an obstacle like a tree on Wall 3 are required to shade the walls. The overhanging roof will shade more than half of the wall from the overhead north sun during midday. At about 18:00 Wall 4 attains its maximum temperature. A thermal time lag of 2 hours was observed between the indoor and outdoor wall temperature of Wall 4 and an average thermal difference of 1.00°C. Wall 4 is mostly shaded all through the week. Figure 1.3d shows that the indoor temperature is higher than the outdoor temperature. This means that, the house losses heat via Wall 4.

3.2 Wind speed

Wind is air in motion, as air moves its carries along its temperature (warm or cold air). When warm air moves to a shaded cool area on a sunny day it increases the temperature of the air in that area, making the shaded area warm. A similar situation takes place in a cold day, outside cool air drifts into the house through openings in windows and doors of a house reducing the indoor temperature. The wind steers up the temperature of the surroundings [6]. The wind speed and direction determines the effect of the wind, an increase in wind speed increases the cooling and warming effect of the wind on the surrounding. The area where the wind is blowing from tends to get more of the effect (cooling or warming) of the wind. Figure 4 shows the effect of wind speed and direction on the indoor temperature.

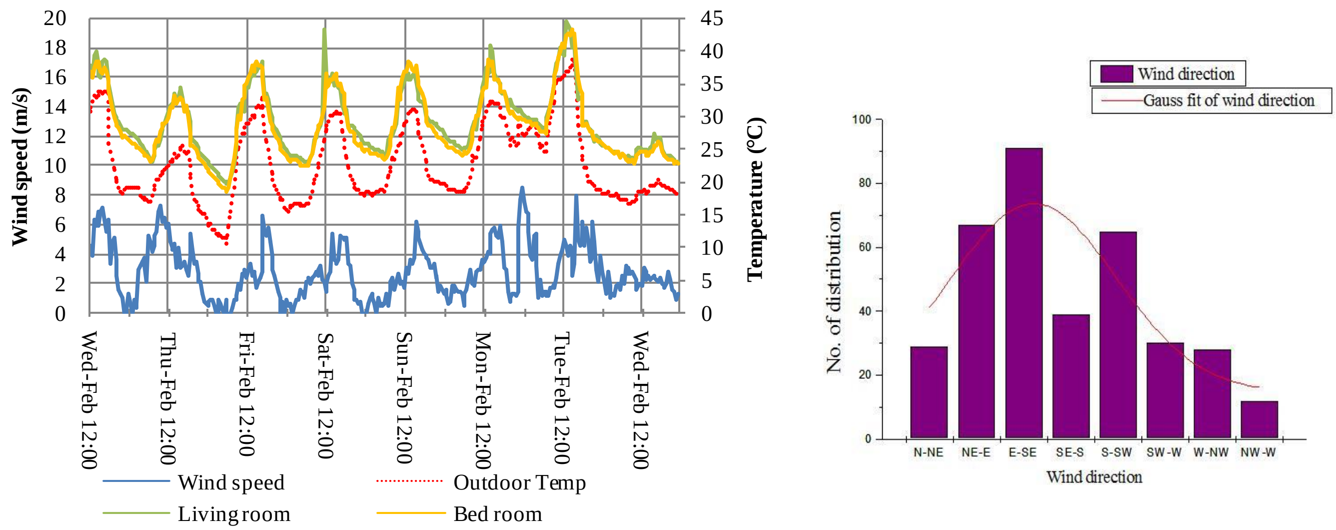

Figure 4 (a) The impact of wind speed on indoor temperature (b) Wind direction

From Figure 4(a) it was shown that as the wind speed increases during midday warm air drifts into the house more, resulting in an increase in indoor temperature of the house. In Figure 4(b) it was shown that the E-SE wind predominate the building. This implies that the building experiences the Southeast trade wind as such the NW area of the building will encounter more of the wind effects. From Figure 3(b) it was observed that Wall 3 has the highest temperature during the day and the lowest temperature at night. The wind concentrates warm air during the day and cool air at night on Wall 3, increasing and reducing the temperature respectively.

3.3 Solar radiation

As the solar radiation passes through the atmosphere most of its radiation is absorbed and scattered, a little fraction (about 21%) of direct solar radiation reaches the surface of the earth. The fraction of the solar radiation that reaches the surface of the earth is known as insolation, derived from the word "incident solar radiation" [7]. Insolation is primarily composed of visible and infrared radiation. When the sunlight is absorbed by the earth and the atmosphere, they both emit infrared radiation. The difference is that the incoming radiation consists of visible light and short-wavelength infrared radiation whereas the outgoing will be long-wavelength infrared radiation [8]. The incoming radiation (visible light) is what we receive on the earth as sunlight. The outgoing radiation (far infrared radiation) heats up the air and creates the warm air which is felt on a sunny afternoon. Figure 1.7 shows the indoor temperature response to solar radiation

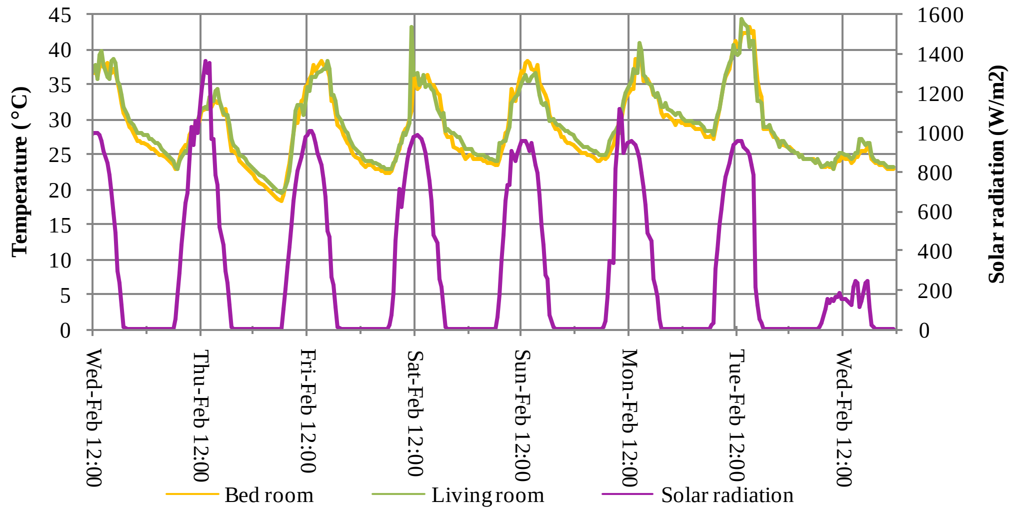

Figure 5 Indoor temperatures and solar radiation response

From figure 5 it is observed that the indoor temperature is influenced by solar radiation. This means that, heat from the sun is directly transmitted into house with very little resistance from the building envelop. As the solar radiation increases the wall temperature also increases. This increases the rate of heat transfer within the indoor and outdoor wall surface.

4 Conclusion

The ability of a material to resist heat flow is defined by its R-Value. R-Value is an opposite reaction of U-Value; U-Value is the thermal transmittance of a material. These factors made up the thermal properties of a material (wall) and they are determined by the thermal conductivity of the material. A thermal conductivity experiment of the walls of the house shows that, the R-Value is 0.021 m^2 °K/W while the U-Value is 47.36 W/m^2 °K. In conclusion, a maximum of 47% and 63% heat is gain and lost respectively within the walls of the house. This is depending on the temperature difference across the wall.

5 References

Al-Jabri K.S, Hago A. W., Al-Nuaimi A.S., and Al Saidy A.H. (2004) *Cement and Concrete RWall 1arch: Concrete blocks for thermal insulation in hot climat*e, August, p. 1473

Dilavore, P. (1984) *Energy: Insight from Physics*, Canada: John Wiley & son, Inc

Hinrichs, R. and Kleinbach M. (2006) *Energy: Its Use and the Environment*, New York: Interactive Composition Corporation

Horstmeyer, S. (2001) *Relative Humidity to What*, [Online],
Available: http://www.shorstmeyer.com/wxfaqs/humidity/humidity.html [16 Mar 2012]

International Energy Agency (IEA), *(2011) Key World Energy: STATISTICS*, Paris

Klunne W.E. (2002) *Energy efficient housing to benefit South African households*, November, p. 27

Thermal Insulation Association of South Africa (TIASA), (2010) *Thermal insulation-the invisible energy saver: The Guide to Energy Efficient Thermal Insulation Buildings*, Midrand: AAAMSA administered