The Potential of the Sun As a Tool in Achieving Energy Efficiency in Temperate Buildings

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Abstract:

Energy efficiency is a key tool in achieving environmental sustainability. Due to its importance, it is a key arm of Sustainable Energy for All (SE4ALL). In buildings, energy efficiency can best be achieved by the use of less energy in the daily operation of buildings. This research analysed the suns potential in temperate buildings as a tool to lessen energy use. After analysing the weather data and buildings of the case study area, buildings oriented to the south were the best option for Nottingham. When the building fabric was modified for more heat gains, less energy was needed to heat up the buildings. Roofs of buildings were also oriented to the south and this received a lot of solar radiation. An active solar system when placed on the roof generated a yearly total of 17,486kWh. With the average yearly energy demand of buildings in UK around 18,000kWh, this energy produce can be sustainable to an average home in the UK. Even though financial analysis should be done to conclude on profit, this gives a good sign. This paper therefore proved the relevance of the sun in the design and construction of temperate buildings for energy efficiency and this should be encouraged in all temperate regions

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Introduction

The sun is the most powerful source of energy in the world today. Solar radiation from the sun can directly be converted into various technologies. The building structure can also be designed to modify the macro climates into a desired micro climate for thermal comfort. In cold climates, heat gains are maximised as well as good distribution and storage of this heat. In warm or hot climates, heat gains are minimised to avoid overheating. The design of a single building without the effect of other buildings is always very easy. But when it is in a cluster, one must look at the effect the other buildings have on each other. Cluster of buildings create their own microclimates through shading, shelter, wind deflection and the emission of heat. Depending on the weather of location, these factors above can either be used to the advantage or disadvantage of the building. Due to the complex nature of determining the optimum setup of buildings to achieve thermal comfort, a lot of tools and guidelines have been developed to help achieve this. These include CIBSE, ASHRAE and some computer based tools such as Energy plus, Ecotect, TAS etc.

The sun contributes greatly to various sources of energy across the world. Radiation from the sun can be directly useful in generating electricity or passively used in buildings for heating or lighting purposes. Indirectly, the sun plays a major role in the formation of various energy forms. Evaporation from the earth due to the suns radiation on the earth surface brings rain into rivers and lakes to be used for hydropower. Wind and wave power is generated from currents which are as a result of heat flow from the hotter areas to colder areas of the earth. This heat is cause by solar radiation and this radiation plays a major role in photosynthesis. Photosynthesis makes plants grow and plants are a major source of bio energy in the world today. This means that the sun is of great importance to the world with regards to energy generation. (Alexander and Boyle, 2004). This power of the sun cannot be undermined as various publications such as Bradford (2006), Lund et al. (2008), Probst and Roecker (2012), Otis (2011) and Hastings (2009).

Solar architecture has been in existence for ages especially in cold climates. Its use was lessoned with the advent of industrialisation which brought the discovery of energy and mechanical systems of heating spaces. According to Socrates, "In houses that look toward the south, the sun penetrates the portico in winter, while in summer the path of the sun is right over our heads and above the roof so that there is shade." (Tabriz et al, 2011). The people of the Anasazi tradition that inhabited the Four Edges section of Colorado, Utah, New Mexico as well as Arizona lived within big caves that faced south. They created their homes recessed significantly from the opening, so that the cave roof shades them from scorching summer months. A more contemporary example is the saltbox design, favoured by the early colonists in New England. Saltbox houses were oriented to the south with a two-story elevation fenestrated by windows. The north roof sloped down to one story and had few windows. This took the chill out of cold New England winters when the sun was out. (Greenbuilding.com, 2013)

There has been a shift back into these systems of design and construction of buildings. This is because fossil energy prices are high and the issue of global warming has struck the world. The direct use of the suns radiation to heat up building is Passive solar architecture. With high fossil energy prices and its harmful effect on the environment, cleaner and cheaper alternatives have been brought in. The suns radiation is converted into various forms of energy to use in buildings. This is active solar architecture and when it is used directly for heating or lighting buildings, it is passive solar architecture. The question however asked is, can these energy forms be substantial and cost effective for comfortable human habitation in buildings?

There are various strategies and techniques in achieving passive solar. Depending on what one want to achieve, an appropriate design must be employed. Direct gain is the most basic passive design technique. In winter sunlight is allowed into a house through windows or glazing usually south-facing. The sunlight then hits masonry floors or walls, which absorb and store the solar heat. The wall or floor should be of thermal mass to be able to store up the heat. The surfaces of these masonry floors and walls are normally made of dark colour because dark colours usually absorb more heat than light colours. During nights, as the room cools down, the heat stored in the thermal mass converts and radiates into the room. In summer the gains are prevented to avoid overheating. This is done by creating a small overhang control to cut off the sun which will be at a high angle. Indirect passive solar gain is actually the opposite of direct gain. Radiation of the sun is not direct into a space but uses a medium to collect the sun and then transfers it into the space. The medium is normally a thermal storage in between the window and the space. Actively, solar collectors are used on buildings to collect the suns radiation for heat energy or for electricity production. (Everett, 2004). In the quest of achieving thermal comfort in buildings, cooling might be needed in warm climates and heating in cold climates. Energy then comes into the scene. With the world faced with global warming and climate, there have been advocacies on less energy use in various industrial sectors. As professionals in the built environment, our role will be the design and construction of buildings to use less energy for either cooling or heating. The aim off this research is to analyse the potential of the suns solar radiation as a tool to achieve energy efficiency in temperate buildings.

This research is contributing to knowledge in the academic and research fields. Human capital of this world is mostly developed by institutions and therefore with the right kind of knowledge such as research findings of this paper, right knowledge will be impacted on the up and coming professionals and therefore empowering the human capital. The built environment industry has the enlightenment to design and design with the sun in focus for less energy use which will give monetary and environmental savings.

Methodological approach

In achieving this research, case study buildings was analysed with the use of passive solar design options for optimum solutions. Data in the form of building drawings were taken from the Nottingham City Council as well as site visits to take photographs. These drawings were then modelled in Bently Tas and results analysed for optimum output. Analysis for potential active solar energy generation for temperate homes was also done. The roofs of the buildings were modelled in Ecotect and available and incident solar radiation was generated. This radiation was then converted to energy for use in the building. Weather analysis was another key method adopted. The weather for the chosen site was analysed for optimum comforts in the buildings.

Case study area.

The case study area is located in Lenton - Nottingham in the United Kingdom. This site was chosen due to its proximity to researcher at the time of data collection. The site for the research area is about 3.83 acreage (15499.46m^2) in size. The site is bounded on the north by the A609 (Ilkeston Road), on the south by the A6200 (Derby Road), on the west by the Kimbolton Avenue and on the east by the Balfour Road. There are two roads going through the site and these are Albert Groove and Derby Groove.

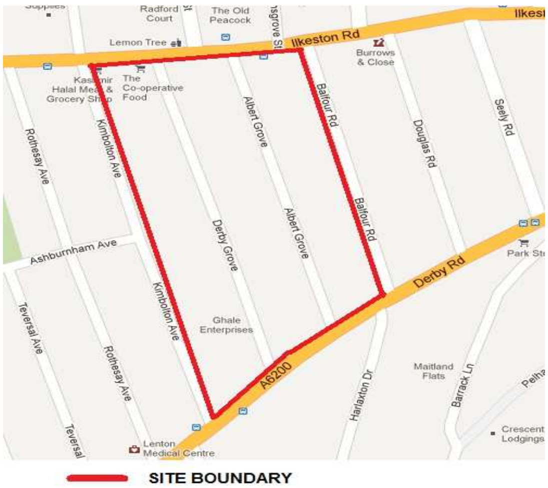

Figure 1. Map showing the site of Project (Source: http://maps.google.co.uk)

Figure 2. Image showing the site of Project (Source: http://maps.google.co.uk)

The built environment of this site is mainly residential with a few commercial buildings at the northern perimeter of the site. Percentage wise there residential buildings contribute 95% whiles the commercial buildings are just about 5%. There are roughly 215 residential houses and these are mainly terraced buildings. The orientation of the buildings was east – west and therefore only had a little percentage of their roof space facing the south. The south has high solar radiation and this could be used for active systems been in cooperated on the roofs.

Weather data analysis

The weather data for Sheffield was used for the stage one even though the site is in Nottingham. This is because there was difficulty finding the weather data of Nottingham which could be used in TAS for simulation. Sheffield was also chosen because it had the closest latitude to Nottingham. Nottingham falls on latitude 52.95; longitude -1.15 whiles Sheffield is 53.38; longitude -1.48. (Source : http://www.metoffice.gov.uk). This shows how close they are and therefore climatic conditions will be very similar.

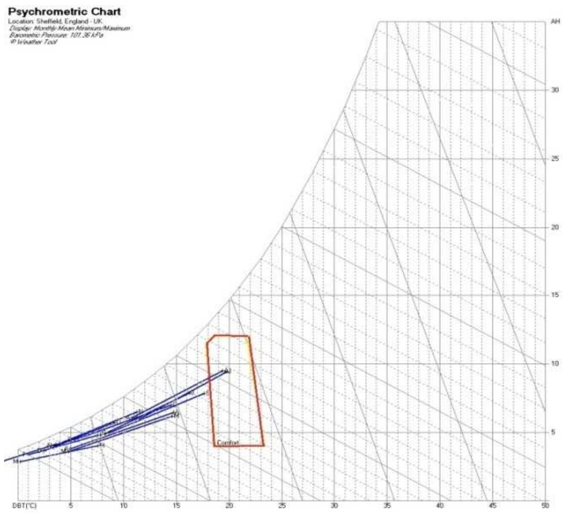

Figure 3. Psychometric Chart showing thermal comfort (Source: Autodesk Ecotect Weather Tool)

From figure 3 above which is the psychometric chart, shows the comfort zone is between 17.9°C to 23.5°C. The monthly data point's shows none in the comfort zone almost all through the year with a little comfort achieved in July and August. All data points are to the left of the comfort zone and this gives an indication of heating needed all through the year.

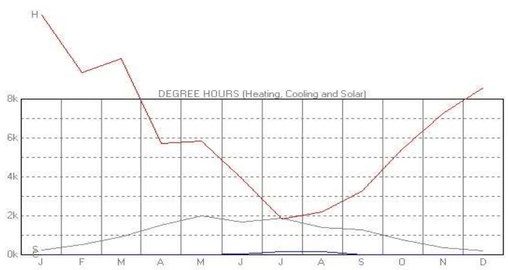

Figure 4. Heating and Cooling Profiles (Source: Autodesk Ecotect Weather Tool)

Figure 4 shows the heating and cooling profile of Sheffield. The red line with label H is heating and as it can be seen it is all through the year with very high values in January and low recordings in July. It had the lowest due to the fact that solar radiation was high in the month and therefore less heat was required. The high solar radiation in summer as shown above with line S has made it necessary for some cooling during these periods especially from June to September. From the above it is very clear that heating is the major issue with this weather and therefore the suns position was looked at to see how best it could be used to reduce the heating loads during winter.

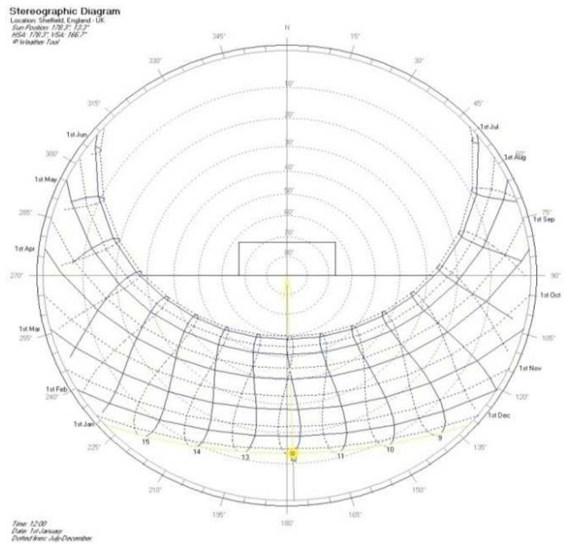

Figure 5. Sun Path Diagram (Source: Autodesk Ecotect Weather Tool)

The sun path shows a straight southerly movement during the winter and this bends into the east and west as it gets into the summer months. To utilise the sun in winter to reduce the heating loads, the building should be oriented with the greater length facing the south. The south elevation can then be exposed to the sun by using glazing to admit heat into the building.

Results and Discussion

Existing buildings

Based on sites visits and photographs taken, it was very clear that the existing building structures were old and therefore porous to climatic conditions. The buildings were not able to modify the macro climate to give a thermal comfortable micro climate. This data was gathered through casual interview with residents.

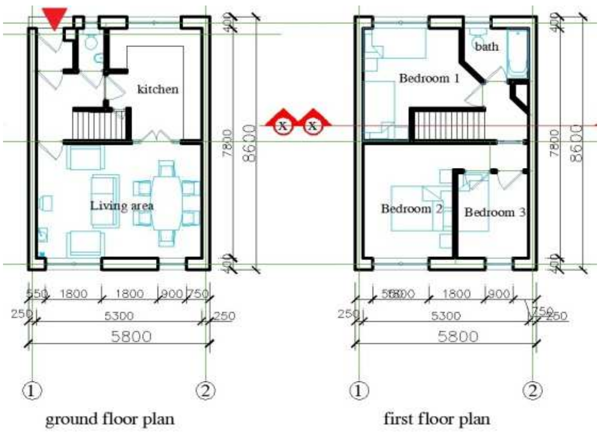

Figure 6. Existing House Plans

Depending on the side of the street this plan will be placed, the orientation of the front and back facades will be east – west orientation. The north and south walls will be adjourned to each other for a terraced layout. The thickness of the walls exposed to the external climatic conditions is 0.4m. The front and back elevations exhibit this wall thickness. This was not altered because the thicker a wall, the higher its thermal resistance even though the material components is a factor. A section through the building shows a proposed room height of 3.0m. A lower roof height will be a better option. This is because lower room height is to prevent hot air from having so much height to rise. The lower the room height, the more hot air will be felt. Therefore in a climate such as Nottingham where a lot of heating is required, this is a good option.

Analysis of existing buildings

The building was modelled in Bentley Tas and simulated to generate results of the first the indoor temperature achieved in each room as well as the energy demand needed to heat or cool down the building. In the simulation for the indoor temperature, no internal conditions were set. This was done intentionally to get a result that is the indoor temperature achieved just by the building fabric. Below is a plotted graph showing the results.

Table 1. Indoor Temperatures of existing buildings.

Month	Ext. Temp.	Living Area	Kitc-hen	Bed. 1	Bed. 2	Bed. 3
Jan.	1	8	8	5	5	5
Feb.	3.8	8	8	6	6	6
March	3.9	9	9	7	7	7
April	9.8	12	12	13	13	13
May	9.9	15	15	17	16	16
June	12.4	16	16	18	17	17
July	15.7	19	19	22	21	21
Aug.	15.2	18	18	20	20	20
Sept.	13.1	17	17	19	18	18
Oct.	10	14	14	13	13	13
Nov.	7.5	10	10	9	9	9
Dec.	5.9	9	9	7	7	7

From the above table, it can be seen that January is the coldest month and July is the hottest month. The average external temperature for January is $1^{o}C$. At this temperature the building fabric is able to achieve an average internal temperature of $5^{o}C$ for all the bedrooms upstairs. From the Psychometric chart discussed earlier, this internal temperature is out of the thermal comfort zone and therefore heating will be required to get a comfortable temperature. This internal temperature increases as the external temperature increases but still not within the comfort zone. In June, when the external temperature is around 12.4°C the internal temperature for bedroom 1 read 18°C and the other 2 bedrooms 17°C. There was an increase by a degree in July and a drop by a degree in August. Generally, it was clear that thermal comfort was achieved in the months of June, July and August.

In the cold months, the kitchen and living area which were downstairs recorded slightly higher internal temperature than the bedrooms upstairs and vice versa. The only argument to this is that the bedrooms which are upstairs have a boundary as the roof and it is exposed to the external environment. This is as a result of more heat loss and gain in the bedrooms. Having knowledge of all the above, internal conditions were then set and simulation for energy loads done. The key setting for this simulation was the indoor design temperature. Since this has to be a single figure and the comfort zone was a range, the minimum and maximum comfort range were added and divided by two. This will be 17.9°C +23.5°C = 41.4°C/2 = 20.7°C. Rounding this up, an indoor design temperature of 21°C was chosen. After simulation, the results were plotted in excel.

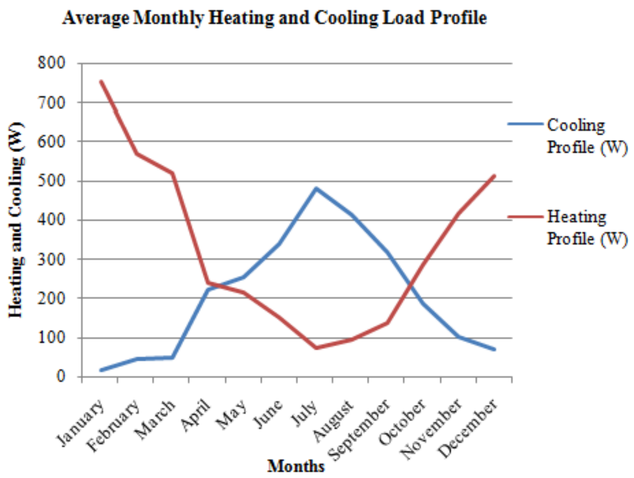

Figure 7. Graph showing Heating and Cooling Profile of existing buildings.

Comparing the above to the heating and cooling profile given earlier by ecotect, the heating profile is very similar but there are some differences in the cooling loads. Even though the profile is similar, the values are very different. The total heating load for this simulation is around 4175.5 Watts whiles that of the ecotect is over 8000 Watts. To know the cost of gas needed for this heating, the value was converted to kilowatt hours.

4175.5W = 4.2kW

Total hrs in a year = 365 days x 24hrs a day

= 8760 hours.

= 4.2kW x 8760 hrs

= 36,792kWhrs

Therefore the total watt hours needed to heat up the house in the year is 36,792kWhrs. To know the monetary value of this, a search into price per kilowatt hour was done.

Last Updated	26th March 2014					
GAS	Standard Credit		Direct Debit		Prepayment (meter)	
	Unit (kWh) cost	Average annual cost	Unit (kWh) cost	Average annual cost	Unit (kWh) cost	Average annual cost
Highest	5.33 pence	£ 959	5.07 pence	£ 913	5.32 pence	£ 957
Lowest	4.56 pence	£ 820	4.36 pence	£ 785	4.73 pence	£ 851
Average	4.98 pence	£ 896	4.57 pence	£ 823	4.95 pence	£ 890
An average annual energy consumption of 18,000 kWh is assumed for all calculations, and all figures include VAT						

Figure 8. Prices of gas per kilowatt hour. (Source: www.confusedaboutenergy.co.uk)

Using the highest price from the above table, the amount of money needed to pay for gas as a person living in this house for the year will be:

Amount = 36,792kWhrs x 5.33 pence

Amount = 196,101.36pence

Amount = £1,961.01p

To spend £1,961.01p for heating in the year is relatively expensive. This is because the average annual cost of gas from the table above is £831. This proves the fact that the existing buildings in the Lenton community are not energy efficient. Looking at the cooling profile, there seems to be overheating especially in the summer months. The high insulation is preventing the heat in summer to be lost. This can be drastically reduced by opening windows. The above simulation graph was done with all windows closed and therefore it will be appropriate to open windows more in the summer months. Further research can be done into simulating with ventilation during the summer to really see the effect of ventilation on the cooling loads.

Redesign of buildings (Stage 2)

The site layout in stage one was redesigned for more solar access into the buildings. Even though the internal plan of each house was not changed, the heating and cooling loads for the site after changing the layout became better. The original site had buildings oriented to the east - west whiles the new layout had the buildings oriented to the north – south. The walls north and south elevations of buildings were thickened to about 400mm to serve as Mass wall for the building. The reason for doing it for all the north and south walls are that depending on the plans position on the site, the north walls can change to south walls. Sunspaces were introduced at the back of the back living room. The mass wall of the back living room remains unchanged and this will be a means of achieving some solar gains into the building. To prevent heat loss, the floor should be thickened as well and the glazing used should be of very low emissivity. When buildings are placed at the opposite site of the road, this sunspace will be facing the north and therefore the building will not benefit that much. This is why the bay windows were maintained at the front of the house to serve as direct solar gains into the building. Due to the terraced nature of the layout, the east and west walls are treated plain without any windows or doors. The buildings are joined to each other by these walls. When these walls end the whole lot in a block, the walls are treated as external and therefore thickness is given to them for thermal mass.

The integration of solar PV on the roofs of the building was also looked at. Even though there will be some radiation in summer, the focus was getting enough radiation incident of the roof for the PV. For this reason, the roof pitch was not changed.

This picture means when the back elevation is facing south, there is lesser space to mount PVs due to the smaller roof that joins the main roof. To get more space on that elevation, the smaller roof can be turned into a flat roof or the height of that side of the building lowered to lower the roof. This can be well seen in the elevations.

Analysis of redesigned buildings

At this stage, simulations were done to see the quality of the building fabric designed. The first point of call was to check how the building fabric alone was able to modify the macro climate into its own micro climate. After simulation, an average indoor temperature of 12°C and 20°C was achieved in winter and summer respectively. This was as a result of the materials listed below.

Table 2. Materials and their U-values.

Building Element	Components	U-Value W/m^2C
Roof	Concrete Roof tiles, 10mm Loft space, 200mm Mineral Wool quilt, 250mm Plaster board ceiling, 10mm	0.15
Wall External	Brick,100mm, Mineral Wool,200mm Thermalite shield block (aircrete), 100mm Plasterboard-13mm	0.15
Window	4mm low-e glass 12mm argon filled cavity 4mm low-e glass 12mm argon filled cavity 4mm low-e glass	0.814
Wall Internal	Min. wool quilt-100mm Plasterboard-13mm	0.358

The above table shows very low U – values for the building envelope. The external walls and the roof achieving the same U – value is good. The walls were adopted from the BRE 2007 offsite Hanson Ecohouse. With these material specifications, the heating and cooling loads were looked at.

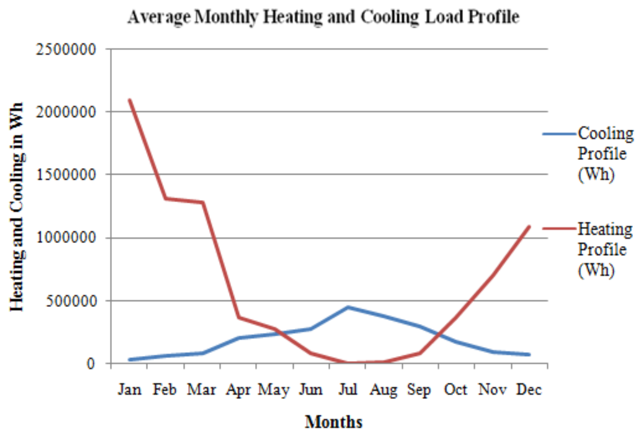

Figure 9. Graph showing Heating and Cooling Profile of modified buildings.

The above figure shows the heating and cooling loads for two terraced buildings which are together. Therefore the actual loads for one building will be exactly half of the figures above. This was plotted in line graph to see how close the trend is with the general ecotect trend. The trend looks very similar to that of the ecotect results with very high heating needed as usual in January the coldest month.

The monetary value of the total heating for the whole year which is 7645kWh will be 7645kWh x 4.62pence/kWh

Amount = 35,311pence

Amount = £ 353.11

This value as stated earlier is for two houses and therefore a house will be £ 176.56. To spend this amount for a year is really good and I will recommend for the houses in

Lenton if redesigned to this new layout. Due to the thermal resistivity of the building, there is a reasonable amount of cooling needed. Natural ventilation must be the first option to cool down the building an if not enough, mechanical ventilation can be introduced. Even though I am proposing the above for the Lenton houses, a comparison of the two sites was done to affirm this.

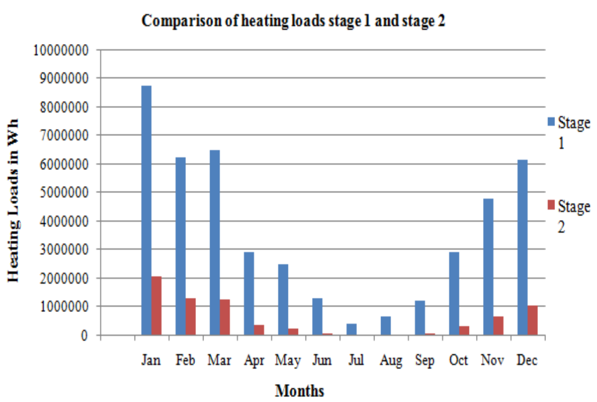

Figure 10. Total Monthly Heating loads Stage 1 versus Stage 2.

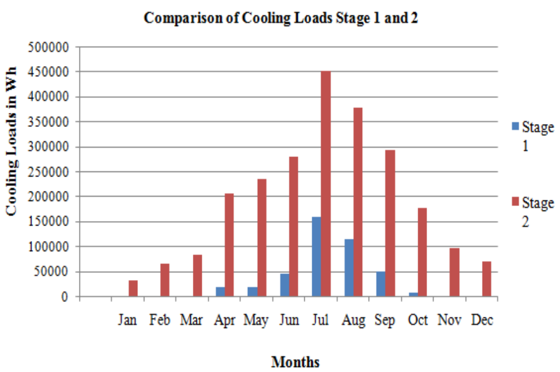

Figure 11. Total Monthly Cooling loads Stage 1 versus Stage 2.

The picture presented in figure 10 shows a huge margin between the heating loads in stage 1 and 2. Reference to January shows that stage 1 needs approximately 9000kWh to heat up the building whiles stage 2 needs approximately 2000kWh. This is a clear indication of how good the building fabric of stage 2 is. It is using less than a quarter of the energy needed in stage 1. On the cooling side, the picture is different.

The cooling load presents the direct opposite of the heating loads. Stage 1 needs very low cooling loads whiles stage 2 needs some appreciable cooling. A school of thought can now say that stage 1 is also good for the summer month, but this is technically wrong. It rather shows how low the thermal resistivity of the building is and this is why in most of the months no cooling is even needed at all. The cooling load of stage 2 can always be removed by natural ventilation. In a worse scenario where natural ventilation is not possible, energy generated from south facing PV cells can be used to ventilate the buildings mechanically. The highest cooling load in the year is in July and it is about 450kWh of energy. The total cooling energy load for stage 2 in a year is approximately 2,386kWh for 2 terraced buildings. Therefore the total for 1 building will be 1,193kWh. This means that the energy produced by PV cells should be equal to or more than 1,193kWh of energy.

Integration of Photovoltaic

This part gives in depth into PV cells integration on the roofs of buildings in stage 2 and the energy to be generated. The total roof space which is south facing is 28m^2. However not all this space can be used to mount PV cells. An offset of 0.20m was done from each side and then this was used as the effective area for PV cells. Approximate area of 24m^2 was used and modelled in Autodesk Ecotect.

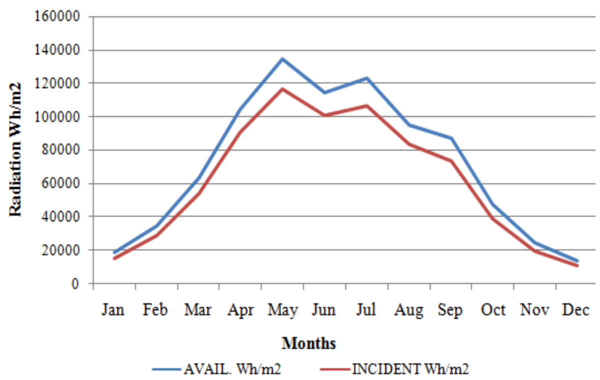

Figure 12. Plot of available solar radiation against incident solar radiation.

In July the collector had 107kWh/m^2 of energy incident on the collector. Therefore the total for the month based on the size of the collector is 2,509kWh. This supports the argument made earlier that the PV cells alone can be used for cooling of the building is natural ventilation is not possible. After taking 1,193kWh which is energy needed to cool the building from the generated energy the collector is producing, you will have a surplus of 1,316kWh of energy to run other things within the month. Looking at the trend line of both the available and incident radiation it is actually the same pattern with the incident falling a little lower than the available. This shows that there are some losses and it is higher in summer. The total energy produce by this collector on the roof in this stage is 17,486kWh. Even though there might be some losses before it is actual power to be used by appliances in the home, this can almost to take care of an average home in the UK with an annual electric energy demand around 18,000kWh. The option of exporting surplus into the grid for money or installing solar thermal on an area of the roof can be looked at. Removing some PV cells and installing solar thermal instead will reduce the cost of gas which would have been used for hot water. One thing that should not be ignored in all of this is that the PV cells or solar thermals are not free and comes with a cost. Therefore in depth financial analysis should be done factoring in the cost of setting these up for conclusions and choices.

Conclusion

The sun which gives solar radiation definitely has a great potential of been used for the heating of buildings in temperate regions. However since buildings create their own micro climates, it is only possible to get this potential benefit when planned and designed well. From the analysis above the key tool for realising the suns potential is by analysing the suns path with your chosen location. It was clear from this research that the sun in Nottingham can be best utilised by placing both active and passive systems southerly. This therefore shows that when planning for a cluster of buildings, weather data analysis should be done to know the best orientation of buildings for solar use. When this proper planning is done, developers will be able to in-cooperate solar design systems into their buildings for energy efficiency. The sum of it all is that the sun is of great potential for energy efficiency so lets us analyse and plan rightly for a sustainable future.

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