Mini-project report

Reducing a building's heating load with a rooftop greenhouse

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Abstract

A greenhouse has been built on top of the Seawater Greenhouse office in London to reduce the heating load of the building. Air warmed in the greenhouse by incoming solar radiation will be used to heat the office below. This report undertakes a preliminary investigation of the thermal behaviour of the building during the heating season from October to May using the New Method 5000, a simple manual method for evaluating the thermal behaviour of passive solar buildings. It has been found that the addition of the greenhouse generally reduces the heating load by 50% depending on the greenhouse construction.

1. Introduction

The current focus on reducing carbon emissions from buildings is producing ever stricter building regulations to drive up their energy efficiency [1]. In many buildings, space heating accounts for more than half of their energy consumption which provides a strong incentive to reduce heat loss from buildings and use lower carbon heating technologies [2]. This report details the preliminary investigation of one such technology; the integration of a greenhouse into the roof of the Seawater Greenhouse office in London. It is hoped that the office below will be heated at least in part by air from the rooftop greenhouse warmed by trapped solar radiation. As well as reducing the heating demand of the building, the greenhouse will provide a growing area for small crops.

The thermal behaviour of the greenhouse and office building has been modelled using the New Method 5000 (detailed in the European Passive Solar Handbook) during the heating season from October to May [3]. From this, estimates of the building heating requirements have been made. The calculation method has been tested against temperature measurements taken from the greenhouse, and results are presented on the effect of adding a rooftop greenhouse, of lowering the office thermostat, and of using different materials to construct the greenhouse.

2. The building

Figure 1 shows a schematic diagram of the greenhouse and office building. It consists of two heated floors topped with an unheated greenhouse. The building is situated in the end of a row of terraced houses, separated from the next house on the north side by an uninsulated brick wall.

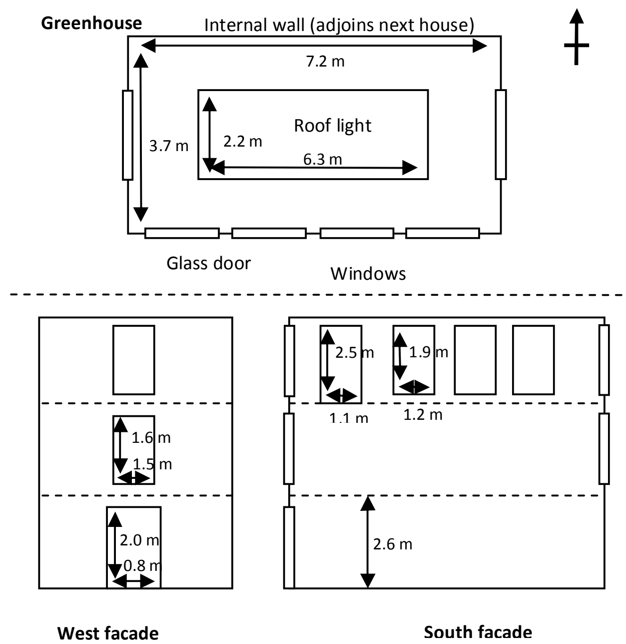

Figure 1. Schematic diagram of greenhouse and office layout.

The walls of both the office and greenhouse are steel frame with timber studs and high levels of insulation. The roof is of the same construction, differing only in outer surface covering. South-facing windows are single glazed while east and west-facing windows are double glazed. The roof is mostly taken up by a roof light made from an inflated double layer of polythene. The construction of the greenhouse was completed shortly before Christmas 2010, so the office space was not fully insulated during the project. Photographs of the greenhouse are shown in Figure 2.

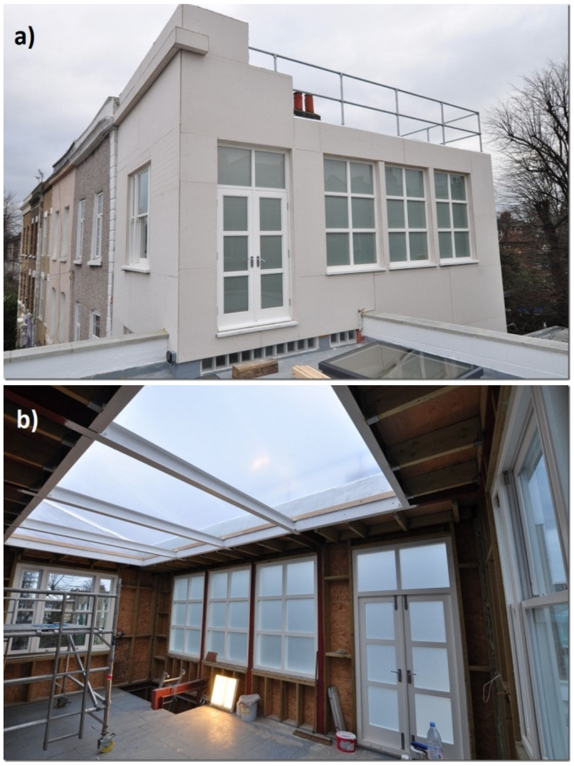

Figure 2. Photographs of a) the greenhouse exterior and b) the greenhouse interior.

3. New Method 5000

The New Method 5000 is a simple manual method allowing for a preliminary analysis of the thermal behaviour of passive solar buildings. The rooftop greenhouse has been modelled as an unheated buffer space or sunroom. It is assumed that plants will not be grown in the greenhouse during this period since this would require the greenhouse to be heated at least at night.

The total rate of heat loss from the building (LL) is evaluated from the heat loss rate across each building element (walls, floors, windows, and so on) based on its thermal conductance and area, and the ventilation rate of the building. The ventilation heat losses of the office are reduced on the assumption that it is ventilated by preheated air from the greenhouse. Monthly heating loads (Q_{ng}) are then calculated according to the difference in the average monthly outdoor temperature (t_o) and the thermostat set temperature (t_t) of the office. This is the heating load based purely on heat losses from the building, given in Equation 1:

$$Q_{ng} = LL(t_t - t_o)N \qquad (1)$$

where N is the number of days in the month.

Heat gains are calculated separately. They are split into solar gains which can be direct (sunlight entering through the office windows) or indirect (solar energy trapped in the greenhouse), and internal gains arising from the heat given off by people and equipment in the office. Standard figures for sources of internal gains were taken from CIBSE Guide A [4]. Calculation of the useful fraction of these gains takes into account the thermal inertia of the building and the gains/load ratio. The auxiliary heating load is found as the difference between the heating load given by Equation 1 and the useful gains.

4. Results

4.1. Validation of model against measured temperatures

The greenhouse temperature and outdoor temperature in London were recorded over 6 days in January. During this period, the office was not heated. The greenhouse temperature was also calculated using half-hourly solar radiation data for Clapton [5-7]. The solar radiation entering the greenhouse (E_s) and its resulting temperature (t_g) are related to the rate of heat loss from the office to the greenhouse (L_h) and from the greenhouse to the outside (L_g) by Equation 2.

$$t_g = t_{gng} + \frac{E_s}{0.024(L_h + L_g)} \qquad (2)$$

t_{gng} is the greenhouse temperature without solar gains, taken as equal to the outdoor temperature. Table 1 compares the calculated results to the measured temperatures.

Solar radiation data was not available for the entire day on 20th and 21st, giving lower calculated temperatures. None was available for the 17th. This leaves the 16th, 18th and 19th of January where the calculated temperatures are in fairly good agreement with the measured temperatures.

Although more data is needed to draw firm conclusions, the agreement of calculation and measurement indicates that the relationship between the total incident solar gains in the greenhouse and the resulting temperature of the greenhouse is reasonable. The calculation takes into account the heat loss from the lower room to the greenhouse and from the greenhouse to the outside, so these figures are also reasonable. However, in order to determine the accuracy of the calculated heat loss rate from the office directly to the outside, records of fuel consumption required to keep the office at a set temperature must be kept.

Date	Outdoor temperature (°C)	Calculated greenhouse temperature (°C)	Measured greenhouse temperature (°C)
16th	10.8	14.9	14.1
18th	5.0	13.9	13.8
19th	3.7	11.9	11.2
20th	4.4	6.4	10.0
21st	3.0	10.4	11.3

Table 1. Comparison of calculated and measured greenhouse temperatures.

4.2. Effect of greenhouse addition

In all that follows it has been assumed that the office is occupied and therefore requires heating for 8 hours each day, with a thermostat temperature of 21°C according to CIBSE's recommendations, unless otherwise specified [4]. Average monthly solar radiation data have been taken from the European Solar Radiation Atlas and average monthly temperature data calculated over a similar period have been taken from Met Office records [8-9].

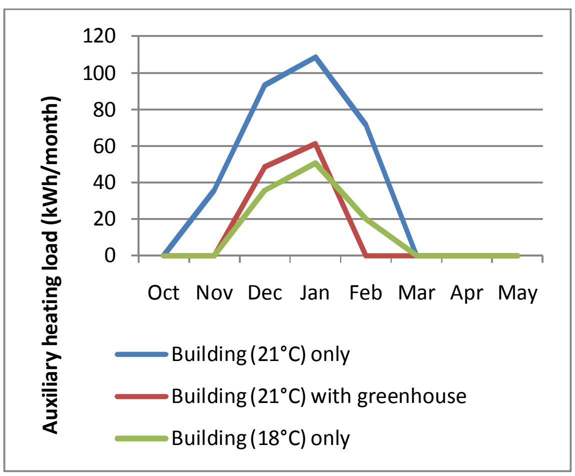

Figure 3. Auxiliary heating load of the building with and without a greenhouse.

Figure 3 illustrates the effect on the auxiliary heating load of adding the greenhouse described previously to the building. Without the greenhouse, the heating season extends from November to February. The addition of the greenhouse reduces the heating load by almost 50%, and consequently the office only requires heating in December and January. For this scenario, the calculations indicate that uncomfortable temperatures might occur in the office in May, i.e. temperatures could be too high unless some form of cooling is used. It should be noted that ventilation of the office with greenhouse air is always assumed. Stopping this airflow solves the problem in this case. Lowering the thermostat temperature by 3°C (shown by the curve at 18°C) more than halves the auxiliary heating load, and reduces the heating season to between December and February. Adding a greenhouse to this scenario eliminates the need for auxiliary heating, and begins to produce uncomfortable temperatures in May which are not alleviated by stopping airflow from the greenhouse.

4.3. Effect of different greenhouse materials

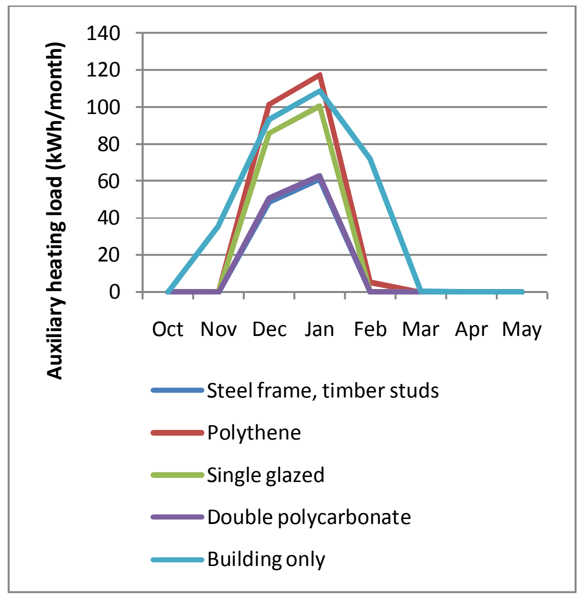

Figure 4. Auxiliary heating load of building with different greenhouse constructions.

Figure 4 illustrates the effect on the auxiliary heating load of using different materials to construct the greenhouse. All of the greenhouses represented are separated from the lower room by a timber ceiling and have a brick north wall. The polythene greenhouse performs slightly worse than the office alone during December and January, but significantly reduces or eliminates the auxiliary heating load in adjacent months when sunlight levels increase. The double polycarbonate greenhouse performs as well as the steel frame one, reducing peak heating season loads by roughly half. However, all but the polythene greenhouse might induce uncomfortable temperatures in May.

5. Conclusions

The results show that the addition of a rooftop greenhouse to a well-insulated building significantly reduces its auxiliary heating load, often by 50% or more, and sometimes eliminates it depending on the thermostat set temperature. The greenhouse constructions producing the greatest heat load reductions are the steel frame walled and polycarbonate. However, it is possible the office will experience uncomfortable temperatures from May onwards with a rooftop greenhouse unless some method of cooling is used.

These results serve as indicators only due to the simplified model used and the accuracy limitations inherent in using monthly averaged data.

6. Further work

There is much further work which can be done given these encouraging results. The results can be further refined using more detailed data such as daily or hourly measurements, and the model tested more fully by comparison with data collected over a year on temperatures within the building and its fuel consumption. The key points which have not been addressed here are the behaviour of the building during the cooling season and the influence of plants in the greenhouse. It might be possible to alleviate uncomfortable office temperatures by passive means such as opening windows, or opening a roof vent in the greenhouse to draw hot air upwards.

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