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Integrated solar thermal upgrading of multi-storey housing blocks in Glasgow

T. R. SHARPE*, C. D. A. PORTEOUS AND W. J. K. MACGREGOR

*Mackintosh Environmental Architecture Research Unit
Mackintosh School of Architecture
Glasgow School of Art
167 Renfrew Street
Glasgow G3 6RQ
T.Sharpe@gsa.ac.uk

Abstract

This paper will describe a proposal to upgrade a thermally sub-standard multi-storey housing block (Type T84), where height and climatic exposure are significant, to demonstrate the effectiveness of passive, active and hybrid solar techniques to minimise space and water heating loads while enhancing the quality of air in both shared and private spaces. Proposals include large-scale freeze tolerant SDHW array, multi-storey, part-glazed, part opaque, permeable solar air collectors delivering pre-warmed air to a north-facing cavity wall, small window-integrated, east/west facing vertical solar air collectors and glazed-in east/west facing recessed balconies, and heat recovery from the extract system for kitchens and bathrooms.

SOLAR TOWERS IN GLASGOW: INTRODUCTION

Local Authority Housing in Glasgow

Glasgow City Council is Scotland's largest landlord of rented housing. Over the past 30 years significant changes to some statutes and standards, together with changes to social norms and aspirations, but without corresponding investment in energy conservation and convenient, affordable systems of heating and ventilation, have resulted in thermal discomfort and extensive incidence of condensation and mould growth in housing through the city.

Tower blocks have had the added disadvantage of greater exposure to the cooling effects of driving rain, and in order to address these problems Glasgow City embarked on a programme of recladding in the mid-1980s. However whilst the Scottish House Condition Survey of 1996 [1] indicates investment in heating systems, insulation, double-glazing and so forth, there is no corresponding drop in the incidence of condensation. Therefore, there is an evident need for higher standards of energy efficiency and ventilation. Accordingly improvement programmes are becoming more comprehensive, moving from partial cladding of facades to overcladding of all vertical facades and the roof. Once the decision for such major investment has been made, it seems to make sense to spend the relatively little extra required to upgrade the thermal role of the overcladding to address the issues cited above more comprehensively. Two eight-storey blocks, designated T84s and sited just south of the M8 on Glasgow's south side, have been chosen by the City Council to test this proposition.

Existing Characteristics and Challenge

The blocks are 8 stories high with four flats to each floor, two being, 3-apartment, and two being 2-apartment, the asymmetry being taken up with the core of lift and stairs and a drying area on the east edge of each floor (Figure 1).

Figure 1. Block as existing.

The structure comprises precast concrete floors and roof supported on loadbearing brick walls with reinforced concrete spines at each corner. The general arrangement is an east/west orientation with living rooms and kitchens located on the north and south edges. This arrangement leaves substantial amounts of the north and south facades clear of windows. External cavity brickwork has a U-value of 1.55 W/m^{2}K, and there are cold bridges around windows and in other locations such as the wall between bedrooms and the unheated staircase. The recessed balconies also add to the exposed perimeter of one bedroom in each flat. The original steel-framed, single-glazed windows set in timber sub-frames, have had secondary glazing added due to the proximity of a motorway, and each room has had a mechanical ventilator added. Means of heating is a mixture of electric storage units and on-peak radiant heaters. The tower therefore represents a typical situation of excessive heat loss as well as an awkward means of heating and ventilation.

THE PROPOSALS

North and South facades

The north and south facades constitute the largest areas of uninterrupted wall. By cladding in the form of solar air collectors on the south facade, one on each side of the kitchen windows, and transferring preheated air to the cavity in the north wall, the effective U-values will be significantly lower than with the equivalent standard recladding and insulation. This has an added advantage since these walls bound the most highly heated rooms. In the north wall the cladding and insulation will be placed on the outside of the outer leaf of brickwork; while on the south wall the existing outer leaf will act as the absorber with the insulation blown into the cavity behind. In order to increase efficiency of the system and ensure distribution throughout the cavity in the north wall, a fan will transport the air from each south facing collector across the roof in insulated ducts (Figure 2).

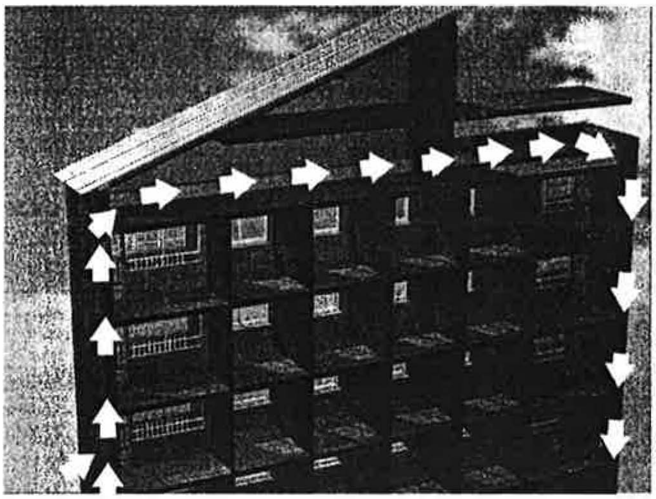

Figure 2 Air flow from South to North facade

Air enters the system from the first to fourth floors of the south wall which will be clad in opaque overlapping slates. Macgregor [2] has reported this technique with respect to small tilted arrays, which built on a feasibility-study by Stuart [3]; and Kennedy and Macgregor [4] reported the results of further tests with respect to vertical transpired plate solar air heating collectors. Part of the 5th floor cladding will be a photovoltaic array sized to power the fans, with the thermal energy, given off as electricity is generated removed from the back of panels in the upward air flow. The remaining floors plus parapet will be clad in single glazing, partly designed to boost the rise in temperature and partly to prevent flow of air back out at the top, given its height. The system is designed to be self-regulating in that during very overcast conditions and at night the fans will not run and dampers will inhibit reverse thermo-circulation driven by heat lost to the north cavity via the inner leaf of brickwork.

East/West Facades

The highly fenestrated east and west facades will also have their U-values reduced by a combination of external and cavity insulation to take account of specific cold bridges at recessed balconies and drying areas. In addition the recessed balconies will be glazed-in by means of full-height sliding units (Figure 3).

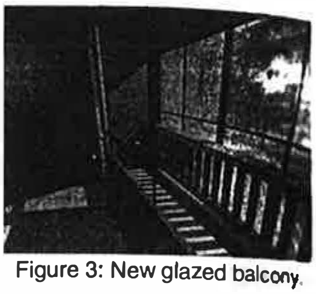

Figure 3: New glazed balcony.

When closed, trickle vents in inner and outer screens will admit pre-heated air from this new unheated buffer space to the living room, the flow controlled to some extent by a new extract fan in the kitchen which connects directly with the living room. In cold or overcast weather, heat lost from the living room to balcony is recovered in terms of ventilation, while in spring and autumn solar radiation will be the dominant input.

When completely open, the space can revert to an open-air balcony. If the inner windows and door are wide open, the balcony will tend to merge thermally with the living room, but provided periods of such opening coincide with sunny weather, the performance will not be adversely affected. The existing precast concrete balustrades are retained and now have a secondary function as solar absorber cum thermal store. The south-facing side walls of the balcony will also be mostly in radiant view of the sun for significant periods and the other side wall and floor will function as secondary storage. All windows will be double-glazed, including the outer screens of balconies. Not only does this ensure comfort in the buffer space for more of the time than would have been the case with single glazing, it also inhibits surface condensation.

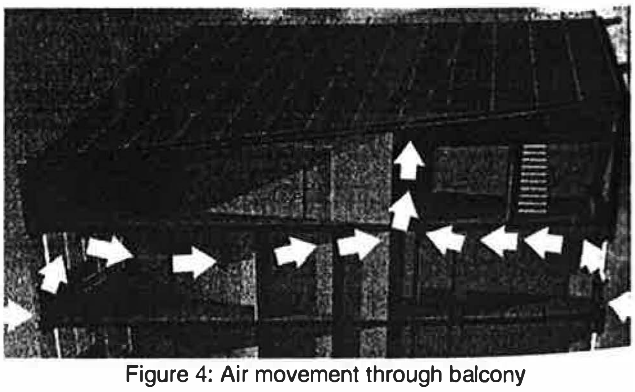

Figure 4: Air movement through balcony

In addition, the new windows to bedrooms will incorporate small solar air collectors below cill level. Mock-ups measuring the performance of such devices have been reported by Porteous, Ho and Kilmartin [5] and Porteous and Baker [6]. It remains a passive system which exploits solar radiation during daytime (to air the bedrooms even when unoccupied) and recovers heat lost from within the room at all times provided the direction of air-flow is inwards. This will depend on a number of circumstances - the influence of the mechanical extract from bathrooms (located across the hallway from bedrooms), thermal buoyancy due to the rise in temperature within the collector and the velocity and direction of wind (Figure 4).

Extract air is ducted up through an existing shunt system which serves bathrooms, now extended to include kitchens on a continuous 24-hour basis. Fresh air enters below the roof-cladding, and is passed through an air-to-air heat recovery unit and then utilised to supply air to the communal lobbies at each floor level. The purpose of this final component is to improve the poor quality of air within the communal lobbies without cooling them.

Roof

Having designed the vertical cladding/glazing to minimise U-values and tackle loss by ventilation, the roof offers the opportunity to again minimise heat loss by transmission, but more importantly, to address the cost of heating water for all the flats. Recent work by MacGregor [7] at Napier University indicates several advantages for a freeze-tolerant flat-plate collector. These include reduced time for installation and reduced maintenance, as well as the ability to handle both salt water and fresh water. The proposed array would be of approximately 90 m^2 and integrated with a new 'umbrella' roof tilted at 30 degrees to the horizontal and covering the existing plant room together with an additional volume used to house new plant such as the 2,700 litre preheat tank associated with the collector (Figure 5).

Figure 5: View of new roof.

MODELLING - PREDICTED SAVINGS

TAS has been used to model the 28 dwellings in the T84 tower together with associated spaces on each of the seven floors, firstly as existing, and then as proposed.

Heating demand schedules/temperatures and levels of occupant-induced ventilation acknowledge measured data from other energy-efficient projects in Glasgow [8]. At Easthall the mean rates of air change (infiltration + ventilation) were estimated to be 1.83 ac/h for autumn, 1.27 ac/h for winter and 2.00 ac/h for spring; while mean 24-hour living room temperatures from September to May were 21.4^{0}C, while the mean for the rest of the house was 19.0^{0}C and outside averaged 6.8^{0}C. In this case the weekday heating periods are from 7.00-9.00 and 17.00-22.00 and continuously from 7.00-22.00 at weekends. The settings during periods of heating are 25^{0}C for living rooms and 22^{0}C in other spaces for both 'before and 'after' scenarios. This means that the former will achieve lower temperatures compared with the latter. Therefore the difference between respective heating loads is an underestimate in terms of comparing like with like. The following indicates achieved temperatures for living rooms and bedrooms for typical days in autumn, winter and spring:

	before improvements	after improvements
Sep. weekday	18.1^{o}C living room	19.8^{o}C living room
	17.4^{o}C bedrooms	18.6^{o}C bedrooms
Jan. weekday	16.0^{o}C living room	17.3^{o}C living room
	15.0^{o}C bedrooms	16.0^{o}C bedrooms
Apr. weekday	18.1^{o}C living room	20.2^{o}C living room
	17.4^{o}C bedrooms	18.6^{o}C bedrooms

Table 1: Average internal temperatures

The 'before' scenario represents the present heating system of combined storage and direct electric emitters, while the 'after' scenario has the proposed new wet system with thermostatically controlled valves on radiators and with centralised gas-fired boilers (Table 1).

Simulations by computer, using a standard climate-year for Glasgow, have been supplemented by manual calculations for the south and north walls using climatic data by Page and Lebens [9], and with other critical values based on previous measurements of test rigs and pilot projects in Edinburgh. Such values are: 0.022 kg/sm^2 specific air mass-flow rate transpired through the solar slates (set 65 mm from original brick wall surface to keep duct velocities low), based on work by MacGregor [10] solar slate collector efficiency approximately 50%; mass flow rate of 1.58 kg/s for outside air being drawn through each side of the collector (this is primarily what governs efficiency), and corresponding volume flow rate of 1.32 m^3/s; velocity behind glass of 3.38 m/s; the efficiency of the upper glazed section at this flow rate is also estimated to be 50% based on experimental work by Kennedy and MacGregor [11], so that the combined transpired plus glazed is taken at this value. The air flow through the paired collectors will be driven partly by natural buoyancy (thermosyphon or chimney effect) and partly by variable-speed fans, one per collector and each powered by PV. The principal resistance to air flow to be met by the fans arises from the need to suck air through the transpired plate (solar slate) collector, and the pressure drop is estimated to be 100 Pa, based on experimental work by Stuart [12]. It is assumed that resistance's due to other ducts and cavities will be balanced by the natural syphonic action of the heated air.

Table 2: Summary for one tower block (Jura Court, Glasgow): (all values in kWh)

	Existing tower block (before)			Proposed tower block (after)			
Space Htg.	Q^{gr}- Q^{i}	Q^{sol}	Q^{htg}	Q^{gr}- Q^{i}	Q^{sol}	Q^{htg}	SAVING
Autumn (Sep.-Nov.)	110,429	20,889	89,540	43,052	21,632	21,420	68,120
Winter (Dec.-Feb.)	147,462	6,962	140.500	59,893	11,705	48,188	92,312
Spring (March-May)	120,391	45,934	74,457	47,709	43,010	4,699	69,758
Summer (March-May)	59,669	52,776	6,893	23,062	23,062	00,000	6,893
Totals	437,951	126,561	311,390	173,716	99,409	74,307	237,083
Water Htg.	Q^{w}	Q^{wsol}	Q^{wnet}	Q^{w}	Q^{wsol}	Q^{wnet}	
	49,770	0	49,770	49,770	31,300	18,470	31,300
TOTAL	for one tower block						268,383

Legend: Q^{gr} = gross space heating load; Q^{i} = incidental gains; Q^{sol} = useful solar gains; Q^{htg} = net space heating load;
Q^{w} = gross water heating load; Q^{wsol} = useful solar gains to water; Q^{wnet} = net water heating load.

Sizing of the PV-array is based firstly on peak solar irradiance and flow rate conditions, the former approximately 500 W/m2 on a south-facing vertical surface in Glasgow; and secondly on a typical efficiency of crystalline PV cells of 10% using gross area. Two fans, one per 8.6 m^2 PV array located on each side of the kitchen windows, with a peak electrical power of 430 W are estimated to be required and the maximum temperature rise through the collector is estimated to be 37 K.

PREDICTIVE RESULTS

Predictive results indicate an annual saving of 237,083 kWh for each tower (average of 8,467 kWh per flat) with respect to space heating and 31,300 kWh (average 1,118 kWh per flat) with respect to water heating (Table 2).

Taking the solar irradiation at 477 kWh/m^2, the manually estimated solar yield of the south facing collector on each block over a heating season from September to May is 55,810 kWh (average of 1,993 kWh per flat):

The relatively prolonged heating season results from the high latitude and cool maritime climate of Glasgow - e.g. average dry-bulb air temperatures are only 12.3^{0}C and 10.3^{0}C respectively in September and May; and it is assumed that any of the available solar heat which is not useful from September to May will be compensated by some useful solar gains from June to August, when cold 'spikes' often merit space heating.

CONCLUSIONS

1] In terms of space heating, there is a respectable 76% energy saving, or over 9,500 kWh per flat per annum. Taking into account the favourable switch of fuel from a combined storage and non-storage electric tariff, estimated to be 5.5 p/kWh, to gas at a negotiated tariff of 0.58 p/kWh (0.68 @ 85% efficiency), the financial difference is very significant, much of the benefit passed directly to the householder.

2] In terms of water heating, compared with typical consumption for dwellings of this size, the predicted contribution of 31,300 kWh represents a saving in the order of 63% and over 1,100 kWh per flat.

3] The extra cost of the innovative solar features compared with a normal overcladding project with an upgraded heating system, but without a computerised building management system (BMS), is estimated to be approximately £10,000 per dwelling.

4] Although the extra investment is significant, the aim and objectives of the project (that of validating solar techniques which enable energy efficiency with warmth but without stuffiness, and plentiful hot water) are considered imperative rather than optional ideals. In particular, with respect to space heating, it secures quite high, but realistic and healthy, rates of air change for a very modest energy load of 2,650 kWh.

5] In the pay-back analysis of such packages it is of course recognised that the cheap components such as insulation do much of the work in terms of reducing the kWh-load, as do relatively more expensive aspects such fuel-switching in terms of reducing final running costs. Nevertheless the broader consequences of a warm and healthy indoor environment (e.g. in relation to reducing incidence of asthma) and the extra money put into the pockets of those on low-incomes due to low running costs, underpin the worth of the project (Figure 6).

Figure 6: Block as proposed.

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