Displacing Electrical Energy for Drying Domestic Laundry by Practical Solar Upgrades - Proposed Glasgow Housing Case Studies

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Abstract

Recent surveys in Glasgow carried out as part of a project 'Environmental Assessment of Domestic Laundering' have provided figures for electrical consumption for drying washing loads by tumble drier. Case studies include communal provision for drying, varying from covered areas (passive drying) to full laundrette facilities (active drying) and equivalent individual facilities. This paper will propose theoretical upgrades that evaluate how much of the average electrical consumption for tumble driers (communal and individual) can be displaced by solar energy. In the case of communal tumble driers, the objective is to install as much building-integrated PV as practical and compare its total predicted annual electrical output with demand. In the case of communal passive drying spaces, the objective will be a hybrid solar upgrade such that such passive drying becomes significantly more efficient than at present with some active solar assistance; thus motivating greater usage and displacing electricity that might otherwise be used for individual tumble driers in dwellings. The underlying aim is to eliminate the need for energy-sapping drying in the home by whatever means, thereby also lowering internal humidity. In this quest, the paper also outlines practical solar techniques to improve the potential to dry some washing passively within the footprint of the dwellings. It concludes that such solar upgrades are technically feasible, could displace significant amounts of grid electricity and at the same time enhance internal domestic environments.

Keywords: BIPV housing retrofit; tower blocks; low-rise blocks

1. Introduction

The output agenda from a survey of environmental impacts arising from domestic laundering inevitably centres around displacement of energy derived from fossil fuels, and utilising solar irradiation, as one means of enabling such displacement, is an appropriate goal. Although the proposals described in this paper are entirely theoretical and at feasibility stage, the buildings and existing conditions are real, and both the housing associations in Glasgow involved have indicated an interest in exploiting solar energy in order to assist in tackling both fuel poverty and carbon emissions. As housing becomes more energy efficient in terms of space heating and water heating, which may be achieved in part by both passive and active solar thermal techniques, and use of low energy lighting becomes universal, the relatively large electrical loads for appliances provide opportunities for further solar savings. Since drying of domestic laundry has moved historically from an entirely passive process, with solar energy playing a key role, to a predominantly active and energy-intensive process reliant on grid electricity, it currently consumes a significant amount of energy. The status quo in this regard uses data acquired from the two specific housing associations, as well as others in Glasgow, which can be compared with key national figures:

90% of homeowners now own a washing machine and 59% a tumble drier [1];
drying domestic laundry comes to 4.3% of domestic energy consumption in the UK [2];
in the Glasgow survey of 100 houses, 38% used tumble driers, less than the homeowner UK value;
in the same survey sample, 37% of those who dried exclusively passively inside their homes had mould in rooms associated with drying, and turning up heat to assist drying was common;
measured electric consumption in this survey per load for a domestic tumble drier was found to be 5.1 kWh, while that for washing was 0.9 kWh - a differential factor of 5.7 [3];
mean weekly consumption/person for washing (20 houses) was found to be 2.36 kWh [3];

mean weekly consumption/person for tumble drying (4 houses) was found to be 11.53 kWh [3];
extrapolating the last two lines for a family of 3 suggests annual washing+drying of 2,166 kWh;
the equivalent figure for drying alone is 1,800 kWh, 7.5% of mean UK domestic energy totals [4];
weekly monitoring of the communal laundry in the 15-storey tower indicated 70 cycles of drying at 8.5 kWh = 595 kWh, and 84 cycles of washing at 0.7 kWh = 58.8 kWh, differential factor > 10 [3];
extrapolating these values suggest almost 31,000 kWh for drying and just over 3,000 for washing;
the equivalent value for drying only at the 19-storey towers is 42,120 kWh, the pro-rata weekly cycles being 112.5 at 7.2 kWh, based on the maximum designed population for respective towers.

Accepting that the sample size in the Glasgow surveys is relatively small, extrapolation of values should be treated with some caution. However, if one treats the figure of 1,800 kWh for drying by a family of three as indicative, it would be a large proportion of the total energy consumption once space heating and hot water loads drop in line with anticipated efficiency gains. Similarly the values for the two tower blocks will serve as benchmarks for the purposes of this paper.

The specific housing schemes used for this feasibility study both date from the 1960s and are due for thermal upgrading to satisfy the Scottish Housing Quality Standard (SHQS). Although both housing associations involved have shown an interest in exploiting solar energy, this feasibility study is theoretical. The aim is to outline what might realistically be possible, especially once the UK Feed In Tariff (FIT) is operational. A relatively large-scale building integrated photovoltaic (BIPV) option is offered for tower blocks - one a 15-storey tower with a well-used communal laundry at ground level; another a 19-storey tower with free communal electric dryers only, again at ground level. More modest interventions are proposed for 4-storey linear blocks, these common to respective tower-block housing areas - this time BIPV linked to air-source heat pumps to augment an enhanced passive solar strategy for shared covered drying spaces adjacent to stairwells. Both types are typical of this period, and although not all towers have a communal laundry facility, the capability of such a provision is present. The other fairly consistent factor for towers is their orientation. The main facades of the particular two cases used here face east and west, and have relatively blank south-facing walls. The only windows are to kitchens and these have a relatively high sill height, and so offer reasonable scope for stacked PV arrays. Orientations of low-rise, 4-storey blocks vary from east, through south to west. The block chosen to illustrate the solar intervention for this study is on the same site as the 19-storey towers, faces due east-west and has shared drying rooms at first and 3rd floor levels, each serving ten households. The potential for PV is thus more handicapped here than is the case for the tower blocks.

2. Methodology

The methodology reflects the feasibility stage of the proposed interventions. It is therefore very straightforward, involving design-stage architectural details and ballpark calculations of PV output, based on measurements for other PV installations in Scotland and the UK. Rather than detailed modelling, indicative shading of arrays at key points in the year supports these values - mainly from neighbouring buildings, but also self-shading to a limited extent. In the case of the high-rise communal facilities, estimated PV output totals can be compared with specific laundering energy demands. For the low-rise communal drying spaces, the PV output can be tested against the energy needed for improved efficiency, integral to the proposed intervention; in this case also adopting a speculative approach as to consequent changes in individual habits that result in energy savings.

Thus, in the case of the tower blocks, predicted net annual output from PV is compared with the predicted energy demand for machine drying, based on extrapolation of short-term measurements. Should output exceed laundering demand (drying in the first instance), there are other significant communal electric loads that can be usefully offset - notably for lifts and lighting.

In the case of the 4-storey blocks, the aim of the proposed upgrade is to make communal drying more efficient, and therefore more appealing than at present; thus lessening the use of individual domestic tumble drying and/or other unsuitable means of drying within the home. There are therefore two key aspects to the methodology: a) to determine whether the reconfiguration of the existing window apertures to include BIPV can supply enough energy to significantly shorten drying time in association with improved passive solar gain, targeted radiant heating and actively augmented ventilation; b) conduct a range of 'what if?' scenarios in terms of the potential energy reductions and related environmental benefits this efficiency gain could bring about, with quantities based on previously monitored data for social housing in Glasgow.

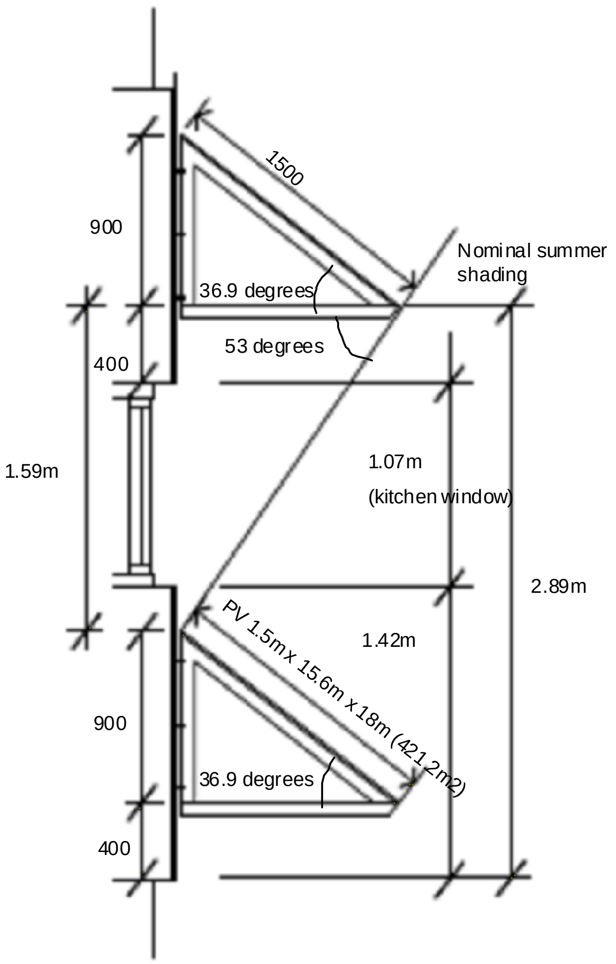
3. High-rise BIPV proposal targeted at communal electric drying facility

There are four 19-storey towers owned by Queens Cross Housing Association (QXHA) located at Westercommon in north Glasgow, oriented on a near due north-south axis and positioned relative to each other so that only the most northerly tower will be significantly shaded by another during the main part of the day. For example, at the equinoxes half of the arrays will be fully shaded for approximately 20 minutes before midday, and partially shaded for 1 hour 20 minutes; while at the winter solstice full shading of all the arrays will last about 30 minutes and partial shading of all arrays for 1 hour 45 minutes; and no shading will occur from this source at the summer solstice. Also, at the time of the summer solstice, two of the southerly towers will be shaded in late afternoon, by the adjoining tower to the west. - for example, circa 20% PV shaded at 17.20 British Summer Time, the partial shading having edged on to the facade some 80 minutes earlier and due to finish about an hour later when the azimuth of the sunlight is parallel to the PV array.

Arrays are also designed so that, on the summer solstice, the topmost one is not shaded at solar noon by the projecting eaves of the roof. However the eaves will shade the top array during the first and last hours of sunlight at this time. The sizing of the proposed arrays has been based on maximising available collection area on the one hand and minimising shading from one tier to the next on the other. This led to a projection of 1.2 m and an array width of 1.5 m set at a favourable tilt of 36.9 degrees for this latitude of 55.9 degrees, Fig. 1 (note that array width has been increased since submission of the extended abstract). That will give some shading during the central summer period to the top row of cells only on each array around solar noon. Thus overall, self-shading from the eaves, from one array to another, and from one tower to another, is of a minor nature, and one must also bear in mind that a relatively large proportion of useful solar radiation for PV in Scotland is diffuse. This resulted in the pragmatic adoption of 80 kWh/m^2 net annual output. This value is also based on grid connection, with the number of inverters per block kept to the minimum practical. Since there will be 18 arrays, starting at 1st floor level and each 15.6 m long, the total collector area per tower is 421.2 m^2, giving a predicted annual output to the grid of 33,700 kWh.

Estimated annual consumption from three tumble driers in each tower being 42,120 kWh, the BIPV output represents 80% - i.e. a 20% reduction in usage could result in total displacement.

Similarly there are five 15-storey towers owned by Cube Housing Association (CHA) located at Maryhill, somewhat further west in north Glasgow, this time oriented 8 degrees off a north-south axis (i..e. south façade facing 8 degrees west of due south), with two of the five blocks capable of shading neighbouring towers. However, since the blocks are lower by four floors, or about 10 m, and the spacing is not proportionately closer, the partial over-shading between adjacent blocks is rather less than the Westercommon set. Since the floor-to-floor heights are the same in each location, the PV sectional dimensions and tilt also remain the same, and with the width marginally greater at 15.9 m, the total area of PV array per tower is 333.9 m^2 (1.5 x 15.9 x 14). Using the same net annual output value of 80 kWh/m, this indicates a contribution to the grid of some 26,700 kWh, which is 86% of the predicted drying load in the existing communal laundry. Hence in this case a smaller 14% reduction of drying cycles over a year would provide total BIPV displacement.



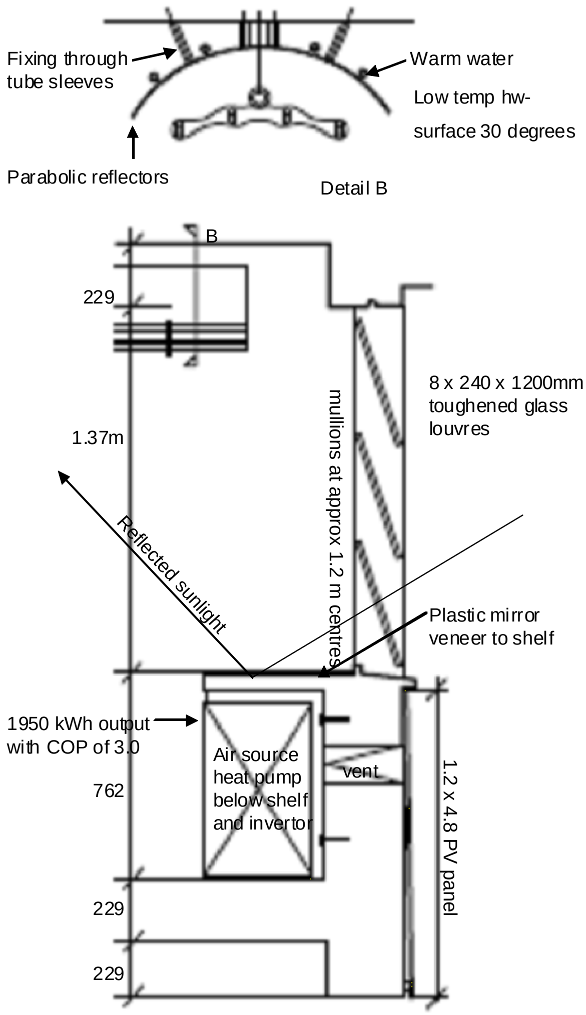


Figure 1. Westercommon Road - South Façade Detail of PV Arrays	**Figure 2b.** Detail Section A

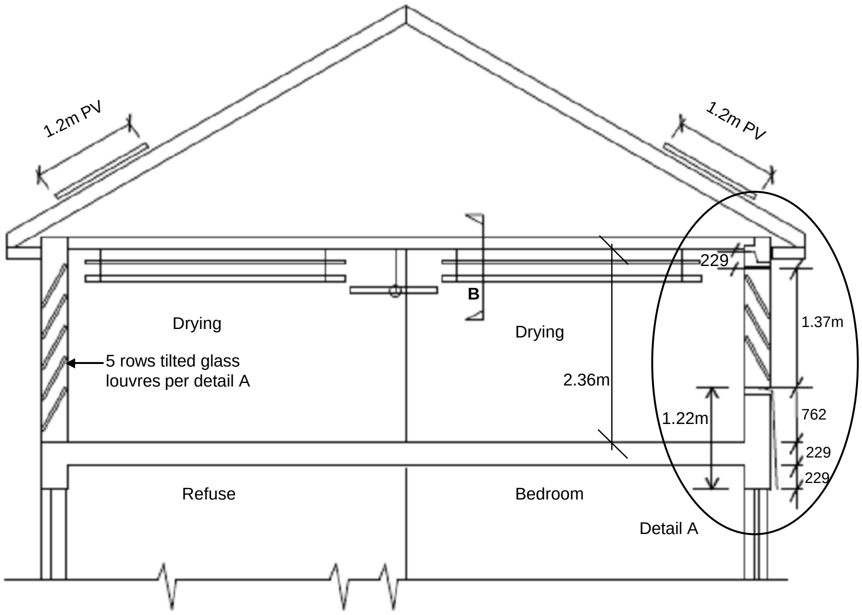
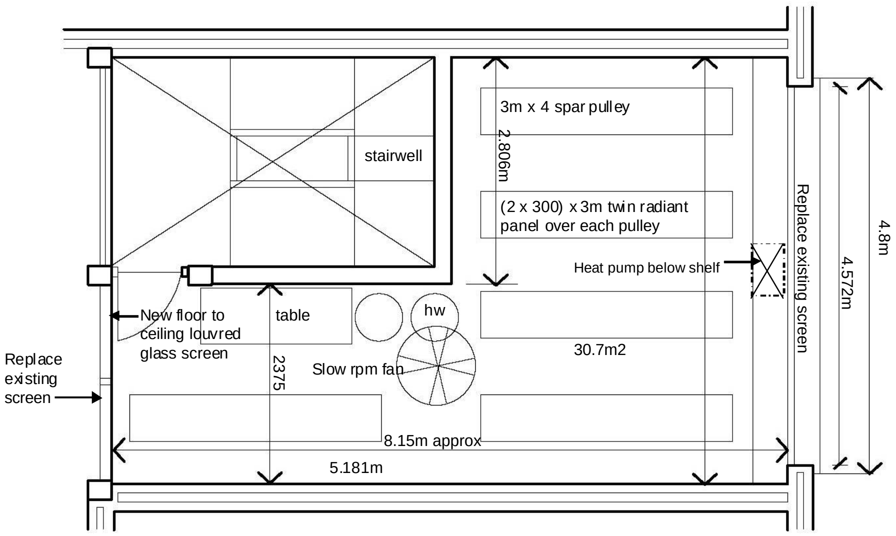


Figure 2b.
Section through 1st Floor Drying Space – 4 Storey Maisonettes (Above)
Plan of 3rd Floor Drying Space (Below)



4. Low-rise BIPV plus associated upgrade to communal drying spaces

For the four-storey blocks, the proposal concerns a more complex interactive upgrade to existing covered drying spaces. These are presently poorly lit, naturally ventilated, unheated indoor rooms, where the drying time in winter can be well over 24 hours. The principle adopted here is to use solar energy through, and adjacent to, the existing apertures on opposite facades, the purpose of the captured energy to significantly shorten drying time. As stated in the introduction above, the east-west configuration at Westercommon has been chosen to test viability. Key limitations are that aperture on the east side is half the width of that on the west, the lower drying room additionally shaded on the east by the projecting end maisonettes and access deck. Although the west side is unobstructed, direct solar gain will not be effective in terms of transmission through, or absorption on, the facade until the sun has reached an azimuth of about 40 degrees from due south. Effectively this means minimal useful solar capture at the winter equinox, no gain until 14.20 at the equinoxes and 1340 at the summer solstice. Moreover, the anticipated yield from east/west vertical PV arrays will be significantly less than for the optimally tilted south facing arrays envisaged for tower blocks. Therefore the solar strategy here is: a) enhance direct solar radiation and ventilation through existing apertures by means of tilted glass louvres and a mirrored light shelf at sill level; b) install a hybrid thermal/electrical PV array from sill down to adjacent lintel level, its heat output helping the performance of a small air to water heat pump; and c) augment the vertical PV panels with an equivalent area of 30 degree east and west facing panels, aligned immediately above the drying rooms in order that the annual electrical output meets the demand for the heat pump.

For design cohesion, the tilted roof arrays and the vertical west façade arrays, Figs 2a and 2b, are the same size - 4.8 m by 1.2 m, providing 5.76 m^2 of each tilt to each drying room. Having established 80 kWh/m for the south tilted arrays on the tower blocks, the proportionate net annual output values adopted are 68 kWh/m^2 for the roof panels and 45 kWh/m^2 for the façade ones. The predicted output, taking relatively full advantage of the diurnal solar cycle, is therefore approximately 650 kWh for each drying room - (5.76 x 68) + .(5.76 x 45) = 392 + 259 = 651.

Earlier work in Scotland with regard to the hybrid thermal-electrical performance PV [5] indicated a mean annual heat to electrical ratio of 2.64 for Glasgow. On this basis, if one were able to capture the heat from both PV arrays, one might be able to gain over 1,700 kWh to each drying space. However, it was decided to only attempt such capture from the vertical PV panels below the main openings on the west side. Thus the net annual heat gain from the PV that could be potentially directed to the interior would be 684 kWh (259 x 2.64). However, it is unlikely that all of this could be of benefit as an enhanced ambient air supply to an air-source heat pump. The pragmatic assumption is that a COP of 3.0 should be attainable with the simple device of directing a vent from the back of the PV towards the heat pump. What the heat pump does not capture will dissipate within the space as convective thermal enhancement.

This being the case, with a total net annual output from PV of 650 kWh, the pump would be able to supply 1,950 kWh heat to assist the drying process. Since the L-shaped plan of the drying rooms favours the installation of five traditional ‘pulleys’ (pulley-operated airers), the aim is to utilise the thermal output from the heat pump in the form of warm water to speed up the drying by radiant energy. Five paired parabolic reflectors are proposed, with warm water pipes welded to them. This means that the heat pump can supply circa 390 kWh to each radiant panel annually if its electrical supply is rationed to the net output from the PV. If this is confined to the months of September through to May, it translates to 1,429 Wh/day, and if the drying day averages 8 hours, the output per paired radiant panel to the pulleys would be 178.6 W; in turn divided by a panel area of 1.5 m^2, means that there is a radiant energy delivery to the pulleys of approximately 120 W/m^2. Thus the system is shown to be viable, especially assuming that warm-water circulation to the radiant units would be regulated by humidistat so that the heat is only required to circulate from the thermal store (insulated cylinder located adjacent to the existing refuse chute) when there is damp laundry to be dried. This improvement to the drying process also has to be seen in the context of much improved access for direct solar heat gain, there being virtually none at present. Transparent tilted glass louvers replace the present opaque staggered system of baffles, and a wide mirror-veneered sill will further enhance reflected solar heat Finally a low-revolution ceiling fan is proposed to supplement cross-ventilation facilitated by the improved glazed louvres, its electric load relatively nominal with the fan switched on during periods when wind pressure is low and washing in place.

It is therefore posited that the combination of improvements will enable effective drying within a normal diurnal cycle, and that this will improve the popularity of the facility. The range of 'what if?' scenarios, taking the predicted annual figure for individual tumble drying in a household of three people as 1,800 kWh is: 1,800 kWh if 1 ex 10 households stop using tumble driers

5,400 kWh if 3 ex 10 households stop using tumble driers

9,000 kWh if 5 ex 10 households stop using tumble driers

Apart from the first line of such scenarios, all are predicted to save significantly more than the estimated thermal input for 10 dwellings - 1,950 kWh, and compared with the initial PV electrical output, estimated as 650 kWh, all scenarios provide a reasonable return on energy investment - ranging from a factors of 2.77-13.85 more energy saved than generated.

5. Other potential individual solar improvements to facilitate passive drying

In reality, not all the households will be using tumble driers in the first place, those that are used will vary in efficiency, frequency of use will vary and not all households with tumble driers would be persuaded to change. Accordingly, it is also proposed that passive drying potential within the footprint of these dwellings should be solar-enhanced. Lean-to glazing canopies, with vertical 'skirts', can be added above semi-projecting private balconies. This would follow a similar profile to that for the PV arrays on towers as shown in Fig. 1, but the lean-to section would be clear single glazing, and a vertical glazed 'skirt' would provide additional weather protection to the same sort of pulley arrangement (without radiant heater) devised for communal drying rooms. This would allow them to be housed above lintel height, sheltered from rain and trapping some of the available solar irradiation. An additional refinement between the top of balustrades and the underside of the canopy 'skirt' might be a proprietary sliding-folding, single-glazed screen, so that the complete intervention can form a thermal buffer in winter, and enable more flexible use of the balcony year round. Such installations would be equally beneficial to the recessed balconies of the tower blocks. Even encouraging residents to use them for drying would assist in displacing use of the energy-intensive driers in the ground floor laundry. However, the Westercommon towers and low-rise blocks of QXHA do not presently have such balconies. Although, these could be added fairly economically to the low-rise blocks, it would be a major additional investment for the towers.

More generally, and more economically, it would be helpful if the housing association concerned mounted a doorstep campaign to dissuade residents from using tumble driers or other heat-consuming drying methods inside their homes, and to persuade them to make greater use of communal facilities, but only after being opportunistic in using completely passive methods. Although initial upgrading suggestions were made for the Maryhill estate of CHA during an options appraisal [6], they did not include specific techniques to tackle drying loads - there had been no quantification of the problem at that stage [3]. This paper has been able to include the necessary data in support of the propositions. Estimated costs are not included on the assumption that FIT will give an adequate return on retrofit investment. Apart from the technical viability and economics, there is a health incentive of improved air quality, in particular lower humidity and mould and/or dust mite propagation associated with respiratory disorders. Concluding comments are qualified in the sense of placing such specific building-integrated measures relative to other electrical loads, and in the wider energy 'landscape' of Glasgow, now receiving renewable electricity from a wind farm of over 300 MW.

6. Concluding comments

The estimated annual output from the proposed PV arrays on the tower blocks is of the order envisaged to displace the present electrical consumption for communal drying appliances.

The solar interventions associated with the low-rise communal drying rooms are adequate to significantly shorten drying time and hence can reasonable be expected to attract use in favour of individual tumble-drying within the home.

Other relatively simple upgrade measures are possible that would facilitate passive drying within the footprint of individual dwellings, especially where semi-recessed or projecting balconies exist.

The cost of BIPV interventions will provide a reasonably attractive return on investment once FIT is in place, thus supporting the financial, as well as technical, feasibility of the proposals.

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