The Potential for Urban Turbine use on Multi-Storey Housing in Glasgow

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He currently lectures in Architectural Science and is part of the Mackintosh Environmental Architecture Research Unit (MEARU). This unit undertakes strategic and applied research into energy efficiency and sustainability in architecture, with particular expertise in passive solar design and user participation. MEARU is been involved in a wide number of research and consultancy projects, with a particular emphasis on housing.

ABSTRACT

This paper describes the findings of a study that examines the feasibility of using wind turbines to meet residual energy demands of type T84 multi-storey housing blocks in Glasgow.

The context for this work is the nature of housing provision in Scotland, which has a legacy of poor insulation and expensive heating, leading to significant problems of cold, dampness and fuel poverty. These problems are particularly prevalent in high-rise housing, which has additional problems associated with high exposure, and are further exacerbated by the technical difficulties of possible improvement measures.

The study indicates that certain characteristics of multi-storey housing blocks may be used to their advantage when considering the use of turbines. Advantages include; increased wind-speed with elevation, robust structure, good services infrastructure, availability of thermal mass and storage heating, and available grid connections. The study concludes that some or all residual demand could practically be met using existing turbine forms, depending on other energy saving interventions. The study also identifies areas of further research that include investigating developments in both building and turbine form to increase capacity.

INTRODUCTION

This paper discusses the findings of an outline study that investigates the feasibility of using wind turbines to meet energy demands of multi-storey housing. The work is derived from an earlier study that the Mackintosh Environmental Architecture Research Unit (MEARU) undertook for Glasgow City Council in 1996, which investigated options for solar thermal upgrading to meet the energy needs of an 8 storey block referred to as T84 [1]. Whilst this study found that energy demand could be significantly reduced, it was not eliminated entirely. Furthermore, some of the techniques proposed were experimental, and it is therefore likely that installation costs of these would be high. To address these issues, further work is was undertaken that examined the use of wind turbines as a means of meeting the residual energy needs of the building.

The paper describes the general context for this work, related areas of research, and discusses the main benefits and difficulties of such an installation. Finally, areas of future research are outlined.

CONTEXT

There is a long history of public housing in Britain, particularly in cities, where local authorities were the largest providers of housing for many years. During the 20th century the scale and types of provision changed, with the most significant of these changes occurring during the mass housing developments of the 1950s and 60s.

Up until the 1970s issues of fuel use and thermal efficiency were not a significant part of the social housing agenda, due in part to the relative cheapness of fuel and heating, but also because of the attention given to other pressing issues such as sanitation and overcrowding.

However, since then the importance of the thermal performance of housing has been steadily increasing. This is due to a number of factors. These include; changes in types of heating systems and fuels in new housing; replacement of existing (coal) systems due to clean air acts; increase in fuel prices, beginning with the fuel crisis of the 1970's; alterations in funding for housing provision and maintenance, variations on social patterns and welfare provisions; and latterly, concerns about global warming.

The effects of these changes have effectively reduced the thermal efficiency of public housing stock, which in turn has resulted in marked incidences of thermal discomfort, fuel poverty, dampness and mould growth. These changes have a particular significance in Scotland, in relation to the rest of the UK, which suffers from a colder climate and long heating season.

Whilst thermal construction standards have improved gradually over the past 20 years, these only apply to new-build projects and so there is a pressing need to examine measures to improve existing dwellings. A number of attempts have been made to solve these problems utilising renewable energy technologies, and some of these, such as passive solar design, have achieved success and have become mainstream techniques. Nevertheless, restrictions in funding mean that a great many dwellings remain in a poor condition.

Multi-storey housing blocks are a particular dwelling type that only appeared in the 1960's and 70's and therefore tend to exhibit most of the characteristics of thermally deficient dwellings of that period: poor u-values, expensive and uncontrollable heating systems and inadequate provision for drying and ventilation [2]. They also have the added disadvantage of greater exposure to wind and the cooling effects of driving rain. Furthermore the installation of thermal improvements such as insulation is hampered by their height and construction.

In order to address these problems, Glasgow City Council commissioned MEARU to develop proposals for the solar thermal improvement of two 8 storey housing blocks located on the south side of the city and this work has been described previously [3]. The measures included solar air collectors on the south wall utilising a PV array with heat transferred to the north wall cavity, glazed sun buffer spaces to the balconies, mini solar air collectors to the windows and a freeze tolerant hot water flat plate collector.

Table 1: Summary for one tower block (Jura Court, Glasgow): (all values in kWh)

	Before	After	SAVING
Space Htg.	311,390	74,307	237,083
Water Htg.	49,770	18,470	31,300
TOTAL (for one tower block)	361,160	92,777	268,383

The study concluded that in terms of space heating, the proposals could achieve a respectable 76% energy saving, - over 9,500 kWh per flat per annum - and in terms of water heating, savings in the order of 63% and over 1,100 kWh per flat. However, the extra cost of the innovative solar features compared with a normal overcladding project with an upgraded heating system, was estimated to be approximately £10,000 per dwelling.

Whilst savings were significant (based on an equivalent before and after demand regime), a residual energy demand remained, and the savings that were achieved were based on some experimental – and therefore expensive – technologies. In considering methods of meeting the residual demand wind power was an obvious option for a number of reasons; it is available when solar power is not (e.g. at night and through the winter); the climate of Glasgow is appropriate; it is a mature technology with commercially available systems; the exposure of the blocks would contribute to the available wind resource; its use has not been attempted in such buildings. Further work is now being undertaken by MEARU to examine the potential contribution of wind power to both meet the residual energy demand and to provide alternative means of generation for the T84 blocks.

URBAN TURBINES

Wind power has been used successfully and commercially since the early 1980's with a global capacity of over 23,300MW [4]. To achieve this, most research has been directed at increasing output through the use of large-scale turbines and wind farms. Much of the thrust of wind energy research has been directed at increasing yield through use of larger turbines (>100m high) in areas with a high wind resource, which now include offshore installations.

Because of difficulties associated with reduced wind resource, turbulence, and environmental concerns such as noise, there has been relatively little use of turbines in urban locations. There are however, some important advantages to using turbines in this situation: generation is local and directly benefits a building and its users; there are no transmission losses; the form of the building may concentrate airflow, improving output; it enables end users to engage with energy use and generation in their building.

Some research has been initiated in this field [5], [6], [7] and has developed the term 'Building Augmented Wind Turbines' (BAWTS). BAWTS attempt to take advantage of airflow around buildings or structures to enhance the turbine efficiency and this has led to a number of innovative proposals. These range from large scale new buildings such as those of Project WEB [8] and Project ZED [9] that propose large buildings with integrated turbines, to the development of small modular ducted systems, such as those demonstrated at the Lighthouse Building in Glasgow [10] which included seven ducted turbines integrated with a PV array.

In either case, the loss of orientational flexibility is offset by an increase in efficiency derived from augmented airflow around the building or duct. In the case of the Project WEB proposal, studies indicated that this would overall result in a higher output than a standalone turbine and this illustrates the potential of this form.

The difficulties with the large scale uses are that, whilst they produce very interesting images, the practicality and costs of such measures are unlikely to be commercially viable, given the constraints on the building form, and are necessarily restricted to new buildings. In the case of ducted turbines, whilst there is a great deal of potential in the system at present the output from these systems is not sufficient to meet any significant demand.

The use of Vertical Axis Wind Turbines (VAWT), is also of interest in urban situations. Their form allows them to be more easily integrated on to a building, and they are less sensitive to turbulence and wind direction. Examples include forms of Savonius and Darrieus rotors. In general terms, however their power output is significantly less than equivalent HAWT machines, although this could be offset by the ability to install larger numbers of some building types and more efficient machines are likely to appear within the next few years.

There has been some demonstrative use of commercial turbines on public buildings, for example three 1.5kW Bergey Windpower turbines used on the Green Building, Dublin by Murray O'Laoire architects and the Dutch Pavilion at Expo 2000 by MRDRV architects.

When examining the potential of multi-storey housing, a balance has to be made between the scale of installation. Large-scale turbines would be difficult to integrate and install, and would have associated technical difficulties such as susceptibility to turbulence, noise and vibration. On the other hand, small scale units would not produce enough output. To be effective, the installation should be capable of making a meaningful contribution to the energy demands of the building.

FEASIBILITY

The terms of the study were to examine the practicality of using a currently available turbine system, capable of delivering useful capacity to the T84 block type. The study intends firstly to establish whether wind energy could currently make a useful contribution to meeting the energy needs of this block type and secondly, to identify means of developing this potential.

In examining the existing form and construction of the blocks, a number of useful features became evident:

Height: Whilst the height of multi-storey housing is normally disadvantageous in terms of exposure and costs of external works, when considering wind power it becomes an advantage, giving improved wind resource, reducing turbulence and wind shadow from other buildings.

Structure: The structure is primarily brick and concrete, giving ample stability and rigidity and reducing the risk of vibration and noise transmission.

Distribution efficiency: The blocks contain 28 dwellings each within a relatively small area and with a good service system. This makes the aspects such as distribution and/or storage more effective for the number of houses.

Infrastructure: The blocks have good electrical distribution networks including high power supplies to the roof for the lift motor room. In addition they have electrical switch rooms and substations at the ground floor that may be utilized for grid connection. The roofs contain plant spaces that provide space for other services.

Thermal storage capacity: Gas boilers are not permitted in multi storey housing due to concerns about safety, therefore heating systems utilise off-peak electrical storage heaters. These can be expensive but with an input from wind energy these could be a simple means of heat delivery and a useful thermal storage capacity. In addition the concrete floors and other areas such as the liftshaft may provide further thermal mass. The plant spaces identified above may also be used to provide hot water storage, possibly in conjunction with flat plate collectors used in the solar thermal improvements.

Building form: T84 blocks are sited throughout the city with identical North-South orientation giving rise to easy replication. The central plant space on the roof allows one or more turbines to be mounted higher than those on the parapet, increasing capacity. A new roof enclosure could allow a concentrating roof form, incorporating hot water collectors, without excessive volume enclosure.

The current evaluation is based on the use of the Proven Engineering WT6000 turbine. This is used for a number of reasons. It is a well-established turbine, cable of a reasonable output (6Kw) but at a practical size that would facilitate installation and integration on the building. It is known for its robust performance and is very tolerant of turbulence, a key feature in urban locations. It is a downstream design, with a unique coning system for extreme winds, and it does not have a gearbox, reducing noise and maintenance. It also has a low cut-in wind-speed of 2.5m/s increasing its viability. It is also a proven product with a good record of safety and reliability.

SITING

The turbines have a sweep area of approximately 5.6m. In theory this would allow the placement of a maximum of 8 turbines on the available roof area - 6 at the parapet level and 2 on the motor room. However, due to some over-shading of each other this would give a maximum of 6 turbines with free aspect at best and 3 at worst. Examination of different configurations suggests that the most cost effective solution would be 4 turbines at parapet level and 1 at the motor room roof level.

Interrogation of the British Wind Energy Association UK Wind Speed Database indicates average annual wind-speeds on the site are 5.6m/s at 10m above ground level and 6.4m/s at 25m above ground level. This illustrates an advantage of this building from whereby the average wind resource is higher at roof level (26m). Estimates suggest that wind speeds around the building may be about 20% higher than undisturbed wind away from the building [11]. This would produce an average wind speed of 7.6m/s

Figure 1:Turbine installation configuration.

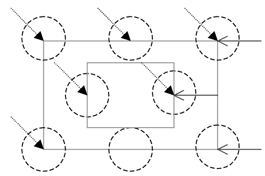
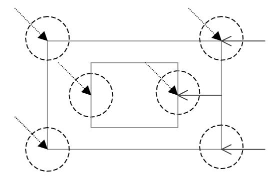
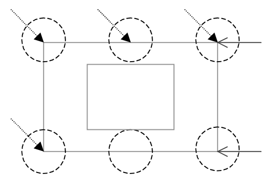
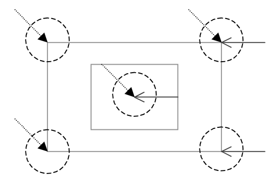
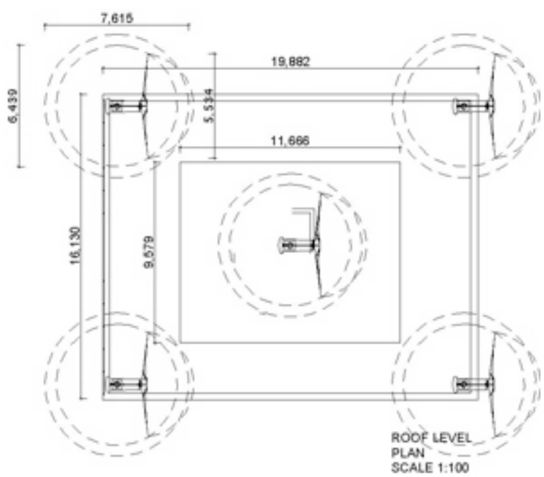
No.	Configuration	Max. No.	Min No.	No.	Configuration	Max. No.	Min No.
8		6	3	6		5	3
6		4	2	5		4	3

Figure 2: Installation on block as existing.



Using this average, a WT6000 (6kW) turbine would produce an annual yield of 25,000kwh, of which 16,500kwh would be in the winter months. Taking into account the prevailing wind direction from the south-west and likely variations, as well as some available output from downwind turbines, an average of 3.8 turbines are used to estimate annual output. This would produce a theoretical yield of 95,000kwh annually, of which 63,333kwh is generated in the winter. These figures may be compared with the energy requirements before and after solar thermal upgrading.

Table 2: Comparison of energy demand and turbine capacity (kWh)

	Existing tower block (before)			Proposed tower block (after)		
Space Htg.	Q^{htg}	Wind capacity	Residual demand	Q^{htg}	Wind capacity	Residual demand
Winter (Dec.- May)	214,957	63,333	151,624	52,887	63,333	-10,446
Annual Totals	311,390	95,000	216,390	74,307	95,000	-20,693
Annual Water Htg.	49,770			18,470		
Total	361,160	95,000	266,160	92,777	95,000	-2,223

This indicates that the wind turbines could provide approximately 30% of the winter space heating load, and over a quarter of the total annual combined water and heating load in the blocks as existing. A key aspect of the calculation of the 'as existing' demand is that they assume the same demand temperatures before and after upgrading. In fact the existing comfort conditions are much lower, as the poor thermal performance of the block, combined with unaffordable heating systems, causes fuel poverty. Thus, the actual existing fuel use is lower and therefore the contribution that the wind component could make is proportionally higher. However, findings of other studies of energy efficient improvements to poor housing indicate that cheaper fuel actually results in improved comfort conditions – that is, as heating becomes more affordable, people use it more to achieve reasonable comfort conditions. Therefore the contribution of wind energy would be to improve living conditions.

Figure 3: Installation with solar thermal upgrading

The figures also illustrate that the turbines could meet and in some cases exceed the residual energy demand that remains after a package of solar thermal upgrading. Excess capacity could be utlised in several ways. Firstly, the solar thermal measures proposed in the original study included a number of experimental techniques that would have a reduced cost benefit. Using wind turbines could offset reductions in savings if these were omitted. Alternatively, excessive capacity could be used for lights and appliances, common use, or sold back to the grid, offsetting other demands.

ENERGY USE

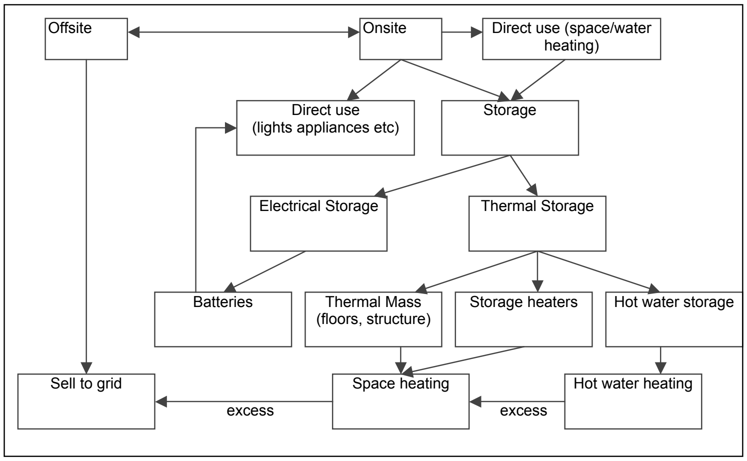
Whilst these figures indicate the potential capacity of the turbines, the question of how this energy is delivered to the dwelling must be examined. There are a number of options.

The ideal solution would be to use the energy generated on site. Whilst electrical energy can be sold to the grid, the gain from this is approximately 2p/kwh and although this may be used to offset purchased energy through reversing meters, it represents theoretical, rather than actual use.

The energy generated may be used directly for lights and appliances. The difficulty with this solution is firstly the need to balance supply and demand, which would require electrical storage. Whilst battery storage is common, it adds to the cost and complexity of the installation, and fundamentally, it does not address the main needs of the building and users, that is, to improve thermal performance.

A preferable use therefore would be to contribute to the space and water heating loads of the building. This also may be direct use through heaters, but again, balancing supply and demand would be problematic. An alternative would be to use thermal storage capacity in the block. This is available in three forms, the thermal mass of the building, the electrical storage heaters (that form the existing heating provision), and hot water storage. Of these the latter two would be the easiest to access and could utilise existing service provision in the block.

Figure 4: Energy utilisation.



The control of the output from the turbines allows for switching of use. So for example, generated electricity could be used to heat hot water storage associated with the solar collectors, and when this achieves a demand temperature, the output could be switched to the storage heaters. This cycle could be seasonal, with space heating being prioritized in the winter. Excess generation beyond this could be sold to the grid or used for lights and appliances, or common area lighting.

TECHNICAL AND ENVIRONMENTAL FACTORS.

There are a series of technical and environmental factors that need to be addressed in considering turbines in an urban situation and guidelines for an Environmental Impact Assessment for a urban turbine installation have been previously established [12]. These include:

Installation: Use of cranes may be possible with the T84 form, but higher building types may need to use a modularization of components to allow access via the lift and roof top assembly.

Structure and construction: Clearly the structure of the building needs to provide sufficient lateral stability due to increased wind loading, and areas of construction for fixing. Given the rigid structure of the T84 blocks this is unlikely to be problematic, but a more detailed analysis would be required prior to installation. The suggested siting of the turbines at the corners and in the centre places them close to a concrete stiffening column and above the lift shaft.

Maintenance: There is need for safe access for maintenance of the turbines. For the WT6000 turbines this is an annual inspection. The roof space allows access and the normal arrangement includes a hinged base to allow the turbines to be tilted flat for access to the generator and blades. The orientation and mechanism for this requires further consideration in relation to the roof design. In the ‘as existing’ situation the flat roof makes this straightforward, but more detailed consideration would be required for sloping and curved roof forms.

Existing and new service requirements: In order to be effective the provision should make the best possible use of existing service provision. Minimal additional requirements would include an inverter and associated switchgear that could easily be housed in the lift motor room. This would also provide plant space for additional requirements such as centralized hot water storage and new roof forms could provide additional plant space.

Safety: Safety is a primary concern with the use of turbines in urban, populated environments. There are three main identified concerns: proximity to people; blade shedding; ice formation and shedding. The situation of the turbines at roof level takes them away from the public as access to the roof can be controlled. The other issues require further investigation, however, one of the reasons for using WT6000 units in this situation is due to their proven safety record.

Environmental impact: Noise and vibration are potentially major concerns associated with turbines. Proven rotors are specially designed to operate at low rpm and so blades and bearings rotate slowly keeping air noise to a minimum. There is no gearbox as the rotor is coupled direct to the generator. This is the main source of noise in turbines with gearboxes. The rounded tips on the blades are designed to reduce the vortices present at the end of any aerofoil keeping wind noise to a minimum. The risk of vibration may be present if transmitted directly to the structure and this may require the use of damped bearings. Other environmental concerns include visual flickering, radio, TV and telephone interference, aircraft safety, and bird life. Given ambient noise levels in urban environments, the potential impact of noise levels is likely to be of far less significance.

Visual and aesthetic impact: When considering the use of turbines in the urban environment, their appearance becomes a key issue. Consideration would include the appearance from a distance, shadow casting (especially of moving blades), integration with building form and the actual turbine design. The images shown here are intended to illustrate a potential installation, but do indicate that the turbines are appropriate to the scale of the building. More work is needed to develop appropriate roof forms for both aesthetic and aerodynamic requirements. The turbine enclosures are currently designed from a utilitarian standpoint and could benefit from further development.

User Participation: Involvement of the building users would be fundamental to the successful implementation of wind turbines in this situation. This would require a program of user participation to communicate the potential benefits and advantages, and also to answer concerns about possible environmental issues such as noise. One of the difficulties of using turbines in the built environment is the greater number of participants – tenants, landlords, housing managers, architects, planners, building control, etc.

FUTHER WORK
Whilst the work so far has suggested that there is considerable potential for use of turbines on high-rise housing, a number of areas of further investigation are required.

Figure 5: Curved roof forms.

It is proposed to make a pilot installation of a turbine on a high-rise building, to measure performance, output, noise and vibration, and to further examine questions of safety and other environmental impacts identified above. It is likely that curved roof forms may enhance airflow and so further studies will be carried out, utilizing CFD analysis to determine appropriate roof structures, turbine location and aesthetic integration.

The study indicates that larger turbines could potentially be installed on these blocks. With the same configuration, turbine diameters of 8.4m could potentially be accommodated. Proven Engineering are currently developing a 15kw machine with a diameter of 9m. However, with larger blocks, the relative roof space becomes limited and so fewer, larger turbines may be appropriate, also increasing yield.

There is considerable potential in alternative turbine forms – ducted turbines such as those being developed by ESRU and the Xygen unit proposed by Ecofys [13] are currently in development and a cowled turbine has been manufactured which claims an output of 12kw with a diameter of 5.3m [14]. A number of VAWT turbines are currently being developed for use in this field. Whilst current VAWT systems are low power, their form allows more of them to be installed on buildings, both at roof level and at building edges and corners. The use of a series of horizontal axis darrieus turbines on, for example building corners and parapet edges may provide a large potential installed capacity. This would be particularly beneficial to very tall buildings where the roof area is limited in relation to the building volume, if issues such as cumulative noise and maintenance could be solved.

Figure 6: Domed roof form.

CONCLUSIONS

Use of an existing, commercially available turbine could make a valuable contribution of energy needs of these dwellings. Their contribution could be used to improve levels of thermal comfort without increased expenditure in existing buildings, but in conjunction with other improvement measures, this could be result in zero energy use, or even a negative figure.

High-rise housing blocks have a number of characteristics that make them particularly appropriate for this kind of intervention – these include high energy use and existing poor performance, but their physical form and construction may provide improved yield and pre-existing infrastructure for power distribution and storage would provide efficient distribution and use.

Whilst large-scale rural and offshore wind farms have a greater yield and efficiency, they do not have any direct benefits to building users. Tenants in these blocks would still be unable to properly heat their properties, wherever their electricity was generated.

The potential site is large; there are over 250 multistory blocks in Glasgow, and some, such as Red Road flats, are the highest in Europe. To demonstrate the potential capacity, taking into account average annual energy consumption/flat of 7000kwh, if a reasonably large turbine was sited on each of these blocks (e.g. Vestas V39 600/39), the total annual capacity for the city is 2.094355e+08 kWh - enough for nearly 30,000 houses. In practice of course this scale would be difficult to achieve. However, adaptations to turbine form that allow their use in urban situations, where there are able to connect to existing infrastructure, and directly benefit users, could have a huge potential.

A number of questions arise that require further research. These include a series of short term studies that could be addressed through a pilot study monitoring an installed turbine to answer outstanding question raised by an environmental impact assessment, medium term studies to develop modifications to existing building and turbine forms and longer term studies developing new turbine forms.

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