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THE RETROFITTING AND UPGRADING OF THE ADMINISTRATION CENTRE IN VICTORIA, GOZO – MINIMISING THE ENERGY CONSUMPTION THROUGH THE IMPLEMENTATION OF ENERGY EFFICIENT MEASURES

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ABSTRACT: The retrofitting of existing buildings offers considerable opportunities for reducing the global energy consumption and the resulting greenhouse gas emissions. Achieving a higher energy efficiency in existing buildings is considered as one of the most favourable approaches towards implementing sustainability in the built environment. The study in this paper is divided into two sections. In the first part, the current situation present at the Ministry for Gozo is studied and the energy consumption patterns and the inefficiencies leading to these patterns are assessed, in order to determine the state of the building's energy performance. The second part of the paper analyses possible recommendations that could be implemented to render the Ministry for Gozo's Administration Centre more energy efficient.

Keywords: energy efficiency, net-zero energy building, building services engineering.

1 INTRODUCTION

The increasing energy consumption patterns and their resulting greenhouse gas emissions present one of the world's biggest concerns. The building sector alone accounts for 40% of the energy consumption in the EU, which equates to around 36% of the total carbon dioxide emissions. About 35% of the buildings in the EU are more than 50 years old and 75% of the buildings are energy inefficient, while only an average of 0.8% of the building stock is renovated each year [1]. For this reason, the building sector presents a large potential for significantly reducing the energy demand and the harmful emissions.

In view of this, the European Union through Directive 2010/31/EU has adopted the concept of net-zero energy buildings. The concept aims at designing more sustainable buildings and improving existing buildings and is based on two pillars: energy efficiency and renewable energy.

In existing buildings, one possible solution to reduce energy consumption is by retrofitting them to net zero energy buildings through enhancing the building envelope, as well as the services linked to lighting, water heating and space heating and cooling, as well as introducing renewable energy in the building or nearby to generate green energy.

This paper presents salient results from the energy audit carried out at the Ministry for Gozo during September 2016 and November 2016, in order to enhance the building's energy efficiency status.

2 BACKGROUND

The Administration Centre, Ministry for Gozo is a two-storey building that is principally used as offices. The ground floor level is divided to two levels by an internal steel structure. The total floor office area of the Administration Centre is around 6,500 m^2. The building has a square layout with a corridor running along the large central courtyard as shown in Figure 1. The building was built around 1750, however it has undergone several renovations and refurbishments throughout the years.

The building originally served as a hospital but was then converted into offices. The Administration Centre is active daily between 07:00 and 17:00

excluding Saturdays and Sundays, during the winter period and between 07:00 and 15:00, excluding Saturdays and Sundays during the summer period.

The annual electrical energy consumption of the building is around 326,000 kWh, while the average annual water consumption is about 340 m^3.

The building also incorporates a PV system having a peak power of 108.1 kWp, which operates through a net metering arrangement. The PV system is made of a mixture of polycrystalline and monocrystalline PV panels and generates between 150,000 and 180,000 kWh annually, which covers 50% of the premises' electricity demand.

Figure 1: The Ministry for Gozo Administration Centre

3 BUILDING ENERGY AUDIT

A preliminary energy performance certificate was issued for the Administration Centre in 2013 in an effort to understand the consumption patterns. An energy performance rating of 118 (equivalent to Grade C) [2] was produced. The EPC assessment identified air-conditioning and lighting as the main drivers of energy demand, with a combined consumption of almost 80% of the total energy requirement of the premises, as shown in Figure 2.

In an effort to understand more the energy performance of the building and its services systems, a detailed energy audit was carried out between September and November 2016 with the objective to determine possible retrofitting opportunities. The energy audit identified a number of measures to enhance the Administration Centre's energy efficiency.

4 PRESENT SITUATION

The aim of this section is to first give an overview of the data collected during the on-site inspection and study of the Administration Centre.

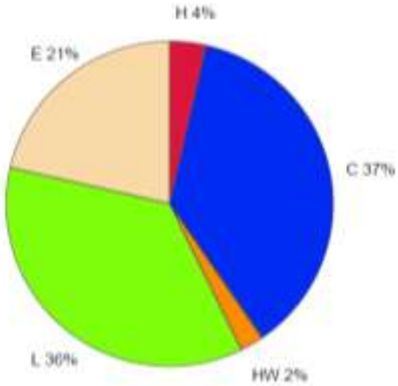

Figure 2: The distribution of energy consumption at the Administration Centre according to SBEM-mt (H stands for heating, C for cooling, HW for hot water, L for lighting and E for equipment end-use)

4.1 Space heating and cooling

The current measure to achieve space heating or cooling is through the use of split-type air conditioning units, which is considered to be highly inefficient for this type of building use. In addition, most of the split type units are without an inverter, having fixed speed on-off compressors, thus providing highly inefficient running conditions. Moreover, some models are very old with physical damage to the fins and fan; this effectively lowers the heat transfer properties, hence resulting in high inefficiencies. Also, in some units, the insulation covering the copper pipes which transfer refrigerant between the indoor and outdoor units has deteriorated completely and this results in a high energy loss from the refrigerant due to the lack of insulation.

4.2 Ventilation

In most parts of the premises, natural ventilation flows in the enclosed areas by the opening of the windows. In an air-conditioned environment, this presents a major shortcoming in terms of energy efficiency, because the air-conditioned air escapes from the same windows, creating energy losses from the transfer of treated (hot or cold) air to the outside environment. The air-conditioning system has to replace the energy lost every time the window is opened, resulting in poorly cooled/heated areas and highly inefficient use of energy.

4.3 Water heating

The use of hot water for sanitary purposes and kitchenettes at the Administration Centre is supplied by electrical water heaters. Although the use of hot water within the Administration Centre was found to be minimal, it was noted that most of the electric water heaters are old, having inefficient filaments which leads to additional energy consumption to reach the desired temperature.

4.4 Lighting

The lighting system installed at the Administration Centre consists of a mixture of halogen, tungsten filament lamps, compact fluorescent lamps (CFLs), T5 and T8 lighting luminaries. The lighting is controlled by the building's occupants via on/off push switches located in each room.

4.5 Building Envelope

The Administration Centre's ground floor level has a total thickness of 1.7 m, made up of limestone walls with air gap and bond stone. The offices located in the central courtyard were built at a later stage and these are constructed from single limestone walls.

The first floor façade walls have a total thickness of 0.7 m and are built of limestone with air gap and bond stone. The other walls are constructed from single limestone walls.

The second floor is constructed from single limestone walls. Only three walls are made up of double limestone walls with air gap.

The upper roof level is made from 150 mm concrete slab and 280 mm roof screed (*kontrabejt*). The roof is currently shaded by the photovoltaic panels, which cover 90% of the roof.

4.6 Building Apertures

The apertures consist of a mixture of timber, aluminium and metal frames, all being single glazed windows. Most of the offices include a corridor, which is located along the central courtyard. Large apertures along this corridor provide natural lighting. The central area has a roof light which provides sufficient natural light during the day.

4.7 Rainwater

The rainwater is collected into a rainwater reservoir through a number of floor drains spread along the central yard. The central yard drains into a storage tank and this is then pumped into a large rainwater reservoir by means of a submersible pump.

4.8 Office Equipment

The equipment used is typical for office space and includes desktop computers, laptops, laser printers, photocopiers and electric kettles. In total there are 307 desktop computers installed and 52 laptops.

5 RETROFITTING INTERVENTIONS

The objective of this section is to describe the possible retrofitting interventions that can be undertaken at the Administration Centre, and the possible savings in energy.

5.1 Space Heating and Cooling

The current equipment for space heating and cooling is deemed inefficient for this type of building. Apart from the fact that most split-type units are not inverter driven, it is considered that this technology does not maximise on the potential savings accruing from other more advanced air-conditioning systems. Given that air-conditioning is the consumer of more than 40% of the energy consumption at the premises, this sector should be given priority for improvement, within the limited structural conditions and the space of the site. In view of this, a variable refrigerant flow (VRF) air-conditioning system is being proposed.

A VRF system consists of an outdoor unit (comprising of one or multiple compressors), several indoor units, refrigerant piping running from the outdoor to all indoor units using refnet joints and communication wiring. Such a system regulates the temperature within the offices. The cooling and heating requirements of these spaces inevitably change throughout the day, typically as a result of varying occupancy, heat-emitting office equipment and lighting, changes in outdoor temperature and the position of the sun. The ability of a VRF system to vary the load based on the demand is one of the main factors that makes it more efficient compared to existing split-type units.

The main advantages of a VRF system over the conventional split type units are represented, firstly, by energy efficiency. The system is designed to provide exactly the required amount of cooling needed for the current conditions, which means it runs less frequently and at a lower capacity. The VRF system is also designed to recover heat from the cooling process and reuse it in other areas that may need heating. For this reason, this system also allows to have areas being cooled and other areas being heated, simultaneously. Besides, the system's compressor can detect the precise requirements of each zone and send the precise amount of refrigerant needed. As a result, each area is consistently comfortable with well-controlled humidity and no hot or cold spots occur. This further eliminates human intervention in adjusting room temperatures according to preference, thus reducing wastage due to negligent use. Moreover, wear and tear would be reduced, given that the system operates according to demand. VRF systems also operate more silently, where the noisier condensing unit is typically outside, and the indoor air handlers are small and quieter than a traditional system.

As an addition to the above, a centralised control can be introduced with the VRF system. The centralised controller shall have energy saving features that simplify energy management by tracking energy consumption data and identifying inefficient operation.

Another possible measure integrated with the VRF system is the introduction of presence sensors in each room. The presence sensors are capable of detecting movement in the room, to control the operation of the indoor unit, thus providing additional savings. Furthermore, wireless window sensors can be added to the windows (through a building management system) to switch-off the air-conditioning systems when the windows are open.

An air-conditioning system accounts for between 50-60% of the running costs of the building [3]. Hence, one can assume that the actual estimated electrical energy consumption by the air-conditioning system for the building is 163,000 kWh. A VRF will provide a minimum EER of 3.5 when compared to the EER of 2.8 of fixed speed split type air-conditioning units [4], and so the proposed VRF system is expected to provide 25% energy savings which amount to 40,750 kWh [5].

5.2 Ventilation

The use of natural ventilation for fresh air through the opening of windows presents a major shortcoming in terms of energy efficiency since the air-conditioned air escapes from the same windows, creating energy losses from the transfer of treated (hot or cold) air to the outside environment. Therefore, given that the solution is to monitor and keep the windows close, this action needs to be compensated with a mechanical ventilation system to provide optimal air quality for the occupants. In this regard, a mechanical ventilation system with heat recovery is being proposed, which helps conserve energy by recovering heat from exhaust air and by using energy efficient ventilation equipment.

Heat Recovery Ventilation is a system which comprises a number of heat recovery units and a network of ducting connected to each room. The mechanical ventilation system is composed of a fresh air supply fan, an extractor fan and a heat exchanger. The purpose of the heat exchanger is to recover energy from the exhaust-treated air and to transfer it to the supply air. With such a system, up to 60% of the heat can be recovered. Besides, the electrical consumption of the fan can be considered to balance the electrical energy being wasted by the air-conditioning systems when the windows are opened [5]. These two advantages will notably contribute towards the optimisation of the energy-efficient investments under this scenario.

5.3 Water Heating

The use of hot water was found to be minimal. However, the electric water heaters have very old elements which needed replacing and the water heater itself has been in use for more than 10 years. In view of this, an air-to-water heat pump system backed up by an electric heating element is being recommended.

A heat pump system uses a thermodynamic cycle to heat the water inside the storage tank. Thermal energy is absorbed from the surrounding air through a refrigeration cycle that uses a refrigerant fluid (R410a). The hot water tank acts a condenser for the cycle and hence the water is heated.

Hot water is estimated to account for 4% of the total electrical consumption of the building. Hence, the estimated hot water electricity consumption is around 13,000 kWh/year. An air-to-water heat pump typically has a COP of 3.5 when compared to a COP of 1 of electric water heaters [4], and so the proposed change is expected to account for 9,000 kWh of energy savings [5].

5.4 Lighting

Lighting is one of the major consumers in the Administration Centre, accounting for 36% of the building's energy demand. The current lighting systems installed at the premises were found to consist of a mixture of halogen, CFLs, T5 and T8 lighting luminaries. The most cost-effective measure in a building to increase energy efficiency and reduce energy consumption is through the use of energy efficient lighting. In this regard, it is being proposed to replace the present luminaries with LEDs.

A LED is made from a semi-conductor material which transfers electrons through and produce UV-radiation. The UV radiation emitted is transformed into white light by the diode's fluorescent coating rather than heating a filament like in incandescent lights. The main benefits of LEDs are their high energy efficiency, long lifetime and good colour rendering.

An additional measure which could be introduced and provide more savings is the introduction of occupancy and motion controls. By using a passive infrared sensor for example, the system detects movements or lack of movement in the space, and turns on/off the lights accordingly.

Based on the sizing of the proposed LED system and assuming that 15 W are conserved by each LED panel and the LED is on for 9 hours per day, the total electrical savings amount to 25,000 kWh/year [6].

5.5 Building Management System

The introduction of a Building Management System can further reduce the energy bill by 5%. The BMS integrates all the individual mechanical and electrical equipment into one system managed centrally. This computer-based system consisting of hardware and complementary software monitors and controls all lighting, air-conditioning, fire and security systems, ventilation and all other types of mechanical and electrical devices. The primary functions of a BMS is the control of the building's environment, the operation of systems according to occupancy and energy demand, the monitoring and automated correction of system performance and the alerting system. The ultimate objective is the optimisation of energy use by adjusting the input to demand and controlling energy losses and waste. The proposed BMS shall be used to monitor and control the following systems:

a) Lighting: Using PIR sensors, the system detects movement or lack of movement in the space, giving information to the BMS to switch the lights on or off accordingly. It also detects the level of natural light and adjusts the lumens (light intensity) of the LEDs to avoid unnecessary energy consumption.
b) Air-conditioning: The centralised controller of the VRF system shall be interfaced with the BMS to monitor and report on the energy performance of the system. The BMS shall also include connections to PIR sensors which switch off the air-conditioning when the rooms are unoccupied.
c) Apertures: Sensors shall also be installed with windows to indicate whether a window is open. In such case, the sensor will signal the BMS to turn off the air-conditioning unit.

Given the above interventions, where the BMS will monitor and control the lighting and air-conditioning, it is prudent to assume that the envisaged energy savings will be around 2.5% of the electricity consumption [5].

5.6 Building Envelope

The double limestone walls forming the building fabric have a low heat transmittance coefficient (U-value) and thus provide a good resistance to the transfer of heat. On the other hand, the thermal transmittance coefficient of the roof was found to be high. In this regard, it is being proposed to insulate the roof by means of 50 mm expanded polystyrene.

In a Southern Mediterranean climate like that in Malta, this measure is beneficial throughout the year. The insulation acts as a barrier to heat, keeping it from passing through the roof and enables the office space to remain cooler in summer and warmer in winter, thus minimising the interventions needed by the air-conditioning unit, resulting in higher energy savings. Another important benefit deriving from this option is the increased amount of rainwater harvesting through the levelling of the roof to facilitate the gravitational flow of water towards the current piping system leading to the water reservoir adjacent to the premises.

The roof consisting of 150 mm in-situ concrete layer, 150 mm roof screed (*kontrabejt*), 50 mm torba and an internal plastering of 6 mm and bitumen layer of 5 mm on the external was found to be 1.65 W/m^2K. Thus, it is being recommended to install 50 mm thick extruded polystyrene as a form of thermal insulation between the concrete slab and the roof screed (*kontrabejt*). The insulation layer would lower the U-value to 0.49 W/m^2K.

5.7 Building Apertures

The type of window included in the building envelope has an effect on the amount of heating and cooling required, so it will influence the amount of energy consumed by the building. The current single glazed windows have a high U-value leading to energy losses. Replacing these windows with double glazing may be regarded as another energy efficiency measure to reduce the energy losses from windows. In this regard, it is being proposed to replace the single glazed windows with double glazed aluminium windows with 6 mm air gap, a 4 mm thermal break and a UV reflective film. This reduces the thermal transmittance coefficient and hence lowers heat losses through the glazed apertures and reduces the energy requirement to maintain comfortable indoor ambient temperatures. The use of reflective and low-e films or tints on such windows contributes to a better performance by reducing the solar radiation gains and glare inside the building, thus reducing the cooling load.

The U-value for a single glazed aluminium window with no thermal break is 6 W/m^2K, while that for double glazed aluminium window with a 6 mm thermal break is 4 W/m^2K. The wall U-value of a double limestone 230 mm leaf masonry wall with an air gap of 50 mm and 6 mm rendering on each side of the wall, with one side exposed to the external is 1.37 W/m^2K. Assuming a wall area of 43 m^2 and a window area of 4 m^2, the weighted average U-value wall with single and double-glazed window are 1.79 W/m^2K and 1.61 W/m^2K.

The overall savings for insulating the roof and changing the apertures is not a straight forward calculation and requires detailed dynamic simulation, using specialised software. However, it may be safely estimated that a saving of at least 5% would be achieved.

5. RESULTS

The energy audit identified a number of opportunities to render the Administration Centre more energy efficient. In particular the total energy savings resulting from all the interventions proposed is envisaged at 99,200 kWh as shown in Table 1.

Table 1: Summary of Energy Saving Measures

Retrofitting Measure	Energy Saving (kWh)
Space Heating/Cooling	40,750
Water Heating	9,000
Lighting	25,000
BMS	8,150
Glazing Apertures Roof Insulation	16,300
Total	**99,200**

Given that the original annual electrical consumption is 326,000 kWh, it implies that the implementation of the above energy efficiency measures would reduce electrical consumption by 30%. The equivalent carbon dioxide emission reduction amounts to 87,000 kg/year.

6. CONCLUSION

This paper presented salient results from the energy audit conducted to help proposed retrofitting measures to enhance the energy efficiency of the Administration Centre. An overview related to the calculation of energy savings for the proposed retrofitting measures is provided. The proposed retrofitting measures could help lower the energy consumption of the building by 30% and decrease the greenhouse gas emissions by 87 tonnes of CO_2 equivalent.

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