A Case Study of Energy Efficient Measures Undertaken in an Industrial Facility

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Recommended Citation
doi:https://doi.org/10.21427/D74C07
Available at: https://arrow.tudublin.ie/sdar/vol6/iss1/3

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A case study of energy efficient measures undertaken in an industrial facility

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Published by ARROW@TU Dublin, 2018
Abstract

Energy and facility operational costs are a large part of the overheads of Irish manufacturing and distribution companies. This paper deals with the design and implementation of low-carbon technologies and engineering innovations which have evolved over recent years, including integration of network-based programmable logic controllers (PLC), to enhance interconnectivity and control.

Recording of the energy consumption of production plant and associated services, including heating and ventilation (HVAC) systems, compressed air systems, water usage/recovery, power systems, information technology support systems and facilities were undertaken prior to commencing upgrade works.

The paper describes how upgrade and retrofit works were identified following research into the latest equipment and controls, and these were undertaken as part of three separate projects on a phased basis. The initial project concentrated on simple achievable savings in common services for the complete facility, and included compressed air, exterior lighting, water heating and control of the main incoming water and gas services. Completion of the initial phase brought about an ongoing annual saving of 146,600 kWh in energy consumption within the facility, reducing direct costs.

The reduced energy consumption savings achieved from the first phase were used to part finance capital expenditure on the other two project phases, and combined with the timing of equipment upgrades and periodic maintenance, as in the case of lighting, over a three-year period.

The second phase incorporated changes to the main heating and ventilation systems, along with IT infrastructure and centralised control of production processing machines.

A major lighting upgrade to LED of the production and warehouse lighting fittings was undertaken as part of the third phase project, with occupancy controls integrated into zoned areas. Continuous monitoring and evaluation over the three years has enabled adjustments to systems, ensuring optimisation of savings and a further annual reduction of over 450,000 kWh in energy.

The savings have been achieved in a period of expansion in facilities and production, combined with a reduction in the maximum import capacity (MIC).

Keywords
Accelerated Capital Allowances (ACA); heat recovery; solar thermal; computer control; carbon emissions; virtualised networking; heat pump; programmable logic controller.

Glossary
AC Alternating Current
ACA Accelerated Capital Allowances
CNC Computer Numerical Control
DC Direct Current
DHCP Dynamic Host Configuration Protocol
EIM Excel Industries Manufacturing
EN European Standards
HVAC Heating Ventilation & Air-conditioning
IT Information Technology
LED Light Emitting Diode
PLC Programmable Logic Controller
MIC Maximum Import Capacity
kWh Kilo Watt Hour
SEAI Sustainable Energy Authority of Ireland
SEU Significant Energy User
TCA Taxes Consolidation Act
1. Introduction

Irish manufacturing companies have had to adapt and transform to survive in an ever-changing economy, combined with rising energy costs and environmental pressures. Companies that improve their energy efficiency and management can establish real competiveness, making the difference between profit and loss (Turner, W.C. and Doty, S. 2007).

Demand for products, both for export and in the Irish marketplace has evolved, as have work-cycle patterns. This paper details the design, implementation and monitoring of retrofitting advances in engineering innovations over a three-year period to reduce energy usage and waste. The facility included a manufacturing division, warehousing and distribution, research and development laboratory and back-end support offices.

The benefits of a project approach in developing energy efficient solutions are described in a joint study by the Greenov Partners in How to Develop Energy Efficient Refurbishment on a Large Scale which illustrates a range of technical and software solutions to support reductions in energy consumption.

A phased approach was adopted for the implementation and upgrading of energy saving products to ensure the costs were self-financing, and delivered further capital savings by the accelerated capital allowances for energy efficient equipment under Section 285A TCA 1997 Finance Act 2008. As some of the processes and production systems have changed or adapted over the years and additional mezzanine floors were installed, a revised approach to the services, including lighting designs and space heating, were required.

The buildings are over 30 years old and services were designed and installed based on concepts and technologies available at the time. The refurbishment and upgrading works were designed to utilise as much of the original core service systems of wiring and piping and ducting while, at the same time, upgrading equipment types and controls to achieve substantial reductions in energy consumption and waste.

2. Background

The facility has three separate buildings with a combined total area of 65,998 sq ft internally. Electricity is provided via a main incoming three-phase 400V supply from a dedicated transformer, and also from a mains incoming natural gas supply for process and space heating. The buildings are linked by a main cargo “in out” building as per Figure 2.1. Most of the operational areas cover two floors and are split as follows:

Figure 2.1: Layout facilities of the three main buildings.
Facility layout of main three buildings

**Building 1**
Ground floor – Manufacturing
First Floor – Pre-packaging manufacturing/component storage.

**Building 2**
Ground floor – Manufacturing
Mezzanine floor – Component storage, main canteen, toilets, showroom
Office/support – Sales office, locker rooms/wash room, shower facilities.

**Building 3**
Ground floor – Distribution warehouse racking
Ground floor – Technical research laboratory
First Floor – Distribution warehouse racking
Office/support – Admin/finance offices, computer room and facilities.

There is further storage outside the building and sections for cargo loading and truck parking. These areas are enclosed by security fencing and access to the building is via automated gates for security requirements.

Because of the different functions in each building, it was decided to undertake a survey of the main loads and operational factors throughout the buildings, evaluating the possible savings that could be implemented and the costings of different engineering solutions. Preparation of a plan based on production/process changes would be the key aspect of a continuous improvement program in the facility to reduce production energy consumption, waste and inefficiencies.

The principal energy consumption parts of the facility can be broken down into the following categories:
- Heating ventilation and air conditioning;
- Compressed air;
- Motive power;
- Production processing, e.g. welding, thermal seaming, induction heating;
- Lighting (internal and external);
- Process plant and equipment;
- IT infrastructure, networking, communications and control;
- Support services, canteens and facilities.

3. Methodology

The initial part of the project was to establish energy consumption patterns in the manufacturing and distribution parts of the facility as they covered the larger areas, and then all other areas through metering and recording. To achieve this an energy audit of the facility was conducted to determine where opportunities existed to improve current thermal and electrical energy consumption requirements. The audit identified significant energy users (SEU) of both thermal and electrical energy, and also the daily operational profile mapped against the main energy usage. A Fluke 3 phase 1732 energy logger (Figure 3.2) was installed permanently on the main incoming supply (Figure 3.1) to monitor the profile of energy consumption on a weekly basis.

Further measurement was also undertaken on sub-distribution boards with other instruments (Figure 3.3) to profile and record the daily operational characteristics (Figure 3.4). Energy recorders were also installed on SEU loads such as compressors, extraction plant, CNC, welding plants and IT servers to enable accurate monitoring and analysis of consumption.

Lighting loads were calculated by surveying the number of light fittings in use, both internally and externally, and their load and annual operating hours entered in the lighting section of the SEAI Energy Map spreadsheet toolkit shown on Figure 3.5. Monitoring and recording of the main incoming supply gave a good indication of the load profile over the week and the consumption out of hours. Not only did the energy audit identify areas and opportunities for improvement throughout the manufacturing and warehouse facility, but it also heightened interest and awareness among staff and the management team in each area.

Energy bills for gas, electricity and water consumption for the previous three years were analysed to identify overall consumption patterns...
for the facility. This showed the ratio of thermal and electrical energy consumption by month and season. Energy bills were analysed to identify the max demand load monthly, to identify if patterns were evident in the use and cost of energy, and whether consumption patterns varied between winter and summer.

4. Design Concepts

The data collected was collated into a main load survey summary covering the maximum demand as per Figure 4.1. By analysing the audit data, large consumption variations were identified, primarily relating to the compressed air system, night storage load and the
heating ventilation incorporating dust extraction. Research was undertaken into newer and more efficient equipment and how some of the production processes could be modified. A number of different programmable controllers (PLC) were tested for both operational integration and network communications. Siemens Logo 8 was chosen because of its flexibility in dealing with both AC and DC inputs/outputs, and also because of its ability to connect multiple devices on an existing Category 6 cabled, RJ45 computer connection, and to communicate across a standard dynamic host configuration protocol (DHCP) computer network.

For a retrofitting project this substantially reduces the physical control cabling as units can be installed as “slaves” around the facility, receiving control instructions from the master unit across the standard IT infrastructure.

4.1 Main installed Load

From the information recorded three areas were identified for main projects to be undertaken in stages over a three-year period commencing in March 2015

<table>
<thead>
<tr>
<th>Building</th>
<th>Original Load</th>
<th>Total Rating</th>
<th>kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Compressed Air 1 x 37kW Compressor running at base load.</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 x 30 kW compressor covering peak load.</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2 EIM</td>
<td>Process heating</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Water heaters – Canteens/facilities</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Exterior lighting Metal Halide/Sun</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>2 EIM</td>
<td>Heating Ventilation and Air Conditioning Space Heaters</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Night Storage Heating</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>IT Server Infrastructure</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Met Fab Production processing equipment welding, thermal seaming, induction heating</td>
<td>62.4</td>
<td></td>
</tr>
<tr>
<td>2 EIM</td>
<td>Production processing equipment Laboratory</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>2 EIM</td>
<td>EIM Production processing equipment CNC, Edging, Machining</td>
<td>80.6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lighting Production Dispatch Link, Mezzanine and Offices</td>
<td>16.42</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Lighting EIM Manufacturing and Showroom Production/Storage Mezzanine’s, Storage and Canteen</td>
<td>19.48</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Lighting Warehouse and Offices</td>
<td>18.724</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Canteen Water Heating 3 Burko Boilers</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Max Demand Loading kW: 462.324kW

Figure 4.1 – Main Load Survey Summary

The compressed air system was an important service for all areas but was also one of the highest daily loads. There were also a number of sub-compressors around the building for different processes. It was decided to completely re-design the compressed air system, storage and air drying and to install loading and zone control valves, as well as solenoid control valves, at each machine. By recording and monitoring the air usage profile it was noted that the Base 37kW compressor cycled regularly into idle mode and back to compression, but never off. This was a significant factor for the new design.

Project Phase 1
- Compressed air system overhaul and upgrade;
- Programmable logic control network;
- Water facility heating and process heating;
- Exterior lighting;
- Services control – water, natural gas.

The primary ventilation load consisted of an environmental dust extraction system for the Excel Industries Manufacturing (EIM) building. Redesign of the ducting layout within the building and extraction point controls ensured that the system load was limited to the operational equipment. Further changes involving removal of ducting to areas where production had changed over the years were also planned.

Replacing the central IT server system required extensive research into systems and software, ensuring developments in applications used in the facility were covered for the next five years. The existing IT infrastructure contained nine physical servers with a total load of 10.6kW operating around the clock. From research a Dell VORTEX, Virtualised server configuration was chosen as a preferred replacement for the existing server array, enabling multiple “virtualised” to be installed on a single physical unit with significant reduction in the power consumption.

Production processing equipment in the metal fabrication area tended to be left switched on, so auxiliary relays were installed and wired back and configured to the main programmable logic controller network to enable controlled switch-off of equipment and auxiliary plant during break-times and on completion of processes.

Project Phase 3
- Lighting and controls;
- Motive power;
- Support services, canteens and facilities.

Lighting was identified as an area where substantial improvements could be made by illumination of the workplace as recommended by the EN12464 Standard. The standard specifies the lighting level for the task area, the level of light immediately surrounding by a width of at least 0.5m, and from this the background area at least 3m. Technological advances of lighting types and integrated controls.
A case study of energy efficient measures undertaken in an industrial facility provided a number of solutions in areas of direct lighting, or where natural light for daylight linkage could be incorporated. Innovations in high-output fluorescent daylight linkage and LED lighting were also considered. Movement detection was designed into the daily operational requirements based on the standard, ensuring the correct illumination was available for the task.

Motive power consumption was improved by the installation of electronic invertors controlling the start-up and running of some of the larger motors. Load recording and upgrading of the central power factor system on the main incoming supply ensured the system was optimised to respond to inductive load variations from the retrofit projects.

While a relatively small load for the overall facility, changes to the water heating for locker-room/toilet facilities and canteen were also looked at. The design plan finalised incorporated installing a central solar thermal heated storage tank in each building, complemented with a closed-loop circulated hot water pipe network supplying canteens and facilities, ensuring hot water was always available at the taps during operational times.

5. Implementation

Project Phase 1

Compressed air system overhaul and upgrade

A program of extensive maintenance was initiated, repairing all air leaks on equipment and removing all quick-coupling fittings. Next the complete air system was revamped and zoned into production areas. Solenoids were fitted at each zone (Figure 5.1), controlled from a network-interfaced Siemens programmable logic controller that manages the flow of compressed air to plant and machinery when required.

Remote controls were fitted allowing operatives to switch on air to the production zone that they were working in (the control system selects the most efficient mode of compressor cycle operation at a given time). Additional solenoids were also fitted at each machine, isolating air supply when not in use.

The existing compressors were replaced with three 11kW compressors working to a higher pressure 8bar (Previously 7.5bar) complemented with three 2000 litre compressed air storage tanks (Figure 5.5).

Programmable logic control network

Following the selection of Siemens Logo 8 programmable logic controllers (PLC) as the preferable mode of control units, they were installed in the main distribution board and in each power sub
distribution board (Figure 5.6). Each unit was connected to the main computer network, eliminating the requirement to run control cabling. An overview of the Siemens 8 PLC can be seen on the layout diagram Figure 5.7.

This system enables multi-application flexibility for the control of compressed air, HVAC, lighting control, etc. and the integration to all existing equipment as part of the retrofit programme. PLC inputs can be AC/DC voltage or current at different voltage levels. Control can be set by calendar, ensuring that equipment is off at weekends, holidays and bank holidays. This system has the flexibility going forward of integrating new equipment and changes in the production process.

Water facility heating and process heating

Surprisingly, it was discovered that the load from facility water heaters and process heating had grown significantly over the years with the addition of small under-sink heaters ranging from 700W to 1.6kW. Because individually their load capacity was small they had largely gone undetected but the cumulative load was recorded at 24.6kW throughout the facility.

Washroom, canteen facilities and locker rooms were re-plumbed to a central tank in each of the three buildings, heated primarily from solar thermal panel (Figure 5.8) and backed up by electric elements on the night rate tariff at a total load of 3.6kW. Process heating for the chemical production section was supplied from a heat pump thermal recovery (Figure 5.9), converting waste heat in the central compressor room.

Exterior lighting:

External lighting was completely revamped, from metal halide fittings consuming between 400W and 250W each to high-output LED
fittings varying between 70W and 30W, depending on location. Movement controls were installed in some areas where all-night security lighting was not required, bringing an energy saving of over 70%.

**Services control – water, natural gas:**
Isolation valves controlled for out-of-hours and weekends were installed on the incoming mains water, natural gas to space heating units and urinal flushers in toilets to reduce waste. This alone brought a considerable saving in water consumption of nearly 9,000 litres per month.

**Project Phase 2**
**Heating ventilation and air conditioning:**
The extraction system ducting was overhauled to adapt to changes over the years in the manufacturing process. Extraction shut-off valves were fitted at each machine to auto-isolate when not in use. The major change in structure was a recirculation damper and ducting back into the building from the filtration output to return air to the building in the winter. This also enabled a damper to divert the air externally in summer mode to cool the manufacturing environment. The motor was also replaced with a 55kW high drive (Figure 5.10) not running at full capacity because of changes in ducting and recirculation of air in normal operation.

**IT infrastructure, networking, communications and control**
The nine main physical servers in the computer room running 24/7 all year around were replaced with a single Dell VORTEX virtualised server configuration (Figure 5.11), enabling multiple software virtualised servers to operate from this single physical unit. While this project involved significant capital expenditure and planning, the substantial reduction in operational energy consumption can be seen from Figure 5.12 Vortex UPS Supply showing an operational load of 636W.

The equipment chosen was on the SEAI Triple E Register, ensuring funding through the Accelerated Capital Allowance (ACA) which is a tax incentive aimed at encouraging companies to invest in energy efficient equipment. The incentive allows eligible companies the opportunity to write off the total purchase value of the equipment in one year against their corporation tax. Capital allowances provisions require companies to own the equipment and use it specifically for
the purposes of that trade, ensuring that it is still in use at the end of the chargeable period (Revenue Commissioners, Reviewed January 2015).

Production processing, e.g. welding, thermal seaming, induction heating

The metal fab production area consists of an array of welding plants, induction spot welders, plasma cutters, CNC equipment and ancillary equipment such as guiltinges, presses. Overall operations are infrequent but it was noted during the survey that they were left turned on during the day. Simple control interfaces were introduced to auto-shut down or place on standby when not in use.

Project Phase 3

Lighting and controls

For the implementation reference was taken from the EN12464 Standard to ensure light levels were at an appropriate level for the task and background. Fitting types and controls selected depended on the areas where lights were located, reliability of the solution, and payback cost benefit analysis for each area of application.

For the first floor areas of the building and the main EIM manufacturing area high-frequency, high-output fluorescent type fittings with daylight linkage were chosen as these areas had a high level of natural light from roof skylights. The fittings were connected in groups to electronic controllers monitoring light level to predetermined task levels and adjusting the output frequency to the fittings, reducing energy consumption up to 90% depending on the level of natural daylight. The T5 lamp fittings were selected for this application, reducing the maximum power consumption by 60% for the fittings being replaced.

For the ground floor and lower mezzanine areas the existing fittings were replaced with LED fittings (Figure 5.13) along with an occupancy presence detection (Figure 5.14), ensuring lower energy consumption and fast reaction to movement sensors. Integration of controls with the Siemens Logo 8 programmable controllers ensure only required lights are switched on and at break times, 75% of lights are automatically switched off, so only necessary and walkway lights remain on.

In office areas fittings were retrofitted with LED lamps as the optimum option, whereas in larger floor areas high-efficiency LED flat panel fittings were installed to replace the existing fluorescent types.

Motive power

Variable speed drives were used to replace a number of conventional motor-gearbox drives, mainly on CNC machines, and on cutting and sanding machines. The variable speed drives have reduced operational costs in the woodworking production area by approximately 18% per unit produced while, at the same time, providing better and more accurate means of speed control. The control from the Siemens Logo system ensured that equipment start-ups were not simultaneous, reducing the max demand level at any given time.

Support services, canteens and facilities

Burco boilers were replaced with two high-efficient wall-mounted water heaters controlled by the main programmable controllers. This ensured that water was heated at night-rate tariff and boosted for
lunch breaks and not left turned on. All other hot water sink, locker and shower facilities were supplied from the newly-installed building solar thermal storage tanks (Figure 5.15) with back-up electrical elements on the night rate tariff.

6. Results

Monitoring and measurement of consumption continued after the implementation of each stage of the projects. This enabled continual adjustments of controls and revision of programmes on the Siemens Logo 8 programmable control network. The primary result of the changes was a reduction in the maximum available demand by 195.65kW. Further annual operational reductions and savings achieved from each project are summarised below. The summary breakdown between the original load and post-retrofit for Project Phase 1 can be seen in Figure 6.1.

Maintenance of the air system to minimise leaks and increasing the compressed air back-end air pressure by 0.5bar accompanied by 6,000 litres of primary storage enabled significant operational energy savings. Figure 6.2 shows the energy totals for Project 2 monitored originally and post-retrofit.

Changes to the main extraction system contributed to lower demands on the main drive motor, reducing operational costs. Changes to control of the night storage heating system and switching off at weekends/bank holidays added to the energy savings. In three areas of the facility (canteen, toilets and locker rooms), the storage heaters were replaced with ceiling panel induction space heating devices controlled to heat during the periods of occupancy. Combined with reductions from the virtualised server system, and production machine control, Project 2 accounted for nearly 50% of the overall savings but nearly 70% in the capital investment costs to implement. Figure 6.3 shows the energy totals for Project 3 monitored originally and post retrofit following a major upgrade primarily of the lighting:

while not as significant a capital expenditure as other equipment, required considerable resources in time to install.

Savings from each project are summarised in the comparison graph Figure 6.4.
The implementation of low-carbon technologies and engineering innovations were carried out in a period of increased production and installation of additional production equipment to meet production requirements. Cumulative reductions from each project have brought significant savings to daily operational energy consumption and costs with an annual reduction at year three of 627,525 kWh of energy. The annual savings going forward from each project can be seen from Figure 6.5.

Reductions in energy consumption as a consequence reduced the carbon emissions from the facility. Using the carbon footprint calculator from Energia, the retrofit works implemented in the three projects have reduced the CO2 emissions to the environment by 333,843 Kg.

7. Conclusions

Significant advances in electronic equipment and controls for motor drives, lighting, communications and information technology equipment are enabling significant savings in the cost base of energy and a reduction in carbon emissions for businesses.

A balance has to be struck when retrofitting facilities covering large floor areas between the cost of the equipment and installation works against the ongoing savings. For this facility, having undertaken the initial energy audit, it was decided to undertake the energy savings and retrofit through a phased approach. Upgrading the compressed air system was selected as one of the first projects as it did not require significant resources in labour to implement. The savings made through the initial project were used to complement the costs of project implementation.

After three years there is a total annual reduction 627,525 kWh for the facility and a further reduction of 333,843 Kg of CO2 waste. Other financial savings have been achieved by the reduction of the maximum import capacity (MIC), enabling savings on monthly maximum demand billing charges. Capital investment of energy efficient products from the SEAI Triple E Register accounted for a further write-back of €36,917 against the corporation tax. However, the final real pay-back across all projects over the three years is difficult to calculate as some of the measures, for example the replacing of servers computers required large capital investment, whereas other measures such as changes to the heating and ventilation systems and extraction, and upgrades to main compressed air system, required relatively small investments for the large energy reductions achieved.

Reduced ongoing maintenance costs and longer operational life from equipment such as LED fittings, optimising occupancy controls, reduced CO2 emissions, changes in kWh from day to night rates and accelerated capital allowances are other factors that will affect the actual pay-back.

There are plenty of new technologies available in the marketplace for improved performance and efficiency of equipment. These are ideal and easily designed into new installations. However, retrofitting of older installations, especially where processes and applications have changed, require more thought at the design and integration to ensure that the implementation of technological advances have a pay-back and positive impact for the environment.

It is important post implementation stage of any system to continue with regular monitoring and recording, and with making adjustments to controls and equipment, to ensure optimisation of operation and savings.

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