Knowledge based tool to aid the preliminary evaluation of CHP for a building

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ABSTRACT

The benefits of CHP are equally applicable to new and refurbished buildings but CHP is seldom installed in new build situations due, in part, to problems with determining a suitable size of unit. This is unfortunately a missed opportunity as when CHP is installed at the start of a building's life it comes to be viewed as an integral part of the building, rather than an optional extra as is sometimes the case in existing buildings. Another advantage in the new build situation is that the services can be designed with CHP in mind.

Up until now there has been no established guidance available to assist in the sizing of CHP for new buildings. This paper discusses the UK Government's Energy Efficiency Best Practice programme (EEBPp) project to develop, in collaboration with Transco, a simple computer based methodology for sizing CHP in new buildings. The software is not intended to replace a feasibility study, it is merely to act as an indicator of whether a more detailed investigation is required. As part of the project a decision support tool, developed for PCs running windows 95 and NT, has been developed to help the building services engineer select and size CHP systems for buildings (this tool is now available under the UK Government's Energy Efficiency Best Practice programme). A preliminary evaluation of the sizing can be made with only knowledge of the building's type, size, location and a few key elements specific to each sector. This enables the model to be used when designing new buildings. For an existing building the user

can enter the actual energy consumption data for the building. The paper will present some of the core energy consumption and building data that the software is based upon. It will also highlight the various steps the software goes through in conducting a preliminary evaluation.

1.0 INTRODUCTION

In suitable applications, combined heat and power (CHP), or cogeneration, can provide reduced energy costs and lower CO_2 emissions in a cost-effective manner. At the end of 1998, 3,929 MW_e (electrical output) of CHP was installed throughout the UK [DTI (1999)], supplying around 6% of the UK's electricity requirements. It is regarded by the UK Government as having the greatest potential of any single technology for achieving carbon savings in business by 2010 [DETR (1999)].

CHP plants have been installed in around 1000 buildings throughout the UK, applications include hospitals, hotels, and leisure centres (see table 1). CHP in individual buildings and community heating accounts for an installed capacity of 464 MW_e. These installations range from large gas turbines in very large acute care hospitals to small gas fired reciprocating engines in leisure centres.

Table 1 - CHP in UK Buildings and Community Heating (CH)

Building Type	Sites (1998)	Installed Capacity (MW_e)
Education	48	23.9
Hospitals	230	102.2
Hotels	263	28.7
Offices	42	14.3
Public Buildings	18	8.0
Retail	5	5.4
Leisure Centres	340	27.3
Other Buildings	30	40.9
Residential CH	44	14.5
Multi-use CH	26	199.6
TOTAL	1046	464.8

Despite the existing installed capacity, there are still significant opportunities to install CHP in many more buildings [ETSU, 1997]. It is estimated that there is an additional cost-effective potential of up to 2GW_e in individual buildings with further potential in community heating [ETSU, 1997].

The benefits of CHP are also applicable to new buildings. However, CHP is seldom installed in new build situations due, in part, to problems with determining a suitable size of unit. A computer programme has been developed which assists the engineer in the sizing process and can allow sizing support information to be derived in minutes.

2.0 THE OPERATION OF CHP PLANT

The generation of electricity at a conventional power station often results in about 60-70% of the available primary energy being lost in cooling towers, conversion and transmission. CHP systems aim to reduce the waste of primary energy by recovering as much heat as possible, resulting in efficiencies of around 80% for engines running at full load on natural gas (based on Gross Calorific Value).

The main types of prime movers used in CHP in buildings are reciprocating engines and gas turbines. In addition to the prime mover, the main components of a CHP system are the fuel system, generator, heat recovery system, cooling system, combustion and ventilation air systems, control system and enclosure [CIBSE, 1999]. Most new CHP installations include a cooling system (heat rejection equipment) to enable the CHP to run when the heat demand drops below the CHP heat output. Some CHP systems also include absorption cooling systems.

3.0 SIZING MODELS FOR CHP IN BUILDINGS

A number of computer programmes have been developed to aid the design engineer in sizing CHP units for existing buildings. In addition, many CHP suppliers use in-house spreadsheets to offer feasibility studies.

One approach requires the user to enter daily profiles after obtaining them from measurements. It then uses hour-by-hour simulation to predict the optimum size unit [Griffiths, 1995]. A different model utilises a spreadsheet in conjunction with decision analysis techniques to select units [Hughes et al, 1994].

Two other models have been produced which could be employed to simulate the installation of CHP in new buildings. One model uses conventional building modelling to predict the thermal demand of the building from the envelope dimensions and fabric, then requires the user to estimate the electrical demand [Babus'Haq et al, 1989]. The other model uses mathematical functions, the projected maximum electrical demand and the average demand for space heating, together with load duration curves to predict the size of plant [Sawillion et al, 1994].

The model described in this paper uses empirical data which has been collected from existing buildings to estimate load profiles for the building under consideration. Hour-by-hour simulation is then used to predict the financial return. The key advantage of this model is that it enables initial sizing estimates to be obtained for new buildings as well as for existing buildings.

4.0 THE DECISION SUPPORT TOOL

The computerised decision support tool has been developed to aid the building services engineer in conducting a preliminary evaluation of CHP for a building. The tool is not intended to replace a full feasibility study but should rather be used as a precursor. The programme currently covers hospitals and hotels only, however data is currently being collected so that it can be expanded to cover sports & leisure buildings and higher education buildings.

The software predicts the heat and power profiles for the building then calculates the financial return of a group of CHP engines, for a specified set of electricity/fuel prices and CHP operating hours. The programme uses a semi-empirical model based on observations that buildings of similar type and design have comparable energy demand profiles. The programme offers the user various input options depending upon the level of information available about the site. Using option 1 (see figure 1), for example, an initial assessment of the sizing can be made with only knowledge of the type, size and location of the building, together with a number of sector specific parameters. The ability of the model to make an assessment of the sizing with limited knowledge of the site enables it to be used in new build situations. For an existing building, the accuracy of the predictions can be progressively improved by providing more information about the building's energy use i.e. options 2 and 3. Option 3 allows the user to enter the actual heat and power profiles obtained from measurements. In the flow chart, the Building Energy Consumption Estimator and Profile Generator are part of a library of building energy use information stored within the programme.

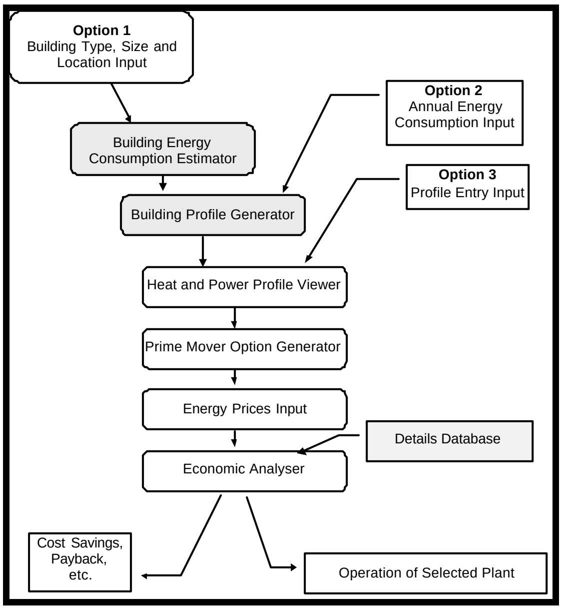

Figure 1 - The elements of the Computer Model

4.1 Building Energy Consumption Estimator

The energy consumption estimator predicts the annual fossil fuel and electrical consumption by multiplying the floor area (supplied by the user) and the relevant performance indicator stored within the programme. These performance indicators vary dependent upon the type and design of the building. The performance indicators for modern hospitals, developed from analysing the energy performance of 50 UK hospitals, are extensively discussed in the paper *'New energy performance indicators for hospitals'*, therefore, they will not be repeated in this paper [Williams et al (1999)].

The hotel sector electricity data is shown in figure 2. It can be seen that consumption ranges from 100 kWh/m^2 to over 500 kWh/m^2, with the average consumption being 227 kWh/m^2.

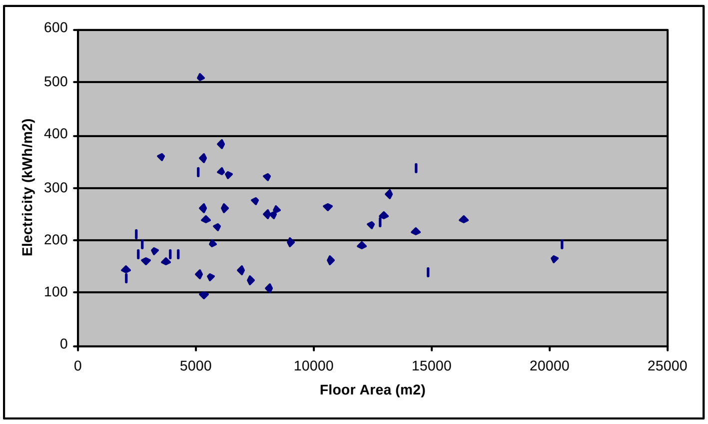

Figure 2 - Electricity data for modern hotels

The hotel sector fossil fuel data is shown in figure 3. It can be seen that consumption ranges from 100 kWh/m^2 to over 600 kWh/m^2, with the average consumption being 317 kWh/m^2.

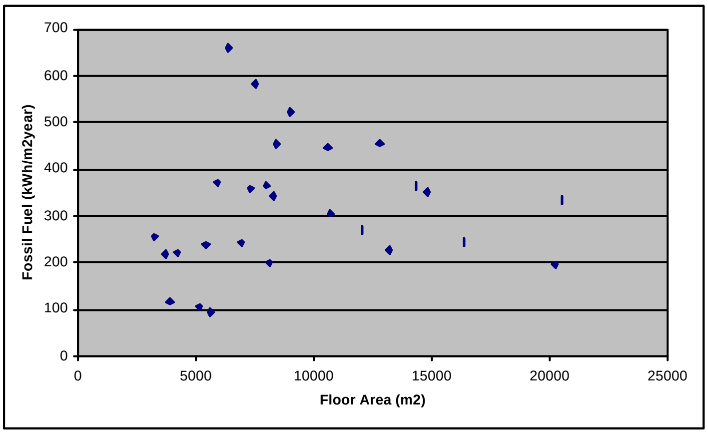

Figure 3 - Fossil fuel data for modern hotels

Each of the hotels was further categorised in terms of the factors that could affect the energy use. The data subsets defined by these categories were then analysed to determine the major factors affecting the energy use. The energy use of various types of hotels is summarised in table 2. The analysis of the data showed that the energy consumption of the hotels was found to be affected by two main factors: the way the bedrooms were serviced and whether, or not, leisure facilities were provided.

Table 2 - Performance indicators for new hotels

HOTEL TYPE	Electricity Use (kWh/m^2)	Fossil Fuel Use (kWh/m^2)
Naturally Ventilated Bedrooms	143	289
Naturally Ventilated Bedrooms and Swimming Pool	164	359
Bedrooms with individual Air-conditioning & Swimming Pool	203	291
Centralised Mechanical Ventilation Bedrooms with Air-conditioning	200	318
Centralised Mechanical Ventilation Bedrooms with Air-conditioning &	274	457

Pool		

The major heat demands for UK buildings consist of space heating and domestic hot water. The model uses information stored in its database to apportion the fossil fuel usage between the main users of fossil fuel. The model then corrects the space heating consumption dependent on the weather conditions found within that area. From the initial estimate of space heating demand the system then estimates how much fossil fuel will be used for space heating in a particular month of the year. For options 1 & 2 (see figure 1) the monthly fossil fuel used for domestic hot water in buildings is assumed to be the same throughout each month of the year. Similarly in options 1 & 2, it is assumed that the total monthly electricity used is the same throughout each month of the year, as the measurements that have been taken for the two sectors covered show this to be the case.

4.2 Profile Generator

The profile generator module estimates the hourly thermal and electrical demand based on a combination of information supplied by the building energy consumption estimator and a database of demand patterns included within the module.

4.2.1 Electricity

The profile generator module generates daily profiles of electrical usage for every hour of the year, using daily average electrical demand profiles of existing buildings stored within the programme. The average demand profile for hotels is shown in figure 4. The profile has been developed from half-hourly electricity data for 50 modern hotels. The average electricity demand for the building, obtained by dividing the predicted annual electricity consumption by the number of hours in the year, is multiplied by the electrical demand factor to give the electrical demand at a given time i.e. 0.7 at 05:00.

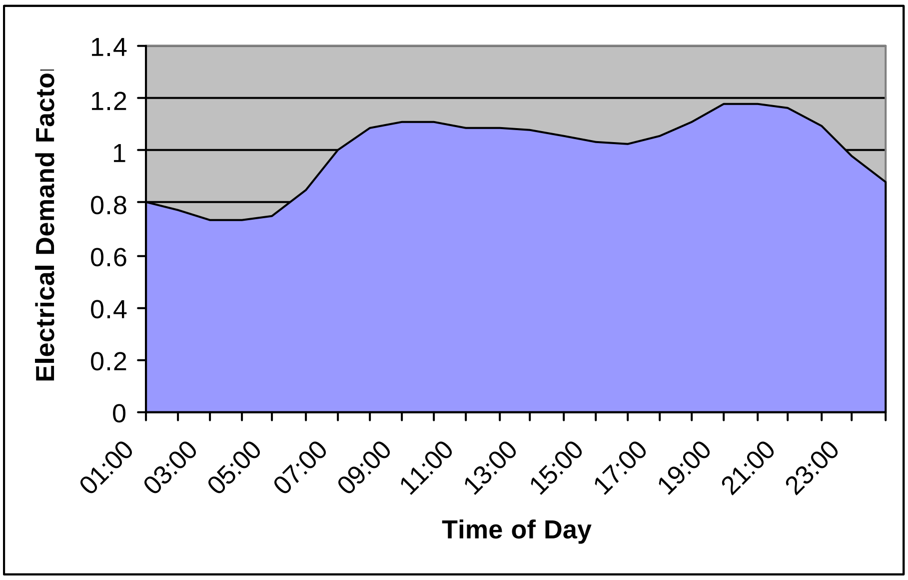

Figure 4: Average Electrical Profile for a Hotel

4.2.2 Heat

The Profile Generator module also generates daily profiles of thermal usage using a model of the space heating demand developed using standard weather data [CIBSE, 1986] and daily profiles of domestic hot water (DHW) use obtained from monitoring. Once generated, the heating demand profiles for the building are stored within the programme. The fossil fuel consumption for space heating and hot water is converted to heat usage by applying an 'average' boiler efficiency in the absence of specific boiler efficiencies from the sites studied. The affect of all assumptions influencing the heat and power loads are discussed in a previous paper [Williams et al, 1996].

The daily demand for space heating varies throughout the year. The module assumes the temperature profile for a given month can be represented by a standard day, based on the average maximum and minimum temperatures occurring in the month. A degree day base temperature of 15.5°C for UK hotels is assumed. Where necessary the base temperature is varied to reflect the particular nature of the building being modelled, for example, 18.5°C is used for hospitals. The average monthly space heating consumption, supplied from the energy consumption estimator, is apportioned using the space heating demand factor for each hour. The profile for a 24-hour building in January, is shown in Figure 5, where A is the standard outside temperature and B is the average temperature difference for the month [CIBSE, 1986]. Profiles for all the other months of the year are also stored within the model. As the model assumes an average profile for each month there will undoubtedly be some variation in the actual daily demands occurring. However, these variations are not large and hence do not have a major impact on the predicted financial returns. In practice, many other factors will also influence the space heating profile of the building.

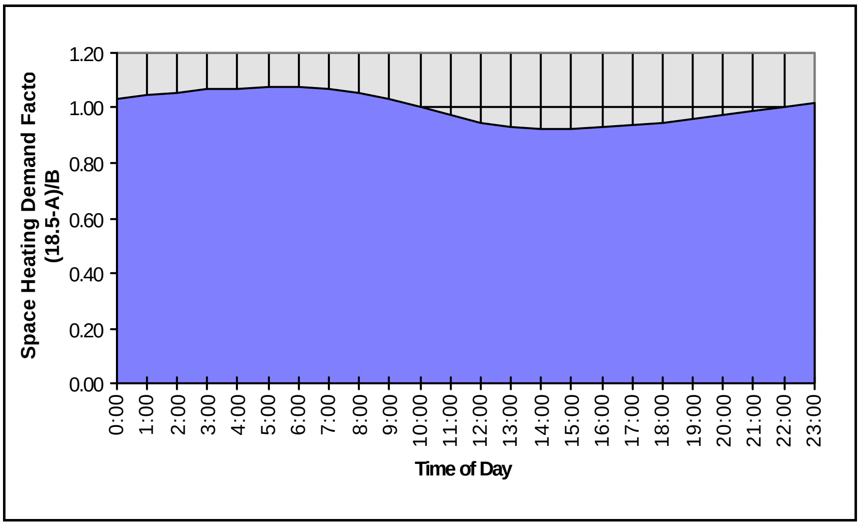

Figure 5 - Space Heating Profile in January

The model uses an annual DHW consumption figure to estimate the hourly DHW demand. For hotels, this equates to fossil fuel use of 96 kWh/m^2 of floor area [DoE, 1993]. The demand for DHW is predicted from measured daily demands for DHW in buildings, and then superimposing this pattern of usage on the building under examination. For hotels, the data in figure 6 has been used [British Gas, 1983]. The average DHW heat demand, obtained by dividing the predicted annual DHW heat energy use by the number of hours in the year, is multiplied by the hot water demand factor for each hour.

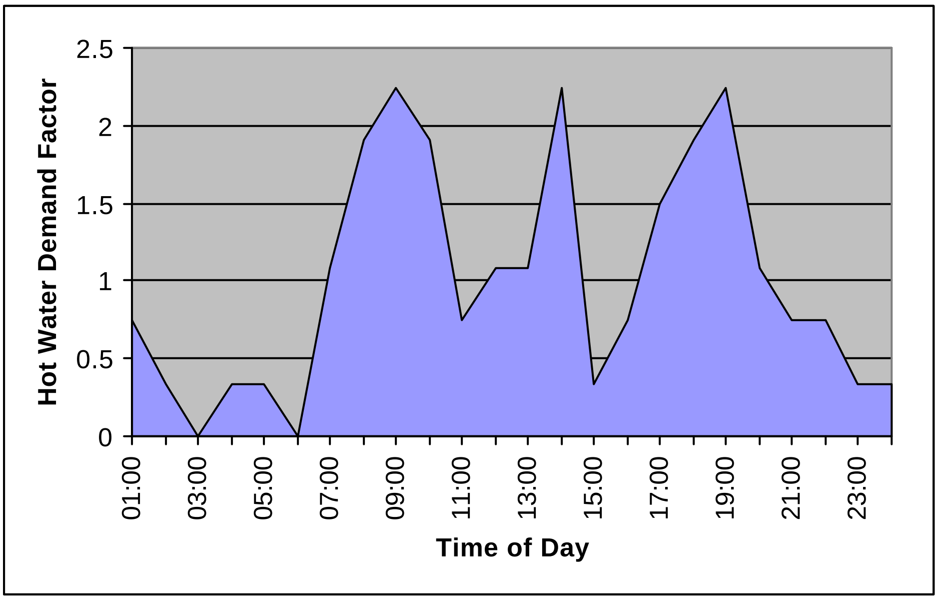

Figure 6 - Hot Water Heating Profile

4.2.3 CHP Details Database

The CHP database contains CHP plant information that enables the programme to predict how each unit will perform in practice. Currently, information on the following items is stored:

- electrical output,
- heat output,
- fuel input,
- capital cost,
- maintenance cost

Standard installed prices for 'packaged' CHP systems based on typical spark ignition turbo charged internal combustion engines with heat exchangers, controls, acoustic enclosures, etc., have been obtained from leading manufacturers and are updated periodically. These figures can be used in the early stages of the CHP study, but more detailed costings should be obtained as required.

Modulation equations are also stored which describe the heat recovery, electrical output and fuel input under part load operation. These modulation equations enable the model to predict electricity savings, heat recovery savings, fuel costs and maintenance costs under part load operation, as well as full load operation.

4.2.4 Prime Mover Option Generator

The options considered by the programme include:

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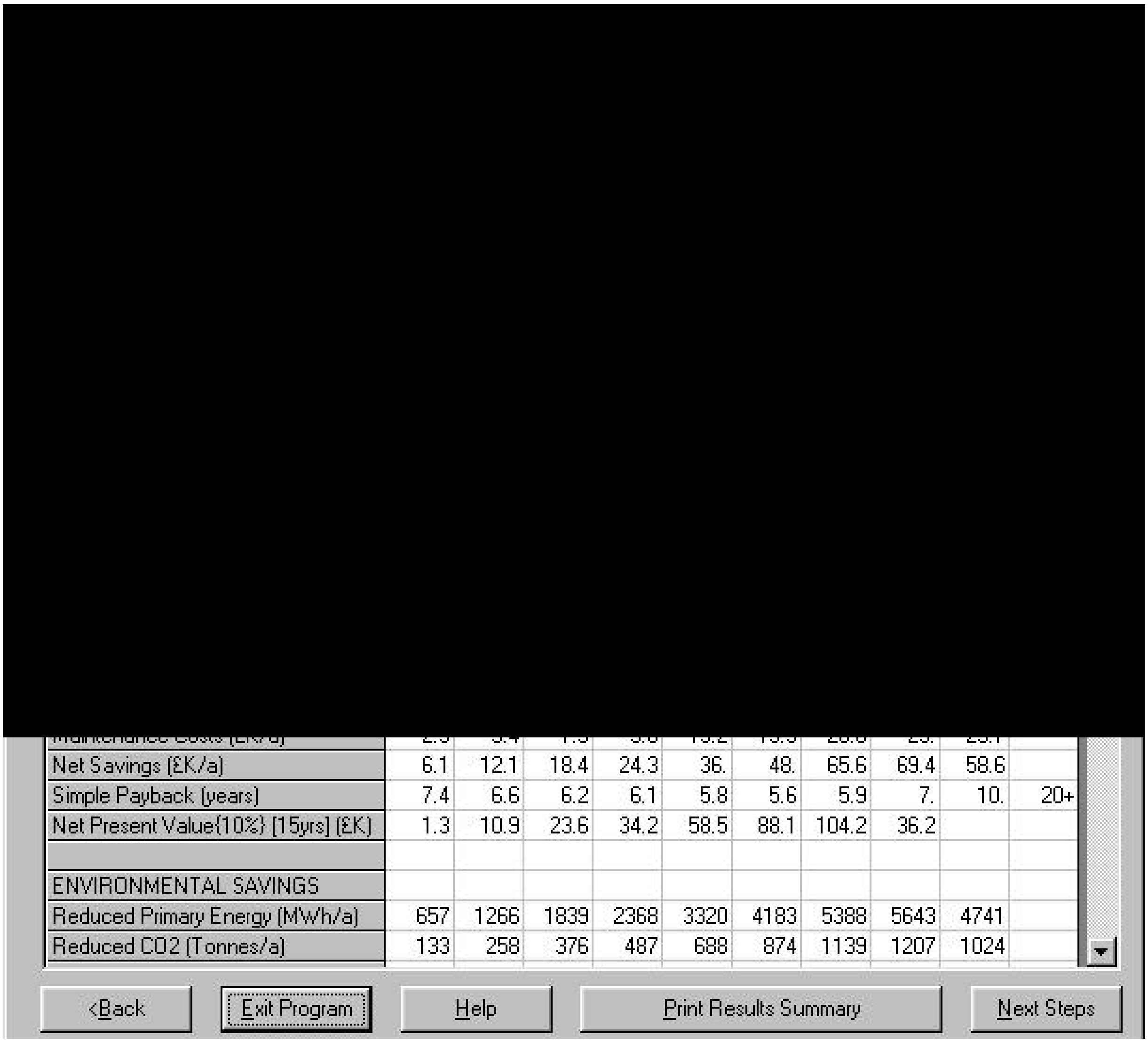
The building services engineer is then able to select the unit and operating strategy most suited to the building taking into account capital expenditure, net savings and payback required. The model allows the user to examine the selected unit in greater detail, for example the predicted operation of the plant in particular months of the year can be shown in graphical form. An example of the results output screen is shown in Figure 7. The issues surrounding the optimum sizing of plant, and how the software deals with this, are discussed further, and illustrated, in a previous paper [Williams et al, 1996].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Net Savings (£K/a)	6.1	12.1	18.4	24.3	36.	48.	65.6	69.4	58.6	
Simple Payback (years)	7.4	6.6	6.2	6.1	5.8	5.6	5.9	7.	10.	20+
Net Present Value(10%) [15yrs] (£K)	1.3	10.9	23.6	34.2	58.5	88.1	104.2	36.2		
ENVIRONMENTAL SAVINGS										
Reduced Primary Energy (MWh/a)	657	1266	1839	2368	3320	4183	5388	5643	4741	
Reduced CO2 (Tonnes/a)	133	258	376	487	688	874	1139	1207	1024	

Figure 7 - Main Output Screen from the Software

5.0 CONCLUSIONS

A computer model has been developed to aid in the sizing of CHP plant for buildings. The model allows a preliminary evaluation of CHP to be undertaken with limited information about the building, such as the floor area, type and location. The ability of the model to make sizing estimates with only limited information enables it to be used when sizing CHP for new buildings, as well as existing buildings. The software is not intended to replace a feasibility study, it is merely to act as an indicator of whether a more detailed investigation might be worth pursuing. It will be a key tool in enabling the building services engineer to consider CHP for new, and existing, buildings. This tool is now available under the UK Government's Energy Efficiency Best Practice programme.

ACKNOWLEDGEMENTS

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