# The Implementation of Condition Monitoring Techniques for the Automated Generation of Display Energy Certificates

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## Abstract

The amendments in Approved Document L (Part L) have had a significant impact on the building industry. Monitoring energy consumption and provisions for a logbook are all now mandatory by Part L, additionally further legislation has been implemented that require building owners/operators to demonstrate the energy performance of the building via Energy Display Energy Certificates (DEC). The DEC is only applicable for public buildings with a useful floor space greater than 1000m2; this requires the use of metering data for production of the energy performance of a building. DEC are updated every 12 months, however, in the period between inspections serious degradation in performance could occur only to be uncovered at the next site-based inspection. A more preferable solution would be to monitor the building in real time be alerted to faults or poor performance before they become a serious problem. Condition Monitoring (CM) is the process by which the state of a system is determined by monitoring the parameters that are indicative of its health. The increased levels of monitoring as stipulated by the amendments in Part L now provide the opportunity for introducing CM techniques for building energy performance monitoring. CM would highlight inadequate performance via benchmarking as well as informing the end user of potential maintenance faults via the signals monitored. An automated system would eliminate the need for the time and cost intensive process of generating a manually audited DEC. This paper outlines a CM methodology utilising a numerical covariance analysis technique to evaluate building performance and perform fault detection and diagnosis based upon the energy consumption and external temperature.

**Key words**: Energy Performance, Buildings, Maintenance, Condition Monitoring, Display Energy Certificates

# 1. Introduction

The reduction of carbon emissions has become a prevalent issue within developed and developing nations; beginning with the Kyoto Protocol participating states have been set the challenge of reducing CO2 emissions (UNFCCC 1997). The challenge to reduce carbon emissions within the building industry is a significant factor in lowering the overall production of CO2 given that the building sector is the second largest contributor of emissions after the transportation industry with 30% of carbon emissions being generated by buildings (CIB 1999). The commitment to Kyoto and other CO2 reducing initiatives (Defra 2002) have led to the implementation of several legislative changes for the building industry in the UK. As of April 2006 amendments in Approved Document L: Conservation of Fuel and Power (Part L) came into force enforcing the use of Target Emissions Rates (TER) as a benchmark for building performance (Regulations 2006). Furthermore, the recent consultation for Part L 2010 has aimed for even further reductions in CO2 emissions (Government 2009). A key feature of the Part L legislation amendments is the requirement of building owners to account for 90% of energy consumed within commercial buildings. In essence, monitoring of energy consumption is essential for the illustrating and improving of energy performance, without adequate monitoring poor performance is difficult to track and isolate.

In addition to the previously mentioned legislations further performance monitoring initiatives have been introduced, public buildings with a floor space of greater than 1000m2 must now produce a Display Energy Certificate (DEC) illustrating the energy performance of the building (Government 2008). The DEC utilises metering information to compare against typical building based upon the building type and function with a grading system that relates performance into a categorical band. Whilst DEC's are useful for illustrating the performance of a building the auditing process takes place annually, this leaves a significant period of time in which degradation of building performance can occur. Additionally, maintenance faults in the HVAC (heating, ventilation and air conditioning) systems can lead to an increase in wasted energy. Fault detection and early remediation can aid in keeping the energy consumption at the optimal level. It is the opinion of the author that in order to improve building efficiency in the long term, it is necessary to continually audit energy performance.

Condition Monitoring (CM) is process by which the health of a system is derived by measuring/monitoring the parameters that are indicative of the health of the system (Rao 1996). This provides the opportunity to take advantage of the greater levels of metering made mandatory by the amendments to Part L for use as 'health monitoring parameters', allowing for the implementation of an automated system of auditing the energy use of a building in relation to its pre-defined benchmark. Building Energy Management Systems (BEMS) are typically installed in the majority of sizeable commercial buildings, with the primary function of the BEMS being the regulation of the internal environment via the building services systems to maintain occupant comfort. Most commercially available BEMSs possess the ability to log and store data from meters from which analysis can be performed.

# 2. Application of condition monitoring to building energy performance

The development of condition monitoring methodologies and techniques originated in the manufacturing industry, primarily focussing on signal analysis from manufacturing equipment, the aim of which was to reduce machine downtime and predict costly failures before they occurred. Faults and failures in the majority of technologically dependent industries incurs undesirable cost penalties, CM provides a non-destructive means of the analysing the ‘health’ of equipment whilst delivering the end user with key information on the state of the system. CM has grown in popularity and spread outside the realms of manufacturing into sectors such as the rail and aerospace industries. Traditionally, the monitored parameters were measured using a wide variety of techniques ranging from vibration monitoring to oil wear debris analysis. In its application to the building industry, the monitoring technique shall log process measurement signals. Process measurement signals are those data streams generated by sensors and other systems that relay information about the given system, in the case of DEC’s the metering data forms the main measured parameter. DECs are compiled using energy meter data from the target building, given that the benchmark is also reliant on weather data this shall also be taken to be a the second key process parameter.

Further to CM techniques, CM strategies are an integral element of any CM methodology, these systems, detect and diagnose faults based upon the signals. CM strategies can be placed broadly within 3 categories Knowledge based, Numerical/data driven and model based approaches (Isermann 2005). For the purposes of this paper, Numerical system shall be used to analyse the measured parameters  for fault detection whilst a Knowledge Based System shall provide diagnostics. Numerical systems work well at levels with large amounts of data and given the lack of additional points of reference (i.e. sensor data, control information) a Model based analysis would be inappropriate.

Given that DEC’s are based primarily on energy consumption but also takes into account external weather conditions, hence a co-variance numerical analysis system shall be employed as set out in figure 1 shall be utilised.

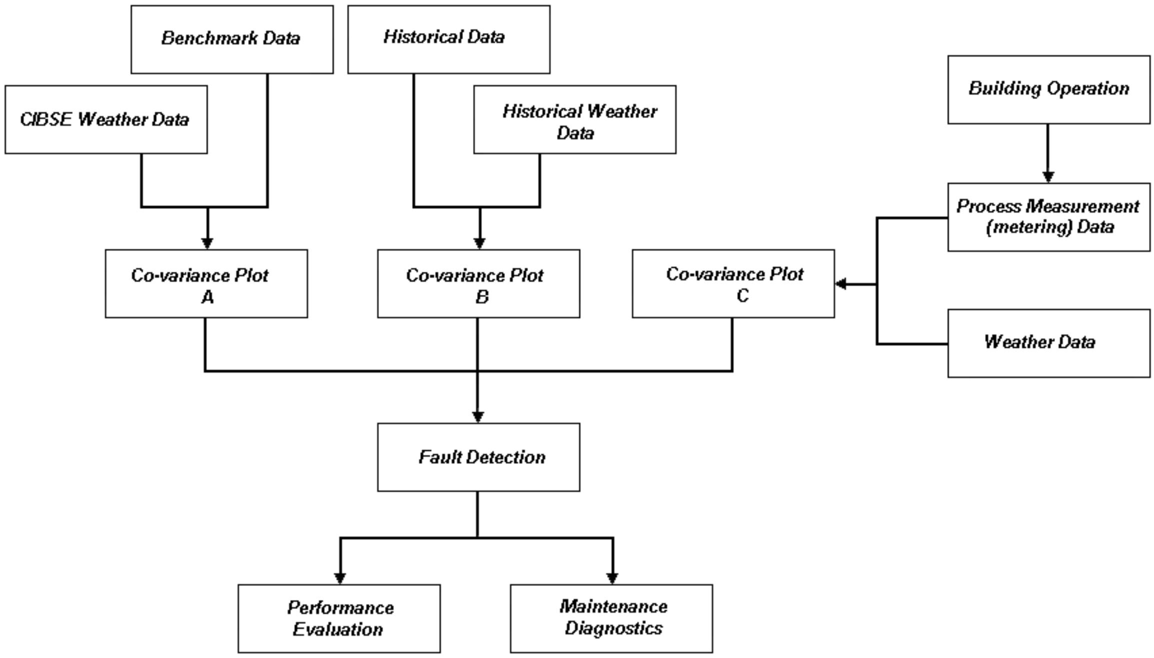


Figure 1 – Condition monitoring overview

The utilisation of process measurement and pre-prepared data allows for automation in the evaluation of performance and maintenance fault highlighting. The current performance is evaluated against the historical (previous year) performance and the benchmark performance. The majority of commercial Building Energy Management Systems (BEMS) have the ability to log data streams such as the past and current energy consumption. Additionally, given that most HVAC plant schedules are based upon the external conditions, outside air temperature is typically logged as well. This allows the covariance analysis tool detect and abnormalities in the current performance. In addition, the actual energy consumption can then be utilised to provide a DEC grading along with potential problems and a theoretical rating of the building should the stated problems be resolved. Maintenance and areas of performance improvement can be delivered through the use of Expert System diagnostics that utilise the process parameter information to deliver a meaningful output to the facilities management for corrective maintenance. However, it must be stated that in utilising the metering/external temperature data as the only process parameter measurement will not allow for in-depth diagnostics hence the output shall primarily be an advisory notice for the facilities management on potential problems that are/could (with extrapolation) cause problems both currently and in the future.

# 3. Methodology

The application of co-variance analysis for building energy performance evaluation requires the utilisation of the key process measurement data streams, the real-time metering data, historical performance data (addressing the issue of typical external weather conditions) and the Target Emissions Rate (TER) as derived from the governmental standards set out in the legislation. Covariance analysis is limited to measuring the correlation between two data sets and as such can be beneficial in simple aspects of the model, for example, measuring the magnitude of the deviation between the current energy performance and the historical BEMS data (expressed below)(Wildt 1978).

$$Cov_A(B,CW) = \frac{\sum_{i=1}^{n}(B_i - \overline{B})(CW_i - \overline{CW})}{n-1} \quad \text{(EQN 3.1)}$$

$$Cov_B(H,HW) = \frac{\sum_{i=1}^{n}(H_i - \overline{H})(HW_i - \overline{HW})}{n-1} \quad \text{(EQN 3.2)}$$

$$Cov_C(P,WD) = \frac{\sum_{i=1}^{n}(P_i - \overline{P})(WD_i - \overline{WD})}{n-1} \quad \text{(EQN 3.3)}$$

Where the first term of each covariance equation contains the energy consumption (kgCO2/m2) and the second term is the external temperature (oC). B, H and P represent the benchmark, historical and measured process metering parameter respectively. Whilst CW, HW and WD represent the CIBSE, historical and measured weather data respectively. Terms with an overscore indicate the mean value of the data set.

Equations 3.1-3.3 sets out the covariance equations utilised to analyse the trends between energy consumption and weather data in three separate cases. The total number of sample points (n) is to be previous 30 days worth of samples to provide accurate analysis. Typically, BEMS log data at 15 minute intervals, this is sufficient for the purposes of analysis since the rate of change is relatively low. The covariance equations signal correlation between the two variables, a value of 1 means that both variables are increasing or decreasing together; whilst a value of -1 indicates a divergence (a value of zero indicates no correlation).

Comparison of the energy consumption with the external conditions effectively standardises the analysis between each co-variance set, given that other factors such as occupancy is already accounted for within each set of data (consumption trends are relatively predictable for office/school buildings) it allows each covariance set to be compared like for like.

## 3.1 Fault detection and detection

The detection of faults can be identified as deviations from the expected range of values for the measured parameters. Deviations in energy consumption due to external weather conditions is the most likely cause for false alarms, hence by analysing the variation in the trend against external temperature it is possible to ensure that acceptable increases in consumption are not falsely labelled as faults. Aside from analysing the total energy consumed, the additional monitoring provides for the means of plotting of additional covariance plots for example figure 2 illustrates an example covariance plot between the external temperature and heating energy consumption, as would be expected; during the colder periods there is a clear correlation between the colder external temperature and increase in heating system load. The flat lines represent the weekend periods where the heating system is not utilised. The increase in co-variance value illustrates the increase of energy consumption during the occupied periods (08:00-16:00hrs), whilst the decreasing value indicates the time in which the building is not in use and the HVAC systems are not utilised (16:00 – 08:00).

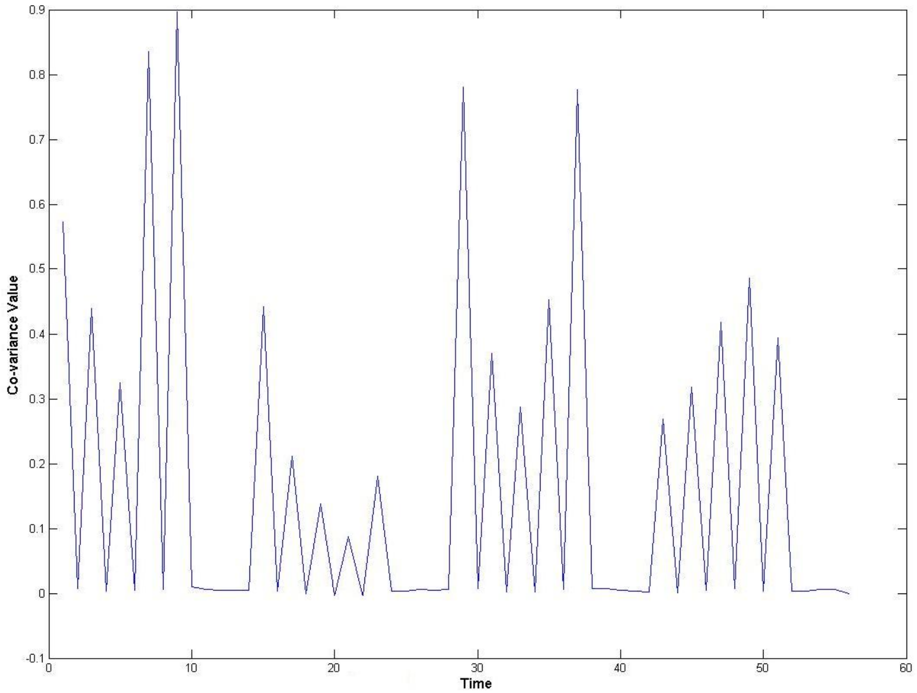


Figure 2 - Covariance analysis performed for January weather data

Whilst diagnosis can be performed, further process signals would be required to provide a confident diagnosis, hence only recommendations can be made in which areas could possible causing excessive consumption and where faults are possibly occurring. Fault data was introduced into the January heating load data set giving producing the following negative value of co-variance as shown in figure 4.

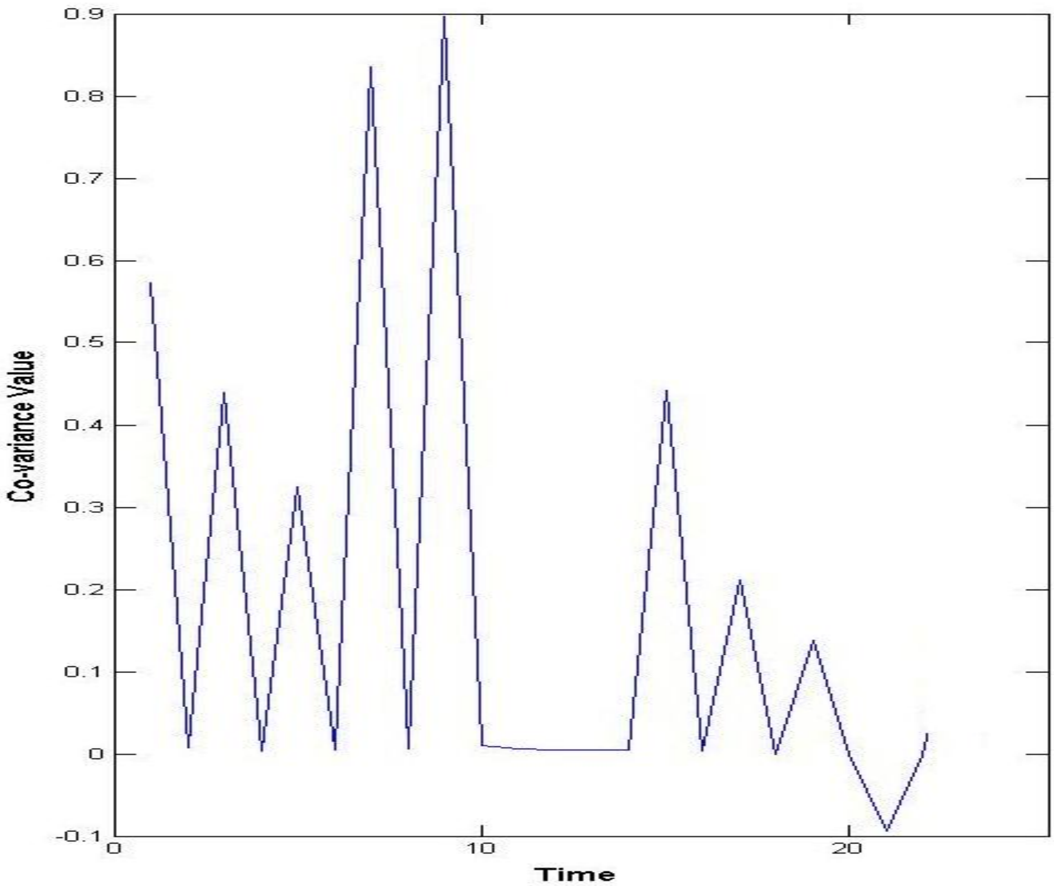


Figure 4 - January co-variance analysis with fault data

In the case of the divergence in figure 4 an expert system could be employed to perform rudimentary diagnostics, expert systems encapsulate human knowledge via a set of inference rules which is converted into software code as IF/ELSE/THEN statements. Typically, the end user provides information to the system from which an output is produced that would mirror an expert in that field. However, to provide a fully automated system rules can be pre-defined to utilise the covariance data points as shown:

*NegativeCoVARcounter;*

*IF CoVAR<0 AND NegativeCoVARcounter>2*
    *Output = Fault Occurred*
*ELSE*
    *Output = Heating system operational*
*END*

The divergence of energy consumption during colder period highlights a potential fault, the creation of seasonal profiles allow for the detection of faults throughout the year. For example, a prolonged increase in temperature with rising external temperature (surpassing the set point) during the summer period could indicate a faulty sensor or control system.

### 3.3 Performance evaluation tools

To evaluate the energy performance energy consumption a two step process can be implemented, firstly comparisons can be made with both historical and benchmark data. The covariance analysis determines the level of change between consumption and weather data, by creating adjusted data sets for all three consumption patterns a means is provided to account for variations for external temperature changes. Hence in cases where energy consumption is noticeably higher per unit change of temperature it can be deemed that the building is underperforming. Figure 5 illustrates an example of the use of adjusted data sets for comparison of current energy consumption.

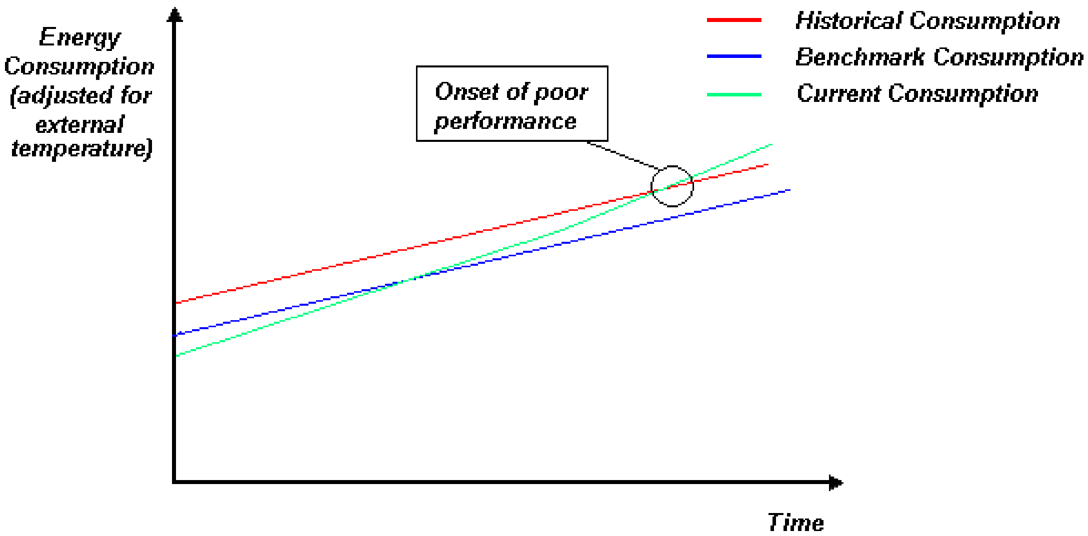


Figure 5 – Performance evaluation compared to benchmark and historical performances

The second performance evaluation tool makes use of the ability to account for external conditions by introducing a varying threshold, the threshold bands provide scope for acceptable variations outside of which are considered to be exceptional or poor performance (lower and upper bands respectively). Figure 6 illustrates the variable threshold adapting to external conditions in the first case of increased energy consumption, whilst in the second case the increase of energy consumed is not caused by changes in external conditions and hence breaches the threshold and can be said to be using excessive energy.

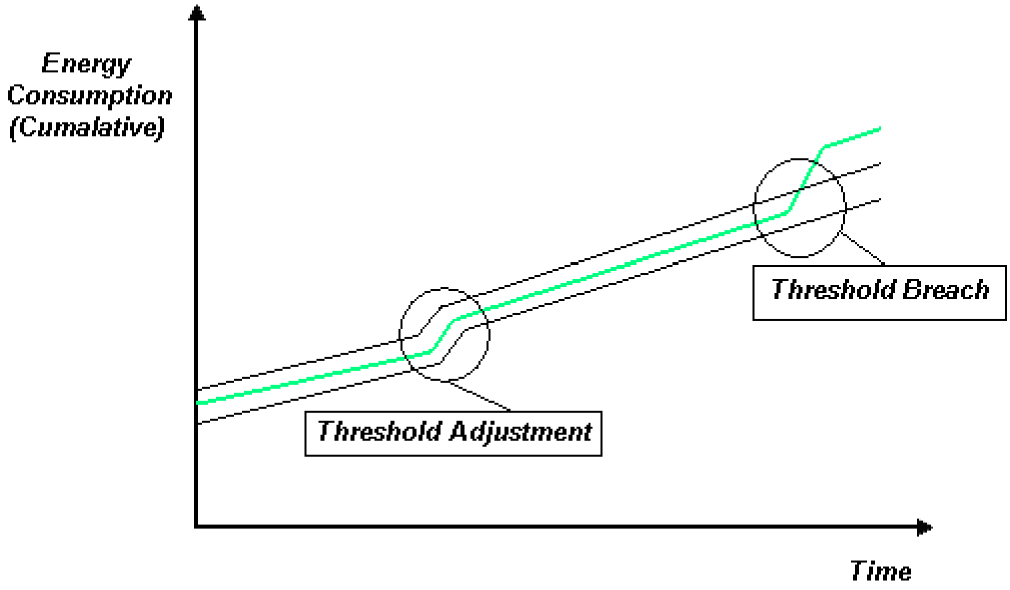


Figure 6 – Performance evaluation with variable threshold

The use of these two performance evaluation tools allow for cross correlation in determining the output, to ensure accuracy both indicators would be used to make a final evaluation of the performance. It must be noted the first evaluation tool is dependent on the historical performance being fault free, in such cases further analytical tools (outside the scope of this paper) could be employed.

# 4. DEC generation

The grading system of the DEC is based upon the Operation Rating (OR) of the building under consideration, which is based upon the energy consumed over the period of one year. The OR is based on the assessment of building performance compared with a typical building based upon its size and function shown in equation 4.4.1 (Government 2008):

Operational Rating = (BER/Building Area)*(100/Typical $CO_2$ emissions per unit area) (EQN 4.4.1)

OR's that achieve a value between 0-25 are A graded, whilst 26-50 is a B grade and so on. To ensure an fair and appropriate comparison there are several factors that can be adjusted within the calculation process. For the purposes of this paper the relevant factors that would need to be taken into account for automated DEC generation include (Government 2008):

- Weather Data
- Occupancy rates
- Proportion of non-electrical energy used

In the methodology described previously the automated OR rating would be calculated based upon the previous 30 days of energy consumption, allowing for continuous real time performance evaluation. As part of the automated energy evaluation, the integration of such features is not foreseen to be problematic, with the end user initially setting the appropriate information for the typical building calculation.

## 4.1 Example DEC

Implementation of the previously detailed methodology would aim to provide an improvement to the current system. Figure 7 illustrates a possible output to the end user as opposed to a static certificate currently issued.

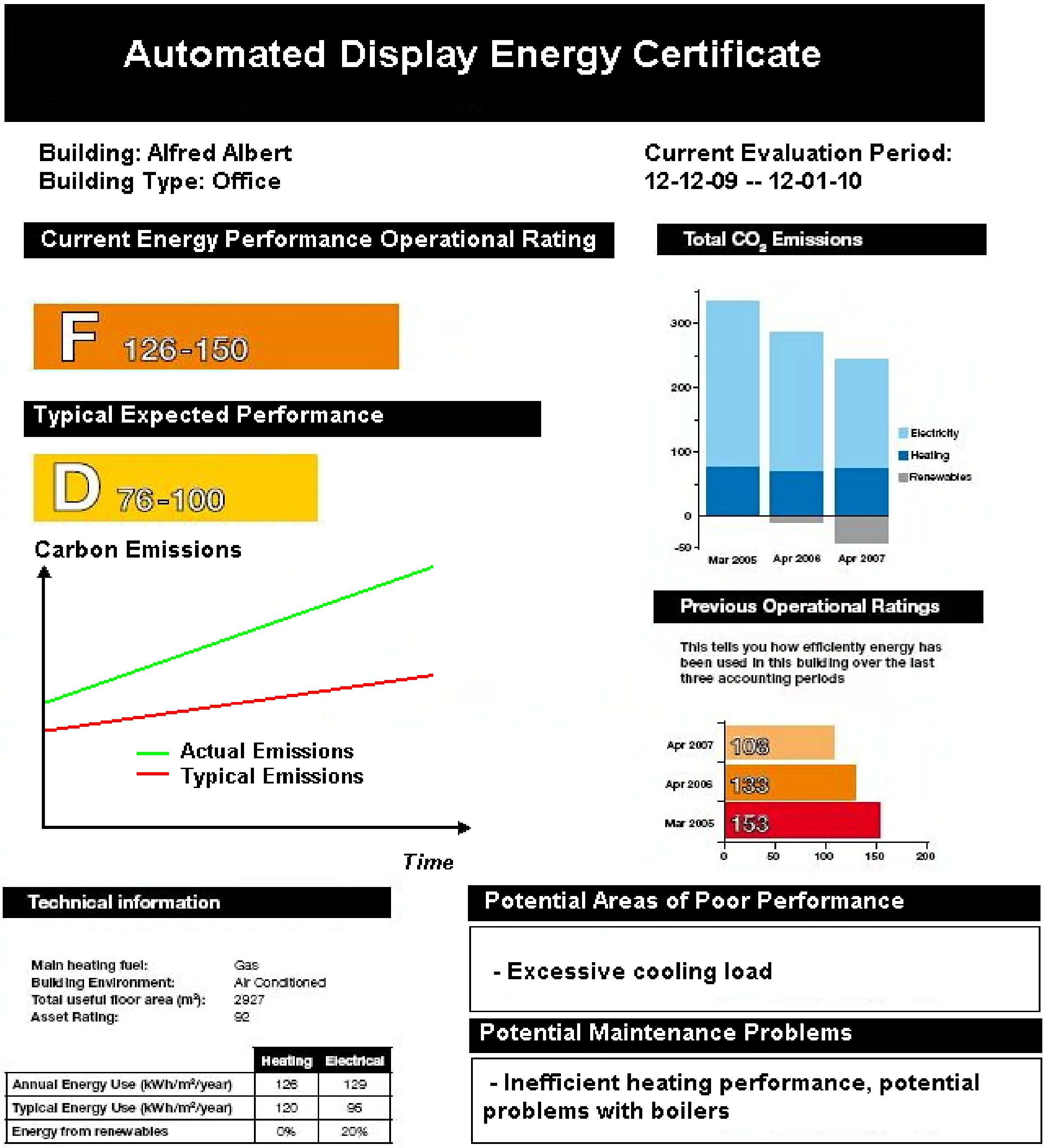


Figure 7 – Example automated DEC (amended from (EU 2009))

## 5. Conclusion

This paper details a methodology for providing real time energy performance evaluation with maintenance fault highlighting. This paves the way for improving the current system of energy auditing, namely the Display Energy Certificate. Poor performance and faults with the HVAC can be identified with remedial action taken before excessive energy is wasted or occupant comfort compromised. Whilst the numerical analysis is relatively simplistic, it can provide a surface level diagnostics system for the facilities management. Furthermore, the continuous performance evaluation provides the opportunity to not only utilise the extra metering for the very purposes it was made mandatory but to also provide a alternative method to the cost and time intensive method of calculating the DEC. Modern BEMS provide an graphical interface for the end user and with appropriate software amendments the monitor can be utilised to display the self updating DEC.

# 6. Further work

The next natural evolution would be to employ a system such as Principal Component Analysis (PCA); PCA itself has gained popularity in recent years for the function of providing FDD for HVAC plant. Additionally, the implementation of a pattern extrapolation algorithm will allow for future trend plotting and prognostics of building performance and maintenance requirements.

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