ACTUAL AND CALCULATED ENERGY PERFORMANCE OF RESIDENTIAL PROPERTY IN MALTA

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ABSTRACT

The scope of the Energy Performance of Buildings Directive (2002/91/EC and 2010/31/EC) is the reduction of energy use in buildings in the EU. A principal aspect of the directive is the calculation of an energy certificate for new and existing property. This certificate is intended to provide a measure of the energy efficiency of a building.

This research investigates the accuracy of the current methodology used to establish the energy performance of buildings in Malta, where the load profile for energy demand is significantly different to Northern and Central Europe, with a much lower heating load in winter, and a requirement for cooling in summer.

The analysis is carried out by a comparison between the official calculation procedure, the use of a dynamic hourly analysis program, and the use of metered data for a case study.

INTRODUCTION

In North and Central Europe, home heating can account for over half of residential energy use. Even prior to the Energy Performance of Buildings Directive (EPBD), several EU member states had already legislated towards improving the energy performance of their homes, either through building regulations, or by introducing specific legislation. There has been significant research into energy efficient housing in colder climates, and the favoured strategy has focussed on improving the insulation level of the building envelope, and the reduction of infiltration or air leakage. Paradoxically, in these colder climates, the improvements made in the building envelope, together with, to a lesser extent, the temperature increase attributed to global warming, have increased the possibility of summer overheating and introduced a new albeit small requirement for summer air-conditioning.

The milder Mediterranean climate experienced in South Europe meant that historically, energy use in housing was not an economic or social issue in these regions. Traditional housing was designed to minimise the use of summer cooling and, even in recent years, thermal insulation was not often included in construction. Consequently, the energy performance of buildings in South Europe has not been investigated as thoroughly as in North and Central Europe. The implementation of the EPBD obliged the introduction of energy performance legislation in regions where this did not exist, and also compelled the upgrading of legislation where this was already present.

In order to implement the EPBD, a substantial body of European (EN) and international (EN ISO) standards were drafted so as to define the procedures to be followed, particularly in the calculation of the energy performance of buildings, components, and systems. However, these standards were developed chiefly within a background where the primary energy use in housing was heating, and this emphasis is apparent in the standards. The primary standard for the calculation methodology EN 13790:2008, currently undergoing revision, was developed from the 'Calculation of Energy Use for Space Heating' (EN ISO 13790, 2003), the successor of the possibly still better known residential-only standard EN 832 'Calculation of Energy Use for Heating – Residential' (van Dijk et al, 2005). These standards were developed within a very constrained time frame so as to be made available for the implementation of the EPBD, which was postponed from 2006 to 2010.

Researchers have recommended that the continued further refinement of the cooling calculation methods is warranted so as to better evaluate the consumption of all possible means of cooling, including and in particular the low energy methods (Laskari & Santamouris, 2010). Comparative studies have shown considerable disagreement in the prediction of zone temperatures and energy loads even for very simple test case buildings, especially in situations that are strongly solar driven (Judkoff, 1988). It has been advised that attention be paid to the proper setting of default values. In particular, a differentiated approach between the heating and the cooling season is often justified, certainly for the variables that have a major impact, e.g. air tightness and thermal bridges (Laskari & Santamouris, 2010). It is also suggested that there are modelling levels and assumptions inherent to the current calculation methods, and recommended in some of the European Committee for Standardisation (CEN) standards concerned, that are not sensitive to relevant design decisions in summer performance.(Alvarez et al, 2010).

STATEMENT OF CASE

Introduction

The Energy Performance Rating for Dwellings in Malta (EPRDM) was developed in 2008 as the national calculation tool forming the basis of the Maltese official procedure for calculating the energy performance of dwellings. The procedure is based on ISO EN 13790:2008 'Energy Performance of Buildings – Energy Use for Space Heating and Cooling' and uses the simplified monthly method outlined in this standard. The implementation of the methodology commenced in 2010. Implementation and take-up of the Energy Performance Certificate (EPC) has been slow in Malta, as well as in other Mediterranean regions (Abela et al, 2012), and the methodology has not been reviewed since its introduction.

The purpose of this study is to investigate the accuracy of the current methodology used to establish the energy performance of dwellings in Malta, by comparing the official methodology (EPRDM) with a dynamic hourly analysis simulation program (IES-VE) together with the use of actual metered data for a case study apartment.

Case study property

This is a second floor occupied apartment in a block of four apartments (see Figure 1). The block is terraced with the façade facing west. The east and west facades are exposed whilst the north and south walls adjoin third party property. This is a three-bedroom apartment with an open plan lounge diner, separate kitchen, and bathroom.

The apartment block is constructed with limestone load bearing walls and concrete slabs cast in situ. The west façade is built with a double skin and air gap, whilst all the other walls are single leaf walls. Internal walls are also built in limestone or hollow concrete blocks.

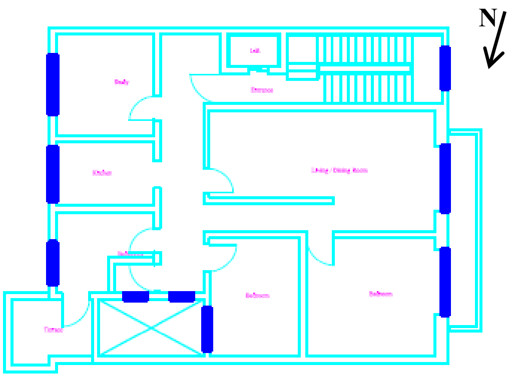

Figure 1 The case study floor plan

The flat is fitted out with electric power and lighting and a reverse cycle heat pump for cooling and heating in the lounge diner. A cooling only air conditioning unit is installed in the main bedroom. Domestic hot water is provided by an electrical water heater of 80 litres capacity. The apartment has a single occupant who is retired and hence the apartment is occupied twenty-four hours a day seven days a week.

Measurements were taken using three Hobo data loggers installed in three different rooms, namely the bedroom on the west façade, the study on the east façade, and the lounge diner on the west façade. The data collection took place between the 1st December 2011 and the 30th November 2012.

An energy meter was also installed to monitor the electrical consumption. The only source of power to the apartment is the electrical supply and this is metered by the electrical company.

A weather station was installed on the roof of the block for monitoring of the weather conditions.

Methodology

The validation of building energy simulation programs has been categorised into three specific approaches (Judkoff, 1988). These are empirical validation, analytical verification, and comparative testing.

Energy performance analysis of buildings can be classified into two categories, namely, steady state and dynamic. Steady-state analysis is appropriate when the building operation and the efficiency of the HVAC systems are constant, although the EN 13790 standard defines the monthly method as a quasi steady-state procedure with the possibility of a correction for intermittency. The EPRDM methodology is based on this standard and the energy performance certificate software could be classified as a simplified building energy simulation program. No formal validation of this program has been carried out. This research was carried out through the application of two of the above approaches for the validation of the results of the EPRDM software. Monitored data from the building are used for the empirical validation of the results of the software, whilst comparative testing is also carried out by comparing the EPRDM results to a dynamic analysis, carried out using the IES-VE software. Dynamic analysis software provides a thermal simulation of the building, but generally requires more precise information about the building construction and operation. IES-VE is a dynamic simulation software that has been tested and is recognised to produce accurate and consistent results, having been used as a benchmark in several research papers (Pollock et al, 2009, Short et al, 2010, Kershaw et al, 2011).

The energy performance certificate calculation is based on a number of assumptions that are supposed to define the standardised usage of the property. It is acknowledged that the behaviour of the occupants can have a significant effect on the energy performance of the property, and can cause variations of up to 50% of the predicted energy use. When carrying out the empirical validation exercise, the possible variance between the standardised conditions assumed by the EPRDM methodology and the actual behaviour of the occupants need to be identified and possibly quantified for the exercise to produce significant results.

Similarly when performing comparative testing between EPRDM and IES-VE, the standardised conditions assumed by the EPRDM methodology have to be reflected in the input parameters to the IES-VE software.

The energy performance of a building is a complex analysis, involving over a hundred different parameters. However, a sensitivity analysis of the building energy rating (Corrado, 2009) has identified a small number of parameters to be the most significant in generating the final result. The three main parameters identified, in decreasing order of importance, are the indoor temperature, the air change rate, and the number of occupants.

The main parameters applicable to the case study building are listed in Table 1. These parameters were utilised for the EPRDM certificate calculation and the IES-VE building simulation.

Table 1
Main parameters for test case

BUILDING DATA		
	Dimension	U- values
Floor	108.0 m^2	
Volume	325.0 m^3	
Ext wall	109.0 m^2	2.20 W/m^2K
Glazing	23.6 m^2	4.20 W/m^2K
EPRDM PARAMETERS		
No of occupants	2	8 hrs/day
Infiltration rate	0.68 ach	
Lighting	1.0 W/m2	over 24 hours
Internal loads	1.5 W/m2	over 24 hours
Metabolic gains	1.2 W/m2	over 24 hours
Heating set point	19.2°C	single zone
Cooling set point	26.4°C	single zone

Temperature Data

The monitoring equipment installed in the apartment was used to record the indoor temperature, humidity, and lux levels at 10-minute intervals. The temperature was measured in three different rooms of the apartment and an average apartment indoor temperature was calculated. The measured data showed that the temperature variance between the three rooms was small, with the maximum range between the average room monthly temperatures not exceeding 1.6°C. This was unexpected when considering that not all rooms in the apartment were fitted with heating and cooling systems, and one of the monitored rooms was practically unutilised for the whole of the year.

The average monthly indoor temperatures calculated from the data recorded are indicated in Figure 2. The EPRDM procedure calculates a seasonal temperature set point for the apartment, which for the case study was established at 19.2°C for the heating season, and 26.4°C for the cooling season. The methodology assumes that the apartment is maintained at the set point temperatures for the duration of the heating and cooling seasons respectively. The methodology takes into account the fact that Maltese properties are not fitted with central heating or cooling systems, and hence cooling and heating tend to be used on a room-by-room basis. The resultant temperature set point is based on an actual cooling temperature set point of 25°C for occupied areas and 28°C for unoccupied areas, and an actual heating temperature set point of 23°C for occupied areas and 15°C for unoccupied areas. The seasonal average daily temperatures measured in the apartment were 19.4°C for the heating season and 27.5°C for the cooling season.

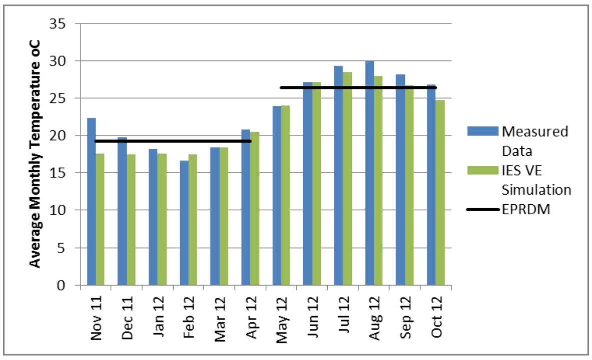

Figure 2 Average indoor temperatures in apartment

Weather Data

The data collected from the roof-mounted weather station did not cover the entire monitoring period. In order to ensure that the correct indoor/outdoor temperature difference was being considered during this exercise, particularly for the purposes of the IES-VE simulation, a complete set of hourly weather data was purchased from the meteorological weather station located 5 miles away from the case study. This data consisted of the hourly average wind speed and direction, dry bulb and dew point temperatures, global and reflected radiation, and the atmospheric pressure and cloud cover reading every three hours. The actual weather data collected on site (hourly wind speed and direction, dry and wet bulb temperatures) was crosschecked against the complete set to ensure that the two sets of variables matched.

Power data

The only energy supply to the apartment is the mains electrical supply, and this is used to provide heating, cooling, domestic hot water, lighting, cooking, and miscellaneous appliances. Daily data was collected using a Current Cost ENVR meter, and this was crosschecked against the electronic meter installed by the power company. The data collected was analysed to separate the power used for heating and cooling of the apartment from the remainder used for domestic hot water, cooking, lighting, and other activities. This exercise was performed by identifying the periods of the year where no heating or cooling equipment was used, and defining the power consumption for this period as a baseline. Any additional power during the summer and winter months was considered as cooling and heating power demand respectively.

The EPRDM methodology calculates the heating and cooling power demand on a monthly basis, separate from the power for lighting, domestic hot water, and auxiliary systems. Figure 3 presents a comparison of the monthly power demand for heating and cooling calculated by EPRDM against the heating and cooling component of the metered power supply to the apartment.

Table 2
Heating / cooling power demand for apartment

	Measured	EPRDM	IES
Heating	539	511	1410
Cooling	860	927	1063
Total	1399	1438	2473

Table 2 indicates a close match between the metered power values and the values calculated using the EPRDM methodology, with a variance of only 3% between the total power measured for heating and cooling the apartment during the test year and the total power calculated for the issue of the energy performance certificate. Figure 3 demonstrates that there is a much greater variance between the EPRDM and the measured power consumption on a month-to-month basis.

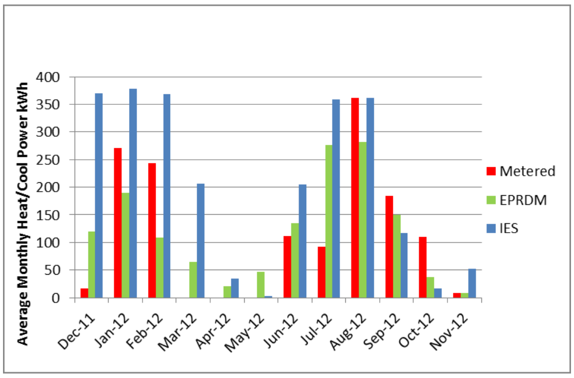

Figure 3 Power demand for heating and cooling

Figures 4 and 5 display the heating and cooling power demand of the apartment against the average monthly indoor/outdoor temperature difference for each of the three data sets, namely, EPRDM, IES-VE and the metered data. It is interesting to note that the average temperature in the apartment during summer never rises above the outdoor average. The maximum cooling load occurs as the two temperatures approach.

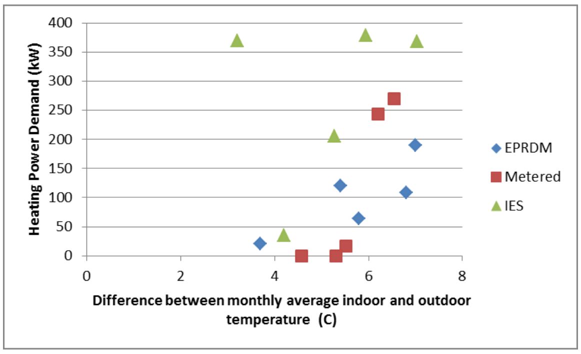

Figure 4 Relationship between heating power demand and monthly average outdoor/indoor temperature difference

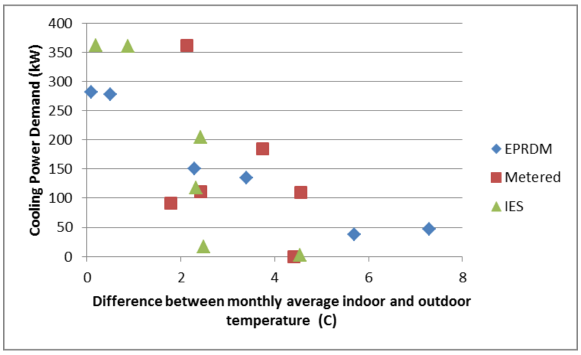

Figure 5 Relationship between cooling power demand and monthly average indoor/outdoor temperature difference

Dynamic Simulation

IES-VE is an integrated suite of applications linked by a common user interface and a single integrated data model. The program provides an environment for the detailed evaluation of building and system designs. It has been externally validated to the BESTEST standard. It models building performance using user definable time steps. The package is focussed on the simulation of non-residential buildings, which tend to be more complex than the apartment used for this case study.

Dynamic simulation allows for more precise modelling of the building energy performance than the simple monthly calculation utilised by EPRDM. In order to be able to compare the output of the two methods, the input data used by EPRDM as listed in

Table 1 were used for the IES-VE model also. The actual weather data for the test year were also used rather than the standard data provided with the software. Since IES-VE required an occupancy schedule, the eight hours occupancy assumed by EPRDM was defined as being from 5 p.m. to 11 p.m. and from 6 a.m. to 8a.m.

The software provides a complete and comprehensive range of outputs. The first comparison made was the indoor temperature. The simulated average monthly temperature in the apartment is displayed in Figure 2, and it can be seen that this closely follows the actual measured temperatures.

The software was also used to tabulate the power required by the heating and cooling plant to maintain the apartment at the seasonal temperature set points for the stipulated daily eight-hour occupancy. The monthly heating and cooling power requirements are compared to the values metered and whilst there is a significant variance between the three different sets of figures displayed on a monthly basis, the total cooling demand calculated by both EPRDM and IES-VE closely approximate the actual metered power. On the other hand, the total heating power demand calculated using IES-VE is nearly three times the value of the measured heating power and the EPRDM calculated heating power.

DISCUSSION AND ANALYSIS

The building energy performance certificate depends on the characteristics of the building, as well as the standard occupancy, operational schedules, and the relationship between the indoor environment and the outdoor climate. On the other hand, building simulation software is designed to simulate the actual operation of the building, using computational thermal and fluid dynamic analysis to model the building. In both cases, the uncertainty of the input data, the predicted operating schedules, and the expected indoor conditions all contribute to errors in the output results. Even in the case of a method which appears to produce output results close to those obtained through actual measurement, this could be a situation of opposing errors. In fact when examining the average monthly temperature data in Figure 2, it is clear that the actual measured temperatures in winter are generally lower than both the EPRDM set point and the IES-VE simulated data, whilst the actual measured temperatures in summer are generally higher. Thus before considering the monthly average data presented above, it was decided to investigate the thermal behaviour of the apartment during typical days from the heating and cooling season.

Figures 6 and 7 show a comparison of the temperature measured in the lounge and the simulated temperature in the lounge using IES, for a week in the coldest month of the year, February, and a week in the warmest month of the year, July. In winter it is clear that the heating has not been switched on every day, whilst in summer although the air conditioning has been switched on daily, the resultant room temperatures are still higher than the temperature set point of 26.4°C presumed by the EPRDM methodology. The different timing of the peaks and troughs in the two graphs are representative of the differences between the actual schedule of the occupant and the occupancy schedule assumed for the IES-VE simulation.

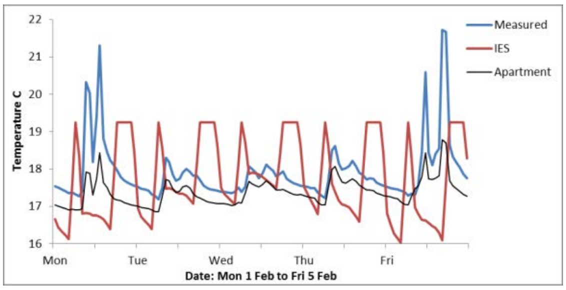

Figure 6 Temperature in lounge- winter.

Figure 6 also presents the average temperature calculated from the three measured temperatures in the apartment as compared to the measured temperature in the lounge. This is consistently lower than the lounge temperature, indicating that the use of heating in the other rooms is negligible. The lowest measured temperatures during the night and early morning show little or no variation from day to day, with a range of just 0.19°C over the week charted, unlike those generated by IES-VE, which exhibited a range of 1.02°C over the same period. The maximum temperatures in the lounge were between 20 and 22°C, significantly higher than the heating temperature set point of 19.2°C. However, the average apartment temperature never reached the temperature set point.

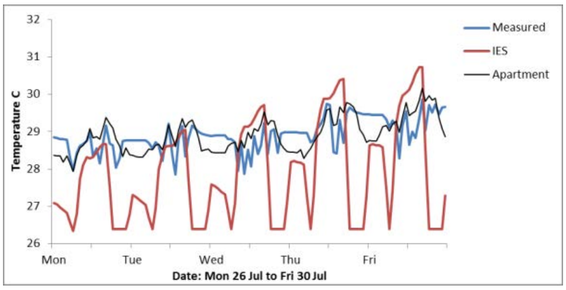

Figure 7 Temperature in lounge - summer

During the summer season, the average apartment temperature, which is also plotted in Figure 7, is lower than the lounge temperature. This indicates that the use of cooling is not limited to the lounge but extends to other rooms as well. Neither the average apartment temperature nor the individual room temperatures approach the cooling temperature set point of 26.4°C, with temperatures in the apartment varying between 28 and 29°C, with a maximum average temperature of 30.2 °C recorded during the period charted. Once again, the recorded temperatures reached during equipment off period do not exhibit much variation from day to day, whilst the simulated temperatures during the same period show more of a difference.

The energy signature method is a steady state method used for evaluation of the energy performance of buildings from measured data. In this method the average heating (or cooling) power is plotted versus the average external temperature, with the assumption that the internal temperature is maintained constant by the HVAC equipment. This results in a straight-line curve where the gradient of the line corresponds to the heat transfer coefficient of the building in W/°C. Now the actual driver of the heat transfer between the building and the environment is not the external temperature but the temperature difference between the inside and the outside. For the purposes of this exercise, the method has been adapted by plotting the energy use for heating and cooling against the average internal temperature.

In order to investigate the discrepancy in the data produced by IES-VE and EPRDM, the heating and cooling temperature set points were varied in increments of 0.2°C and the resultant cooling and heating power demand were plotted in Figures 8 and 9.

Figure 8, which shows the variation in the cooling power demand with the cooling set point, clearly shows that the variance between IES-VE and EPRDM is not great, with IES-VE producing values approximately 14% higher than EPRDM for high temperature set points and approximately 30% lower than EPRDM for lower cooling set points.

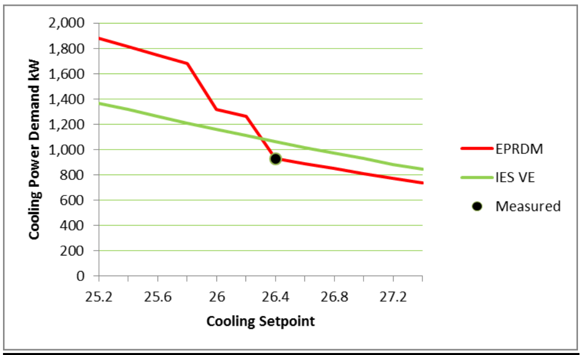

Figure 8 Variation in cooling power with set point.

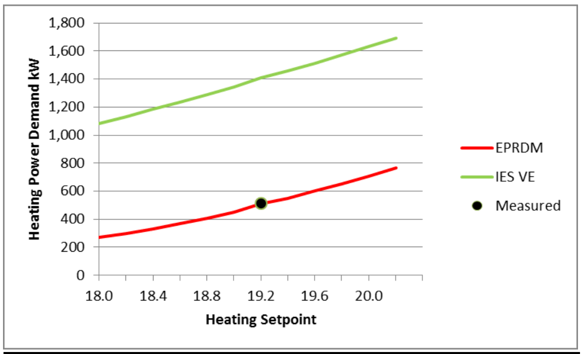

Figure 9 Variation in heating power with set point..

Figure 9 shows that the differences between IES-VE and EPRDM are significantly more pronounced for heating simulation, with IES-VE calculating the heating power demand to be double that of EPRDM at higher temperature set points and four times higher than EPRDM for lower temperature set points.

SUMMARY AND CONCLUSIONS

Indoor Temperature

The analysis of the metered data together with the comparison of the EPRDM methodology and the IES-VE simulation has highlighted that the parameter of primary importance in the energy performance of the case study is the indoor temperature, particularly during the heating season. In the case of the cooling season, although the indoor temperature is still the parameter of primary importance, the relationship between the cooling power demand and the temperature is less pronounced.

Whilst indoor temperature is a factor which is completely user dependent, the above analysis highlights the fact that both the energy performance certificate value and the dynamic simulation are dependent on an accurate prediction of the actual indoor temperatures. This suggests that the EPRDM could be modified either to permit calculation using a user defined indoor temperature, or alternatively the calculation could be performed for a range of three indoor temperatures characteristic of economical, normal, and comfort settings.

Based on the metered consumption for the case study, the IES-VE simulation clearly resulted in a considerably higher heating power. This discrepancy was sufficiently high to question the validity of the IES-VE results. Regression analysis of the data graphed in Figure 9 produced the following linear relationships

$$Q_{Ih} = 277.4\,\theta_H - 3920 \quad (1)$$

$$Q_{Eh} = 227.5\,\theta_H - 3853 \quad (2)$$

Where Q_{Ih} is the heating power demand calculated using IES-VE, Q_{Eh} is the heating power demand calculated using EPRDM, and θ_{Hh} is the heating temperature set point.

The equations demonstrate that the rate of change of heating power with reference to temperature is similar for both approaches, with IES-VE calculating an increase in heating energy demand of 277.4 kWh per year for each degree increase in the heating season set point, whilst the EPRDM graph shows an increase of 227.5 kWh per year.

Internal Loads

Figure 6 shows that the IES-VE simulation results in a lower apartment temperature during the 'equipment off' period than the actual measured temperatures. Since the heating and cooling equipment are being operated intermittently, the energy required to heat up the apartment using the IES-VE simulation is definitely increased by the lower starting point reflected in the lower night-time temperatures generated by the simulation. The higher temperatures measured in the apartment during the 'equipment off period' could have been caused by a number of possibilities, amongst which the most likely were considered to be

a. Higher internal loads
b. Heat transfer from adjoining properties
c. The high thermal mass of the construction

Analysis of the metered power data indicated that the internal loads were actually substantially lower than those estimated by the EPRDM methodology and input to the IES-VE simulation. The adjoining properties were residential apartments with similar occupancy profiles, and any possible heat transfer from these properties could not be expected to exceed the difference between the estimated and the actual internal gains.

Infiltration

The total heat losses of a building are the sum of the conduction losses and the ventilation losses. Due to the mild Mediterranean climate, local construction techniques in Malta do not attribute much importance to airtightness. Most residential buildings use trickle ventilators for natural ventilation and the use of mechanical extraction is very limited, even in kitchens and bathrooms.

The EPRDM methodology calculated an infiltration rate of 0.68 air changes per hour, and this value was also applied to the IES-VE simulation. Both methods appeared to handle the effect of infiltration in the same manner, with improving airtightness showing an improvement in the building energy performance during the winter season, with a corresponding albeit reduced decline in the energy performance during the summer season. Approximately half of the energy saved during winter by improving airtightness of the building was required for additional cooling in summer.

Conclusions

A simplified comparison of the EPRDM methodology and the IES-VE simulation, together with verification against metered temperature and energy data from a case study has been presented in this paper. The data collected for the case study property indicated that heating the apartment accounted for approximately 18% of the total energy demand, and cooling the apartment, accounted for approximately 28% of the total energy demand. It is estimated that a further 25% was used for domestic hot water with the remaining 29% being used for lighting, cooking, and other appliances.

The measured data and the EPRDM certification methodology appear to indicate that the indoor temperature set point is the most significant parameter affecting the energy performance of the apartment, and that this is particularly the case during the heating season, with a reduced effect on the cooling load. The case study confirms the validity of the EPRDM method for calculation of the heating and cooling temperature set points. Areas for further research are the effect of thermal mass and how this is treated by both EPRDM and IES-VE, the effectiveness of EPRDM in managing the aspect of intermittent operation of the heating and cooling plant, and the accuracy of the estimate of both the actual infiltration rates and the actual internal loads used by the EPRDM methodology.

Whilst the EPRDM does not offer the facility of modelling the performance of the HVAC equipment, this can also be carried out using IES-VE. The above analysis used the design parameters at the rated conditions for the installed HVAC equipment and it is probable that more accurate modelling of the plant would result in an improved building energy performance.

In order to extend this analysis it is necessary to increase the size of the property database. Since collecting actual data from properties is time consuming and involves a number of different factors, it was hoped that the IES-VE dynamic simulation could provide an accurate model of the actual use of the property. The case study has demonstrated that further calibration of the IES-VE model is required before the output of this model can be used to supplement the availability of actual data.

Although the use of a single case study limits the applicability of this study, the initial findings indicate that the EPRDM methodology is robust enough to provide a reasonable approximation of the actual energy performance of a typical apartment in Malta. Refining the methodology would enable the user to differentiate more precisely between the factors contributing to poor energy performance and to identify energy conservation opportunities.

The energy performance certificate is a calculation-based approach to energy quantification that is expected to reflect the actual measured energy usage of the building. The possibility of combining the energy certificate with actual metered energy use in an integrated approach, to use the certificate as a tool for investigating the financial benefits of energy improvements, has been investigated in other countries. Further work in this area is currently being carried out by the lead author as part of his PhD research.

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