ENERGY CERTIFICATION OF RESIDENTIAL BUILDINGS IN THE MEDITERRANEAN CLIMATE

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Copyright Statement

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Abstract

The Energy Performance of Buildings Directives (EPBDs) are political initiatives taken by the European Union to tackle the problems of climate change and security of energy supply. One of the key measures of these directives is the energy performance certification of housing, which has widespread social and economic implications, as well as the potential to impact upon the direction of these initiatives and their environmental consequence. This research is focused on the application of Energy Performance Certificates (EPCs) to housing in the Mediterranean regions of Europe, with the purpose of establishing whether the current calculation methodologies in use for the generation of EPCs accurately represent the energy performance of housing in the region.

The analysis was carried out by comparative testing using different national methodologies from Cyprus, Italy, Malta and Spain on four test case properties. The test results were validated against the output from dynamic simulation software and against monitored temperature and energy data from the test case properties. Considerable differences in the outputs from the various national methodologies currently in use were found. It was concluded that:

- Several of the EPC calculation methodologies have not been calibrated against the energy profile representative of the national or regional building stock;
- The accurate definition of the operating parameters for the heating and cooling system is particularly significant if a more precise prediction of the energy performance of the dwelling is required;
- The underlying assumptions made by the national application of the EN ISO 13790 standard for the calculation of the energy use for space heating and cooling have a greater influence on the outputs from the certification methodology than the choice of calculation method.

It is quite clear that calibration of the EPC methodology is essential for the certificates to provide an effective means of achieving the aims of the EPBD. However, at a conceptual level, the results from this research have also shown that the mild Mediterranean climate with its inherently low energy demand for residential space heating and cooling could justify a different regional approach to tackle the EPBD goals of reduction in carbon emissions and dependency on imported fuels.

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List of Abbreviations

CA	Concerted Action
CCM	Contextual Constructs Model
CDD	Cooling Degree Days
CEN	European Organisation for Standardisation
CERMA	Calificación Energética Residencial Modo Abreviado
CTE	Spanish Technical Code for Buildings
DOCET	Diagnosi e Certificazione Energetica di Edifici Residenziali Esistenti
EPBD	Energy Performance of Buildings Directives EPBD
EPC	Energy Performance Certificate
EPRDM	Energy Performance of Residential Dwellings in Malta
EU-15	EU – 15 Member states (1995)
EU-27	EU – 27 Member states (2007)
HDD	Heating Degree Days
MAEPB	Methodology for Assessing the Energy Performance of Buildings (Cyprus)
NMS-12	12 New member states which joined EU in 2004/2007
PHPP	Passive House Planning Package
SBEMcy	Simplified Building Energy Model Cyprus)
TRNSYS	Transient System Simulation Tool

Chapter 1. Introduction.

1.1. The Energy Performance of Buildings Directive

The Energy Performance of Buildings Directives (EPBDs) form part of the initiatives taken by the European Community in relation to climate change and the security of energy supply. The first directive 2002/91/EEC (European Commission, 2002) was intended to counteract the increasing dependence of the European Community on external energy sources, as well as to meet commitments made under the Kyoto Protocol to cap and to reduce greenhouse gas emissions. Whilst the European Community can have little influence on energy supply, it has the potential to take measures to influence energy demand, and the EPBD is one such measure with the aim of reducing energy consumption by improving energy efficiency. An earlier directive 93/76/EEC (European Commission, 1993), often known as the SAVE directive, was intended to limit carbon dioxide emissions by improving energy efficiency, and this directive also instructed member states to draw up and implement programmes for the energy certification of buildings. This directive was non-mandatory and resulted in low implementation of the requirements for energy certification of buildings across member states (Pérez-Lombard, et al., 2009). The European Commission acknowledged that a complementary legal instrument was required to lay down more concrete actions with a view to achieving the great unrealised potential for energy savings in the building sector (European Commission, 2002). Directive 2002/91/EEC entered into force on the 4th January 2003 and obliged member states to apply minimum requirements with regard to the energy performance of new and existing buildings, to ensure the certification of the energy performance of buildings, and to require the regular inspection of boilers and air-conditioning systems in buildings. The original deadline for transposition in the member states was the 4th of January 2006. The preamble to the directive referred to the requirements set out by the Treaty establishing the European Community to integrate environmental protection into the definition and implementation of Community policies and actions and to make prudent and rational utilisation of natural resources including oil, gas, and solid fuels, as well as the importance of demand management of energy in ensuring the security of energy supply in the medium and long term. This was to be achieved by four key points, namely:

a) The adoption of a methodology for the calculation of the energy performance of buildings;
b) The setting of minimum energy performance requirements for new buildings and for existing buildings undergoing major renovation;
c) The issuing of energy performance certificates for buildings that are constructed, sold or rented out;
d) The inspection of boilers and air-conditioning systems.

The member states were delegated the responsibility for defining the calculation methodology, setting the minimum performance requirements, and establishing the inspection procedures for boilers and air-conditioning systems. The development of the calculation methodology, and the training of experts to implement the methodology, took longer than expected, and the member states were allowed a further three years up to the 4th January 2009 to implement the sections of the directive relating to the issue of energy performance certificates and the inspection of boilers and air-conditioning systems.

Bearing in mind that the scope of the directive was the reduction of energy demand by improving energy efficiency, it is appropriate to highlight that whilst the issue of an energy performance certificate in itself might not contribute towards this aim, the directive specified, "the certificate should be accompanied by recommendations for the cost-effective improvement of the energy performance". On a similar note, the preamble to the directive stated that "regular maintenance of boilers and of air-conditioning systems by qualified personnel ... will ensure optimal performance from an environmental, safety, and energy point of view".

Following the enactment of the directive in 2003, a mandate was issued to the European Organisation for Standardisation (CEN) by the European Commission to develop and define standards for a methodology to calculate the integrated energy performance of buildings and estimate the environmental impact, in accordance with the EPBD (European Commission Directorate General for Energy and Transport, 2004). This body of standards was scheduled for publication in draft format by the end of 2004, but the development of the standards took longer than expected, and this may have influenced the European Commission's decision to allow the three-year extension of the time frame for implementation of the related sections of the directive, already envisaged in Article 15 of the directive. The objective of the standards was to establish common calculation methods in Europe for the energy performance of buildings, as well as to support those member states that did not have similar national regulations or calculation methods in place, but due to the late commencement of the standardisation work, several countries had already adopted national calculation methods before the standards were completed (Olesen & de Carli, 2011).

Over the years, it became clear that most member states encountered difficulties with the transposition of the first EPBD directive, and struggled with the implementation (Dascalaki, et al., 2012). According to the results of the European Commission's Internal Market Scoreboard, the EPBD was the worst performer in terms of transposition before the deadline date of May 2006 with nine countries (Belgium, Greece, France, Cyprus, Luxembourg, Hungary, Malta, Austria, Slovenia) failing to fully transpose the directive as at May 2008 (European Commission Internal Market and Services Directorate, 2008). A comparative analysis of progress towards implementation in the member states revealed significant diversity and found that only some member states managed to fully implement the directive with most countries still at the half way point (Andaloro, et al., 2010), and a small number still in the early stages of implementation (Abela, et al., 2013).

The Renewable Energy Directive 2009/28/EC (European Commission, 2009) on the promotion of the use of energy from renewable sources set targets for a 20 per cent reduction in greenhouse gas emissions by 2020 compared with 1990 levels, a 20 per cent cut in energy consumption through improved energy efficiency by 2020 and a 20 per cent increase in the use of renewable energy by 2020. One of the steps intended to achieve these targets was for member states to require the use of minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation by 31st December 2014. Member states were also directed to take into account measures to promote substantial increases in energy efficiency through the use of passive, low-energy or zero-energy buildings (European Commission, 2009).

In 2010, the European Commission reiterated that buildings accounted for 40% of total energy consumption in the European Union and that this sector was expanding and bound to increase its energy consumption. The reduction of energy consumption and the use of energy from renewable sources in buildings were considered important measures needed to reduce the Union's energy dependency and greenhouse gas emissions. Whilst the first EPBD was clearly a step in this direction, it became necessary for the European Commission to implement more concrete strategies to achieve the great unrealised potential for energy savings in buildings and to reduce the large differences between Member States' results in this sector (European Commission, 2010). The recast directive was approved on the 19th May 2010, and was intended to strengthen the energy performance requirements and to clarify and streamline some of the provisions from the 2002 Directive it replaced. Some of the key features introduced by the 2010 recast directive were:

a) By 31st December 2020 all new buildings are to be nearly zero-energy buildings, and for new buildings occupied and owned by public authorities this deadline is brought forward to the 31st December 2018;
b) The submission of national plans for nearly zero-energy buildings, including the national definition of nearly zero-energy buildings, intermediate targets for 2015, and policies and financial or other measures for the use of energy for renewable sources;
c) Member states are obliged to ensure that the minimum energy performance requirements for buildings and building elements are established at cost-optimal levels, with an additional obligation to report to the Commission all input data and assumptions used for the calculation of these levels;
d) The introduction of a requirement for property advertisements to include the energy performance certificate;
e) The introduction of independent control systems by member states to check the correctness of energy performance certification.

1.2. The background to Energy Certification, both within the directive as well as outside the EU context.

According to the International Energy Agency, there are three main policy instruments to reduce energy demand in the building sector: regulatory instruments such as building codes or regulations; information instruments such as labelling or certification schemes; incentive schemes complementary to the regulatory and information instruments used to increase the attractiveness of energy efficiency investments (IEA, 2013). Mandatory energy efficient design requirements for buildings were first introduced in Europe and North America in the late 1970s. The EU adopted a framework directive 92/75/EEC (European Commission, 1992) of the 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances and subsequently issued individual labelling regulations from 1995 onwards. The energy labelling of appliances is considered a useful instrument in the reduction of energy demand and has been adopted worldwide. In the EU SAVE Directive 93/76/EEC, (European Commission, 1993) energy certification of buildings is presented as one of the key strategies to achieve energy efficiency in buildings, but this aspect of the directive was not universally adopted by the member states. Following the success of domestic appliance labelling schemes, mandatory energy labelling was extended to buildings a decade later by the EPBD, which emphasised the energy certification of buildings as fundamental to the reduction of energy demand in buildings. However, it has been claimed that despite all the efforts required to implement the energy certification scheme mandated by the EPBD, there has been no discussion of its expected impact or its effectiveness as a policy instrument for carbon savings (Sunikka, 2006). The Organisation for Economic Co-operation and Development goes even further stating that "although environmental labelling schemes have been drawing much attention of policy makers and experts, ... there appears to be no clear empirical evidence that labelling schemes can significantly improve the energy performance of buildings", whilst acknowledging "the great potential of this instrument" (OECD, 2003).

Sunikka (2006) suggests that the EPBD certification scheme is based on a mandatory energy certification scheme for all existing buildings that has been in force in Denmark since 1997. An evaluation of the Danish scheme in 2001 showed that it increased energy savings to a small extent, but was unable to calculate the energy-saving effect of the scheme precisely. Nevertheless, the report identified a significant potential for energy savings in existing buildings (Laustsen, 2001). In the Netherlands energy consumption of new buildings has been regulated since 1975 and an energy performance coefficient for space heating, space cooling, hot water, ventilation and lighting was introduced in 1995, but researchers could not find a statistically significant relationship between energy consumption and the energy performance coefficient (Jeeninga et al., 2001, Uitzinger, 2004 cited by Guerra Santin, 2010). Perhaps the difficulty in associating the implementation of an energy certification scheme directly with tangible energy savings can be attributed to the intrinsic distinction between the calculation methodology used for the definition of the certified building energy performance and the actual energy demand of the building in operation. In general terms, the energy certificate is based on a simplified or detailed simulation of the energy performance of the building under a standardised set of conditions amongst which are climatic and operational factors. However, energy savings cannot be measured against this standardised prediction, and are only of value when established against the actual energy demand of the building in daily operation. The discrepancy between calculated energy savings, and actual energy savings, combined with the difficulty in establishing the energy-saving effect of a certification scheme, have together generated considerable condemnation of certification schemes by politicians, academics, and professional associations (Kordjamshidi, et al., 2006) (Brounen & Kok, 2011). Significant differences have been identified in the implementation of certification schemes in Europe, and this has led to further criticism (Rodriguez Gonzalez, et al., 2011). Nevertheless, it is understood that, despite the difficulty in identifying measurable benefits, the implementation of an energy certification scheme is the first step towards influencing consumer awareness and market transformation (Sunikka, 2006).

An alternative viewpoint is that energy certification is basically a marketing tool, with the primary objective of promoting higher performance standards than the minimum requirements specified by regulation (Casals, 2006). There is growing awareness for the need to reflect sustainability considerations within property valuation assignments and this has been confirmed empirically by recent studies (Lutzkendorf & Lorenz, 2011). On the other hand, it is often cited that householders are not enthusiastic to improve the energy efficiency of their homes as the investment is not reflected in an increase in the value of their property (Tuominen, et al., 2012).

The success of building energy certification is intrinsically linked to: (1) the possibility of improving the building energy rating in an cost effective manner, (2) the credibility obtained by achieving real energy savings and (3) the degree of commitment to the environment in general and more specifically to improved building energy performance by the stakeholders in the sector (Pérez-Lombard, et al., 2009).

1.3. The importance of residential energy consumption in the context of the need to reduce overall energy consumption and improve energy efficiency.

Whilst it is regularly quoted that buildings account for 40% of total energy consumption in the European Union, the focus of this study is on the residential energy sector and hence it is appropriate to present the statistics pertaining to this sector. Energy consumption in the residential sector accounted for 26.65% of total energy consumption in the EU in 2010, second only to the transport sector. Final energy consumption in the residential sector in the EU was 307,321 ktoe in 2010, representing an increase of 12.41% over the value for 1990 of 273,384 ktoe. However, this was not a steady increase, as consumption reached a peak in 2005, and thereafter decreased until 2009, starting to increase again in 2010. This follows the same trend as total energy consumption in the European Union, which however showed an overall increase of only 6.92% over the period 1990 to 2010. Between 1990 and 2010 the population growth rate was of 4.05%. The average residential energy consumption per dwelling in the EU in 2009 was 1.46 toe, with a range from 2.91 toe in Luxembourg to 0.48 toe in Malta. Residential electricity consumption accounted for 29.71% of total electricity consumption in the year 2010. Between 1999 and 2010 residential electricity consumption increased by 7.07%. Electricity consumption per capita in the 2010 was 6271 kWh in the EU-15, 5661 kWh in the EU-27 and 3314 kWh in the NMS-12. The average electricity consumption per dwelling in the EU in 2009 was 4137.52 kWh, which is approximately 64% of total residential energy consumption per dwelling (Bertoldi, et al., 2012). Residential energy consumption shows considerable variation within the EU with the main factors being climate (generally defined by the number of heating degree days), and level of economic development (defined by the gross domestic product per capita).

Buildings also account for 40% of all energy use in the United States of America, where they have been the principal source of energy consumption since 1998. Energy consumption in the residential sector accounted for 22% of total U.S. energy consumption in 2005. The average residential energy consumption per dwelling in the US in 2009 was 2.268 toe, with a range from 1.839 toe in the West to 2.832 toe in the Mid-West. The average electricity consumption per dwelling in the US in 2009 was 11,320 kWh in 2009, out of which the largest portion was for appliances, electronics, lighting, and miscellaneous uses, with heating and cooling accounting for 48% (U.S. D.O.E., 2012). Electrical consumption in US dwellings is approximately 42% of total residential energy consumption per dwelling. The energy use in US homes is nearly double the EU average, and electricity consumption is three times as much.

1.4. The Mediterranean climate

According to the Roman architect and civil engineer Vitruvius, in order to design housing properly, an architect must take note of the climate from the outset (Morgan., 1914).The Mediterranean climate is characterised by mild, wet winters and warm, dry summers and is generally found between the latitudes of 30 and 35° on the western margins of continental landmasses. The most frequently used climate classification map is that of Wladimir Köppen

(1846-1940), subsequently updated by Rudolf Geiger in 1954 and 1961 (Kottek, 2006). The Mediterranean climate forms part of the group of warm temperate or mesothermal climates. Whilst the origin of the climate classification system was actually based on vegetation groups, the system was developed further into subgroups depending on temperatures and precipitation. It is generally accepted that the Mediterranean climate is characterised by bi-seasonality, i.e. a hot dry summer and a mild rainy winter. Köppen defined the Mediterranean climate as the region when (a) the mean temperature of the coldest month is between -3 and 18^{o}C; (b) the summer season is generally dry and the rainfall in the wettest winter month is more than three times greater than the rainfall in the driest summer month; (c) the rainfall in the driest summer month is less than 40mm; (d) the mean temperature of the warmest month is above 22^{o}C (Kottek, 2006).

During summer, the Mediterranean regions are dominated by subtropical high pressure cells, with dry sinking air capping a surface marine layer of varying humidity making rainfall impossible or unlikely except for the occasional thunderstorm, while during winter the polar jet stream and associated periodic storms reach into the lower latitudes of the Mediterranean zones, bringing rain, with snow at higher elevations. As a result, these areas receive practically all of their rain during their winter season, and generally have no significant rainfall during the summer (Bar-Matthews, 2012).

The majority of regions with Mediterranean climates have relatively mild winters and very warm summers. However, winter and summer temperatures can vary greatly between different regions with a Mediterranean climate. In many areas frost and snow are practically unknown, but some regions, such as Madrid for example, have colder winters with annual frosts and snowfall.

The Mediterranean Sea contributes to the warm temperate climate, retaining heat in summer and releasing it in winter. Hence, temperatures are generally moderate with a comparatively small range of temperatures between the winter low and summer high. Temperatures during winter only occasionally fall below the freezing point and snow is seldom seen. In the summer, the temperatures range from mild to very hot, depending on distance from the coast, elevation, and latitude. Even in the warmest locations with a Mediterranean climate, temperatures usually do not reach the highest readings found in adjacent desert regions because of cooling from the sea, although strong winds from inland desert regions can sometimes boost summer temperatures (Nasella Flores, 2011).

As is the case for every climatic type, the highland locations of the Mediterranean region experience cooler temperatures in winter than the lowland areas.

A study of building legislation carried out by the International Energy Agency (Laustsen, 2008) identified substantial differences in how prescriptive requirements are implemented in the northern and southern parts of Europe. The milder Mediterranean climate reduces the heating load and construction techniques in the region focus less on insulation and air tightness than in the colder climates of northern Europe. Traditional Mediterranean architecture attributes greater importance to preventing summer overheating than to keeping buildings warm in winter. Regulatory U-values in northern Europe are significantly lower than in southern Europe. Statistics indicate (Laustsen, 2008) that heating and domestic hot water account for up to 80% of home energy use in northern Europe, but this values drops to between 40 and 50% for homes in southern Europe. Summer air-conditioning accounts for approximately 30% of home energy use in southern Europe. However, in a review of both theoretical and experimental techniques for the defining the energy performance of buildings, the scarcity of methods for modelling the performance of active cooling in buildings was noted (Wouters & Loncour, 2005).

1.5. Residential property in Mediterranean regions: statistical data and energy usage.

The specific energy consumption of buildings for cooling needs is dictated by the climate, the type of building, and the internal loads. A comparison of the specific energy consumption for cooling in large air-conditioned office buildings shows that, despite the Mediterranean climate, Greek office buildings do not use more electricity than Swedish or British offices for ventilation and air-conditioning during the summer (Butera, 1994). This can be attributed to the relative high internal loads characteristic of this type of building. These loads are not present in residential property and hence there is a considerable difference between the residential cooling energy consumption in southern Europe and the rest of Europe. In addition, the effects of climate change in the Mediterranean are predicted to reduce the demand for heating but also to increase the requirements for cooling by approximately twice as much as the reduction in heating (Papakostas, et al., 2010), thus continuing to increase the proportion of cooling energy demand included in total building energy requirements.

1.5.1. Residential Energy Consumption in the Mediterranean

In an analysis of the potential environmental improvement of residential buildings in the EU, Nemry and Uihlein (2008) identified three main zones in Europe approximately corresponding to the three climatic regions. These were defined by the number of heating degree days (HDD). A Heating Degree Day is a proxy for the energy demand needed to heat a home or a business; it is derived from measurements of outside air temperature. The southern European climatic zone was defined to correspond to between 564 and 2500 HDD. Table 1 displays the relevant data for the countries corresponding to this classification. Eurostat calculates HDD using the following relationship:

$$HDD = (18 - Tm) \times d \text{ when } Tm \leq 15°\text{C}$$

and

$$HDD = 0 \text{ when } Tm > 15°\text{C}$$

where Tm is the mean outdoor temperature over a given period of d days.

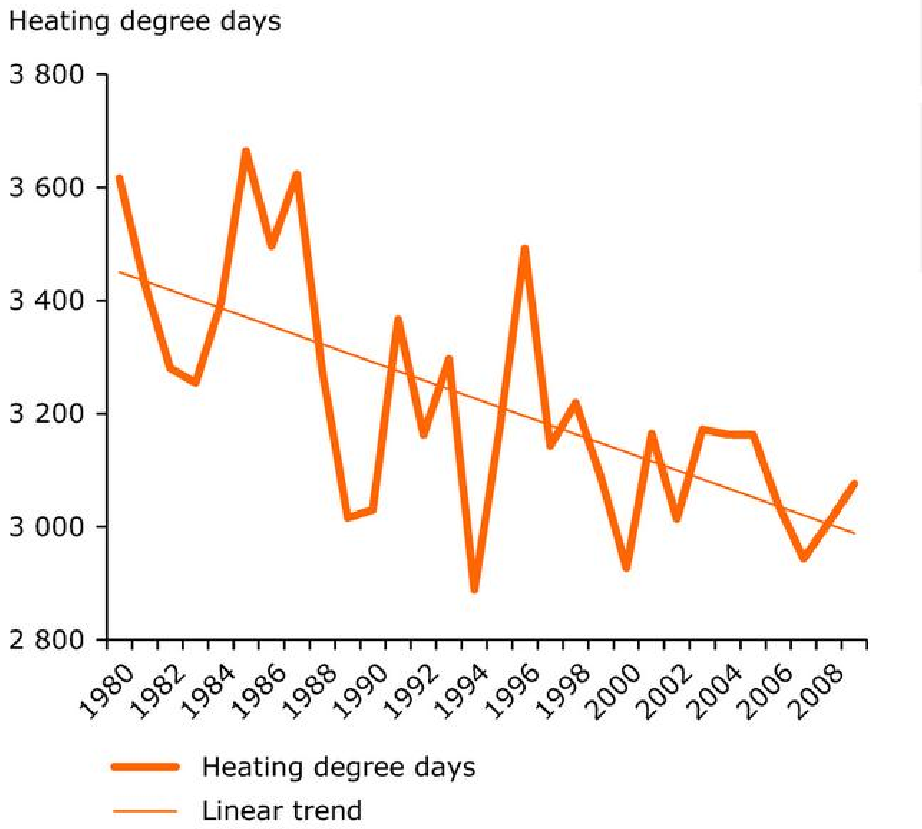

Figure 1.1 Trend in Heating Degree Days in the EU-27 (European Environment Agency, 2012)

Eurostat has collected data for calculation of HDD for decades (Eurostat, 2010) and therefore this indicator is considered very reliable. The number of HDD has decreased by 13% over the last three decades, yet with substantial annual variation (European Environment Agency, 2012). The decrease in HDD has not been homogeneous across Europe with the largest absolute decrease in the cool regions in northern Europe where heating demand is highest. The same data can also be used for the calculation of cooling degree days. Whilst a cooling degree day (CDD) indicator is currently not available, it is considered to be highly policy-relevant and could be calculated with little additional effort from the existing data set (European Environment Agency, 2012). Whilst the classification of climatic zones on the basis of both heating and cooling degree days would lead to more realistic results (Tsikaloudaki, et al., 2012), the use of CDDs as an indicator has not yet been established, and there is no accepted definition of a representative base temperature for the calculation (Tm).

South European countries: 564 to 2500 HDD			
Country	HDD*	Population in 2003 (million)	Building Stock (million m^{2})
Malta	564	0.40	11
Cyprus	787	0.72	40
Portugal	1302	10.41	337
Greece	1698	11.01	351
Spain	1856	41.55	1454
Italy	2085	57.32	2076
France	2494	59.64	2109

*Based on long term average of data for period 1980-2004

Table 1.1 Heating Degree Days in South Europe (Gikas & Keenan, 2006)

Whilst considerable data exist on the consumption of heating energy in European buildings, no corresponding data are available for the cooling energy demand for European buildings, and specifically for residential buildings. Dalin et al (2006) defined and introduced a European Cooling Index in order to explain the geographical distribution of the average specific space cooling demands in Europe. On this basis, it was estimated that the total potential cooling demand in Europe (EU-25), if 100% of all useful space were to be air-conditioned, would be an annual 1,171 TWh, which could be broken down into 672 TWh per annum for the residential sector and 499 TWh per annum for the commercial sector. The actual cooling demand is significantly lower and depends on the actual used fraction of the theoretical potential cooling demand.

Nemry et al (2008) utilised the specific cooling energy potential defined by Dalin et al to show that the actual residential cooling energy consumption in southern Europe was 4.82 TWh in 2006, out of a total of 5.074 TWh for the EU-25. However Dalin et al estimated the cooling energy consumption in 2000 for Italy, France, Spain, Greece and Portugal at 7 TWh for residential applications and 19 TWh for commercial applications.

Country	Specific cooling energy potential (Dalin et al, 2006) kWh/m^{2}yr	Expert judgement of fraction of actual consumption (Nemry et al, 2008) %	Specific cooling energy consumption kWh/m^{2}yr	Residential building stock Million m^2	Total cooling consumption GWh/yr
Malta	53	3.0	1.590	11	17
Cyprus	53	3.0	1.590	40	64
Portugal	38	1.0	0.380	326	124
Greece	59	3.0	1.770	342	605
Spain	54	3.0	1.620	1414	2291
Italy	49	1.5	0.735	2037	1497
France	35	0.3	0.105	2062	217
TOTAL					4815

Table 1.2 Residential cooling energy consumption for South European countries (Nemry & Uihlein, 2008, Dalin, et al., 2006).

Based on an earlier study co-ordinated by Adnot and Waide (2003), Nemry estimated the actual residential cooling energy consumption in southern Europe in 2005 at 3.809 TWh out of a total of 4.491 TWh for the EU-15. This estimate is based on a total cooling energy demand of 78.1 TWh with a European average share of 5.75% for cooled residential areas. Whilst Nemry claimed that the figures for the EU-15 drawn from the expert judgement based on Dalin and with the values derived from Adnot showed good consistency with just a 7% variation, the variation for the countries in the southern region is considerably higher. Adnot also predicted that the total cooling energy demand would rise to 109.6 TWh in 2015 and 114.6 TWh in 2020

Rising electrical power demand in summer is an easily identifiable key indicator of the increase in cooling demand. It has been estimated that 6% of all U.S. energy and 17% of the electricity consumed in the U.S. is used for cooling residential and commercial buildings (Koomey, 1996). More recent statistics from the U.S. Energy Information Administration show that residential air conditioning energy consumption increased from 4.6% of total energy used in homes in 1996 to 6.2 % in 2009, representing an average of 702 kWh per home per year (E.I.A., 2013).

Country	Total Cooling Energy Demand – 2005 (Adnot et al, 2003) GWh/yr	Residential fraction of consumption (Nemry et al,2008) %	Total residential cooling consumption GWh/yr
Malta	N/A	5.75	N/A
Cyprus	N/A	5.75	N/A
Portugal	2049	5.75	118
Greece	5365	5.75	308
Spain	2833	5.75	163
Italy	24336	5.75	1399
France	8213	5.75	472
TOTAL			2461

Table 1.3 Residential cooling energy consumption for South European countries (Nemry & Uihlein, 2008, Adnot & Waide, 2003).

According to the International Institute of Refrigeration, (Lucas, 1998), the energy required to run all refrigeration machines, including air-conditioners and heat pumps, accounts for between 10 and 20% of worldwide electricity consumption. However, at the European level, the proportion of energy demand of HVAC is unknown, even though many sources show a significant increase in the use of air conditioning, especially in southern countries, creating serious supply difficulties during peak load periods (Pérez--Lombard, et al., 2008). Nevertheless, it has been shown that temperature is a major determinant of electricity consumption in Europe and that the sensitivity of electricity consumption to temperature has increased over the last two decades (Bessec & Fouquau, 2008).

Continuing to focus on the southern European states, the total electrical power demand in this region for the period 2008 to 2012 has been analysed here in order to provide an estimate of the energy demand for air-conditioning. The monthly data for electricity available for the inland market were utilised and typical annual charts are shown in Figure 1.2. These figures clearly show the summer peak which is mainly attributed to air-conditioning use. Other contributory factors may include increased refrigeration loads and an increase in the number of inhabitants due to the increase in tourism during the summer months. On the other hand, during the winter months, there is a limited amount of air conditioning use, particularly in retail outlets and similar commercial establishments. The summer peak is clearest and most pronounced in Malta and Cyprus, but it is also manifest in Greece, Italy, Portugal and Spain. The data for France, however, do not display a summer peak electrical load, and this is possibly attributable to the fact that the Mediterranean climatic zone forms only a small part of the French national territory and hence the summer cooling peak in this region is outweighed by the winter heating load in the whole territory.

Based on the data analysis presented in Table 1.4, and making an allowance for France where the data were not available, the total electrical energy consumption for cooling in the southern European zone between 2009 and 2012 was of the order of 30 TWh per annum. This is just 1% of the total electrical energy generation in the EU-25. However cooling energy consumption accounts for between 10 and 15% of total electrical energy consumption in Malta, Cyprus, and Greece, and between 2 and 4% of total electrical energy consumption in Italy, Spain and Portugal.

Whilst the total electrical energy for cooling in the southern European region generated by this analysis is of the same order (30 TWh/yr) as the estimate made by Dalin (26 TWh/yr), it is dubious whether the figure calculated by Nemry for domestic cooling energy (between 2.4 and 4.8 TWh/yr) is precise.

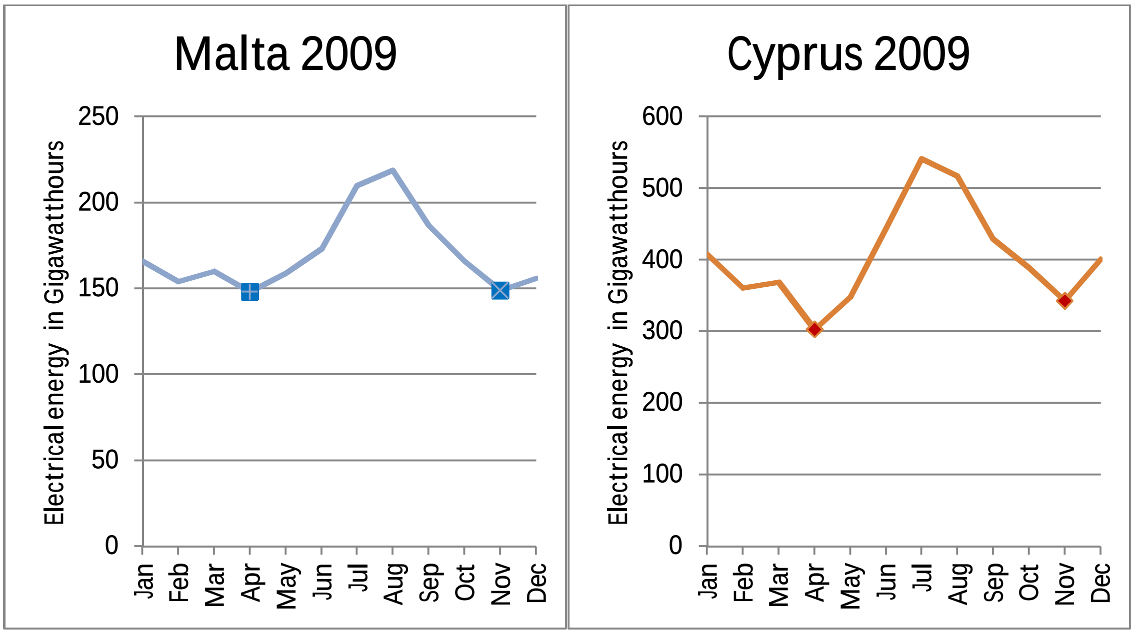

Figure 1.2: Monthly electrical energy available for Malta and Cyprus 2009 (Eurostat, 2013)

Dalin indicates that should the air-conditioning market achieve U.S. saturation levels, the residential air conditioning electricity demand would account for 58% of the total electricity demand for cooling, whilst an alternative European saturation level would have residential air conditioning electricity demand constituting 49% of total electricity demand.

	2008	2009	2010	2011	2012
Greece	5564	5201	5630	4335	6491
Spain	3536	9086	8583	12797	8970
France	na	na	na	na	Na
Italy	6166	9286	9469	6450	9982
Cyprus	747	851	840	348	672
Malta	na	226	211	221	279
Portugal	1103	2623	1573	1104	885
TOTAL	17116	27273	26306	25255	27279

Table 1.4 Electrical energy consumption for cooling in South European countries in GWh per annum.

On this basis, assuming that residential air-conditioning accounts for half of all cooling energy demand, the values from Table 1.4 are used to estimate the market penetration or fraction of saturation level in each of the southern European states. These values, as presented in Table 1.5, indicate market penetration is highest for the southernmost states. It is realistic to expect that for the larger states a similar bias can be seen between southern and northern regions of the same country.

Country	Specific cooling energy potential (Dalin et al, 2006) kWh/m^{2}yr	Calculated fraction of potential market %	Specific cooling energy consumption kWh/m^{2}yr	Residential building stock Million m^2	Total residential cooling consumption 2012 GWh/yr
Malta	53	20%	10.65	11	117
Cyprus	53	16%	8.47	40	339
Portugal	38	6%	2.37	326	773
Greece	59	13%	7.92	342	2707
Spain	54	6%	3.49	1414	4930
Italy	49	4%	2.16	2037	4398
France	35	4%	1.45	2062	3000
TOTAL					16264

Table 1.5 Market penetration of residential air conditioning in South European countries.

1.6. Aim of the Study – Research Questions

1.6.1. Background

The reduction of energy consumption is one of the priorities of every country in Europe, and the residential housing sector has been identified as a significant consumer of energy.

The scope of the Energy Performance of Buildings Directive (European Commission, 2002, European Commission, 2012) is the reduction of energy use in buildings in the European Union. A principal aspect of this directive is the issuing of energy performance certificates for new and existing buildings with the intention of providing a measure of the energy efficiency of these buildings.

Whilst the usefulness or otherwise of the energy performance certificate as a measure for improving energy efficiency in buildings is still being debated, there have been significant improvements in the energy efficiency of European housing, particularly new housing.

Research into energy efficient housing in North and Central Europe is based on the established policy of improving insulation levels and airtightness, in order to minimise the predominant heating load. This focus on the space heating load is a recurring theme, and manifests in several diverse areas amongst which are the publication of statistical data and the standards that have been drafted in connection with the implementation of the EPBD.

The Mediterranean regions of Europe experience a warmer climate than North and Central Europe, and as a result, comfort in the built environment includes keeping cool in summer as well as remaining warm in winter.

The implementation of the EPBD in South Europe is relatively recent and the methodologies for energy performance certification of housing cannot be compared to the mature schemes implemented in North and Central Europe due to the additional requirement for summer cooling.

The availability of reliable data quantifying the contribution made by residential cooling to overall energy consumption is limited, as demonstrated in Section 1.5.1, but there is no doubt that this contribution is increasing and will continue to do so.

1.6.2. The aims and objectives of the research

The raison d'être of the EPBD is the reduction of energy consumption in buildings, and the Energy Performance Certificate is one of the main tools put forward by the EPBD to achieve this goal. Whilst it is acknowledged that the correlation between the Energy Performance Certificate and the actual energy consumption of a building is tenuous and questionable, the Energy Performance Certificate is currently the only available measure for the energy efficiency of Mediterranean housing.

The aim of this research is to provide insight into the application of the various methodologies for the calculation of the energy performance of housing in a Mediterranean climate. This will enable a better understanding of the factors that determine the energy performance of housing and enhance the use of the Energy Performance Certificate as a measure or indicator of building energy efficiency, potentially impacting upon improvements in the energy performance of European housing.

The specific research question is:

> "To establish whether the current certification methodologies used in South Europe (Malta, Italy, Spain, Cyprus) provide an accurately calculated value of energy demand in Mediterranean housing."

> The research question contains a number of intrinsic issues that are outlined as sub-questions of this study:

a. What are the consequences of the differences in the energy performance of housing between North and South when implementing a common policy directive?
b. What techniques can be applied to ensure reliability of the energy performance certificate methodologies in a climate where heating and cooling are required for residential buildings?
c. Can the differences between national methodologies applied in similar climates be justified?

The purpose of the research is to establish the usefulness or otherwise of the energy performance certificate in a Mediterranean climate by validating the application of the energy performance calculation methodology in the different national contexts. This is within the framework of an increased focus on the EPC (Energy Performance Certificate) after the recast Energy Performance of Buildings Directive and an ongoing revision of the European Standards defining the calculation methodology.

1.7. Thesis structure and synopsis

Chapter 1, by way of an introduction, sets out to provide a comprehensive background in order to present the context for the description and development of the research question. In Chapter 2, there follows a review and synthesis of relevant literature, which positions this research within the framework of existing knowledge in relation to energy performance certification and Mediterranean housing. Chapter 3 defines an appropriate methodology for the research, including a justification of the philosophical stance taken and the development of the research technique. Chapter 4 introduces the different national methodologies selected for analysis, together with the most commonly used method proposed by the relevant European Standard, and the dynamic thermal simulation tool selected for analytical validation. Chapters 5, 6 and 7 present the results of the implementation of the research methodology on case study properties. A comparative analysis of the data from the various sources identified by the research technique forms the basis for answering the research question. In Chapter 8, the research findings and implications arising are discussed in relation to the scope and validity of the Energy Performance Certificate in a Mediterranean context. Finally, Chapter 9 concludes the thesis with a critical review of the research, including its contribution to knowledge and suggestions arising for further research. A full list of references is located after Chapter 9, and relevant Appendices are included at the end of the thesis.

1.8. Summary

This brief introductory chapter provides an overview of the research and outlines the structure of the thesis. Chapter 2 provides a detailed literature review and synthesis that furnishes the specialist academic background for the development of the research question.

Chapter 2. The Literature Review.

2.1. Introduction

The reduction of energy use in the residential sector has several different facets. These could be broadly categorised into three general areas, namely:

i) Replacing the housing stock with low-energy buildings designed primarily to minimise heating and cooling loads;

ii) Developing and ensuring the uptake of low-energy domestic equipment (e.g. lighting, appliances, IT); and

iii) Promoting and achieving "energy conscious" behaviour amongst occupants (Wood & Newborough, 2003).

This research is centred within the field of transformation of the housing stock into low-energy buildings and focuses on the validity of the EPC as a tool to accelerate this transformation. This chapter examines the status of existing research in this area, within the context of Mediterranean housing.

2.2. Implementation of the EPBD

The European Energy Performance of Buildings Directive (EPBD) 2002/91/EC (European Commission, 2002) introduced various obligatory requirements intended to achieve a reduction in the use of energy resources in buildings and, consequently, the reduction of the environmental impact of energy use in buildings. Article 7 of the Directive formally specified the current European requirement for the energy certification of buildings. In order to implement this requirement, a general framework for establishing a methodology of calculation of the total energy performance of buildings became necessary. A total of 30 European (EN) standards and 24 international (EN ISO) standards were drafted in order to define the necessary procedures to be introduced following the ratification of the EPBD. The CEN (European Committee for Standardisation) standards to support the EPBD were successively published in the years 2007 and 2008. Their role was to provide a common European concept and common methods for energy performance certification (Van Dijk, 2009).

In 2010, a recast of the Energy Performance of Buildings Directive 2010/31/EC (European Commission, 2010) was adopted by the European Parliament and the Council of the European Union in order to strengthen the energy performance requirements and to clarify and streamline some of the provisions from the 2002 Directive.

“The EPBD, reinforced in its Recast in 2010, is a powerful instrument to give practical effect to key energy efficiency, renewable energy and climate policies, which also improve our energy security and provide sustainable job opportunities.

Reflecting the complex and diverse nature of the built environment, it presents a major challenge to all Member States to fully implement all its elements in a manner that is most effective in delivering those positive impacts to the benefit of all EU citizens” (Hogan, 2013).

Hogan’s (2013) introduction to the biannual publication reporting progress on the implementation of the EPBD presents the EPD in glowing terms, approaching the status of a universal panacea. In this section, the emphasis is on endeavouring to assess whether the patient is taking the medicine, and the consequences, or, in other words, determining the extent of the application of the actions required by the EPBD and analysing the outcomes. In order to maintain coherence with the focus of this research, the analysis is centred on the specific aspect of energy performance certification within the EPBD.

The role of the EPC in this transformation of the building sector is one of influencing the decision of potential buyers and tenants whether or not to purchase or lease a building by providing information about the energy performance of the unit as well as recommendations for the cost-effective improvement of the energy performance.

The Concerted Action (CA) EPBD is a forum for EU member states to meet to discuss and analyse the implementation of the directive, to identify areas of co-operation, and to work together to clarify and improve procedures. The outcomes of a review of certification and its related activities (Geissler & Klinski, 2013) arising from this analysis are listed here:

- Databases of EPCs (at national or regional levels) enable the implementation of control mechanisms to prevent fraud and reinforce trust in the EPC. However only three countries (the Flemish region of Belgium, Portugal and Ireland) are reported to have successful mechanisms to prevent fraud in place.
- The effective use of the EPC in advertisements and as a supporting tool for financing is very important in increasing the demand for energy efficient buildings.

- The lack of proper monitoring procedures on the implementation of recommendations for the improvement of the energy performance of certified buildings is a constraint on the evaluation of the effectiveness of the EPCs and their potential impact on energy and financial savings, as well as on the shaping of policy.
- There is considerable variation in the level of experience of Quality Assurance mechanisms for EPCs amongst member states.

Clearly the focus here is on the validity and the applicability of the EPCs. This implies that the system for certification of buildings is in place and operational in all member states and the main difficulties are those of quality assurance and acceptance by the market.

From the outset a number of EU member states found difficulty in the transposition of the EPBD and some are still struggling with practical implementation issues (Dascalaki, et al., 2012). The introduction of mandatory energy certification of buildings was one of the core measures of the original EPBD, and possibly one of the most difficult to implement. A study of the progress made towards implementation of energy certification of buildings (Andaloro, et al., 2010) identified only eight out of twenty-seven member states that had experience of energy certification prior to implementation of the EPBD. This study also identifies at least five member states that had not yet implemented a calculation methodology for certification by 2008. The analysis also revealed that the status of implementation of energy certification varied greatly between member states and that the level of compliance between the adopted methods for energy certification and the CEN standards was partial in many cases (Andaloro, et al., 2010). The transition from the methodologies presented in the standards to the calculation procedures developed by the member states has resulted in large differences in the final energy performance of buildings calculation procedures across countries (Dijk, 2010). The energy consumption of the residential sector varies considerably between states as do the characteristics of residential buildings (Santamouris, 2005).

Apart from the technical and legislative difficulties in the transposition and implementation of the EPBD, compliance and control are essential for the successful operation of the Directive. Three factors have been identified which impact on the effectiveness of a successful compliance and control strategy (Poel & van den Brink, 2009), namely:

- The existing legal and regulatory system in the member state. In states where the legal responsibility is delegated to regions, the federal legal structure should facilitate implementation for the regions. In such states centralised implementation is unlikely and diversity in compliance and control instruments can occur.

- Cultural aspects related to the interaction between the citizen and the state. In some countries strict enforcement is the common approach, while in other countries control schemes may be based on self-regulation.

- The political and economic policy of the government. The current national objectives might not necessarily coincide with the objectives of the EPBD.

2.3. Energy performance of Mediterranean housing

2.3.1. Statistics

The geographical Mediterranean region is a complex area, dominated by its 46,000 km of coastline. The region accounts for 7.2% of total world population, 9% of total primary energy supply, 10% of electricity consumption and 8% of CO_2 emissions. One in three inhabitants of the Mediterranean states live in the coastal regions and 70% of the population is urbanised, living in cities of over 100,000 dwellers (Plan Bleu, 2004). The per capita primary energy consumption in the Mediterranean is somewhat higher (16%, 2100 against 1800 toe/cap[1]) than the world average, while per capita electricity consumption is one and a half times higher than the world average (3900 kWh/cap against 2596 kWh/cap). The Mediterranean states currently have approximately the same population as the EU-25 (about 460 million). The Mediterranean primary energy and electricity consumption represent about half of the EU-25 consumption. Therefore, per capita consumption of primary energy and electricity in the Mediterranean is about half that for the EU-25. However, the Mediterranean situation hides significant disparities between the north/south areas of the region and between the countries themselves. In fact, the largest share of energy is consumed by north Mediterranean states (72%) and the remaining 28% by the south and east Mediterranean states -14.7% for the south east and 13.6% for the south west (Plan Bleu, 2008).

The effects of global warming and of climate change are particularly relevant to human activities and the environment in the Mediterranean climate. According to predictions, the average yearly temperature increase is expected to be between 2.2 and 5.1^{o}C, and the average

[1] Tonnes of oil equivalent per capita

summer temperature increase is expected to be between 2.7 and 6.4°C. This has been forecast to occur by 2100, although some researchers have indicated that the actual time span may be shorter (Hansen, et al., 2007). These climatic changes would result in increasing the length of the summer season, and a decrease in rainfall.

2.3.2. North South differences

The earlier thermal building regulations in Europe were driven by the oil crisis of the 1970s and were mainly concerned with minimising winter heating requirements, but up to the early 1990s building regulations in most European countries continued to ignore the issue of the summer performance of buildings (Maldonado, 2005). Whilst a survey of European building regulations in the early part of the century (Visier, 2002) identified a small number of countries that had introduced specific summer requirements, a more recent study (Laustsen, 2008) identified substantial differences in implementation of legislation between the northern and southern parts of Europe. In the north of Europe the requirements are quite strict, while in the south these requirements are more varied, and generally less demanding than for similar climates in, for example, the United States.

In 2008, an analysis of the energy performance of the European residential building stock determined that this was far from the discussed low-energy standards and had tremendous potential for improvement (Nemry, 2008). The study examined 72 selected building models considered to be representative of about 80% of the residential building stock in the EU-25, and concluded that cooling demand was estimated to be negligible in the total building energy demand, but heating constituted the dominant energy demand for all buildings.

Whilst there is a lack of clear information on the cooling energy demand for residential buildings in the EU, a calculation method for the specific cooling demand defined a specific cooling energy potential of approximately 53 kWh/m^{2}yr in the Mediterranean region (Dalin, 2006). It was estimated that in 2006 only 3% of the cooling energy demand potential actually materialised as consumption, or approximately 1.6 kWh/m^{2}yr. The total demand relates to the cooling of the total living area through the entire cooling season, but in residential buildings, it is customary to cool a fraction of the building area with the cooling equipment switched on for shorter time periods.

Energy consumption is an important issue in the Mediterranean region, and a decisive role in this is played by dwelling air conditioning systems. The market for these products demonstrates a continuous positive trend with a growth rate of 10% in 2006 in Europe with respect to 2005 (Ishida, 2007). Economic development together with the expectation of better living standards is expected to continue increasing the demand for electricity for cooling and air conditioning of dwellings. On the other hand, modern architecture and building technologies, with large glazed areas, reduced thermal mass, and urban layouts, have become more dependent on air conditioning for temperature control during the summer season (Santamouris, 2007). This leads to the curious fact that air-conditioned buildings in northern Europe consume more cooling energy than in southern Europe, with an average of 40 kWh/m^2/yr for southern climates as against 65 kWh/m^2/yr in north European building projects (Santamouris, 2005).

2.3.3. Traditional Housing

Many authors have reported on the importance of vernacular or traditional architecture as a reference model for energy efficient design (Coch, 1998, Serghides, 2010). All over the world, houses, small towns, and villages of the past collectively contain some of the best preserved examples of climate conscious architecture, and today's passive techniques in reducing the energy demand of buildings are based on or derived from systems and components from vernacular architecture (Ferrante, 2012). The traditional architecture of the Mediterranean region demonstrates expertise and ingenuity in adapting to the climate, with both housing and urban design emphasising summer shading, use of natural light and ventilation, and maximising the benefits from the winter sun (Kyvelou & Bidou, 2007). The vernacular Mediterranean architecture is characterised by the use of white and light colours for the building envelope, including the roof (Zinzi, 2010). This traditional solution for reducing cooling demand and ensuring thermal comfort is affected by weathering and ageing.

The traditional Mediterranean habitat often had no heating (Kyvelou & Bidou, 2007, Ghrab-Morcos, 2005). The temperate Mediterranean climate has variable conditions throughout the year, and traditional architecture had to develop flexible solutions to change the building response according to the weather conditions. Typical solutions were the use of moveable shade systems, such as the louvered blind or shutter, which also acted as mobile insulation in the openings, the use of apertures that could be completely opened to allow maximum control of ventilations, and intermediate spaces between indoor and outdoor areas (Coch, 1998).

The behaviour of a building developed to take advantage of the environment differs from that of an air-conditioned building. In a study of Spanish traditional construction methods, the main bioclimatic strategies identified were high thermal mass, protection against solar radiation, use of solar radiation, use of natural resources, judicious selection of the built form, and protection of the entrance (Canas & Martin, 2004).

An evaluation of traditional construction in the town of Mardin, in south Turkey, identified the most important traditional design parameters as being the site and orientation of the building, the building form, and the thermal and optical properties of the building envelope, with the building envelope being the most important parameter (Manioglu & Yilmaz, 2008). Thick and heavy walls are used to slow down the heat transfer through the building envelope and minimisation of the area and number of windows minimises the direct solar radiation gain. Summer temperature measurements of a modern and traditional house resulted in lower indoor air temperatures in the traditional house, and a user survey of 100 buildings in the area supported the results of the measurements.

The transition from traditional housing in Cyprus to the cheaper uninsulated brick and concrete construction of the 1960s came with an energy penalty of nearly double the cooling load and triple the heating load, according to a TRNSYS simulation for a typical model house plan in the Nicosia area. Applying insulation to the walls and roof results in a 10% lower cooling requirement than the traditional house, and a 33% lower heating requirement (Florides, et al., 2001).

The behaviour of a building developed to take advantage of the environment differs from that of an air-conditioned building. The transition from traditional housing to air-conditioned housing in the Mediterranean has occurred in parallel with lifestyle and behavioural changes.

2.4. Low energy housing in the Mediterranean

2.4.1. Principles

Up to 2007, the Italian regulations judged the energy efficiency of buildings based on the heating requirements alone, and the resulting buildings could actually be quite unsuitable for the real climatic conditions in the Mediterranean region (Mingozzi, et al., 2007). In reality, whilst in cold northern climates the technical solution for low energy housing is based on a well-insulated airtight building envelope and maximising solar gains, and in hot dry southern climates low energy housing must minimise overheating through natural ventilation, shading, and high thermal mass, in the Mediterranean the climate is neither cold enough nor hot enough to justify either of the aforementioned approaches (Tronchin & Fabbri, 2008). As a result, low energy buildings have not been considered an issue of importance in most Mediterranean countries until recently (Wenzel, 2009). It has been reported that South European countries have no form of labelling or market infrastructure development of low energy buildings or passive houses (Mlecnik, et al., 2010).

In Mediterranean climates, the energy need for warm water heating is of the same order as heating energy consumption. As building standards continuously improve, there is a clear shift from the dominance of thermal energy (heating) to electrical energy (cooling). Heating energy can be drastically reduced down to 15 kWh/m^2yr even in cold climates, while cooling energy is on the increase due to higher levels of comfort, but also to ever-increasing internal loads. (Eicker, 2009). In spite of the significant interest in the development of low energy buildings in the Mediterranean region, there is still the tendency to underestimate the growing energy demand for cooling purposes and this has been attributed to a number of factors, amongst which are:

- The relatively recent development of passive and low-energy buildings in the Mediterranean region;
- Problems connected with modern architecture and the use of low thermal inertia building components;
- The need for further research into cooling demand and summer energy performance; and
- Economic, social and cultural barriers (Ferrante, 2012) .

2.4.2. Studies (at component level)

Current construction practice in the Mediterranean residential construction sector shows limited signs of change (Ferrante, 2012). This could be related to the combination of the climate and the specific social and economic conditions. The mild winter and warm summer, together with lifestyle choices and economic considerations, appear to induce a resistance to the take-up of the concept of low- or zero-energy housing (Ferrante, 2012). In spite of growing interest in energy efficient housing from researchers and environmentalists, the main results so far are prototype models and experimental pilot studies that have achieved a limited impact on building practices and construction to date (Ferrante, 2012). It could be claimed that research and experimentation in this field have yet to achieve critical mass, with a limited number of projects scattered over the Mediterranean region, presenting quite a variety of published claims. In fact, the majority of low energy residential building case studies refer to projects primarily located in colder climates with a concentration in Northern Europe (Mingozzi, et al., 2009, Kapsalaki, 2011). Regardless of the mild climate and the relative abundance of solar radiation, few Mediterranean regions exploited this technology in their housing units, with the exception of Cyprus and Greece, In Spain, during the construction boom leading up to 2005, the integration of solar energy systems in residential buildings was 2.4% in 2004 (Garcia, et al., 2007).

One of the consequences of the EPBD was the general adoption of stricter requirements for insulation of the building envelope in European legislation. The benefits of increasing the insulation thickness are evident in a northern climate, when a lower U-Value directly reduces the predominant heating load. However, it has been shown that in conditions where the solar and internal gains are not adequately controlled, a highly insulated envelope may cause a rise in the indoor temperature, possibly above acceptable comfort limits, and summer overheating could offset the significance of any energy savings in heating energy during the winter (Chvatal & Corvacho, 2009). Parametric studies using TRNSYS on three building types, with glazed areas of between 10 and 13%, showed that for the specific examples, the solar factor above which increased insulation results in worse building performance in summer is 0.32. It was concluded that when gains (internal or solar) are not adequately controlled, there is a tendency towards summer discomfort as the envelope insulation increases, although this can be reduced through ventilation.

A Greek study to investigate the impact of thermal bridges on the energy consumption of buildings highlighted the fact that thermal bridging can account for a larger proportion of the total conductive thermal losses in winter but this effect, although still present, is less significant in summer (Theodosiou & Papdopoulos, 2008). A similar study considered three different building envelope configurations in the Italian climate and concluded that the correction of thermal bridges was effective in reducing the energy needs for heating but resulted in only a slight improvement in the cooling energy demand of the building (Evola, et al., 2011).

Not many researchers draw attention to the fact that reducing a building's solar energy gains, cooling energy use, and summertime peak demand, will conversely lead to increased energy consumption during the heating season. Several variables have to be taken into account in order to assess the trade-off between energy cooling benefits and energy heating penalties (Zinzi, 2010). These include:

- Climate. The warmer the building location, the higher the need for cooling.
- Mean insulation level of the building. An uninsulated building requires more heating during the winter season.
- Building use. Non-residential buildings generally have a higher cooling demand due to internal loads.
- Technical systems. The relative efficiencies of the heating, cooling, and ventilation systems affect primary energy consumption and set the conditions for the trade-off between heating and cooling demand when building improvements are made.

Social housing represents a significant proportion of the residential building stock of Southern Europe. Characteristically, social housing developments have limited resources for indoor environmental control and these dwellings are typically limited to the use of portable electric heating and cooling systems. A typical analysis using TRNSYS on an apartment block in Spain showed that the total demand could be reduced by approximately 26%, simply by improving the U-values of the building envelope (Dominguez, 2012).

In another simulation exercise it was shown that zero-energy housing is an easily accessible goal in the Mediterranean climate (Ferrante & Cascella, 2011). This was achieved by integrating an efficient building envelope with solar and wind energy micro-generation, together with a heat pump for cooling and heating.

Another study examined the behaviour of a heavy masonry reference building, designed as part of a sustainable neighbourhood in northern Italy, and compared its performance to an identical building model with identical parameters but using a lightweight envelope. The simulation using EnergyPlus demonstrated that thermal mass could reduce peak loads and energy consumption in both summer and winter (Mingozzi, et al., 2007). This work also challenged the effectiveness of using steady-state methods to assess energy performance, and the researchers maintained that dynamic simulation is indispensable to analyse the thermal behaviour of low energy buildings. A similar comparative exercise was carried out on two houses in southern Turkey, and the traditional house exhibited lower indoor summer temperatures than the modern house, although the heat transfer properties of the walls and windows of the modern house were superior (Manioglu & Yilmaz, 2008). Once again, the researchers maintained that the heat transfer calculated in steady state conditions is not suitable for determining the actual thermal performance of a building.

A regression model of the energy efficiency of a sample of 77 bioclimatic buildings, including 45 houses, from all over Europe, indicated that more energy efficient buildings are built in warmer climates (Tzikopoulos, et al., 2005). This analysis also confirmed that the building area and volume have a significant impact on energy efficiency, and buildings with a small surface area to volume ratio are more energy efficient. More controversially, however, this model did not show that the use of passive technologies such as shading or thermal storage walls contribute positively to energy efficiency. Ascione et al (2010) also found that high thermal inertia did not contribute to energy efficiency, unless combined with nocturnal ventilation. They concluded that the selection of surface finishes strongly affects energy requirements, with up to 70% cooling energy reductions in summer for Naples, Italy, when calculated using the TRNSYS dynamic simulation software.

Serghides and Georgakis (2012) carried out a series of optimisation studies using simulations to investigate the effect of varying thermal mass and insulation of the building envelope in a typical Cypriot detached house. The roof construction was identified as the most important element of the building envelope and the addition of external insulation and internal mass resulted in reduction of the cooling requirements by approximately 50%, whilst also reducing the heating requirements to a lesser extent. Similar modifications to the walls had a less significant effect, whilst insulating the floor had a minimal effect on the energy performance of the test building. Olivieri et al (2013) found that the use of green roofs with high vegetation density on a well-insulated roof acted as a passive cooling system in a Mediterranean climate, with a reduction in the thermal gain through the roof in summer of the order of 60%.

Stahl (2009), in his analysis of thermal mass on the cooling demand of a building, albeit in the colder Swedish climate, concluded that the effect of thermal mass is limited to the periodic penetration depth, i.e. the depth at which a temperature oscillation at the surface is reduced to 37% of its original amplitude. Using a numerical simulation technique, Stahl (2009) demonstrated that both the heating and cooling demands are slightly lower in buildings with a heavy structure, but the difference was only between 1 to 2%, and this falls well within the error margins of the calculation.

Following an environmental evaluation of building envelopes in different European climates, the need was highlighted to develop new technologies that respond to climate conditions in the south, where there is a lack of both development and application of high performance energy saving buildings (Pulselli, et al., 2009).

In an analysis of the effect of number of different parameters on the thermal performance of a case study single detached house in North Portugal, Araujo et al (2013) identified the solar factor of the glazing, the indoor air change rate, and horizontal shading devices as having the greatest influence on the cooling energy needs. However, it was also found that the efficiency of the heating system is the parameter that has the largest influence on the energy rating of the building, whilst the cooling system efficiency had very little influence on the energy rating. This should be seen in the perspective that the annual heating energy need in this region is of the order of twenty times higher than the annual cooling energy need.

2.4.3. Projects

One recent project was the construction of two residential buildings in Milan in 2001, each consisting of around 50 apartments on six floors. The buildings were constructed by two co-operatives, CasaEcologica (The Environmental Home), and Bovisa90, and were finished and handed over in 2001. The heating energy consumption was monitored during 2002-2003 winter season and the specific energy consumption for CasaEcologica was 48 kWh/m^2, whilst that for Bovisa90 was 65 kWh/m^2. Domestic hot water consumption was around 15 kWh/m^2 for both buildings. At the time of construction, the regulatory maximum for heating requirements in Milan's climatic zone was 110 kWh/m^2. No cooling systems were installed but the maximum summer temperatures were monitored in five apartments in each block and the CasaEcologica block was approximately 1^{o}C lower. The main differences between the two apartment blocks were different orientation, different heating systems, and possibly the awareness of the inhabitants, as the CasaEcologica occupants were originally more conscious of the environmental impact of energy consumption. The project was one of the earliest cases in Italy of an energy efficient construction project on this scale. The apartment costs were lower than the market prices in the area, and no public funding was received for the project (Ruggieri, et al., 2006).

A regional project financed by the European Union (MED-ENEC) supported the design, construction, and monitoring of ten low-energy demonstration buildings in ten southern and eastern Mediterranean countries. Implementation of the projects commenced in 2009, with half of the projects consisting of residential buildings. Whilst it is accepted that low- and even zero-energy buildings are technically feasible in the region, energy efficient buildings are of low priority in the southern and eastern Mediterranean (Wenzel, 2009). It is suggested that the first priority in the region was keeping down investment costs while constructing large numbers of buildings for a fast growing urban population, at a time when energy prices were low. Whilst the design and construction of the pilot projects have been documented, detailed monitoring data of the buildings in use has not been published. The findings of the MED-ENEC project demonstrated that whilst the pilot projects displayed predicted energy savings of up to 100% of the baseline, the single unit pilot projects were not financially feasible, and MED-ENEC are now investigating the improvement of energy efficiency in large building projects in the region.

A number of researchers have investigated the efficiency of specific techniques for energy reduction in Mediterranean dwellings. A comparative analysis of two building models in ten Mediterranean cities (Zinzi, 2010) showed that cool roofs improved the energy performance of the building during the cooling season and improved the thermal comfort in residential buildings, which do not have cooling systems installed. The design of a bioclimatic terraced house in northern Italy was developed as a test case for the use of thermal mass for passive cooling, minimising the need for air conditioning. The effect of heavy weight construction on the project building was analysed using Energy Plus, and this was found to reduce the internal temperatures and consequently the size and power of the air conditioning plant required (Mingozzi, et al., 2009). Another study investigated the effect of the properties of the roof construction on the thermal performance of the structure, considering the thermal mass, the air permeability of the roof covering, and the roof ventilation, as well as the insulation (D'Orazio, et al., 2010). A series of tests was carried out on a full-scale experimental building near Ancona, Italy, with a pitched roof, using six different roof types. Whilst the ventilated roof solutions were found to be more effective in reducing heat transmission to the building, this had a negligible effect on the internal temperatures due to the low U-value (0.249 W/m^2K) of the various roofs. Further analysis of roof insulation materials compared the effect of reflective insulation and concluded that the beneficial effect of the reflective layer on the energy performance of the building was greatly reduced when the building envelope was well insulated (D'Orazio, et al., 2012).

In the Mediterranean climate, the use of thermal mass in the building envelope has long been identified as having considerable advantages both in energy saving and comfort conditions, particularly during the cooling period (Mingozzi, et al., 2009, Balaras, 1996). This does not mean that mass is always the most appropriate solution to provide the best level of energy performance, and an in-depth analysis of the dynamic properties and its components is essential to obtain the best results. Steady state tools for building energy simulation are simpler to use than dynamic simulation tools. However, they do not adequately assess the differences between a building that simply respects the transmittance limits defined by building regulations, and one designed to meet the climatic changes of the surrounding environment in an appropriate and natural way (Mingozzi, et al., 2009). However, present regulations do not take into account the benefits of dynamic analysis, and the development of the summer energy balance has not been investigated and developed as thoroughly as the energy balance for the heating season. The successful development and implementation of energy saving dwellings is also dependent on the willingness of residents to actively manage their home. In the Mediterranean environment, traditionally, this meant closing windows and shielding them with shutters during the summer day, and opening up at night to encourage air circulation.

Overheating cannot be effectively handled solely by improving the insulation of the building envelope. Researchers have shown that in the Mediterranean climate a highly insulated building can be inefficient and requires air conditioning to ensure comfort conditions in summer (Santamouris & Asimakopoulos, 1996, Chvatal et al., 2005). The combination of solar gains and internal loads causes temperature rise within the envelope. In spite of this, in Italy, (and other Mediterranean states), the tendency has so far been to increase insulation, emulating developments in other European states, particularly the Passive House.

Traditional building practices are often considered as the best starting point to identify the most appropriate design strategies for low energy buildings. Mediterranean traditional architecture indicates that the key to good energy performance is through the use of thermal mass, the control of solar radiation, and night ventilation.

Natural ventilation represents the most efficient passive cooling system and has always featured in Mediterranean traditional architecture. In a research study, the effect of a natural ventilation on a typical two-storey semi-detached house was simulated in three different locations of Italy using the AIOLOS software to analyse the building's cooling performance during three summer months. The data showed a mean energy saving of between 41% and 52% of the cooling load, depending on the location. The comfort conditions were also considered using Fanger's method, and the predicted percentage of dissatisfied occupants varied between 7.5% and 23% (Cardinale, et al., 2003).

The construction of an experimental solar house in Cyprus in 2002 utilised thermal storage in the massive structure, thermal insulation, solar control and natural ventilation. Constant comfortable winter indoor temperatures were successfully achieved, with a minimal requirement for heating. No air-conditioning system was installed, but summer indoor temperatures were also maintained at comfortable levels. The design of the house demonstrated that reducing cooling loads was often a greater challenge than reducing heating loads (Lapithis & Papadopoulou, 2011).

The Leaf House project in Ancona Italy consists of a block of six apartments designed to meet a net-zero energy target. The building has been fitted with a monitoring and building automation system with more than 1,200 sensors and actuators. The metered data from the first year of occupation (2009) indicated that the total space heating and hot water energy requirement for the Leaf House was 27 kWh/m^{2}yr whilst the cooling energy requirement was 20 kWh/m^{2}yr (Spallaci, 2011, Cellura, et al., 2011). This compared favourably to the requirements for traditional housing in the same region of 100 kWh/m^{2}yr for heating and 30 kWh/m^{2}yr for cooling but again demonstrated that reducing cooling loads was more complex than reducing heating loads.

2.4.4. Passive House

The Passivehaus standard is perhaps the best known standard for energy efficient housing in north and central Europe, where residential energy use consists substantially of winter heating loads. The concept was developed in the late 1980s with the first passive houses being constructed in Darmstadt in 1990. Research has been carried out to modify the definition of the Passivehaus to meet the requirements of the Mediterranean climate (Schneiders, 2009), and this concluded that less rigorous requirements for insulation and glazing are necessary than in Germany. However, a southern orientation, ventilation with heat recovery, and moveable solar protection in the summer were identified as indispensable. In addition to the original Passivehaus requirements that the space heating demand should not exceed 15 kWh/m^2 per year and that the primary energy requirement for the total hot water, heating, cooling, auxiliary and household electricity loads should not exceed 120 kWh/m^2 per year, if active cooling is required to ensure comfort in summer, the energy demand for this is also limited to 15 kWh/m^2 per year. All calculations to ensure compliance with the standard are based on the Passive House Planning Package (PHPP). Whilst there are several thousand examples of the passive house, the majority of these are in central Europe, and Mediterranean passive houses are yet a rarity (Ringer, 2011).

In an analysis of the simplified monthly calculation method Asdrubali et al (2006) compared the heating and cooling loads of two building types in Palermo (South Italy). Each of these building types was considered to be constructed to three different standards, namely the Passive House standard, the minimum requirements defined by the 1991 building regulations, and a typical energy efficient construction level representative of the period. Whilst this was a software analysis and not based on actual properties, the results implied that the Passive House construction reduced the heating loads to approximately 30% of the loads in the construction meeting the 1991 legislative requirements but the cooling load was only reduced to approximately 67.5%.

Construction Typology	Apartment		Detached	
	Cooling load (kWh/m^2yr)	Heating Load (kWh/m^2yr)	Cooling load (kWh/m^2yr)	Heating Load (kWh/m^2yr)
Passive House	65.23	17.35	94.95	15.53
Legislation 10/91	110.33	51.53	128.30	56.73
Typ. Energy Eff. Construction 2006	84.93	33.55	114.30	36.98

Table 2.1 Heating and Cooling loads in Palermo (Asdrubali, et al., 2006)

A comparative study of the energy performance of three building types was carried out in four Italian cities and three Spanish cities. The HVAC simulation program was used to calculate heating and air conditioning demand. Each of the three building types was evaluated according to the Passive House standards and to the current (2006) national regulations in Italy and Spain respectively. The evaluation showed that in the case of the buildings constructed in accordance with national regulations, the energy requirements in the North (Valladolid, Spain and Turin, Italy) were approximately double the energy requirements in the South (Murcia, Spain and Palermo, Italy). However, the energy requirements of the buildings constructed according to the Passive House standards were practically identical, regardless of location (Asdrubali, et al., 2008).

Extensive monitoring activity of a green residential building consisting of two blocks in Umbria, Italy was carried out in order to verify the actual energy performance of the buildings. In situ measurements (thermal, acoustical and lighting performance), energy simulations and metered data were compared. The in situ measurements, showed that the actual thermal transmittance differed from the design values, but the metered energy consumption for heating and domestic hot water in two sample apartments was 24.20 kWh/m^2 year showing good agreement with the calculated value (28 kWh/m^2 year) (Asdrubali, et al., 2013).

The first passive house in Sicily (Passive House Institute, 2013) has recently been constructed in 2012 and is occupied by its architect Carmelo Sapienza and his family, whilst another two houses in Portugal (Marcelino & Gaviao, 2013) were completed in 2012, although no monitoring data has yet been published. A passive house in Lleida, Spain was completed in 2009 and this has been inhabited and monitored by its architect Josep Bunyesc (Bunyesc, 2012). This house had a timber frame structure with high insulation and low thermal mass, and no cooling system was installed.

2.5. Analysis of the certification methodologies

2.5.1. Introduction

Several different alternatives to the EN ISO 13790 calculation methodology have been proposed and this section presents an overview of a number of comparative studies that have been carried out. Since the studies sometimes appear to present conflicting results, it is appropriate to remember that the selection of the correct methodology ought to take into consideration the purpose of the evaluation to be carried out by the methodology.

Even the implementation of the standard methodology is open to interpretation with the national context and this has given rise to considerable variation. A comparative analysis of the heating demand of an apartment building using different national calculation procedures but always located in Milan Italy shows differences of up to three times as much. (Ferrari & Zanotto, 2010). A similar analysis of the cooling demand of an apartment building, this time located in the respective national climates, also showed considerable variability (Ferrari & Zanotto, 2010).

It is often suggested that whilst the procedure for calculation of space heating energy demand has been in use and validated for several years, the same confidence cannot be placed in the methodology recommended for the calculation of the space cooling energy requirements (Asdrubali, et al., n.d.).

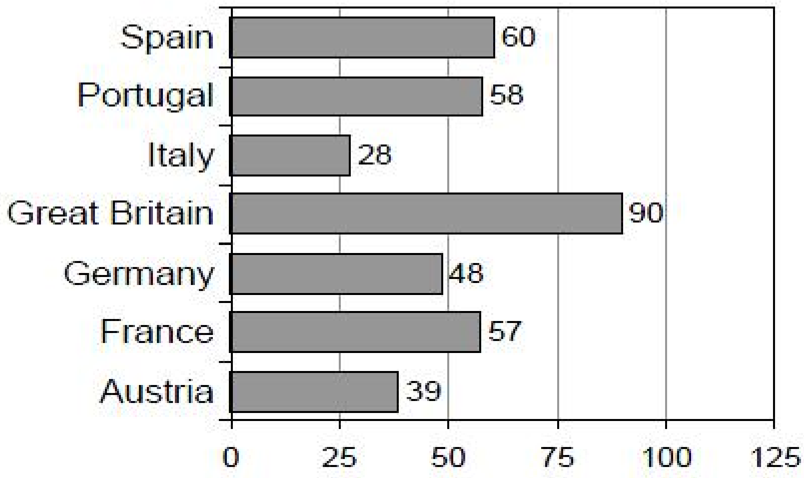

Figure 2.1 Heating demand in kWh/m^2 yr for an apartment block using different national procedures but corrected to the location of Milan, Italy (Ferrari & Zanotto, 2010)

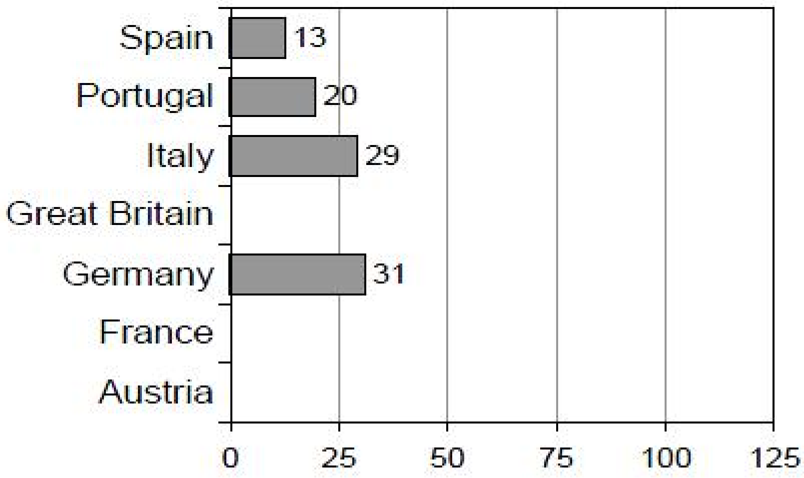

Figure 2.2 Cooling demand in kWh/m^2 yr for an apartment block using different national procedures (Ferrari & Zanotto, 2010)

2.5.2. Software comparisons.

A comparative analysis of the results of the Portuguese calculation methodology RCCTE and the dynamic simulation software EnergyPlus 4.0 was carried out on a case study of three building types in three climatic zones in Portugal (Ferreira & Pinheiro, 2011). The methodology was first applied to the case study buildings using regulation values for the building envelope, and subsequently the effect of the application of a complete range of energy saving measures was considered. When comparing the heating needs obtained by RCCTE and EnergyPlus for the Mediterranean climate, they were found to be very similar, even though the RCCTE methodology does not consider the solar gains of the opaque envelope in winter, whilst EnergyPlus takes these gains into account. However, considerable deviations were highlighted when comparing the cooling needs between the two methodologies. The authors attributed this to the difference between a steady state calculation using a global exterior mean temperature for the whole summer, as applied by the RCCTE methodology, and the hourly calculation method used by EnergyPlus. Another difference between the two methods that would have had some bearing on the deviation between the results of the cooling needs calculation is the different assumptions made regarding the controlling of the window blinds. Overall, the calculated energy performance indicated that maximum regulatory limits were easily attained and could be substantially reduced. The authors maintained that Passivehaus solutions were quite attainable in the Mediterranean climate zone. It was also highlighted that the calculation methodology and regulations appear to favour the use of efficient active systems rather than passive energy saving measures, although it was also pointed out that in the refurbishment market, passive options may not always be applicable.

Another comparison exercise was carried out between the RCCTE methodology and the dynamic simulation software ESP-r using seven case study buildings including different building typologies (Leal, et al., 2008). The computation of the heating needs showed a linear relationship between the two methods, with the results computed by RCCTE approximately about 20% above those computed by ESP-R. The same comparison for the cooling needs did not exhibit such a clear correlation and the authors felt that this could be attributed to the fact that in ESP-r, the solar protection devices have dynamic patterns of use, whilst the RCCTE methodology assumes constant parameters. The value of the cooling needs is typically much lower than the heating needs.

A further study focused on a comparison of the cooling energy needs calculated by the Portuguese methodology RCCTE and the dynamic simulation EnergyPlus using hourly calculation steps (Oliveira Panao, et al., 2011). This analysis suggested that the heat gains terms calculated by RCCTE should be modified specifically in relation to the glazing correction factor, the windows shading g-value, and the weighting day time fraction of active shading devices, and the calculation should also take into account the effect of sky long wave radiative heat transfer.

One of the earlier studies in Italy compared the energy performance of residential buildings in four different locations using a commercial calculation software based on the ASHRAE 1993 computational method and the then draft calculation methodology CEN/TC 89 using the simplified monthly method eventually incorporated in EN ISO 13790. The validation of the calculation methodology focused on the summer performance and the cooling energy demand since the authors considered the heating calculation had already been sufficiently validated. Three building types were analysed in each of the four zones and the difference in the calculation methods varied between 7% and 45%. These variances could be attributed to the use of default calculation coefficients in the simplified monthly method, which had not yet been defined on a national basis (Asdrubali, et al., 2006).

A comparative study performed in Italy, evaluated a variety of different methodologies in a Round Robin test on an existing building located in Ravenna, in the north of Italy. This analysis compared the UNI TS 11300 standards, commercial software implementing the UNI TS 11300 and EN ISO 13790:2008 standards, the officially developed software for energy certification DOCET, and the Design Builder interface for the EnergyPlus software. The difficulty of obtaining the same data input for the building using different methodologies was identified, and the main problems highlighted were the different conventions for the geometrical data input, for input of the thermo-physical parameters of the envelope, and for the heating plant parameters (Tronchin & Fabbri, 2010). The actual energy bills (natural gas for heating and electricity) over three years were also used to calculate an operational rating for the case study building. The methodologies used for implementation of the standards and for certification all generated a value for energy consumption of approximately 30% more than the metered energy consumption, whilst the Design Builder software was 13.6% more. However, the main reason for this variance was attributed to the differences between the actual building operation and the operation assumed by the standards.

Another study compared the first Italian national methodology, DOCET, with three other energy calculation tools for two building types in Naples, Rome and Milan and concluded that the space heating and hot water energy demand calculated by DOCET was in excellent agreement with that calculated by the other tools in spite of large error bands (+/-30%) in the input data (Zinzi, et al., 2007). This highlights the benefits of a simplified tool.

In a similar study, seven different programs for energy certification and energy performance evaluation available on the Italian market were evaluated against the results of the dynamic simulation program TRNSYS. A model of two identical single storey apartments that were mirror-images to each other was set up, and the building was evaluated with climate data from three different Italian regions. The results showed large differences, to the extent that the researchers considered the output values to be illogical and incoherent, and had serious doubts about the reliability of the tools (Milone, et al., 2009).

Zinzi et al (2008) compared three simplified certification tools using the steady state method on the Italian market with TRNSYS. They concluded that steady state tools produced very close results in terms of total annual space heating and ventilation requirements, even when using different methods and approximations. However, when the total figures were broken down into the different component values and analysed on a monthly basis, larger differences were found. The modelling using the dynamic simulation program TRNSYS produced results that were 25% to 35% lower than the steady state methods (Zinzi, et al., 2008).

Another intermodal comparative study investigated the variability in the results generated by the range of accredited tools for demonstrating compliance with energy performance criteria in the U.K. The results generally showed a considerable variability in the value of the benchmarks and a lack of consistency in providing a pass/fail outcome for the same building. Dynamic simulation modelling software produced much lower predicted CO_2 emission rates for each of the three non-domestic building models than the accredited tools. The main reasons identified were the limitation in the scope of applicability of accredited tools, particularly where steady state calculation methods are used, and a lack of input data standardisation particularly for the thermal properties of construction elements and infiltration rates (Raslan, et al., 2009). The difficulty with input data standardisation was also highlighted in a study comparing the outcome of accredited tools in Spain (Macias, 2005).

Another comparison in Italy evaluated the suitability of the CENED+ methodology, based on the EN ISO 13790:2008 standard and used in the Lombardy region for energy certification, for the heating and cooling performance of high-performance residential buildings. The study showed that in winter, the real heating performance, measured using data from three selected apartments in a building complex, was consistent with that calculated during the certification process, assuming that users maintain an internal temperature consistent with the standard temperature of $20^{o}C$ throughout the heating season (Dall'O, et al., 2012). However, consumption data are not homogeneous and the differences are caused by user behaviour. A similar study for the summer period also included simulation using EnergyPlus, as well as the CENED+ methodology and the metered data for the three apartments. This showed that the real performance was better than the energy performance calculated by the certification software, whilst the internal temperature set-points are kept lower than the values assumed by the standard calculation (Dall'O, et al., 2012). The study also showed that the standard certification methodology tended to overestimate the cooling energy consumption, whilst the EnergyPlus model generated energy consumption values very close to the real consumption. Once again, consumption data are not homogeneous and clear differences are caused by variances in user behaviour.

When comparing dynamic simulation models to national calculation methodologies, it is generally considered that dynamic simulation models are far more complex and require more knowledge and a deeper understanding of building physics and geometry than the simplified assessment required for the national calculation methodologies. This increased complexity implies a lengthier and more expensive assessment procedure, which is normally considered prohibitive for certification applications (Ingram & Jenkins, 2013).

Although dynamic simulation tools are often used as the benchmark for steady state calculations such as the EN ISO 13790 simplified methodology to be tested against, Beccali et al (2005) reported that tools such as DOE and TRNSYS are not well adapted for application in a South European context, particularly in view of the high thermal inertia typical of traditional buildings. In a comparative analysis of the solar gains and cooling load calculations using four different dynamic simulation tools on a simple single zone model, the deviation between the solar gains calculation was between 7 to 10% whilst the deviation between the space cooling loads was significantly higher, between 20 to 25% (Waddell & Kaserkar, 2010).

In a review of the different types of validation methods used to verify the accuracy of building energy models used to predict energy use, Ryan and Sanquist (2012) asserted that in order to achieve realistic validation, it is necessary to validate not only the physics inherent in the model, but also the methods used to account for the occupants and their behaviour.

2.5.3. Comparison with monitored results

The energy benchmarking of buildings is a necessary procedure for the adoption of energy certification schemes (Nikolau, et al., 2011). Benchmarking generally involves comparison of the energy performance of a building to that of other buildings with similar characteristics. The use of empirical benchmarks derived from energy analysis and statistics for the building stock are fundamental to the identification of the energy performance of a building (Cohen, et al., 2006).

Differences between the values calculated through the simulation of energy performance and the actual metered values are manifest in most projects, and identification of these variances can either present ways to further improve energy efficiency or highlight areas whether further validation of the model or the data may be required (Calderone, 2011).

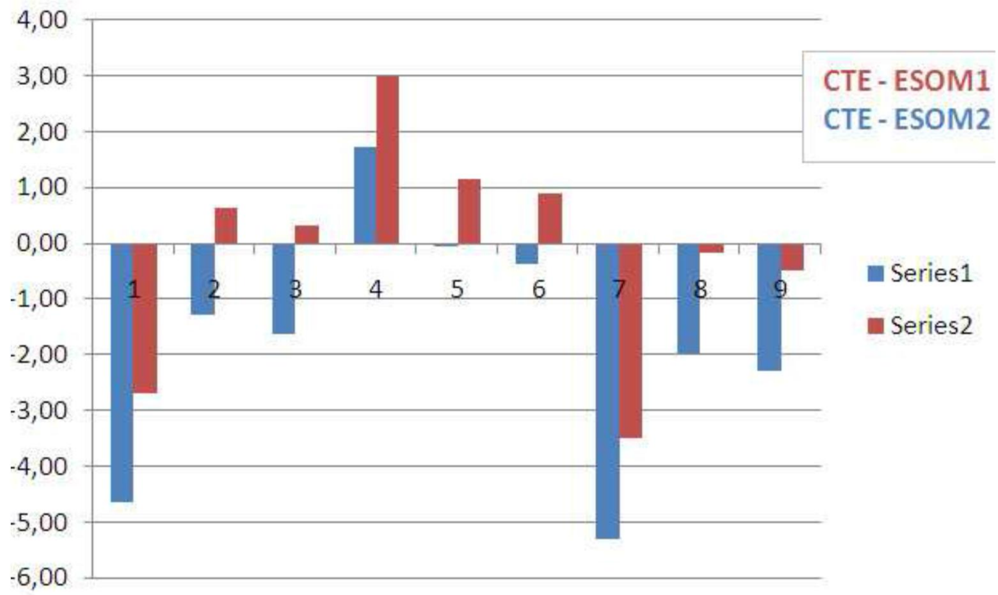

Figure 2.3 Difference between standard temperature profile and temperature profiles collected by data from a 700 dwelling database (Gaceo, et al., 2009)

An analysis of the effect of the user profile defined by the Spanish Technical Code for Buildings (CTE) identified that a more accurate user profile was essential for accurate simulation of building energy performance. A database of hourly energy data collected over seven years from over 700 dwellings was used to generate two indoor temperature user profiles, one representing 42.3% of the samples and the other representing 50.9% of the samples. These profiles exhibit considerable differences, of up to 5^{o}C in July (see Figure 2.3), from the official user profile used for the Spanish certification methodology (Gaceo, et al., 2009).

The EnergyPlus software was used for a comparison between monitoring and simulation using a case study building featuring a Trombe wall. The results of the first analysis showed that the indoor air temperatures calculated by EnergyPlus displayed very wide oscillations in comparison to the measured temperatures (see Figure 2.4).

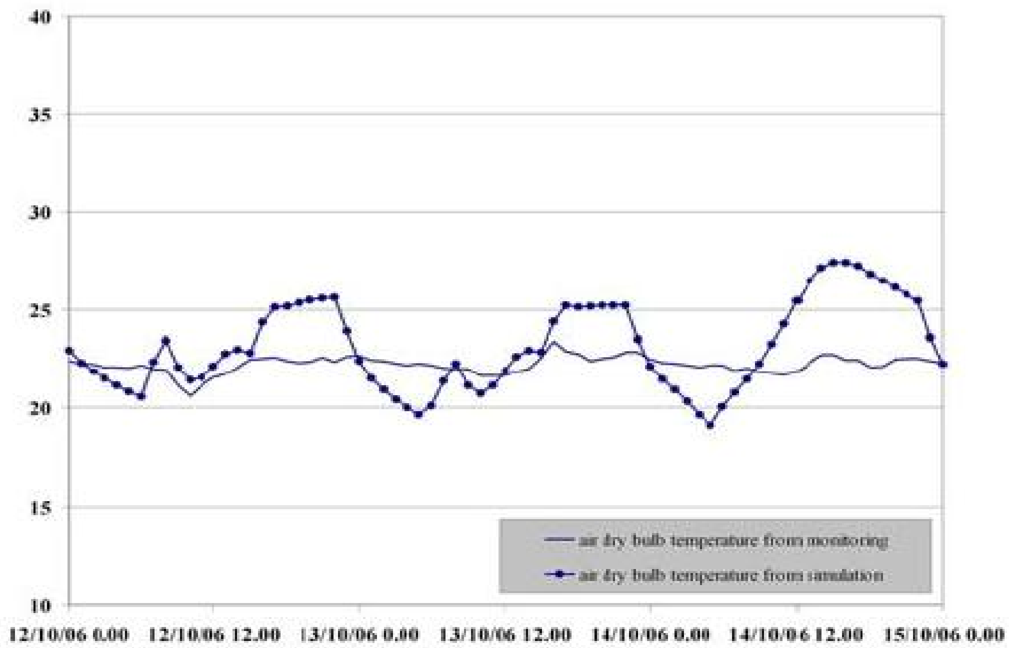

Figure 2.4 Difference between monitored and simulated indoor air temperature (Stazi, et al., 2007)

Several adjustments to the input data were necessary for the model temperatures to approach the actual measured values with the main changes made being to the glazing properties and the ventilation rates (Stazi, et al., 2007). It was concluded that the study demonstrated the initial lack of agreement between measured and simulated temperature values, especially as far as internal air temperatures were concerned.

In an analysis of the sensitivity of the energy consumption calculation of a UK school building to input parameters, IES VE was used on two base models, one set at the level of the UK 2006 Building Regulations, and the other meeting Passivehaus certification requirements. The analysis showed that the Building Regulation model was dominated by the indoor temperature and the envelope specification, whilst for the Passivehaus model, the parameters relating to occupancy and internal loads were most important (Simm, et al., 2011).

Another study examined the uncertainty of the energy consumption assessment of residential buildings in Denmark both theoretically and empirically. The energy consumption of eight almost similar semi-detached houses was calculated using the BSim (version 2007) building simulation program developed by the Danish Building Research Institute and compared with the measured energy consumption. Whilst measurements and simulation were found to correspond reasonably well, the parameters which contribute most to the overall level of certainty are all related to the occupants' behaviour, and were identified as the internal (heating) set-point, the internal heat load, and the occupied period (Brohus, et al., 2009).

In a round robin test of fifteen different software programs available on the Italian market on a test case building located in three different climatic zones, it was observed that each participant, even when using the same software, produced different results. Galbusera (2007) observed that the human element is a significant factor in the use of building simulation software, particularly when inputting data.

In an assessment of the building cooling energy need using the steady-state procedure, five case study buildings in three Italian locations were simulated using EnergyPlus in order to generate the dynamic parameter to be applied in the steady state method. The analysis proved that the simplified steady state procedure is suitable to predict year-round energy needs in the Mediterranean climate, provided that the dynamic parameters are correctly determined. However, in order to determine primary energy consumption, the method has to cater for the coupling effect between a building and the conditioning system, and should include the efficiency of the different components (Corrado & Fabrizio, 2007).

An evaluation of the steady state procedure on a single detached house in central Italy comparing the calculated results with the real energy consumption and the Design Builder software highlighted that the official calculation methodology did not give an acceptable interval of confidence when evaluating the energy performance. (Tronchin & Fabbri, 2008). In an earlier study, Tronchin (2007) highlighted the need for comparability between the input data when evaluating the steady state methodology against dynamic simulation and metered data.

A comparison of the EPC calculation with the measured energy from energy bills was used to investigate the effect of user behaviour and weather conditions for six apartment blocks in Turin, Italy. The calculated energy performance of the buildings analysed ranged from about 200 kWh/m^{2}yr for pre 1970 buildings to 70 kWh/m^{2}yr for more recently constructed buildings. The analysis showed that the calculated rating always overestimated the actual energy demand of the buildings where a central system for heating was installed, but tended to underestimate the demand when an individual heating system was installed for each apartment. This was attributed to possible differences in the temperature set point since buildings with a central heating system generally have fixed temperature/time schedule whilst in the case of individual heating systems the occupant has greater control over the indoor temperature and the operating schedule (Ballarini & Corrado, 2009).

One study in Cyprus compared the measured and the calculated energy consumption for ten dwellings. The measurements were obtained from a questionnaire and energy consumption records, whilst the calculation was performed using the official methodology SBEMcy. It was found that whilst the heating calculation showed a good agreement with the measured data, the deviation between the calculated and the measured cooling loads was greater than 150%. This was mainly attributed to the daily cooling schedule implemented by the official methodology, which does not appear to reflect actual operation (Fokaides, et al., 2011).

A comparison of the calculated and measured energy rating results was carried out in Cyprus using a case study with three typical dwellings (Panayiotou, et al., 2010). The results obtained by the two approaches varied significantly and could not be directly compared, with the ratings calculated using the official methodology indicating an energy use double that actually measured. This was attributed to discrepancies between the assumptions made by the methodology and the actual occupants' behaviour and lifestyle.

Another study in Malta compared the actual measured energy consumption of a recently built apartment and the calculated energy performance using both the official EPRDM methodology and the Design Builder interface to EnergyPlus. Whilst the results showed that the overall energy calculated by EPRDM closely matched the measured energy of the case study apartment (<3%), the breakdown of the heating, cooling, domestic hot water, and lighting components showed considerable differences. Similar results were obtained from Design Builder, with the main variance occurring in the space cooling load, this being approximately six times more than the actual cooling energy measured in the apartment (Yousif, et al., 2012).

In an analysis of a low energy apartment complex in Bologna, Italy, the effect of thermal mass on the calculated energy demand was compared using EnergyPlus and three different certification software programs. Whilst the steady state certification software calculated a heating energy demand of between 20 to 50% more than the dynamic analysis performed by Energy Plus, the main focus of this work was the utilisation factor used by the certification methodologies to account for the effect of the thermal mass. The EnergyPlus simulation indicated that the heavy thermal mass construction had the effect of reducing the heating load by 20%, whilst the effect on the three certification methodologies was of just 10%, 8% and 0% respectively (Medola, 2006).

A detailed analysis of the effect of thermal mass on the summer performance of buildings was carried out using field measurements on four buildings situated in Seville, Spain. These were compared with a series of thermal simulations modelling the internal temperature of a single zone space using the computer program SERI-RES. The temperature swing results showed fairly good correlation between the simulations and the measured data. It was found that optimisation of thermal mass for indoor cooling should be one of the main considerations for building design in predominantly warm climates, as this leads to the reduction of internal temperature swings which are often the main cause of thermal discomfort (Diaz, 1994).

The Building America Research Benchmark was developed in 2003 to enable the repeatable analysis of whole-dwelling energy savings for research houses. In order to verify the Benchmark values, the simulated energy use for the Benchmark was compared to typical whole-dwelling energy data for three climatic zones. While there was good correlation between the results, the Benchmark cooling values appeared to be overestimated for the warmer climate zones, and this was attributed to different usage patterns or inaccuracies in the estimation of the cooling energy portion of the whole-dwelling energy data (Hendron, et al., 2004).

Metered energy data is often used to calibrate building simulation models in order to improve the accuracy of the prediction of the energy performance of the building. Several calibration methodologies have been developed to utilise the data collected from site measurement to calibrate the energy simulation model. Different approaches have been taken, with some researchers focussing on calibrating the operating schedules of the building (Hsieh, 1988) and others analysing differences between the actual and the modelled properties of the building envelope (Ham & Golparvar-Fard, 2013, Manke, et al., 1996). Different calibration periods have also been proposed, ranging from the use of existing monthly energy records generally easily available from utility companies (Carroll & Hitchcock, 1993) to long term energy monitoring using hourly data for six to twelve months to calibrate the hourly simulation results (Bou-saada, 1994) with various interim monitoring periods between a few days and a few weeks proposed for accurate calibration of the building simulation model (Soebarto, 1997, Manke, et al., 1996). Most research into calibration methodologies has been focussed on commercial buildings, but Jankovic and Huws (2012) performed an indoor temperature and energy calibration on the Birmingham Zero Carbon House, using thermal imaging and continuous instrumental monitoring for a period of two years. The data collected was used to calibrate the dynamic simulation model of the building generated by the IES-VE software. A similar calibration exercise was carried out on the IES-VE dynamic simulation model of the Loughborough REFIT project house using two months of monitored data and this identified the use of local weather data as having the greatest impact on the accuracy of the model, with infiltration and ventilation flow rates having the greatest influence on the predicted indoor air temperatures (Vagiou, 2013).

2.5.4. Studies relating to the application of the CEN standards

The use of the steady state method for calculating the cooling energy need involves the use of an adjustment factor known as the loss utilisation factor for cooling (η_C). Prada et al (2011) analysed the influence of weather data on the value of the loss utilisation factor comparing the effect of the use of monthly typical days as opposed to real weather data and determined that the mean outdoor temperature and the variation in amplitude of the solar radiation influenced the evaluation of the loss utilisation factor. The study concluded that the definition of the value of the loss utilisation factor for cooling required further research since the current method was particularly unreliable in circumstances where the solar radiation is high when compared to the heat losses from the building (Prada, et al., 2011).

In an earlier study, Cardinale and Ruggiero (2000) criticised the fact that the gain utilisation factor for heating (η_H) in an extensively glazed area (sunspace) did not consider the fraction of solar energy entering the area that was re-transmitted outside the building. They concluded that the present method of calculation of the gain utilisation factor did not provide an accurate representation of the heat gains in winter. One of the main criticisms of the simplified steady state method is that it is not considered sufficiently accurate for the evaluation of the energy performance of low energy buildings or passive houses (Plessis, et al., 2011). Bartholemew et al (1997) recommended that steady state calculations were not suitable for innovative designs incorporating passive features.

Weber (2004) also questioned the use of the utilisation factor for heating in low energy housing following a statistical analysis of 101 Swedish and German houses. He found that the relationship of the utilisation factor with the time constant was not clear and the expected positive influence of thermal inertia on the heating energy use could not be detected.

Corrado and Fabrizio (2007) used the Energy Plus dynamic simulation software to evaluate the loss utilisation factor for cooling (η_C) to be applied in the simplified steady state method. The results obtained by the dynamic simulation confirm the formula for the loss utilisation factor (see Eq^n 4.9) but propose a new correlation curve for the numerical coefficient a_C which has a significantly higher value than that proposed by EN ISO 13790. Rucinska et al (2010) also proposed different higher values than the default proposed by EN ISO 13790, for the numerical coefficient a_C and the building reference time constant, albeit for the colder Polish climate. On the other hand, Kalema et al (2008) in a comparative analysis of different calculation methods, found that the basic parameters proposed by EN ISO 13790 for the utilisation factor were best suited for calculating the annual heating energy need in the Nordic climate. They also concluded that the difference methods resulted in a wide spread of results for the rather lower cooling energy requirements of the Nordic climate.

The simplified model also assumes that the solar radiation entering the building through glazed surfaces is completely absorbed by the internal surfaces of the environment and does not include the solar irradiation fraction that is reflected outside by the internal surfaces. Oliveti et al (2011) compare this model with the TRNSYS dynamic simulation in the context of a Mediterranean climate and conclude that this assumption is only valid for indoor spaces where the ratio between the glazed area and the opaque area does not exceed 0.23.

A comparative study was carried out between two dynamic simulation programs and both the hourly and monthly simplified methods proposed by the EN ISO 13790 Standard. A single case study building was used with three building locations and climates, with a variety of building envelope configurations and occupation schedules. Whilst there was good agreement between the methods in a number of cases, in general the simplified methods were in better agreement with the simulation programs when used for heating energy use calculations that involve continuous heating applications for heavyweight building constructions, for buildings with low internal gains and/or for buildings with high ventilation rates (Kokogiannakis, et al., 2007).

In another comparative analysis of the performance of the simplified methodology (EN ISO 13790) and dynamic simulation, the dynamic simulation method was more robust than the simplified methodology. However, calibration of the reference numerical parameters and reference time constants for heating and cooling in the simplified method produced results that were significantly identical to those obtained by dynamic simulation (Kim, et al., 2013).

Corrado and Mechri (2009) applied the simplified monthly method proposed by EN ISO 13790 to a house in Turin in order to calculate its energy rating. The input data was identified and grouped into three sets: climatic data, envelope data and building use data and a sensitivity analysis was performed for the different building heat balance terms, in order to identify the most important parameter set that takes into account uncertainty in the model input. The results demonstrated that the EPC energy rating is only slightly affected by data uncertainties, with less than ten input data out of the 129 considered, having a significant effect on the energy rating uncertainties. The analysis also identified the indoor temperature, the air change rate, and the number of occupants as the most important parameters for the calculation of both heating and cooling energy requirements. A similar exercise performed in France identified the weather data and the indoor temperature as the most important parameters for calculation of the heating energy requirements (Humbert, et al., 2011). Whilst the calculation method produced an accurate certificate value (asset rating), the uncertainty of the value for the actual energy use of the house was high and it was suggested that the two values should be related in order to demonstrate the effect of user behaviour on energy performance (Corrado & Mechri, 2009).

In an analysis of the effect of different characteristics of the opaque building components (walls and roofs) in summer, it was found that the steady state method tends to overestimate the solar gains, but still provides an accurate estimate of the reduction in space cooling energy requirements caused by an increase in the solar reflectance of the external surfaces, for the case of continuously air-conditioned buildings (Libbra, et al., 2013).

2.5.5. Analysis of certificate values

The increased focus on the implementation of the energy performance certificate has highlighted the fact that there is a considerable difference between the annual energy use predicted by the certificate and the measured energy consumption. There is a general public expectation that there is some level of comparability between the energy performance certificate and the actual energy use but it has been shown that there is often a substantial difference between the two. This difference has been noted in different European countries with varied housing stocks, different calculation methodologies, and different sociological and cultural behaviour patterns, as well as in other rating systems outside Europe (Williamson, et al., 2010). One of the main criteria for the success of an effective energy certification scheme is whether or not the projected energy savings are tangible (Rajagopalan & Leung Tony, 2012).

Several studies in North Europe have highlighted the differences between the EPC energy calculations and the actual metered energy use, especially for space heating. A review of these studies by Laurent et al (2013) compared the difference between the heat energy calculated using the normative methodology and the measured energy for the UK, Netherlands, France and Germany. In these countries the certification methodology is well established with well over twelve million certified dwellings as at 2011 (BPIE, 2011). It was found that there seems to be a consistent over-estimation of the space heating energy with the actual heating energy accounting for between 60 and 70% of the calculated energy (Laurent, et al., 2013). The potential causes for this could be classified into two categories, namely the validity of the thermal model and the data inputs, and behavioural issues. One of the conclusions identified by Laurent et al (2013) was the necessity of analysing the relationship between the normative calculations and the actual energy use in order to define national correction factors to modify the certificate values, enabling the use of the certificates as more accurate prediction tools of energy use in buildings.

In a comparison between the EPC energy use and the actual energy use for space heating in 41 Belgian dwellings, Bartiaux et al (2005) concluded that the calculated theoretical energy savings are likely to be an overestimation of the real expected savings. It was observed that buildings with a poor energy performance, i.e. with a high calculated energy use, actually used much less energy than expected, whilst buildings with a good energy performance, i.e. with a low calculated energy use, had a lower difference between actual and calculated energy use (Bartiaux, et al., 2005). Audenaert et al (2011) analysed the difference between actual and theoretical energy consumption for space heating and hot water in Belgian dwellings, using a case study of five dwellings. A number of influencing factors relating to the behaviour of the occupants were identified, amongst which were the use of intermittent or zonal heating and variations between actual and calculated air tightness and infiltration rates.

In the Netherlands, an analysis of the difference between the actual energy consumption from gas and electricity bills and the theoretical energy consumption from approximately 200,000 energy certificates was carried out. The study also showed that the less energy efficient dwellings actually used less energy than predicted by the energy certificates but on the other hand, the more energy efficient dwellings consumed more energy than indicated by the certificates (Majcen, et al., 2013). One of the main findings of this study is that the reduction in primary energy consumption, which is assumed to happen when improving a building from the least efficient EPC label (G) towards the most efficient EPC label (A), turns out to be much lower in reality than indicated by the certificates. This could easily lead to inaccurate estimations of the payback times for measures taken to improve the energy-efficiency of dwellings and achieve the targets that have been set for primary energy as well as for reducing CO2 emissions (Majcen, et al., 2013).

Corgnati et al (2005) investigated the energy use for space heating over a ten-year period for fifty apartment blocks in Torino, North Italy, and compared the average values to the values calculated by the methodology stipulated by the Italian standard UNI 832. It was found that the theoretical calculations tended to overestimate the energy use for space heating and Corgnati et al recommended that the methodology be modified to incorporate a correction factor to relate the results of the calculation to the metered consumption.

A study carried out on the heating and hot water energy use of seven homes before and after refurbishment found that the SAP assessment used for the certification of homes in the UK predicted energy savings from the refurbishment that were well in excess of the actual energy savings with an average error of around 100% (Wetherell & Hawkes, 2011). In a review of published studies documenting the difference between the predicted and the actual savings arising from the insulation of homes in the UK, it was concluded that the best estimate for the actual savings was 50% of the calculated savings and that 15% of the difference between the two was attributable to increased internal temperatures (Sanders & Phillipson, 2006).

In the Netherlands the energy performance of new buildings has been regulated by legislation for over fifteen years. However, Visscher et al (2011) examined three surveys conducted over this period to assess the effectiveness of the energy performance regulation against the actual energy uses for heating and concluded that tightening the energy performance regulation did not lead to less energy use for heating. They identified building characteristics (including heating and ventilation equipment) as accounting for between 19 to 23% of the variation in energy demand of modern building stock, and household characteristics and occupant behaviour as responsible for between 3 to 15% of this variance, whilst at least 62% of the variation in energy use could not be attributed to any specific cause. In a larger study, which analysed survey data from 15,000 houses, occupant characteristics and behaviour accounted for 4.2% of the variation in energy use for heating and building characteristics accounted for 42%, with the indoor temperature setting featuring as the most important predictor of energy use (Guerra Santin, et al., 2009).

A study of the thermal performance of two-storey apartments in Adelaide, Australia (where there is a Mediterranean type climate) investigated the relationship between simulation, the energy rating (or certificate) and occupant comfort. This highlighted the importance of assessing the thermal performance of individual spaces in addition to defining the whole building performance as in the case of the energy certificate, since the whole building energy rating can potentially mask the poor performance of certain spaces at critical times (Soebarto & Bennets, 2013).

2.6. Summary

This chapter presents an appraisal of research into the energy performance of Mediterranean housing with a focus on the validity of the EPC as a tool to assess and improve the housing stock.

In one of the earlier comparisons between building simulation programs, Manson (1998) noted that it appeared that one program was required to calculate the energy need for heating and a different program was needed in order to calculate the energy need for cooling, or in other words, none of the twenty four programs tested demonstrated equivalent accuracy in both the heating and the cooling calculations.

Statistical analysis has identified the data set pertaining to the occupants' behaviour as more significant than either the building data or the climatic variables, particularly in mild climates (Pettersen, 1994). In an analysis of user behaviour in office buildings, Hoes (2009) concluded that design tools applying simple models for user behaviour are inadequate for buildings that have a close interaction between the building and the user.

The findings of the literature review provide a background for this research into the current certification methodologies used in South Europe. The selection of a methodology for the investigation of the research question against this background of existing work is developed in Chapter 3.

Chapter 3. Methodology

3.1. Introduction

Having defined the Research Questions within the framework of the Energy Performance of Buildings Directive and its application in the Mediterranean region, the methodology for addressing these questions is formulated in this chapter. This is expounded through an exposition of the philosophical context of the research questions, a definition of the research approach, and the development of the appropriate research technique.

Research could be defined as the systematic investigation into, and study of, materials and sources in order to contribute to a body of knowledge of theory. It is only through the use of the appropriate methodologies and methods of research applied with rigour that this contribution can be established and advanced with confidence (Amaratunga, et al., 2002). The research process should be located within an explicit philosophical framework and follow a justified and appropriate methodological approach. The researcher should be familiar with the philosophical background, locate the research methodology within it, and be able to substantiate the reasons for the selection of the methodology.

The research methodology can be defined as the use of specific methods to:

1. Gather adequate and representative evidence of phenomena;
2. Develop appropriate ways to analyse collected data;
3. Demonstrate the validity or reasonableness of any findings (Knight & Cross, 2012).

The research methodology defines the path selected for the solution of the research problem and the researcher ought to be in a position to demonstrate that the selection of the methodology was an informed decision. The researcher must show understanding of which methodology will work and, crucially, which will not, and needs to adapt different research methods according to the constraints of the background to the research question (Easterby-Smith, et al., 2008). This should be accomplished without losing sight of the ultimate focus of research, which is to add something of value to the existing body of knowledge.

3.2. Research Methodology

The research methodology encompasses both the philosophical framework and the fundamental assumptions underlying research. Construction and the built environment draw on a wide variety of disciplines and it is necessary to establish the framework of a clear and robust research methodology so that the research questions can be clearly articulated to define a problem, and a research approach can be developed within a coherent research philosophy, in order to generate results that are both valid and reliable. Construction-oriented research is a recent academic discipline but this does not preclude it from the requirement to develop and apply the appropriate methodologies for effective and efficient research in the field of construction activity (Fellows & Liu, 2008). It has been argued (Knight & Turnbull, 2008) that a lack of clarity surrounding the epistemology of research in the built environment can result in the application of inappropriate quality criteria and misunderstanding.

Before establishing a research methodology it is appropriate to define the field of research. This provides both the foundation and the backdrop to the research questions and it is preferable that the selection of a methodology should be coherent with the discipline containing the research. Whilst the subject area of the built environment is established as a recognised field of study, its identity has traditionally been defined by the traditional construction and property professions from which it as emerged, as well as the cultural and behavioural aspects developed through research activities (Chynoweth, 2006). One definition of the built environment is that it comprises urban design, land use, and the transportation system, and encompasses patterns of human activity within the physical environment (Handy, et al., 2002). The built environment refers to the man-made surroundings that provide the setting for human activity, ranging in scale from buildings and parks or green space to neighbourhoods and cities and includes their supporting infrastructure, such as water supply, or energy networks. However its precise boundaries are not clearly delineated and it has been described as a knowledge base of practice-oriented subjects concerned with the design, development and management of buildings, spaces and places (Griffiths, 2004). One outcome of the multidisciplinary nature of the field of research is that there is no clear theoretical framework or established consensus for the categorisation of knowledge in the built environment (Chynoweth, 2006). In these circumstances, it is even more imperative that the research be anchored within a sound methodology that defines the philosophy and gives clarity and direction to the research method.

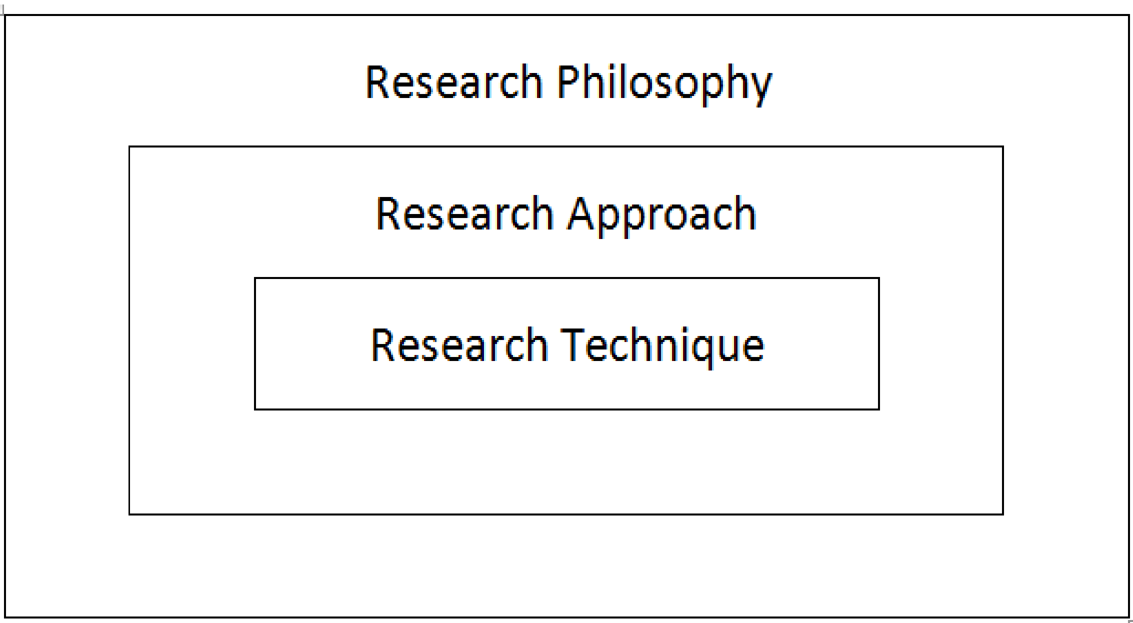

Figure 3.1 Nested Approach (Kagioglou, et al., 1998)

A variety of research approaches have been proposed in general texts (Creswell, 2003) as well as in texts specific to the built environment (Knight & Ruddock, 2008). These acknowledge that the development of a research methodology is a complex process with a wide range of sometimes seemingly contradictory choices of established theory, methods, and applications of methods. A number of models have been proposed to assist in the formation of an appropriate methodology. The underlying concept throughout is the definition of the relationship between the relevant philosophical concepts and the more explicit design of the research, culminating in the development of the methods used to arrive at the findings.

This research uses the 'nested approach' model (Kagioglou, et al., 1998) to develop an appropriate research methodology. This simple representation establishes the focal point of the research – the techniques for generating data that are compatible with the appropriate approach for addressing the research question – within a framework that defines the research philosophy. This is represented diagrammatically in Figure 3.1. The three components of the model are discussed below. The resulting methodology frames the research in a context of the conceptual, philosophical, implementation, and evaluation tasks associated with the research questions.

3.3. Research Philosophy

Philosophy, deriving from the Greek roots meaning the love of wisdom, is the study of the fundamental nature of knowledge, reality, and existence. In a research framework, philosophy refers to the epistemological, ontological and axiological assumptions that direct the focus of the inquiry in a research study, whether implicitly or explicitly. In general terms, epistemology describes ‘how’ a researcher knows about the reality and how knowledge should be acquired and accepted. Ontology describes ‘what’ knowledge is and the nature of reality. Axiology reveals the implicit values of the researcher in finding out about reality. Since these epistemological undertakings, ontological assumptions and axiological purposes about the nature of the world encompass the formulation of the research methodology, it is appropriate to understand and discuss these concepts to select the appropriate research approach and methods (Pathirage, et al., 2008).

3.3.1. Epistemology

Epistemology, derived from the Greek word for knowledge, concerns the origin, nature, scope and limits of knowledge. In research terms, epistemology describes the assumptions that researchers make about their knowledge of reality, and their beliefs regarding how they came to obtain or understand that knowledge. This implies that the way that a researcher perceives the world, or in other words, the philosophical assumptions held by the researcher, determine to a great extent the application of knowledge in the practice of research, whatever the subject of the research (Knight & Cross, 2012).

3.3.2. Ontology

Ontology, coming from the Greek word for being or existence, describes the nature of reality. For a researcher, ontology describes a specific view on the nature of reality, whether this is an objective reality which really exists, independent of the researcher, or a subjective reality, present only in the mind of the researcher.

3.3.3. Axiology

Axiology describes the role of the individual values of the researcher in the research process. The word comes from the Greek for value or worth. The researcher brings implicit values, beliefs and skills to the research, and the recognition of these as part of the research process contributes to development of the research methodology.

3.3.4. Research classifications

Philosophical attitudes define particular strategies for the research process. They influence the researcher's focus of attention, sense of prioritisation, and method of conceptualisation. Various categorisations of types of research have been put forward, but the most frequent classification is the distinction between pure and applied research. In simple terms, pure research is centred on the discovery of theory, whilst applied research is concerned with practical application. In each of these fields, however, the definition of what constitutes legitimate and acceptable knowledge is very much determined by the philosophical attitude adopted by the community of scholars (Chia, 2002). The two principal branches of philosophy that define the methodology of the development of knowledge within the Western tradition are positivism and constructionism.

Positivism, which is closely related to empiricism and rationalism, provides the most frequent held epistemological position within the natural sciences, and combines the logic of Plato with the empirical observation of Aristotle. In simple terms, a researcher with a positivist approach is assumed to be an independent and unbiased spectator of the object of enquiry. Positivism can be said to subsume the empirical under the imperative of the rational (Chia, 2002). Reason and logic are employed for the formulation of theory which is then justified empirically. There is a strong link between positivism and the quantitative approach to research.

On the other hand, the more recent emergence of interpretivism and constructionism as a philosophical research framework provides an alternative approach to that of positivism. The underlying principle here is that reality is determined by the persons involved. In other words, people understand the issues they face in ways that are influenced by their previous experience. Interpretivism is particularly valuable for research in the social sciences and is likely to feature in the qualitative approach to research.

3.4. Philosophical Position of the Research

Within the framework of positivism, the scientific method refers to a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge. To be termed scientific, a method of inquiry must be based on gathering empirical and measurable evidence subject to specific principles of reasoning (Newton & Whitman, 1999). The chief characteristic which distinguishes a scientific method of enquiry from other methods of acquiring knowledge is that scientists seek to let reality speak for itself, and contradict their theories about it when those theories are incorrect, i.e. falsifiability (Gauch, 2003).

This research has an essentially empirical nature, in that the various procedures for the calculation of the energy performance of a building can be considered as different hypotheses to be tested against observations of actual behaviour in the natural world, i.e. metered data of the energy performance of the building. In empiricism, knowledge has to be grounded in sets of actual and possible experiences. The research is focused on the testing of the knowledge inherent in the various calculation methodologies against the actual experience provided by metered data or the possible experience identified from dynamic simulation software or statistical data. On further reflection, this work is an attempt to recognise knowledge from the methodologically ordered experiences associated with scientific experimentation, and could therefore be classified as positivism.

Whilst scientific research is often quantitative, interpretive inquiry uses a qualitative approach to investigate human experience. Each research strategy has its own specific approach to collect and analyse empirical data (Yin, 1994). Another basic expectation of the scientific method is to document, archive and share all data and methodology so they are available for careful scrutiny by other scientists, giving them the opportunity to verify results by attempting to reproduce them (Gauch, 2003). This practice, called full disclosure, also allows statistical measures of the reliability of these data to be established.

For the purposes of this study, it was decided to adopt a mixed methodology, or triangulation of methodologies, combining both the quantitative and the qualitative approaches. A quantitative study is involved in the collection and analysis of numerical data, and the application of tests to the results obtained. The qualitative approach involves examination and reflection on perception in order to gain understanding of the human activities under study (Amaratungha et al, 2002).

Although the main focus of the work is actually quantitative and scientific, focussing on the techniques available to establish a precise measure of the energy performance of a residence, the human activity within the residence has a significant bearing on the building energy demand and it is expected that this qualitative aspect must be included for a comprehensive investigation of the research question. Whilst the qualitative approach may appear secondary from a scientific viewpoint, the energy performance of buildings is intertwined with the sociological and behavioural characteristics of their occupants.

Engineering models can describe the physical sub-system and dwelling behaviour. Social models describe the human subsystem and the occupants' behaviour. Both these behaviours affect the opposing subsystem and thus both engineering and social models must be used together to gain a full understanding. These two aspects need to be integrated for a coherent understanding of energy use (Hitchcock, 1993). This is consistent with the assertion that "all quantitative data is based upon qualitative judgements; and all qualitative data can be described and manipulated numerically", suggesting that quantitative and qualitative research approaches are merely two sides of the same coin (Trochim, 2006).

The theoretical attractiveness of a mixed methodology lies in its ability to effective link judgement and analysis by utilising the plurality of methodologies, viewing qualitative and quantitative research as complementary rather than mutually exclusive. However combining methodologies is not a straightforward undertaking and there are several critics of multi-strategy research whose main argument is predicated on the view that quantitative and qualitative research are entrenched research paradigms that inherently prevent the adoption of seemingly competing philosophical standpoints (Dainty, 2008).

A methodology for research into the application of the Energy Performance Certificate to housing in Mediterranean regions, and the reliability of the calculation procedures used to generate the energy rating for homes in the Mediterranean climate defines the path selected for the investigation of the research problem. This methodology is required to recognise and accommodate the understanding that the Energy Performance Certificates are the outcomes of a clearly defined scientific formulation with a comprehensive array of parameters and the implementation of the various national interpretations of this formulation within the occupied housing sector, with both aspects forming an intrinsic part of this reality. This indicates that the research problem incorporates aspects from both the positivist and interpretivist frameworks of the philosophy of research.

3.5. A Summary of the Research Philosophy

The philosophical framework of research has been outlined and considered in relation to the research problem. The epistemology of the research is the calculation methodology used in Southern Europe for the energy performance of housing. The ontological or existential nature of the research is the application of the calculation methodology and this is carried out within the combined axiology of both the researcher and the region. The scientific nature of the calculation methodology for the energy performance of housing justifies a positivistic philosophy whilst the interpretive nature of the application of this calculation in practice, together with the social reality of the context of the use of housing, locate this research within the domain of the mixed methodology.

3.6. The Research Approach

Referring to Figure 3.2, if the research philosophy encompasses the body of knowledge containing the research, the research approach could be described as the plan for this research journey through the body of knowledge, or in simple terms 'How to research?' This needs to be defined within the overall context of the research: the discipline of the research project; the research object being investigated; previous theory related to the research object; the researcher; and the conceptualisation of the research problem (Knight & Cross, 2012). This research is located within the field of the Built Environment, which is not considered a discipline in the strict sense, and is better classified as interdisciplinary in character (Chynoweth, 2006).

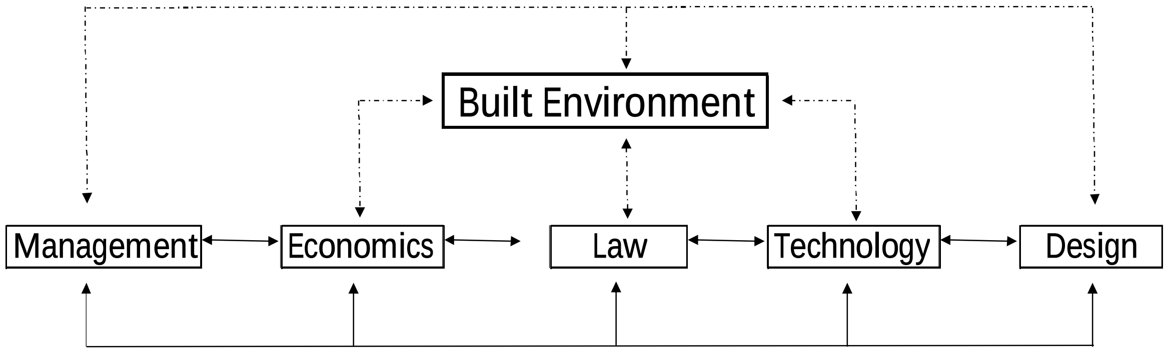

Figure 3.2 The Built Environment Interdiscipline (Chynoweth, 2006)

There is a range of potential research approaches available to the researcher. Table 3.1 (Remenyi, et al., 1998) demonstrates the range of alternative research approaches showing the relationship between the research method and the philosophical approach. The highlighted approaches are those considered relevant to the research area.

Research approaches are often classified as predominantly quantitative, predominantly qualitative, or mixed.

A quantitative approach is one in which the researcher primarily uses a positivistic philosophy for the development of knowledge, employing experiments and surveys for the collection of data for scientific or statistical analysis.

A qualitative approach is more often based on interpretivist perspectives where the strategy of inquiry is based on the use of narratives, ethnographies, or case studies. In qualitative research the data is often collected in the form of words and observations, as opposed to numbers. This data is open-ended and is used for the development of themes of description, comparison or prescription.

Mixed methods is a research paradigm that combines specific positivistic elements of quantitative research methods with specific constructivist elements of qualitative research methods. This reflects an epistemological stance that although knowledge is not absolute, it can be accumulated, tested, and either retained or discarded (Holden & Lynch, 2004).

A selection of the research approaches appropriate to the research questions is assessed, and the determination of the research approach is explained.

Research approaches	Objectivism	Subjectivism
Action research		Strictly interpretivist
Case studies	Have scope to be either	Have scope to be either
Ethnographic		Strictly interpretivist
Field Experiments	Have scope to be either	Have scope to be either
Focus Groups		Mostly interpretivist
Forecasting research	Strictly positivistic with some room for interpretation	
Futures research	Have scope to be either	
Game or role playing		Strictly interpretivist
In-depth surveys		Mostly interpretivist
Laboratory experiments	Strictly positivistic with some room for interpretation	
Large-scale surveys	Strictly positivistic with some room for interpretation	
Participant-observer		Strictly interpretivist
Scenario research		Mostly interpretivist
Simulation and modelling	Strictly positivistic with some room for interpretation	

Table 3.1 Research Approaches and Their Philosophical Bases (Remenyi, et al., 1998)

3.6.1. Case studies

A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident. Case study research considers a technically distinctive situation where there are more variables of interest than data points and relies on multiple sources of evidence with data needing to converge in a triangulating fashion. It benefits from the prior development of theoretical propositions to guide data collection and analysis (Yin, 2009).

3.6.2. Ethnographies

In ethnographic research, the researcher studies an intact cultural group of people in a specific setting over a period of time by collecting, primarily, observational data (Creswell, 2003). Although this research includes the collection of data relating to the day-to-day behaviour of people in their homes, it is not focussed on the day-to-day interactions between the occupants and the homes.

3.6.3. Laboratory Experiments

The scientific researcher proposes a hypothesis as an explanation of phenomena and designs experimental studies to test this hypothesis via predictions, which can be derived from them. These steps must be repeatable to guard against mistake or confusion in any particular experiment. The laboratory setting is highly constrained and the researcher typically has an above average level of control over all external forces that might affect the experiment.

3.6.4. Field Experiments

A field experiment applies the scientific method to experimentally examine an intervention in the naturally occurring environment rather than in the laboratory. Clearly the experimental element of this research, in relation to the measurement of the actual energy performance of Mediterranean housing, takes place in a field environment and not in a laboratory setting.

3.6.5. Simulation and Modelling

Simulation could be defined as an attempt to emulate reality through the construction of a mathematical model to represent the operation of a system, taking into account each possible system flow path and the interactions between them (Clarke, 2001). The simulation approach can be used for several different purposes in research, but two specific areas associated with the research are prediction and performance.

Simulation for prediction takes a model, composed of a structure and rules that govern that structure and produces output. By comparing different output obtained via different structures and governing rules, researchers can infer what might happen in the real situation if such interventions were to occur. The validity of such predictions depends on the validity of the model. Simulation for prediction is a substitute for experimentation and intervention on the actual system. It is undertaken when such experimentation is too dangerous, costly, untimely, or inconvenient (Dooley, 2002).

With an appropriately calibrated and validated model, simulation for performance can be used to determine the occurrence of events at discrete instants. The simulation can be used to obtain estimates of performance measures. Since most performance models incorporate some form of randomness in their inputs, the simulation of a model that incorporates randomness has statistical aspects that need to be taken into consideration.

3.7. The Selected Research Approach

Having assessed these research approaches, it is clear that the nature of the phenomena being researched falls within the scope of a number of approaches. The characteristics of the research problem and the expression of the research questions indicate that the case study and the field experimental approach are suitable for further consideration.

3.7.1. Characteristics of the Research Problem

Case studies are often considered as a useful tool for the preliminary stages of a research project, as a basis for the more rigorous tools required for experimental work (Rowley, 2002). A case study is an empirical enquiry that investigates a contemporary phenomenon within its real life context (Yin, 2009). Case study research can be based on any mix of quantitative and qualitative approaches and typically uses multiple data sources. Case study approaches facilitate the investigation of a phenomenon that is representative of general cases, within a large quantity of contextual variables that are too numerous and qualitatively different for other data collection approaches (Fellows & Liu, 2008). In the context of this research, the phenomenon is the energy demand of housing within the constraints of a Southern Mediterranean climate and this is determined by a large quantity of variables relating to the climate, the building envelope, the technical systems for heating and cooling, and the behaviour of the occupants.

The scientific approach to establish the accuracy of a calculation methodology is experimental in nature, and given the large-scale context of the research problem (housing in Southern Europe), the experimental element of this research is in the field. The advantage of field experimentation is that it provides an intimate connection with empirical reality, and this is considered the cornerstone of the development of a testable, relevant, and valid theory (Glaser & Strauss, 2012). Although the use of field experimentation for research in the area of the built environment appears to be relevant as a research approach for the phenomena under investigation, the large quantity of contextual variables involved and the consequent difficulty in maintaining some, or indeed, any, of the variables even approximately constant, detracts from the potential usefulness of the field experiment as the primary research approach.

3.7.2. Expression of the Research Question

The issue of type of research question is the most significant in determining the most appropriate approach. Most research questions can be categorised into how and why or who, what, where, how many and how much (Rowley, 2002). The research question here is expressed as 'whether', which is defined by the Oxford English Dictionary as expressing an enquiry or investigation with a doubt or choice between alternatives. Clearly the research question falls into the how and why category. This category of question is suited to both the experimental and the case study approach (Yin, 2009). Table 3.2 (Hammersley & Gomm, 2000) presents a comparison of case study and experiment as research approaches.

Although there is clearly overlap between the two approaches, the defining characteristic for the selection of the case study approach for the research is the fact that the study of the energy performance of housing must necessarily be carried out under naturally occurring conditions, and there is no possibility of the control of any of the variables affecting the energy behaviour. Two additional defining characteristics of the case study approach for this research are that it considers a small number of cases and that it is of an exploratory nature.

	Experiment	Case Study
Number of cases	Investigation of a relatively small number	Investigation of a relatively small number (sometimes just one)
Information gathered and analysed	A small number of features of each instance	A large number of features of each case
Control of variables	Study created in such a way as to control important variables	Study of naturally occurring cases
Quantification of data	A priority	Not a priority
Research aim	The development and testing of theory or the practical evaluation of an intervention	To understand the case itself. This could include attempts at theoretical inference or empirical generalisation or both

Table 3.2 Comparison of case study and experimental approaches (Hammersley & Gomm, 2000)

3.7.3. Summary

The characteristics of the research problem and the expression of the research question have determined the selection of the case study approach for this research. The use of multiple data sources by the case study approach allows for the inclusion of data collection through field experiments within the triangulated evidence required to understand and illuminate the research question in its context. A multiple case-study approach is preferred to the single case study since the single-case study is vulnerable to the risks associated with having all the eggs in one basket. It is generally acknowledged that the analytic benefits of having two or more case studies is substantial (Yin, 2009).

It is reasonable to ask how the results from a relatively small number of case studies can be generalised, and the research technique must therefore provide the information needed to judge the validity of the research findings from the case studies. It is important to remember that the case study is not a strictly qualitative research paradigm and can be based on any mix of quantitative and qualitative research approaches. Several different approaches to this combination of methods have been put forward to allow researchers to make deductions from empirical data whilst testing these deductions with the inferences that emerge from qualitative data (Falk & Guenther, 2006). The survey research approach lends itself to statistical generalisation where the research subject is treated as representative of a population but the case study uses analytic generalisation from the results generated to expand and generalise from the purpose that supports the research questions (Yin, 2009).

The analytic framework is derived from the Contextual Constructs Model (CCM) (Knight & Cross, 2012) and this is applied to transform the research data into actual results. The data is not pre-supposed to be only the user-results but can be conceptualised from previous theory, observations from other sources, analysis notes, and the combining of data sets into new constructed categories. This approach to developing findings from the data is based on the contention that "analysis takes place throughout the research process" (Watt, 2007). The research technique for this study is generated from this research approach, justifying analytic generalisation from the findings.

3.8. Selection of Case Studies

This research is exploratory in that it investigates the recent (post 2008) generation of Energy Performance Certificates (EPCs) in Southern Europe, mandated by the adoption of the Energy Performance of Buildings Directive (EPBD), and attempts to determine whether the values for housing energy demand calculated for certification are representative of the actual energy demand in Southern European housing. The research methodology requires 'typical' cases for study. The research criteria are to be met within the geographical location, Southern Europe; the legislative context, the calculation methodology used for the generation of EPCs; and the specific subject area of the built environment that is categorised as residential property.

Figure 3.3 shows the Mediterranean region of Europe and demonstrates how the selection of Spain, Malta, Italy, and Cyprus range from the West to the East providing a comprehensive coverage of the area. Whilst Malta and Cyprus are amongst the smallest EU states, and only have a single approved calculation methodology for the generation of EPCs for housing, the much larger Italy and Spain both have a number of different methodologies. The main criterion for the selection of calculation methodologies and the respective application software for the study was that these had to be officially approved and endorsed by the national body responsible for the implementation of the EPBD in the relative member states.

Other criteria related to the availability of the different software, a requirement that their date of commencement of use pre-dated the research timetable, and the availability of documentation outlining the software methodology.

Figure 3.3 Map of Southern Europe showing the Case Study states in red.

3.9. The Research Technique

Having defined and justified the use of the case study as an appropriate research approach, this section discusses the specific technique to be applied to define the research in a manner that satisfies the criteria for a valid and reliable research methodology.

3.9.1. Software testing

Since the research question is centred on the reliability of the application of the current national certification methodologies, and the main tool for the implementation of these calculation methodologies for the generation of EPCs is a software program, it is appropriate to consider the various aspects relating to the testing of software.

Software testing can be conducted through a variety of approaches, which differ according to the objective required from the test and the scope it covers (Witte, et al., 2001).

Judkoff (1998) defined three categories of software testing, namely

- Empirical validation—in which calculated results from a program, subroutine, algorithm or software object are compared to monitored data from a real building, test cell, or laboratory experiment.
- Analytical verification—in which outputs from a program, subroutine algorithm or software object are compared to results from a known analytical solution or a generally accepted numerical method under very simple and highly constrained boundary conditions.
- Comparative testing—in which a program is compared to itself or to other programs that may be considered better validated or more detailed and, presumably, more physically correct (Judkoff, 1998).

In general, comparative testing involves assessing a tool by comparing results of either multiple runs of the same tool or results of runs from multiple tools and is primarily used for diagnostic and validation purposes. While this methodology provides a more flexible approach than either analytical or empirical testing, it does not provide an absolute standard. However, if adequate measures are adopted to ensure the statistical validity of results, findings can be considered representative of the general case.

3.9.2. Definition of the research technique.

The important choices for a researcher include the primary unit of analysis, how context is to be defined and operationalised, and the time frame of the study (Pettigrew, 1997). The combination of the rigorous scientific approach with the case study technique is emphasised for high quality research (Yin, 2009). With this approach, the research steps can be described as follows:

1. The development of the research problem
2. A comprehensive literature review as a tool for contextualising the research problem. The literature study examines existing work in connection with the Energy Performance of Buildings Directive, EN ISO 13790, different calculation methodologies and simulation tools. More specifically the literature review focuses on other studies

comparing calculation methodologies to either dynamic simulation software or actual operational energy measurements. Particular attention is given to research carried out on residential buildings and/or buildings in a Mediterranean climate. The main scope of the literature review is to place the research in perspective and relate the findings of this work to previous knowledge.

3. Identification of the various national certification methodologies adopted in the Southern Mediterranean EU states of Malta, Italy, Cyprus, and Spain. In the situation where these states utilise different methodologies, a single official methodology is selected for each state. The structure and application of the various methodologies are analysed and compared.
4. Testing of the certification methodologies using
   a. Empirical validation comparing the software results to monitored data from real building case studies and/or statistical data.
   b. Analytical results comparing the software results to the known analytical solution presented by dynamic simulation.
   c. Comparative testing between the different national methodologies.
5. Analysis of the data. There are four sources of data namely:
   a. Results of the certificate software runs.
   b. Results of the dynamic analysis simulation runs.
   c. Metered data.
   d. Statistical data.

At this point it is useful to restate the research question, namely:

"To establish whether the current certification methodologies used in Southern Europe (Malta, Italy, Spain, Cyprus) provide an accurately calculated value of energy demand in Southern Mediterranean housing."

The scope of the analysis is to:

a. Investigate the accuracy of the various methodologies against the dynamic analysis and the metered data.
   i. In order to do this it is necessary to reconcile the dynamic analysis and the metered data.
   ii. In the absence of metered data, it is necessary to reconcile the statistical data with the dynamic analysis.

iii. For accuracy the energy data should be broken down into its constituent components, i.e. heating, cooling, domestic hot water, lighting, others.

b. In the event of discrepancies, consider improvements to the methodologies so that they can provide an accurate definition of the energy use of the property.

i. In order to do this it is important to keep in mind that the EPC is primarily a calculation of the energy performance of the property under standardised conditions of use, but, increasingly, it is also being considered as a measure of the energy efficiency of the property under 'normal' conditions of use. This measure is being considered as a basis for economic decisions for the energy saving measures in new build and refurbishment.

ii. To propose improvements it is necessary to consider the strengths and weaknesses of the various methodologies, the EN ISO 13790 standard that the methodologies are based on, and alternative approaches to calculation of energy performance.

3.10. Conditions of good empirical research

The rigour of case study research is judged by the same criteria of internal validity, construct validity, external validity and reliability as in other forms of scientific research (Fellows & Liu, 2008).

3.10.1. Construct validity

Construct validity is measured by calculating correlations between the measure of the construct and scores on other measures. It concerns the degree to which the variables, as measured by the research, reflect the hypothesised construct. Poor construct validity occurs if the measurements are caused by other variables' influence or random noise. It is inherent within the concept of construct validity that the variables are correctly measured (Bacharach, 1989). Construct validity establishes correct operational measures for exposing and reducing subjectivity by linking data collection to the research questions.

In this research, the certified energy performance of housing is the hypothesised construct since this energy performance is based on a hypothetical use of the residence under standardised conditions. The operational measures taken to reduce the influence of the random variables caused by the actual behaviour of the occupants were the use of four sources of data (metered data, EPC data, dynamic simulation data, and statistical data) in order to identify and isolate the effect of the random variables on the energy demand. The use of multiple sources of data encourages convergence and this chain of evidence develops a logical progression towards this convergence.

3.10.2. Internal validity

Internal validity is the degree to which a researcher draws independent conclusions about the effects of an independent variable. The internal validity is high when the observed and measured effect is due to the identified causal relationship, or in other words, when changes in the independent variable(s) are the sole or main cause of changes in the dependent variable. The recommended strategies for demonstrating internal validity are the use of logic models and the consideration of alternative or rival explanations (Yin, 2009). The literature review is utilised for the collection of alternative calculation strategies for the energy performance of housing in a Mediterranean climate. The research method includes a strategy for the calibration of the software models to minimise the possibility of data input errors. Finally, the analysis of the data from multiple sources facilitates the identification of spurious output data.

3.10.3. External validity

External validity is the degree to which the results obtained in one study can be replicated or generalised to other samples, research settings and procedures. It concerns the questions of how restrictive is the study and whether the findings are applicable to other situations. From the perspective of quantitative research, it is often found that increasing internal validity decreases external validity and vice versa. This relationship does not have to occur with mixed methods employing mixed strategies (Onwuegbuzie & Teddlie, 2003). The main criticism of the use of a case study is that the limited number of examples is generally considered a weak basis for generalisation. However, in this research the use of the case study approach is broadened to include a range of actual properties (four), and a range of national calculation methodologies (four), as well as the use of statistical data and the independent verification of calculated data through the use of accredited dynamic thermal simulation software (IES-VE).

3.10.4. Reliability

The reliability of a study refers to what happens if a study is carried out again. The reliability is achieved through proper documentation of procedures and appropriate record keeping. The goal is to minimise error and bias and the recommended approach ((Yin, 2009) is the definition of a protocol to specify the decisions taken and define how the research should proceed. The protocol outlines how the researcher plans to answer the research questions and provides a link back from the data to the questions. The case study protocol for this research is included at Appendix 1.

3.11. Case Study Design

The methodological requirements for the case study design to be objective, valid and reliable have been put forward by Yin (2009). A good research design should incorporate five key components; the research question, the theoretical propositions or purpose of the study; the units of analysis; the logic linking the data to the propositions; and the criteria for interpreting the findings.

3.11.1. Research questions

The literature review generated the background for the research question which is reprised below:

1. The differences in the energy performance of housing between North and South Europe.
2. The reliability of the energy performance certificate methodologies in a Southern European climate where heating and cooling are required for residential buildings as opposed to the Northern and Central European climate where only heating is required for residential buildings.
3. The differences between national EPC methodologies applied in similar climates.

The outcome of this is the expression of the research question:

"To establish whether the current certification methodologies used in Southern Europe (Malta, Italy, Spain, Cyprus) provide an accurately calculated value of energy demand in Southern Mediterranean housing."

3.11.2. Research propositions

The research proposition defines the scope of the research by stating its context and expressing any assertions that are being challenged by the research. For research of an exploratory nature, the research propositions are reformulated as the research purpose (Yin, 2009), which clearly states what is to be explored, the aim of the exploration, and the criteria for judging the success of the exploration. For this research, the purpose is to explore the validity of the energy performance certificate in its current format in a Mediterranean climate, using an analysis of the application of the EN calculation methodology in the different national contexts in the light of the unique characteristics of the energy performance of housing in a Mediterranean climate.

3.11.3. Unit of analysis

The unit of analysis is the subject of the research and determination of the unit of analysis of the research is of pivotal importance in any research. The observational units of the research are the case study properties used for the data collection and calculations. However, the unit of analysis is the subject of the research and this is the calculation methodology applied in each of the Southern European countries investigated in this study. This links the research question and purpose through the specific issues of climate and location to the sources of the data.

3.11.4. Logic linking data to purpose

The logic is shown in diagrammatic format in Figure 3.4. The unit of analysis and the data are logically linked by the numerical analysis of the calculation procedures, and should be correlated with the actual energy performance data which implicitly introduce a qualitative aspect due to the effect of the behaviour of the occupants within the observational units. This triangulation of data relates to the purpose enunciated in 3.11.2 above.

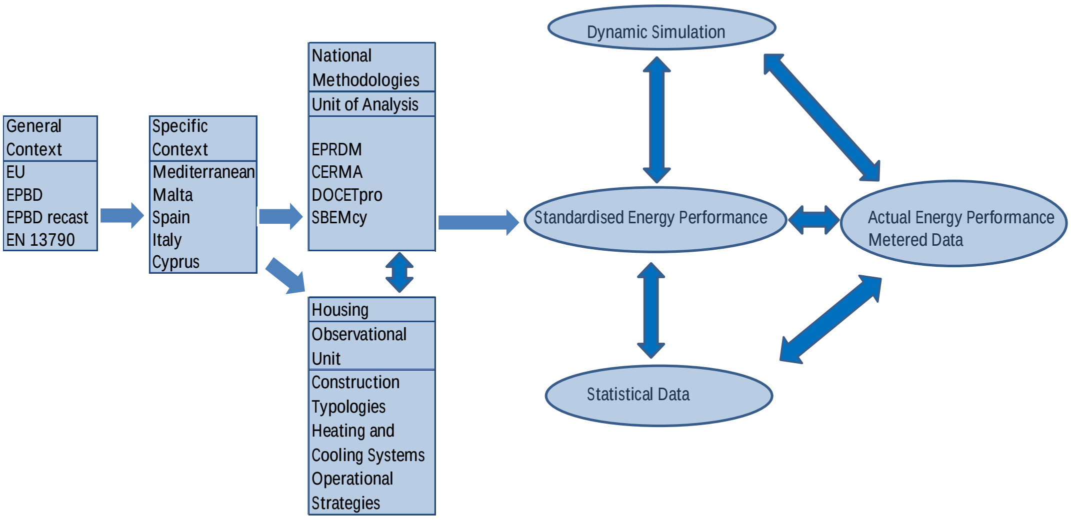

Figure 3.4 The relationship between the research question and the data

3.11.5. Criteria for interpretation of the findings

The interpretation of findings and analysis of data is one of the least developed and most difficult aspects of the case study approach. Results must necessarily be described clearly and interpreted in an objective and critical way, before assessing their implications and before drawing conclusions. Two general analytic strategies are adopted:

1. Relying on theoretical propositions: By analysing the theoretical orientation guiding the calculation methodologies that are the focus of the research helps to focus attention on the more relevant data and to discard other data.
2. Developing a case description: By formulating a descriptive framework for organizing the case study data, the analysis can consequently be organised on the basis of description of the general characteristics and relations of the phenomenon in question.

The analytic techniques used for interpretation of the findings as part of the above strategies are pattern matching (Yin, 2009) between expected outcomes and rival methodologies, and explanation building for the building of an explanation about the case and identifying the causal links between the outcomes.

3.12. Summary

The selection of a mixed methodology, combining both qualitative and quantitative approaches, was justified for this research. The case study has been identified as an appropriate technique for addressing the research question. The design of the research technique has been presented and the conditions for the research have been outlined. The calculation methodologies that comprise the actual case studies are considered next in Chapter 4.

Chapter 4. The EPC Calculation Methodology

4.1. EN ISO Standards and EN ISO 13790

This chapter discusses the basis for the EPC calculation methodology, namely EN ISO 13790 (2008) Energy Performance of Buildings – Calculation of energy use for space heating and cooling, and the related standards. (These standards are currently being revised but the revision process is in its early stages). This is followed by a presentation of the main features for the four national certification methodologies forming the basis of this research investigation.

4.1.1. Introduction

In order to comply with the EPBD, member states were required to establish a common methodology at national or regional level to calculate the integrated energy performance of buildings. A set of European (EN) and international (EN ISO) standards was prepared, on the basis of existing standards where applicable, to provide the calculation methodology and associated procedures for the calculation of the energy performance of a building. This resulted in a collection of nearly sixty different standards relating to the EPBD. These standards and the relationship between them and the EPBD are outlined in an umbrella document (CEN, European Committee for Standardisation, 2008). Annex A of this document groups the standards into 5 main sections, as displayed in Table 4.1.

The energy performance of a building is calculated on the basis of the overall energy use which is the integration of the energy need of the building for heating and cooling, more commonly referred to as the heating and cooling load, with the energy performance of the systems delivering the heating and cooling. The focal standard is thus EN ISO 13790 – Calculation of energy use for space heating and cooling, and this is the basis of the energy performance calculation methodology as defined by the whole group of standards. Many of the other standards define specific aspects of the calculation procedure, such as the transmission properties of the building components and ventilation airflow rates. The final assessment of overall energy use and definition of the energy rating is outlined in EN ISO 15603.

The scope of the EN ISO 13790 standard, as defined in the introduction to the original document, is to

1. Judge compliance with regulations expressed in terms of energy targets;

2. Compare the energy performance of various design alternatives for a planned building;

3. Display a standardised level of energy performance of existing buildings;

4. Assess the effect of possible energy conservation measures on an existing building, by calculation of the energy use with and without the energy conservation measure;

5. Predict future energy resource needs on a regional, national, or international scale, by calculating the energy use of typical buildings representative of the building stock.

Section 1	Standards concerned with the calculation of <u>overall energy use</u> in buildings (based on the results from standards in section 2)
Section 2	Standards concerned with the calculation of <u>delivered energy</u> (based where relevant on the results from standards in section 3)
Section 3	Standards concerned with the calculation of <u>energy need for heating and cooling</u>
Section 4	Standards to support the above A. Thermal performance of building components B. Ventilation and air infiltration C. Overheating and solar protection D. Internal conditions and external climate E. Definitions and terminology
Section 5	Standards concerned with monitoring and verification of energy performance

Table 4.1 Hierarchy of standards relating to the EPBD as outlined by CEN/TR 15615

This chapter presents the calculation methodology proposed by the standard, together with the national calculation methodologies adopted by the Mediterranean states included in this study.

4.1.2. EN ISO 13790 Calculation Methodology

The EN ISO 13790 standard could have allowed only a single method for regulation compliance but it was felt that this would have restricted possible designs to the capabilities of the single method and would discourage the development of innovative technologies that could not be addressed by the chosen method (Kokogiannakis, et al., 2008). On the other hand, the possibility to choose not only between different calculation methods for the energy performance but also between different calculation methods for the input parameters can result in an equivocal determination of the energy performance of the building (Magrini, et al., 2012).

The standard covers three different types of calculation method, a fully prescribed monthly quasi-steady-state calculation method (with the option of a seasonal method for further simplification), a fully prescribed hourly dynamic calculation method, and calculation procedures for detailed (e.g. hourly) dynamic simulation methods. These can be categorised into two model types, namely steady-state (or quasi-steady-state) models, which do not model dynamic effects but take them into account through the use of empirically determined factors, and dynamic models which calculate the heat balance using short time steps taking into account the energy stored in and released from the mass of the building. The distinction between steady-state methods and dynamic calculations is that the latter methods treat time as an independent variable.

While both the monthly quasi-steady-state calculation method and the simple hourly dynamic calculation method are fully prescribed by the standard, in the case of the detailed hourly dynamic simulation methods, the standard gives details for the common procedures and descriptions, boundary conditions and input data that these methods should adopt in order to ensure consistency with the simplified methods. The EN ISO 13790 standard does not specify the validation procedures and performance criteria for dynamic simulation methods but refers to other standards such as EN ISO 15265.

The general calculation procedure is defined as follows:

- The building is either partitioned into multiple zones or treated as a single zone.
- The energy balance is split into the energy balance at building level and the energy balance at system level.
- The building needs for heating and sensible cooling are calculated on the basis of the energy balance of the building zones.
- These energy needs for heating and cooling are the input for the energy balance of the heating and cooling systems and ventilation systems.

- A multi-step calculation can be required to account for interactions between different zones, or between the systems and the building energy balance.

The definition of boundaries and zones apply to all calculation methods. In order to perform a single-zone calculation, where the building is not partitioned into thermal zones, the building must meet all the following criteria:

- Set point temperatures for heating of the spaces differ by no more than 4K.
- The spaces are all not mechanically cooled or all mechanically cooled and set point temperatures for cooling of the spaces differ by no more than 4K.
- The spaces are served by the same heating system (if any) and the same cooling system (if any).
- If there is a ventilation system, at least 80% of the floor area of the spaces are serviced by the same ventilation system (and the remainder are then considered to be serviced by the main ventilation system).
- The amount of ventilation expressed in $m^3/s/m^2$ differs by not more than a factor of 4 within 80% of the floor area, or the doors between the spaces are likely to be frequently open.

These criteria are generally met by the majority of residential properties.

The calculation procedures for the building energy need for space heating and cooling, the heat transfer by transmission, the heat transfer by ventilation, the internal heat gains, the solar heat gains, and the dynamic parameter depend on the type of calculation method, but the assumptions of environmental conditions, user behaviour, and controls, and the basic physical data should be the same for each of the calculation methods. The procedures for the definition of the indoor conditions and the heating and cooling modes are partly general and partly specific to the selected calculation method.

The main classifier of a building thermal model is generally the method of treatment of conduction heat transfer through the elements that constitute the building envelope, even though the heat transfer in building elements is just a single part, albeit a fundamental one, of the complex solution required to model the energy transfer and indoor environment of a building space or a complete building of interacting spaces (Underwood & Yik, 2004). When comparing various models, the focus is generally on space heating and cooling requirements for a number of reasons, amongst which are that the demand for space heating and cooling is usually the largest component of the overall energy demand in building; the complexity of the space heating and cooling calculations; the large number of inputs required for the processes associated with space heating and cooling; and the related uncertainty for determining these inputs (Kokogiannakis, et al., 2008).

The simple hourly dynamic calculation method that is fully prescribed by the standard is based on an equivalent resistance-capacitance model using lumped capacitance applying the analogy of electrical resistance and flow of current to thermal resistance and heat transfer. This involves combining the building elements with higher thermal capacity together into an equivalent capacitance and the model proposed by the standard combines five resistive elements with a single capacitance. The resistive components are the thermal transmission coefficients of the opaque elements, the thermal transmission coefficients of the glazed elements, the ventilation characteristics, the coupling conductance between the air and the surfaces, and the coupling conductance between the mass and the surfaces. With this method, a separate treatment of inter-surface radiation is not considered, and the method is not suitable for applications involving significant heat transfer by radiation nor for situations involving high thermal capacity room elements (Underwood & Yik, 2004).

4.2. National Approaches

This chapter also analyses the different approaches taken for the energy calculation in the four selected states/regions.

As building regulations particularly stipulate that the prescribed method is transparent, robust, and reproducible, the quasi-steady-state monthly method is often used, and this is the case for the Italian, Cypriot, and Maltese methods investigated here. On the other hand, due to the simplicity of the method, dynamic effects such as climatic conditions, user behaviour, equipment operating schedules, etc. are only taken into consideration in a simplified way by time weighted averaged values and dynamic factors, whilst dynamic simulation methods consider energy storage, dynamic phenomena and variations of numerical values in a more realistic fashion (Wauman, et al., 2013). The current form of the quasi-steady-state system was determined in the PASSYS project for residential buildings. The method remains questionable for very well insulated and air tight buildings, and for buildings with intermittent use (Wauman, et al., 2013) (Jokisalo & Kurnitski, 2007).

Since the simplified monthly method is the basis of three of the national methodologies being considered, the main features of the method are presented to have a basis for comparison.

4.2.1. The EN ISO 13790:2008 Simplified Monthly Method

For a single zone building and a monthly calculation step, the building energy need for space heating, $Q_{H,nd}$, for conditions of continuous heating is given by

$$Q_{H,nd} = Q_{H,nd,cont} = Q_{H,ht} - \eta_{H,gn} Q_{H,gn} \quad (4.1)$$

where

$Q_{H,nd,cont}$ is the building energy need for continuous heating, assumed to be greater than or equal to zero, expressed in MJ;

$Q_{H,ht}$ is the total heat transfer for the heating mode, determined in accordance with Equation (4.3), expressed in MJ;

$Q_{H,gn}$ is the total heat gains for the heating mode, determined in accordance with Equation (4.4), expressed in MJ;

$\eta_{H,gn}$ is the dimensionless gain utilisation factor, determined in accordance with Equation (4.5).

For a single zone building and a monthly calculation step, the building energy need for space cooling, $Q_{C,nd}$, for conditions of continuous cooling is given by

$$Q_{C,nd} = Q_{C,nd,cont} = Q_{C,gn} - \eta_{C,ls} Q_{C,ht} \quad (4.2)$$

where

$Q_{C,nd,cont}$ is the building energy need for continuous cooling, assumed to be greater than or equal to zero, expressed in MJ;

$Q_{C,ht}$ is the total heat transfer for the cooling mode, determined in accordance with Equation (4.3), expressed in MJ;

$Q_{C,gn}$ is the total heat gains for the cooling mode, determined in accordance with Equation (4.4), expressed in MJ;

$\eta_{C,ls}$ is the dimensionless utilisation factor for heat losses, determined in accordance with Equation (4.8).

The total heat transfer of the single zone building Q_{ht} is given by

$$Q_{ht} = Q_{tr} + Q_{ve} \qquad (4.3)$$

where

Q_{tr} is the total heat transfer by transmission for the month, expressed in MJ;

Q_{ve} is the total heat transfer by ventilation for the month, expressed in MJ.

The total heat gains of the single zone building Q_{gn} are given by

$$Q_{gn} = Q_{int} + Q_{sol} \qquad (4.4)$$

where

Q_{int} is the sum of the total internal heat gains over the month, expressed in MJ;

Q_{sol} is the sum of the total solar heat gains over the month, expressed in MJ.

The dimensionless gain utilisation factor for heating, $\eta_{H,gn}$ is a function of the heat balance ratio, Υ_H, and a numerical parameter a_H, that depends on the building inertia, as given by the following equations,:

if $\Upsilon_H>0$ and $\Upsilon_H\neq1$: $$\eta_{H,gn} = \frac{1-\Upsilon_H^{a_H}}{1-\Upsilon_H^{a_H+1}} \qquad (4.5)$$

if $\Upsilon_H=1$ $$\eta_{H,gn} = \frac{a_H}{a_H+1}$$

if $\Upsilon_H<0$ $$\eta_{H,gn} = \frac{1}{\Upsilon_H}$$

where for each month

Υ_H is the dimensionless heat-balance ratio for the heating mode, determined in accordance with Equation (4.7);

a_H is a dimensionless numerical parameter depending on the time constant, τ_H, defined by Equation (4.6):

$$a_H = a_{H,0} + \frac{\tau}{\tau_{H,0}} \qquad (4.6)$$

where

$a_{H,0}$ is a dimensionless reference numerical parameter;

τ is the time constant of the building zone, determined in accordance with Equation (4.7), expressed in hours;

$\tau_{H,0}$ is a reference time constant.

The heat balance ration for the heating mode Υ_H is determined by :

$$\Upsilon_H = \frac{Q_{H,gn}}{Q_{H,ht}} \qquad (4.7)$$

The time constant of the building zone, τ, expressed in hours, characterises the internal thermal inertia of the conditioned zone for both heating and cooling periods, and is calculated by using:

$$\mathrm{T} = \frac{\mathrm{C}_m/3600}{H_{tr,adj}+H_{ve,adj}} \qquad (4.8)$$

where

C_m is the internal heat capacity of the single zone building.

The dimensionless loss utilisation factor for cooling, $\eta_{C,ls}$ is a function of the heat balance ratio for cooling, Υ_C, and a numerical parameter a_C, that depends on the building inertia, as given by the following equations,:

if $\Upsilon_C>0$ and $\Upsilon_C\neq1$: $$\eta_{C,ls} = \frac{1-\Upsilon_C^{-a_C}}{1-\Upsilon_C^{-(a_C+1)}} \qquad (4.9)$$

if Υ_C=1 $\qquad \eta_{C,ls} = \frac{a_C}{a_C+1}$

if Υ_C<0 $\qquad \eta_{C,ls} = 1$

where for each month

Υ_C is the dimensionless heat-balance ratio for the cooling mode, determined in accordance with Equation (4.11);

a_C is a dimensionless numerical parameter depending on the time constant, τ_C, defined by Equation (4.10):

$$a_C = a_{C,0} + \frac{\tau}{\tau_{C,0}} \qquad (4.10)$$

where

$a_{C,0}$ is a dimensionless reference numerical parameter;

τ is the time constant of the building zone, determined in accordance with Equation (4.8), expressed in hours;

$\tau_{C,0}$ is a reference time constant.

The heat balance ration for the cooling mode Υ_C is determined by :

$$\Upsilon_C = \frac{Q_{C,gn}}{Q_{C,ht}} \qquad (4.11)$$

Description	Mode	Symbol	Value
Reference numerical parameter	Heating	$a_{H,0}$	1
	Cooling	$a_{C,0}$	1
Reference time constant	Heating	$\tau_{H,0}$	15 hrs
	Cooling	$\tau_{C,0}$	15 hrs

Table 4.2 Reference parameters from EN ISO 13790

Values for the reference parameters are tabulated in EN ISO 13790 and are presented in Table 4.2.

For the simple monthly method, the internal heat capacity of the building, C_m, expressed in J/K, is calculated by summing the heat capacities of all the building elements in direct thermal contact with the internal air of the single zone building, as given by

$$C_m = \sum k_j \times A_j \qquad (4.12)$$

where

k_j is the internal heat capacity per area of the building element j, with maximum effective thickness 0.1m, expressed in J/m^{2}K;

A_j is the area of the building element j, expressed in m^2.

Default values for the dynamic parameters are also indicated by the EN ISO 13790 standard and are presented in Table 4.3.

Construction Type	C_m (J/K)
Very light	80,000 x A_f
Light	110,000 x A_f
Medium	165,000 x A_f
Heavy	260,000 x A_f
Very Heavy	370,000 x A_f

Table 4.3 Dynamic parameters from EN ISO 13790

For continuous heating during the whole heating (or cooling) period, the set-point temperature for heating (or cooling) shall be used as the set-point temperature of the building.

Intermittent heating (or cooling) shall be considered as continuous heating (or cooling) with an adjusted set-point temperature if either of the following conditions apply:

Condition A

- If the set-point temperature variations between normal heating (or cooling) and reduced heating (or cooling) is less than 3K and/or
- if the time constant of the building is less than 0.2 x the duration of the shortest reduced heating(or cooling) period.

In this case the adjusted set-point temperature is the time average of the set-point temperatures.

Condition B

- If the time constant of the building is greater than three times the duration of the longest reduced heating (or cooling) period,

In this case the set-point temperature is the set-point temperature for the normal heating (or cooling) mode.

In the case of intermittent heating which does not fulfil the above conditions, the energy need for intermittent heating, $Q_{H,nd,interm}$, is calculated by :

$$Q_{H,nd,interm} = a_{H,red}\, Q_{H,nd,cont} \qquad (4.13)$$

where

$Q_{H,nd,cont}$ is the energy need for continuous heating, from Equation (1), expressed in MJ;

$a_{H,red}$ is the dimensionless reduction factor for intermittent heating determined in accordance with :

$$a_{H,red} = 1 - b_{H,red}(\tau_{H,0}/\tau)\Upsilon_H(1-f_{H,hr}) \qquad (4.14)$$

with $f_{H,hr}$ O $a_{H,red}$ O1

where

$f_{H,hr}$ is the fraction of the number of hours in the week with a normal heating setpoint, eg. (14 x5)/(24 x 7) = 0.42;

$b_{H,red}$ is an empirical correlation factor with value $b_{H,red} = 3$

$\tau_{H,0}$ is the reference time constant for the heating mode, expressed in hours;

Υ_H is the dimensionless heat-balance ratio for the heating mode.

In the case of intermittent cooling which does not fulfil the above conditions, the energy need for intermittent cooling, $Q_{C,nd,interm}$, is calculated by :

$$Q_{C,nd,interm} = a_{C,red}\, Q_{C,nd,cont} \qquad (4.15)$$

where

$Q_{C,nd,cont}$ is the energy need for continuous cooling, from Equation (4.2), expressed in MJ;

$a_{C,red}$ is the dimensionless reduction factor for intermittent heating determined in accordance with :

$$a_{C,red} = 1 - b_{C,red}(\tau_{C,0}/\tau)\Upsilon_C(1-f_{C,day}) \qquad (4.16)$$

$$\text{with } f_{C,day} \text{ O } a_{C,red} \text{ O} 1$$

where

$f_{C,day}$ is the fraction of the number of days in the week with a normal cooling setpoint, eg. (5/7) = 0.71;

$b_{C,red}$ is an empirical correlation factor with value $b_{C,red} = 3$

$\tau_{C,0}$ is the reference time constant for the cooling mode, expressed in hours;

Υ_C is the dimensionless heat-balance ratio for the cooling mode.

The standard also permits a decision at national level to take into account the effects of intermittency.

4.2.2. EPRDM

The national calculation tool for the Energy Performance of Residential Dwellings in Malta (EPRDM) is the basis for the Maltese official procedure for calculating the energy performance of dwellings. The procedure calculates the net energy required for space heating and cooling, water heating, lighting, and ventilation, after subtracting any savings from energy generation technologies. It calculates the annual values of delivered energy consumption (energy use), primary energy consumption, and carbon dioxide emissions (CO_2) emissions, both as totals and per square metre of total useful floor area of the dwelling per annum.

The procedure is based on a monthly energy balance calculation within a series of individual calculation routines. The individual routines contain equations or algorithms representing the relationships between various factors which contribute to the annual energy demand of the dwelling. The procedure is based on EN ISO 13790:2008 and uses the quasi steady-state monthly method.

The calculation is made using standardised assumptions regarding occupancy, temperature set points and duration of heating and cooling, usage of domestic electrical appliances, etc. It is thus independent of the individual characteristics of the household occupying the dwelling when the rating is calculated, such as :

- Occupancy and composition;
- Individual heating and cooling patterns and temperatures;
- Ownership and efficiency of particular domestic appliances.

The procedure calculates a monthly energy balance for space heating and aggregates these figures over a heating season spanning November to April inclusive. Similarly it calculates a monthly energy balance for space cooling over a cooling season spanning May to October inclusive. The seasonal transitional months of April and November have been included in the heating season since the software calculation for the heating load in these months produces negligible or zero values. It then takes account of hot water energy demand based on the size of the dwelling and the type of hot water system, including the option for solar water heating. Finally, the lighting energy requirement is also calculated to determine the overall results. System efficiencies and renewable energy technologies are then input in order to set-off the energy demand of the building and the final result is calculated. The calculated results are not affected by the geographical location within the Maltese islands (CASAinginiera, 2009).

4.2.3. Input Data for the EPRDM Methodology

The data entry for the methodology is classified into the following groups:

- Dwelling Dimensions.
- Opaque Inputs.
- Glazed Inputs.
- Ventilation.
- Hot Water.
- Solar Water Heating.
- Systems.
- Renewables.

The dwelling dimensional data consist of the total floor area per storey and the height of each storey. The living area is determined by the methodology as a percentage of the total floor area, varying between 60% for dwellings with a total floor area of 60m^2 to 40% for dwellings with a total floor area of 200m^2 and over. The hours of use and the internal temperatures are based on eight hours operation daily and the internal set point temperatures are established by the methodology at 23^{o}C for the living area in winter and 15^{o}C for the rest of the dwelling, and 25^{o}C for the living area in winter and 28^{o}C for the rest of the dwelling.

The external walls, roof, and floor of the dwelling are defined by their orientation, area, shading factor, thermal transmittance (U-value), absorptivity, and emissivity. The user can also input the area and U-value for walls to adjoining unconditioned spaces.   The glazed areas are defined by the input of the orientation, area, frame factor, U-value, shading factor, emissivity, solar energy transmittance factor and light transmittance factor.

The internal gains are calculated by the methodology in relation to the lighting, appliances and occupants. The lighting load is apportioned over the year in the ratio of 60% during the cooling season and 40% during the cooling season.

The infiltration rate is either established by doing an air leakage pressure test and inputting the value or by using the algorithm in the software which calculates the infiltration rate on the basis of the user input of the number of flues and vents, the existence of a draught lobby, the number of stories in the building, the proportion of draught stripped windows and of perimeter party walls.

The hot water demand is established by the methodology on the basis of the number of occupants which is calculated in proportion to the total floor area. The user is requested to input the volume of hot water storage, and the storage losses if known.   If solar thermal heating is installed the user inputs the collector area, orientation, tilt angle, zero-loss collector efficiency and the linear heat loss coefficient of the collector.

The heating and cooling systems are defined by the input of the system efficiency and the system fuel. The user also inputs the proportion of energy efficient lighting fixtures, and the power requirements and controls of any auxiliary pumps or fans associated with the heating and cooling systems.   If a photovoltaic system is installed the data input is the peak power, the type of system (whether fixed or tracking), the orientation and tilt angle. For a wind turbine the user inputs the total installed wind turbine capacity. For other alternative energy systems the user inputs the amount of energy delivered by the system of the year, and the type of fuel displaced.

4.2.4. Output from the EPRDM Methodology

The EPRDM is used to generate the Maltese EPC. This certificate does not have alphabetical grading like most other energy certificates but simply displays the numerical value of the primary energy and carbon dioxide emissions per square metre for the property being assessed (see Figure 4.1). The methodology provides considerably more information than is shown on the certificate, and the 'Results' output include the delivered energy, the primary energy, and the carbon dioxide emissions for each of the energy uses included in the certificate, namely the space heating, the cooling, the lighting, the domestic hot water, and any auxiliary energy required for these services, as well as any energy generated by photovoltaic, wind, or other alternative sources of energy. The methodology does not include the facility to generate recommendations for the improvement of the energy performance of the building assessed, and neither does it incorporate any costing data.

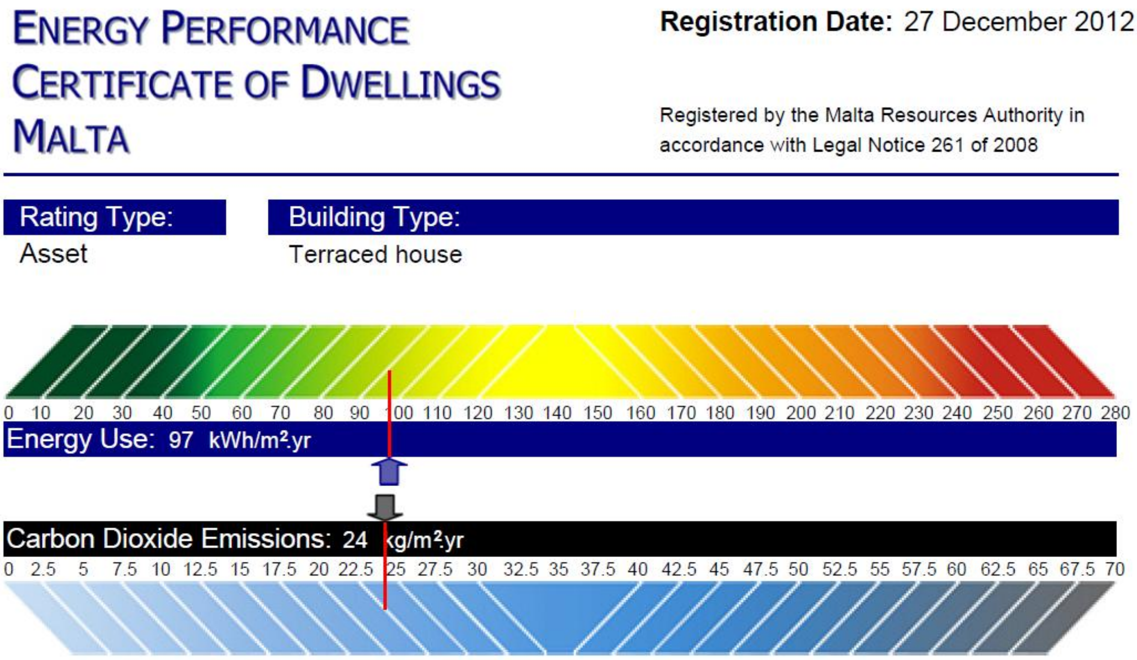

Figure 4.1 Maltese Energy Performance Certificate Rating Scale

4.2.5. CERMA

The official methodology for the energy certification of residential and small commercial buildings in Spain is CALENER-VYP but other methods have been authorised for use after verification. The CERMA (Calificación Energética Residencial Modo Abreviado) software has been developed as a quicker procedure for certification. This procedure involves an hourly simulation over a complete year, modelling the behaviour of the building and the building services in order to determine the CO_2 emissions and the energy certificate value.

The calculation of the energy performance of the building is based on:

- Considering the building as a single thermal zone with a single temperature. This is acceptable for residential applications.
- A pre-simulation (using response factors) of heat transfer through opaque and glazed elements using a constant internal temperature value of 22.5°C for a typical weather year.
- The RTS (Radiant Time Series) method is then used to convert the internal gains inside the thermal zone. This enables the proper distribution of convective and radiant gains inside the building. Convective gains become immediate loads whilst radiant gains impinge on elements such as carpets, furniture, interior walls, ceilings and floors. RTS values in each case (solar radiation, occupancy, lighting) apply to gains reaching radiant elements that are transferred to air, partly becoming part of the immediate radiant gain at that moment and partly transferred later. The RTS values selected are those applicable for buildings with 10% glazing, medium weight construction and no carpeting, on the basis that these conditions are representative for Spanish housing.
- A correction of the heat transferred in each hour throughout the year due to the internal temperature being different from the original assumption of 22.5°C, due to lack of control or variation in the set-point.
- An estimate of the total energy used by the heating and cooling equipment to meet the energy demands, every hour throughout the year, considering both partial loads and operational conditions (indoor/outside temperatures).
- The necessary conversion to CO_2 emissions depending on the type and quantity of fuel/energy using the conversion factors stipulated by the Ministry of Industry, Tourism and Trade of Spain.

Finally the energy label for the building is calculated from the sum of the constituent elements that contribute to the total CO_2 production (heating, cooling and hot water), in accordance with the corresponding index defined by the Royal Decree 47/2007 (Lamas Sivila, 2011).

4.2.6. Input Data for the CERMA methodology

The weather data for the building is taken from a database within the software but the user has to determine the location of the site being assessed. There is also the option to input details of surrounding buildings in order to calculate their shading effect.

The global data for the building consist of the volume and the habitable floor area. The user has the option to define the relative humidity class but the user manual suggests that Class 3 (55%) should be suitable for all residential applications. The number of bedrooms, number of bathrooms, and the kitchen floor area are input in order for the software to calculate the infiltration rate. The user can also select one of three options for the calculation of the effect of thermal bridging in the structure.

The external walls are defined by their orientation, their area, and their thermal transmittance (U-value). Walls adjacent to other buildings can also be defined. The roofs and floors are defined in the same manner. Windows are input using dimensional data, to specify the depth of overhangs and fins, in order for the software to be able to calculate any shading effect from the structure. The thermal transmittance (U-value), the solar factor, and the frame factor are also defined for each window size. The area and number of windows are defined for each orientation. There is an additional routine for specific shading devices in the structure. The types of glass and frames can be selected from a pull-down menu. Different infiltration rates are associated with different window types.

The user also has to input the data for the building services. There are five choices of system available, namely heating and cooling, cooling only, heating only, domestic hot water, and combined domestic hot water and heating. Each system input is associated with the floor area which is supplied by the system. The software provides a selection of options for the heating and cooling equipment and the fuels used. In each case the user is asked to define the size and efficiency of the equipment selected. When a solar thermal system is installed, the user is asked to input the percentage of the domestic hot water requirements that is met by the solar system.

4.2.7. Output from the CERMA methodology

The output from the CERMA methodology provides a rating for the building CO_2 emissions on an A-G scale but also supplies similar ratings for the energy demand for heating and cooling and the CO_2 emissions for each of the heating, cooling and domestic hot water equipment (see Figure 4.2). The software provides detailed data for further analysis, including the monthly energy demand, final energy, primary energy and CO_2 emissions for the heating, cooling and domestic hot water. The software also includes a feature where improvements to the building can be assessed in order to establish what effect these would have on the building's energy rating.

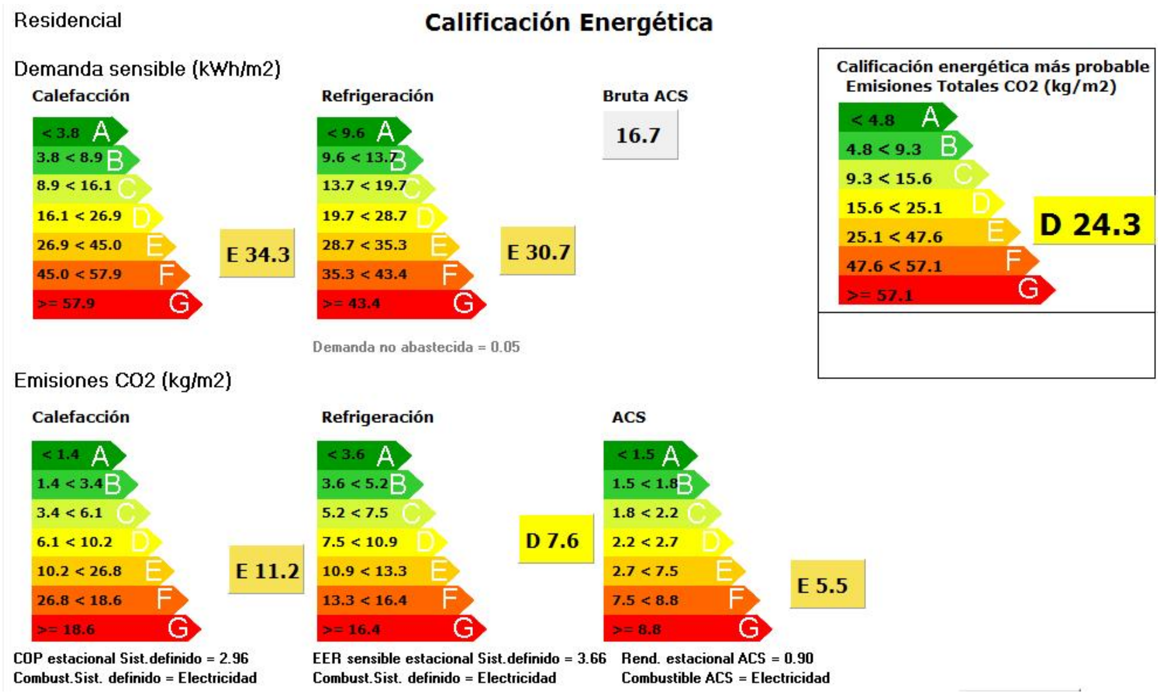

Figure 4.2 Energy Rating Output from the CERMA methodology

4.2.8. DOCET and DOCETpro

DOCET (Diagnosi e Certificazione Energetica di Edifici Residenziali Esistenti) was developed as a tool to assess the energy performance and issue energy certificates for existing residential buildings on the basis of the energy demands for space heating and hot water (Zinzi, et al., 2007). This was further developed into the DOCETpro calculation methodology, based on the Italian standard UNI TS 11300 which is the national implementation of EN ISO 13790. DOCETpro was developed as a national web platform for energy certification (Belussi, et al., 2010).

The building model is defined as a single thermal zone and the building energy need for space heating for each monthly calculation step is determined by subtracting the product of the total heat gains for the heating mode and a dimensionless gain utilisation factor from the total building energy need for heating. The latter is the sum of the building heat transfer losses by conduction and the building heat transfer losses by ventilation. The methodology evaluates the performance of one or more heat generators, including both traditional systems such as boilers as well as non-traditional systems such as thermal solar systems, heat pumps, and micro-generation. The energy calculation considers the energy flow within the building. This is sub-divided into generation, storage, distribution, regulation, and emission to the building. At each stage the procedure determines the efficiency of the sub-system, any auxiliary energy supplied to the sub-system, and any heat recovered by the sub-system.

The calculation of the energy requirements for space heating is based on the following Italian Standards (Raimondo, et al., 2012):

- UNI TS 11300 Part 1 :2008. Energy performance of buildings: Evaluation of the energy need for space heating and cooling.
- UNI TS 11300 Part 2: 2008. Energy performance of buildings: Evaluation of primary energy need and of system efficiencies for space heating and domestic hot water production.
- UNI 10349: 1994. Heating and cooling of buildings – climatic data.
- UNI 10351: 1994: Construction materials: Thermal conductivity and vapour permeability.
- UNI 10355: 1994: Walls and floors: Thermal resistance and method of calculation.
- UNI EN 6946: 2008. Building components and building elements – Thermal resistance and thermal transmittance – Calculation method
- UNI EN 14863:2008. Thermal bridges in building construction – simplified methods and default values
- UNI EN 13786:2008. Thermal performance of building components - Dynamic thermal characteristics - Calculation methods.
- UNI EN 15316-4-3:2007. Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-3 Space heating generation systems, thermal solar systems
- UNI EN 15316-4-6: 2007. Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-6: Heat generation systems, photovoltaic systems.

4.2.9. Input Data for the DOCETpro Calculation Methodology

In order to calculate the energy required for heating the building, it is necessary to input the data relating to the typology and construction of the building, the climatic data, and the data relating to the occupation and use of the building.

The data relating to the typology of the building consist of :

- The internal volume of the conditioned space;
- The area of all the building components;
- The presence of thermal bridges;
- The orientation of all of the building components;
- The shading coefficient of all the glazed components.

The DOCETpro software allows the input of different zones within the building. The data relating to the thermal characteristics of each zone comprise:

- The area and height of the zone;
- The thermal transmittance (U-value) of all components;
- The thermal capacity (C_m) of all the opaque components;
- The area of all the zone components;
- The absorptivity of the opaque components;
- The solar energy transmittance factor for all glazed elements;
- The frame factor for the windows;
- The coefficient of linear thermal transmission for the thermal bridges.

The climatic data are incorporated in the software and the user simply has to select the location of the building for the methodology to apply the appropriate weather conditions. The climatic data consist of the mean monthly outdoor temperature and the total monthly solar irradiation for each orientation.

The data relating to the occupation and use of the building are also incorporated in the software and cannot be altered by the user. This data consists of the indoor temperature (20^{0} C) and the length of the heating season which varies between 3½ months and 6½ months depending in which of the six climatic zones the building is located. The operation of the heating system is assumed to be continuous for the duration of the heating season.

Other parameters that are established by the software are the ventilation rate, which is assumed to be 0.3 air changes per hour in the case of natural ventilation, and the internal gains. The internal gains are calculated through a formula relating to the area of the dwelling with values between 250W for a 60m^2 dwelling to 450W for dwellings greater than 170m^2.

The complete data set for the building is combined with the weather data to calculate space heating and hot water requirements. In order to convert this energy need into primary energy, it is necessary to establish the parameters defining the equipment used to generate and distribute the space heating and hot water. DOCETpro only permits the use of a single heat generator for space heating only or for combined heating and domestic hot water. The methodology considers the efficiency of the heat emitters, the efficiency of the control system, the efficiency of the distribution system, any auxiliary electrical power supplied to the heating system, storage losses, and the efficiency of the heat generator. The DOCETpro includes three options for calculating the equipment efficiency, namely:

- The simplified method which determines the boiler performance according to the installed thermal power, boiler type, chimney height, average operating temperature and whether the boiler has a single-stage or multi-stage burner. All other parameters are predetermined and cannot be altered by the user;
- The method according to the 92/42/CE directive, which calculates the average heating performance on the basis of full load, intermediate load, and no load conditions. The user has to input the relevant boiler data for these three states.
- An analytical method which distinguishes between the energy requirements when the boiler flame is lit and when it is not.

The software also allows the user to define the losses and the efficiency of all the heating sub-systems. When the domestic hot water is not produced by the space heating boiler, the relevant parameters for the domestic hot water generator are also input by the user.

If a solar thermal system is installed, the user needs to input the following data:

- Whether the solar thermal is used for domestic hot water only, or space heating only, or both;
- Details of any pre-heating or supplementary heating;
- Type of collectors, collector area , tilt, and orientation;
- Collector efficiency (default values are suggested by the software);
- Loss in the hydraulic circuit depending on whether it is a direct system (thermo-siphon) or whether heat exchange is required;
- Shading factor;

- Storage tank capacity and location.

If a photovoltaic system is installed on the building it is necessary for the user to input the :

- Area and type of the photovoltaic modules;
- Orientation and tilt angle of the collectors;
- Method of installation on the building.

4.2.10. Output from the DOCETpro methodology

The DOCETpro methodology calculates both the primary and the net energy for space heating, space cooling, and domestic hot water. It calculates the global energy index for the building on the basis of the hot water and space heating only, omitting the cooling. However the methodology generates detailed monthly data outlining not only the monthly heating, cooling and domestic hot water energy requirements, but also indicating the monthly parameters used to calculate these values. Since the building model can be defined as being made up of one or more zones, the energy data can also be output on a zonal basis. The primary energy data report also includes details of any auxiliary energy produced by the building and any energy exported from the building. The basic software does not generate the actual energy certificate, since this is output from an additional module. It does however have the facility to generate a cost benefit analysis for an proposed improvements to the building.

4.2.11. SBEMcy

At the core of the Cyprus Methodology for Assessing the Energy Performance of Buildings (MAEPB), the calculation process compares the calculated primary energy of the proposed building with that of a "reference building". The reference building has :

- The same geometry, orientation and usage as the building being evaluated;
- The same standard operating patterns;
- The same weather data;
- The building fabric, glazing type, air tightness, HVAC and lighting equipment substituted by specified standard default values.

Whilst the MAEPB states that the requirements of the EPBD are most readily achieved by demonstrating that the calculation method complies with the CEN standard umbrella document PG-N37, and in particular EN ISO 13790 *Energy performance of buildings –*

Calculation of energy use for space heating and cooling, it continues to clarify that some necessary parts of the calculation are not dealt with explicitly or completely by these CEN standards or draft prEN standards (Infotrend Innovations & BRE, 2009). The MAEPB follows the monthly heat balance method described by EN ISO 13790, taking dynamic effects into account by the introduction of utilisation factors. The MAEPB is used to calculate primary energy consumption and CO_2 emissions of both the building being evaluated and the reference building.

The MAEPB is based on the following CEN Standards:

- PG-N37 Standards supporting the Energy Performance of Buildings Directive
- EN 15193-1 Energy requirements for lighting – Part 1: Lighting energy estimation
- EN 15217 Methods of expressing energy performance and for energy certification of buildings
- EN 15243 Ventilation for buildings – Calculation of room temperatures and of load and energy for buildings with room conditioning systems
- EN ISO 13786:2005 Review of standards dealing with calculation of heat transmission in buildings – Thermal performance of building components – Dynamic thermal characteristics - Calculation methods
- EN ISO 13789 Review of standards dealing with calculation of heat transmission in buildings – Thermal performance of buildings –
- Transmission and ventilation heat transfer coefficients – Calculation methods.
- EN ISO 13790 Energy performance of buildings – Calculation of energy use for space heating and cooling.
- EN15316-3 Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – part 3 Domestic hot water systems.
- EN 15316-4-3-2007 Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies Part 4-3: Heat generation systems, thermal solar systems.

SBEMcy (Simplified Building Energy Model Cyprus) is the core calculation engine for the implementation of the MAEPB. It uses inputs from the software user and from various databases to calculate a result in terms of the primary energy used by the building and its occupants for space heating and cooling, ventilation, lighting, and hot water. On the basis of these inputs the SBEM calculation engine:

1. Calculates lighting energy requirements on a standardised basis, taking into account the glazed area, shading, light sources, and lighting control systems;
2. Establishes the standardised heat and moisture gains in each zone, from the activity database
3. Calculates the heat energy flows between each zone and the external environment, wherever applicable, using CEN standard algorithms;
4. Applies the appropriate HVAC system efficiencies to determine the delivered energy requirements to maintain thermal conditions;
5. Aggregates the delivered energy by source, and converts it into primary energy;
6. Determines, on the same basis, the primary energy of a reference building with the same geometry, usage, heat gains, temperature, lighting, ventilation conditions and weather but using the standard specified reference building component construction, HVAC and lighting systems;
7. Determines the carbon emissions for both the building being evaluated and the reference building.

SBEMcy is the authorised calculation engine for the energy rating of both domestic and non-domestic buildings in Cyprus. The software also generates the reference building and performs the comparison between the actual and the reference building on the basis of the primary energy calculation for the two buildings. The SBEMcy user guide also defines the rules for zoning the building consistently (Infotrend Innovations & BRE, 2009). SBEMcy also generates recommendations for improving the energy performance of the building and its systems, but the MAEPB strongly advocates that more detailed assessments be carried out before making final decisions on the implementation of any of these recommendations.

4.2.12. Input Data for the SBEMcy calculation methodology

The order of data entry for SBEMcy is displayed in Figure 4.3. The software includes default values for various parameters. However the user manual recommends that all default values be checked by the user since the use of the default values will result in a poor energy performance for the building being assessed.

The construction types are used to define the walls, roofs, floors and doors. The software allows these to be selected from a library or defined by the user. These are specified through the entering of the thermal transmittance (U-value) and thermal capacity (C_m). For user-defined glazing types, the parameters that need to be entered are the thermal transmittance, the solar transmittance and the light transmittance.

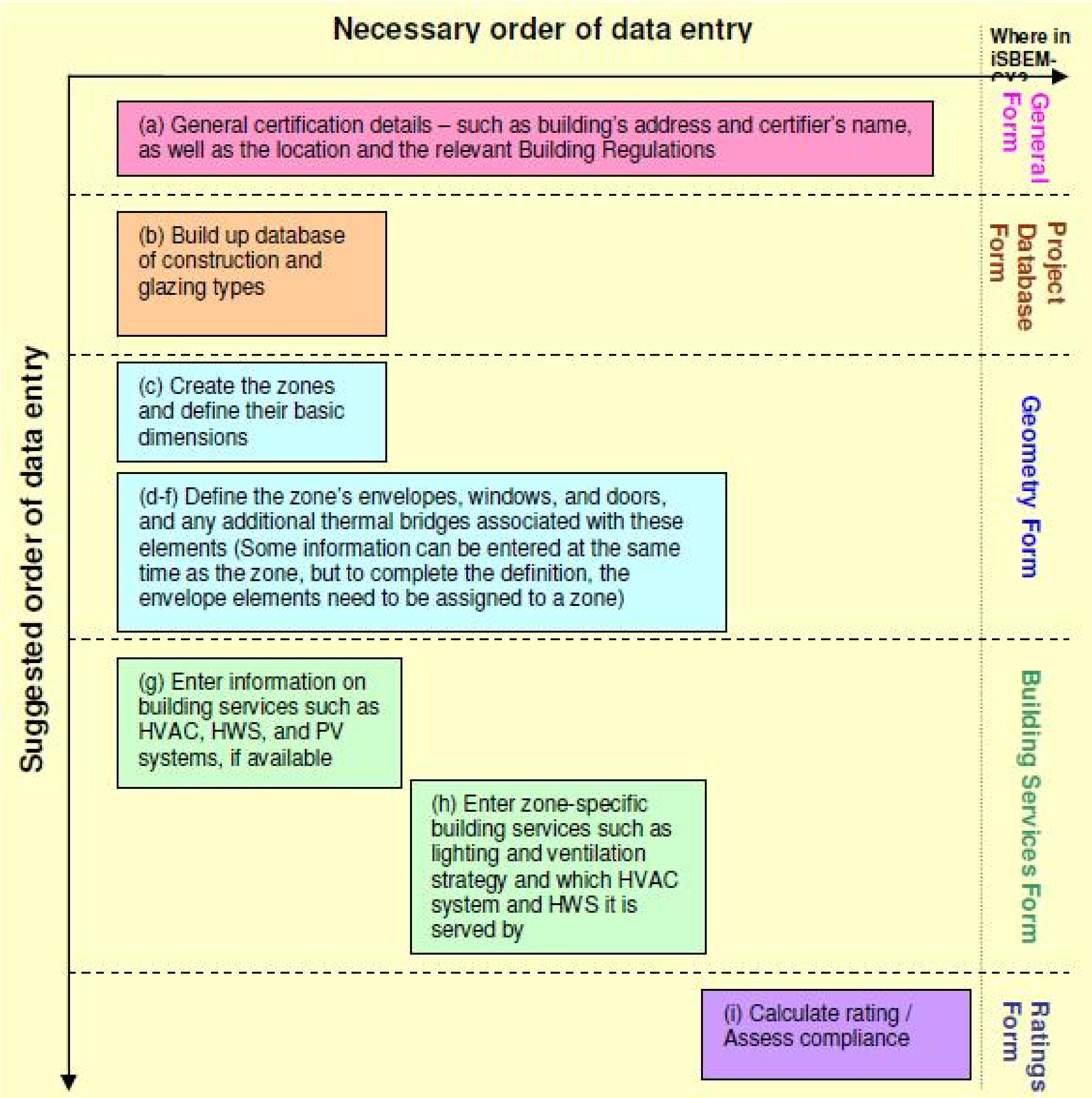

Figure 4.3 Order of data entry for SBEMcy (Infotrend Innovations & BRE, 2008)

The geometry of the building is defined by the total floor area and the zone height. The user then inputs the data for each zone, consisting of the zone area, the opaque elements, the windows, and the doors. The air permeability at 50 Pa can be input globally for the whole building, or for each zone, but if this data is not available, the user manual specifies that a default value of 15m^3/h/m^2 can be used for buildings with less than 500m^2 total useful floor area. However the software default value is 25m^3/h/m^2. The thermal bridges can also be defined by the user globally or for each zone.

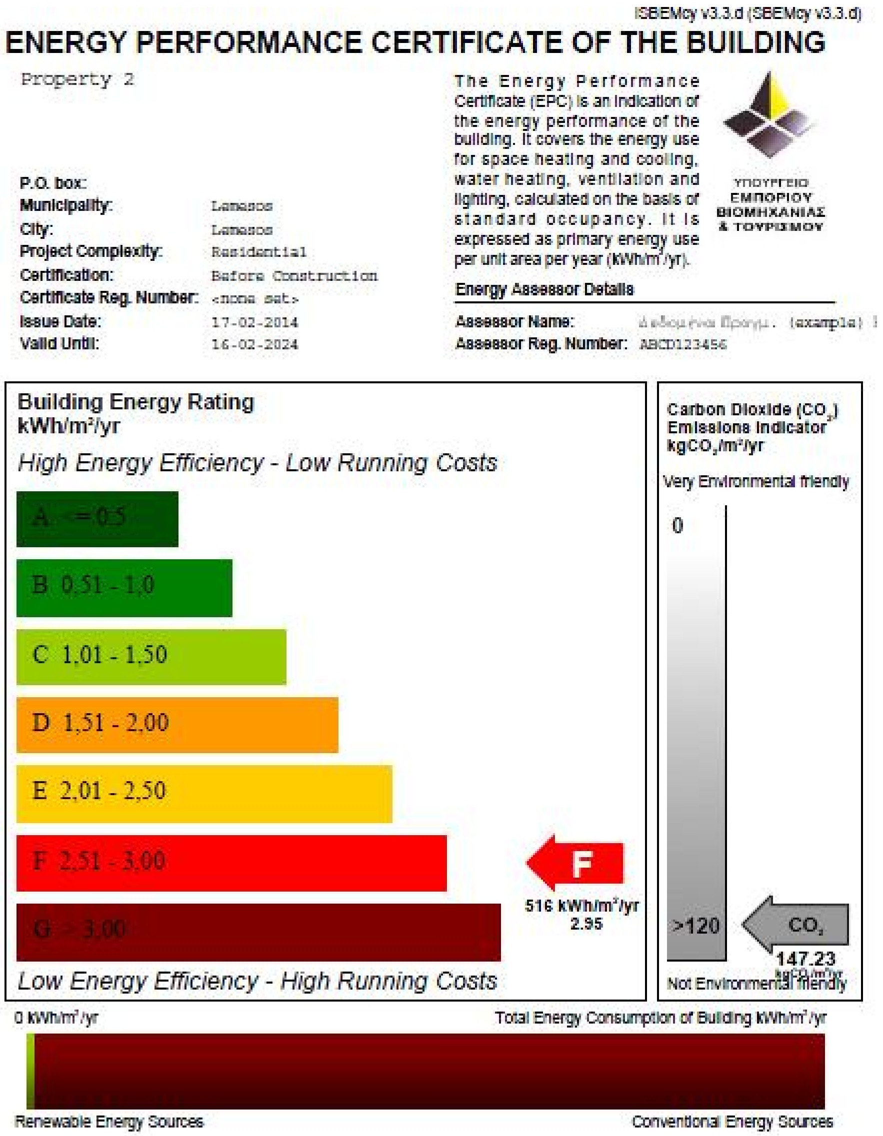

Figure 4.4 EPC generated by SBEMcy methodology

The building services also need to be allocated to each zone. These include the HVAC System, the DHW system, solar thermal system, photovoltaic system, wind generator, and combined heat and power. The zone specific building services also need to be defined and these consist of the lighting and lighting controls, ventilation and exhaust systems.

The HVAC systems have to be defined by the user. This is done by selecting the system type from a pull down menu, defining the fuel, and inputting the seasonal efficiency. This procedure is applicable for the heating, cooling, and domestic hot water systems. For the thermal and photovoltaic solar systems, the user has to input the area of the panels, the orientation, and the inclination. The type of photovoltaic panel must also be selected from a pull-down menu.

The activity type has to be specified for each zone. The software incorporates an activity database from which different types of activity may be selected. The activity parameters include temperature set points, heat gains from people, lighting and equipment, and fresh air requirements.

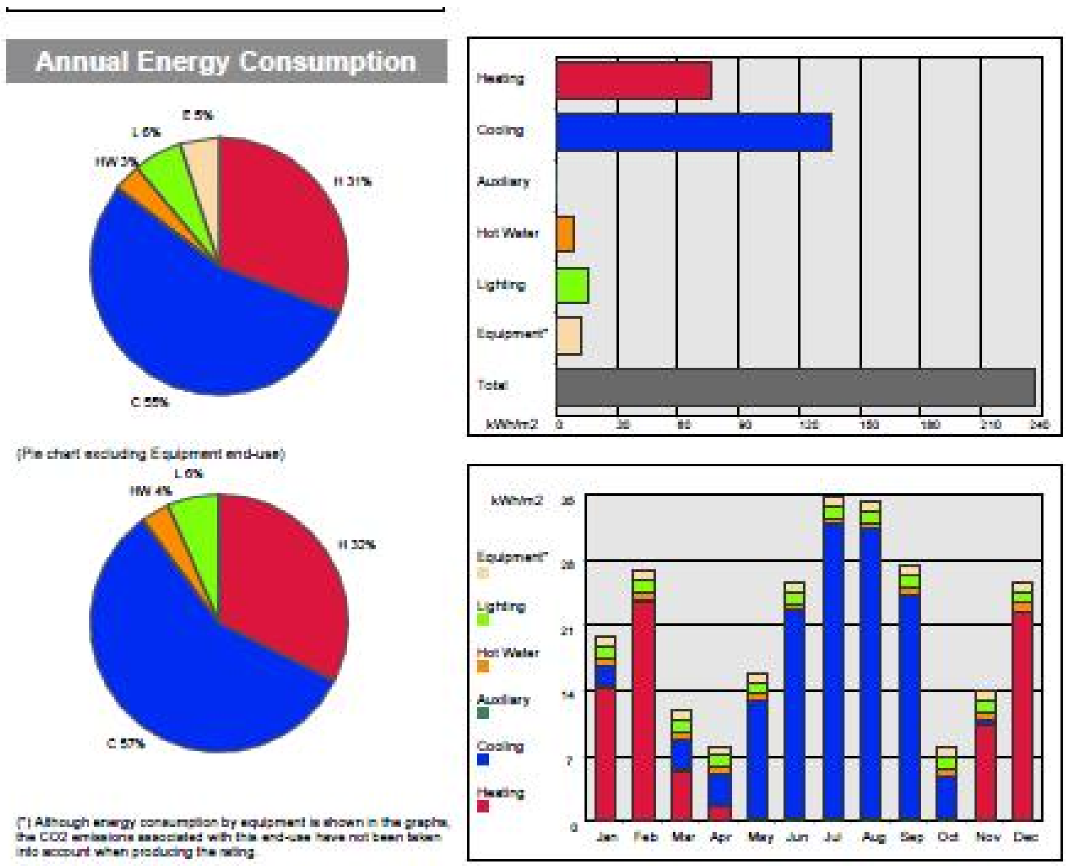

Figure 4.5 Output from the SBEMcy methodology

4.2.13. Output from the SBEMcy methodology

The SBEMcy methodology generates the EPC for the building and this defines the energy performance in terms of an alphabetic rating for the building (see Figure 4.4). This differs from the other methodologies in that the building is rated against its performance compared to a reference building, and not in absolute terms. The certificate does however indicate the primary energy and CO_2 emissions of the certified building. The SBEMcy methodology produces a number of other outputs with a basic pie chart accessible directly from the software (see Figure 4.5). This displays the heating, cooling, domestic hot water, lighting, and equipment loads on a monthly basis. The equipment loads are for reference only as they do not constitute part of the certified energy requirements but are used to produce the internal loads generated within the building. Detailed output from the SBEM methodology is also available in the form of data files which can be accessed through MSExcel or similar spreadsheet software and these display the monthly calculation procedures used to generate the EPC. Since the building is input on a zonal basis, the detailed output is also available zone by zone. The SBEMcy methodology also generates a number of standard recommendations for improving the energy performance of the building and the assessor is then expected to tailor this standard list to the actual building being certified.

4.2.14. Calculation procedures

Whilst the basis for all the methodologies is similar, in that they are all designed to produce an estimate of the annual primary energy consumption of a residential building on the basis of a standard weather year and assuming a typical usage pattern, following the guidelines established by EN ISO 13790, the final definition of these calculation methodologies exhibits considerable differences.

Further analysis of these differences is presented in more detail in Chapter 8, and Table 4.4 presents an overview of the main differences inherent in the methodologies. It is clear that these differences can be attributed to either the assumptions made in defining the typical activity within the building, or the interpretation of the guidelines in EN ISO 13790.

Methodology	EPRDM Malta	CERMA Spain	DOCETpro Italy	SBEMcy Cyprus
Basis	EN13790 simplified monthly method	Simplified hourly simulation	EN13790 simplified monthly method	EN13790 simplified monthly method
Status	Unique national methodology	Compliant with national methodology and approved	Compliant with national methodology and approved	Unique national methodology
Climate data	Single zone Single weather data set	Weather data by city	Six climatic zones Weather data by city	Four climatic zones Weather data by city
Building definition	Single zone	Single zone	Multiple zone	Multiple zone
Internal temperatures				
Winter	Between 18.2 and 19.8°C depending on property size	Between 17 and 20°C depending on time of day	20°C	Defined by activity in each zone with 21°C in lounge and 18°C in all other areas
Summer	Between 26.2 and 26.8°C depending on property size	Between 25 and 27°C depending on time of day with some free running	26°C	Defined by activity in each zone with 25°C in all areas except for bathroom at 27°C
Length of heating and cooling season	6 months / 6 months	6 months / 6 months	Heating between 3.5 months and 7.5 months depending on climate zone	Not defined but possibility for year round operation of both systems
No of hours property used per day	8 weekdays 8 weekends	8 weekdays 24 weekends		Defined on a zone by zone basis between 5 and 14
No of hours heating/cooling system used per day	8 weekdays 8 weekends	8 weekdays 24 weekends	24 weekdays 24 weekends	Defined on a zone by zone basis between 5 and 14
Intermittency factor		Handled by hourly simulation		
Ventilation	Result of pressurisation test or calculated by algorithm typically 0.5 to 0.8 ach	In summer June to Sept 4ach between 24:00 and 08:00 due to opening of windows. Outside this period calculated by algorithm with default 1 ach	0.3 ach	8m^3/hm^2 which is about 2.6 ach
Internal loads	Lighting between 0.2 and 1 W/m^2	Lighting 2 W/m^2		Lighting 7 W/m^2
	Appliances 1.5 W/m^2	Appliances 2 W/m^2		Appliances 5 W/m^2
	Metabolic 1.2 W/m^2	Metabolic 2 W/m^2 sensible and 1.38 W/m^2 latent		Metabolic 5 W/m^2
	Total between 2.9 and 3.9 W/m^2	Total 6 W/m^2 sensible	Total between 4.6 for 45m^2 and 2.65 W/m^2 for 170m^2	Total 17 W/m^2
No of occupants	1 per 60m^2 with minimum 2	1 per 33.3m^2		
Domestic hot water consumption	70l per occupant per day	Between 22 and 30l per occupant per day	Between 1.3 and 1.8l per m^2 per day	
Temperature rise	From 18 to 60°C		From 15 to 40°C	From 10 to 60°C
Specific heat capacity of structure	Default Cm of 370000 or defined by user	All structures considered as middleweight	Default Cm of 165 kJ/m^{2}K or defined by user	Cm 141 kJ/m^{2}K for ext walls Cm 121 kJ/m2K for int walls Cm 240 kJ/m2K for roofs
Time constant				
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Table 4.4 Comparative analysis of methodologies

4.3. Building Performance Dynamic Simulation

During the development of the research technique, it was established that one of the methods to be used for testing of the certification methodologies was that of comparing the results of the methodology software to the known analytical solution presented by dynamic simulation.

Whilst the use of computer simulation of building performance is now widespread, there are several different applications for which programs have been developed. Building simulation programs could be broadly grouped into two categories, design tools, which can also include compliance checking of prescriptive building standards, and dynamic (or detailed) simulation programs, which incorporate sophisticated computational techniques to account for the dynamic interactions amongst the building, climate, and systems (Hong, et al., 2000). There have been a number of studies of advanced thermal calculation programs in order to examine the deviations produced by different computer models (Mansson, 1998). Crawley et al (2008) reviewed twenty major building energy simulation programs and classified IES Virtual Environment (IES VE) as providing "an environment for the detailed evaluation of building and system designs, allowing them to be optimized with regard to comfort criteria and energy use". In a review of design simulation tools for net-zero-energy buildings Attia and De Herde (2011) attributed maximum scores for accuracy and usability to IES VE.

4.3.1. The IES Virtual Environment

The IES Virtual Environment (VE) is an integrated system that generates all of its building simulations from a central building model. The software provides many tools such as thermal analysis, value engineering, cost planning, life-cycle analysis, airflow analysis, lighting, and occupant safety. The Thermal Applications Category of the IES VE is a set of software tools for the analysis of building energy performance.

Templates grouping together thermal input variables are used for the data requirements of the thermal applications. Templates can be assigned collectively to sets of rooms, building elements or other objects. The Construction Templates store descriptions of constructions for the various categories of building element (walls, floors, windows and so on). The Room Thermal Templates store sets of internal gains, air exchanges, plant operation parameters and zoning information associated with rooms of a given type.

The location data includes the latitude and longitude of the site, together with information about the local time zone and any summertime clock adjustment. The weather data covers the requirements of both the heat loss and heat gains calculations and the thermal simulation program.

For thermal simulation the extensive weather data is stored on a simulation weather file. This file contains the values of the following weather variables measured at hourly intervals over a year: dry-bulb temperature, wet-bulb temperature, direct beam solar radiation, diffuse solar radiation, wind speed, wind direction, and cloud cover.

Profiles provide the means for describing the time variation of input variables. They are used to specify how quantities such as internal gains, ventilation rates and temperature set-points vary over the hours of the day, the days of the week and the months of the year.

Information on heat gains from occupants, lights and equipment is required as input to heat gain calculations and thermal simulation. Heat gains may be sensible or latent, and sensible gains are characterised by a radiant fraction.

Infiltration and ventilation rates for rooms are specified by assigning them a maximum value and a profile. Ventilation rates can represent either mechanical or natural ventilation.

Where rooms are conditioned by heating and cooling systems the characteristics of these systems must be specified. The specifications for room control include set-points, heating and cooling capacities and radiant fractions, together with profiles defining periods of plant operation.

ApacheSim is the dynamic thermal simulation within the IES VE suite of programs. It is based on first-principles mathematical modelling of the heat transfer processes occurring in and around a building. ApacheSim qualifies as a Dynamic Model in the CIBSE system of model classification.

The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimised with regard to comfort criteria and energy use.

Within ApacheSim, conduction, convection and radiation heat transfer processes for each element of the building fabric are individually modelled and integrated with models of room heat gains, air exchanges and plant. The simulation is driven by real weather data and may cover any period from a day to a year. The time-evolution of the building's thermal conditions is traced at intervals as small as one minute.

Results output by the simulation include comfort statistics, energy consumption data, CO_2 emission data, and room load statistics, together with detailed performance measures including hourly room temperatures, surface temperatures, plant loads, internal gains and air exchanges.

The simulation engine has the following features:

- Finite difference dynamic heat conduction modelling using the 'hopscotch' method for explicit implicit time-stepping.
- Dynamically calculated surface convection characteristics
- Air temperature, surface temperature and room humidity modelling
- Advanced solar and long-wave radiation exchange models
- External solar shading
- Solar tracking through an arbitrary number of transparent internal partitions
- Angle-dependent glazing transmission, reflection and absorption characteristics
- Accounting for the radiant/convective characteristics of internal gains and plant heat inputs
- Simultaneous solution of sensible and latent heat balance equations for the whole building

4.4. Summary

This chapter presents an overview of the quasi-steady-state model proposed by EN ISO 13790 and introduces the four case study methodologies, namely EPRDM, CERMA, DOCETpro and SBEMcy. The IES VE dynamic simulation software tool used for the analytic verification of the certification methodologies is also introduced. Chapter 5 presents the results of the comparison between the application of the four case study methodologies to the four test case properties.

Chapter 5. A Comparative Analysis of the Calculation Methodologies

5.1. Introduction

The aim of this chapter is to analyse the results obtained from applying the different certification methodologies to a small group of test case properties. This is the comparative testing (Judkoff, 1998) of the software programs applying the methodologies. The following is an overview of the contents of this chapter:

- Description of the test case properties;
- Presentation of the climatic similarities between the different locations selected for the comparative analysis;
- Outcome of the application of the methodologies to the test case properties;
- Comparison and analysis of the results.

5.2. The test case properties

In order to be able to accurately assess the energy performance of a building, it is essential to obtain adequate measured data from the building, of sufficient accuracy to justify the purpose of the assessment. Although energy certification defines the energy performance of a building under a standardised set of conditions, for the purpose of assessing the effectiveness of the EPC energy rating, the measurement system generating data from the building has to be suitable to reflect the operation of the building in the real world. The energy performance of a building is determined by three groups of parameters: the building envelope and the technical systems, the climate, and the occupants. The selection of the test case properties was established on the basis that these properties had to fall within the broad criteria of geographical location (southern Europe) and typical residential typology, with the additional essential criterion of accessibility for data collection and monitoring. The following four test cases were chosen to observe the actual energy performance of these residential properties as a means of empirical validation of the certification methodologies.

5.2.1. Test Case 1 (TC1): St. Vincent Street, Sliema, Malta

This is a second floor apartment in a block of four in a residential area in Sliema, Malta. The block is terraced and therefore only the west facing façade and the rear wall are exposed. The net floor area of the apartment is approximately 108 m^2. The main bedroom and the main living area are air- conditioned, and the main unit in the living area is a heat pump. The apartment walls are in the local limestone with no insulation and the windows are single glazed with aluminium frames. There is natural ventilation throughout the property, with trickle vents in every room. The only energy input to the apartment is the mains electrical supply. There are no alternative energy installations. The block was constructed in the late 1960s but the apartments have been refurbished on an individual basis by the residents. This apartment is occupied on a twenty four hour basis, seven days a week, by a single resident, a pensioner.

Figure 5.1 Test Case 1 Flat 2 St Vincent Street Sliema Malta

5.2.2. Test Case 2(TC2): Goldfinch Street, Kappara, Malta

This is a semi-detached villa in a residential area in Kappara, Malta. The property has a net floor area of 237m^2 over two floors with an overlying washroom on the third floor. This does not include a separate garage. The entire property is air-conditioned by a variable refrigerant flow (VRF) inverter type heat pump system. The walls are uninsulated concrete block and limestone and there is a flat reinforced concrete roof. The property was refurbished in 2005 and double glazing and roof insulation were installed. There is natural ventilation throughout the property with trickle vents. Gas is used for cooking and there is a wood fire installed as a design feature, but the main energy input to the property is the mains electrical supply. A solar water heating system with electrical back-up is installed on the roof. The property is inhabited by a three adults and a teenager, so occupancy is intermittent and variable throughout the day, seven days a week.

Figure 5.2 Test Case 2 24 Goldfinch Street Kappara Malta

5.2.3. Test Case 3(TC3): Peg Street, Swieqi, Malta

This is a semi-detached villa in a residential area in Swieqi, Malta. The property has a net floor area of 210 m^2 over two floors with an overlying washroom on the third floor. This does not include the separate garage. The three bedrooms and the main living area are air-conditioned by individual split type heat pump units. The walls are uninsulated concrete block and limestone and the flat reinforced concrete roof is also uninsulated. Trickle vents in every room provide natural ventilation when the single glazed metal framed windows are closed. The property was built in the 1970s and refurbished approximately 15 years ago. The only energy input to the property is the mains electrical supply. There are no alternative energy installations. The property is inhabited by two adults and three children, which implies an intermittent occupancy, varying throughout all seven days of the week.

Figure 5.3 Test Case3 Peg Street Swieqi Malta

5.2.4. Test Case 4 (TC4): Cyprus.

This is a fully detached villa constructed to an energy efficient design in 2008. The property has a net floor area of 238m^2 over two floors excluding the adjacent garage. Air-conditioning and heating is provided by inverter type split units. A gas boiler was installed for heating and hot water after the monitoring period. A small photovoltaic installation, consisting of 2 x 600W panels, provides a source of alternative energy. The walls, roof and windows are well insulated. The property is inhabited by two adults and two children. This implies that occupancy is variable over the seven days of the week.

Figure 5.4 Test Case 4 Dokimi Cyprus

5.3. The locations and climate data

In order to perform an effective comparison of the case study methodologies, it is important to ensure that there are minimal variations between the test case data input to each certification methodology. The three broad categories of input data are the building and systems data, the weather data, and the data relating to the occupants. Since the same test cases are being used for each of the four methodologies, the building and systems data should not have any variances. The data relating to the occupants form an integral part of the methodologies and the effect of the assumptions made in connection with this data set will be considered in the comparison and analysis of the results. The weather data is also an integral part of the methodologies but three out of the four methodologies offer the option to select the climate or climate zone within the country, whilst the fourth, Malta, does not have this option. In order to minimise the potential effect of differences in the ambient conditions, the zones were selected for similar conditions. A comparison of the chosen weather data is shown in Table 5.1 and Table 5.2.

Methodology State Location	*EPRDM* *Malta* *Malta*	*DOCETpro* *Italy* *Agrigento*	*CERMA* *Spain* *Almeria*	*SBEMcy* *Cyprus* *Larnaca*
Month	Average Monthly Temperatures			
Jan	12.20	10.40	12.68	10.25
Feb	12.40	10.80	13.32	8.42
Mar	13.40	12.70	14.33	14.00
Apr	15.50	15.60	15.88	16.72
May	19.10	19.40	18.71	19.84
Jun	23.00	24.10	20.84	21.13
Jul	25.90	26.90	24.29	26.71
Aug	26.30	26.50	24.49	26.41
Sep	24.10	24.00	21.69	23.81
Oct	20.70	19.90	19.89	18.65
Nov	17.00	15.90	15.74	14.19
Dec	13.80	12.20	13.36	10.38
AVERAGE	18.62	18.20	17.94	17.54

Table 5.1 Temperature data for test case properties for case study methodologies

Methodology	*EPRDM*	*DOCETpro*	*CERMA*	*SBEMcy*
State	*Malta*	*Italy*	*Spain*	*Cyprus*
Location	*Malta*	*Agrigento*	*Almeria*	*Larnaca*
Month	Horizontal Irradiation MJ/m^2			
Jan	9.47	8.80	9.46	8.25
Feb	12.92	12.50	18.12	10.58
Mar	18.00	16.90	21.31	17.7
Apr	21.42	22.20	27.12	20.71
May	26.42	26.90	31.61	27.24
Jun	28.04	29.50	34.09	29.74
Jul	28.51	29.60	34.33	28.15
Aug	25.09	27.00	30.93	25.22
Sep	20.23	20.90	25.07	21.06
Oct	14.76	14.60	18.97	15.94
Nov	10.98	10.10	14.32	11.15
Dec	8.35	8.20	11.54	6.52
TOTAL	224.21	227.20	276.86	222.26

Table 5.2 Solar radiation data for test case properties for case study methodologies

5.4. Data collection and data entry

Prior to the application of the certification methodologies to the test cases, it was necessary to collect the relevant data defining the building envelope and technical systems. The climate data and the parameters relating to occupancy are defined by the methodologies. In each of the four test cases the data was collected from plans and from site visits to the property. The main parameters used to define the building envelope and technical systems are presented in tabular format in Appendices 2A to 2D.

5.5. Output from the methodology case studies

The data collected was input to the four case study certification methodologies in accordance with the procedure defined to generate an energy performance certificate. Although the recommended metric for the EPC is either primary energy (energy which has not been submitted to any conversion process) or $kgCO_2$ per square metre of the property, for the purposes of this analysis the delivered energy per square metre was chosen as the comparative metric. Delivered energy is defined as the energy supplied to the technical building systems through the system boundary to satisfy the heating, cooling and hot water demand of the building (CEN, 2008). The basis for the selection of delivered energy as a comparative metric was in order to eliminate the variations that would have been introduced by the different national conversion factors between primary energy and delivered energy.

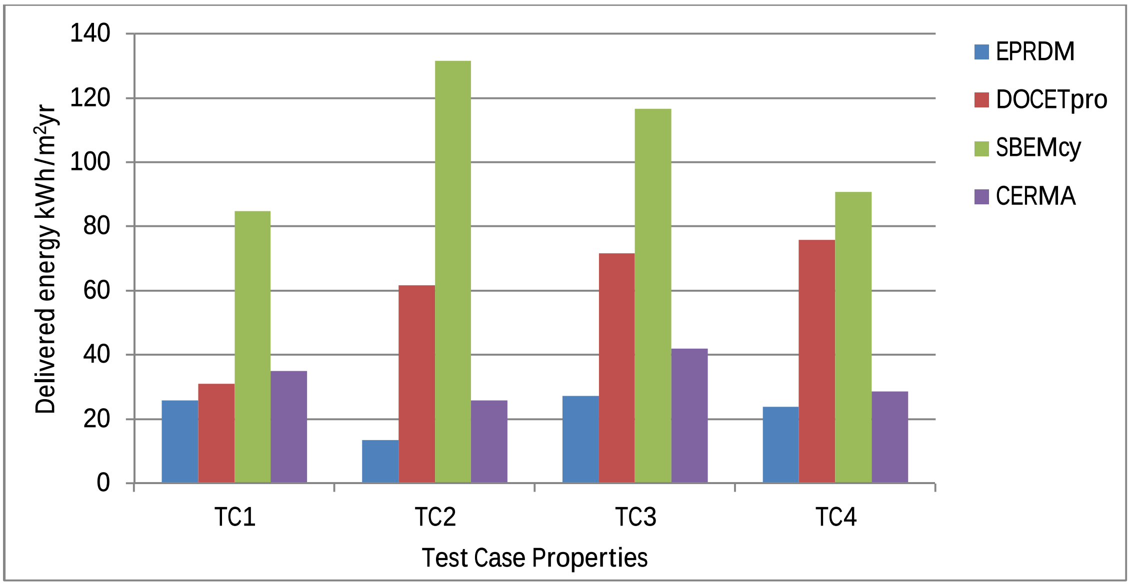

Figure 5.5 Delivered energy for space heating, space cooling, and domestic hot water calculated by national EPC certification methodology.

Three out of the four case study methodologies (EPRDM, SBEMcy, and CERMA) include the delivered energy within their standard output, but DOCETpro did not include the delivered energy for cooling, nor did it include the possibility of calculating the delivered energy for heating with a heat pump installation. For the case of DOCETpro the heating load and cooling load for the building were used to generate the delivered energy using the same procedure as was incorporated in the other three methodologies, namely using the seasonal coefficient of performance of the heating and cooling equipment to calculate the delivered energy on the basis of the calculated heating and cooling load. The considerable variation between the outputs of the four methodologies can be seen in equipment to . In the first test case there is some agreement between three of the methodologies, but in the second and third test cases there is hardly any agreement whatsoever, whilst in the fourth example the results appear to be split into two groups. It is appropriate to reiterate that this is the output obtained by inputting the same test case property four times into four different methodologies with very similar climate data.

In order to identify whether any specific energy use was responsible for the variation, the delivered energy was subdivided into space heating, space cooling and domestic hot water, and these results are displayed graphically in Figures 5.2, 5.3, and 5.4.

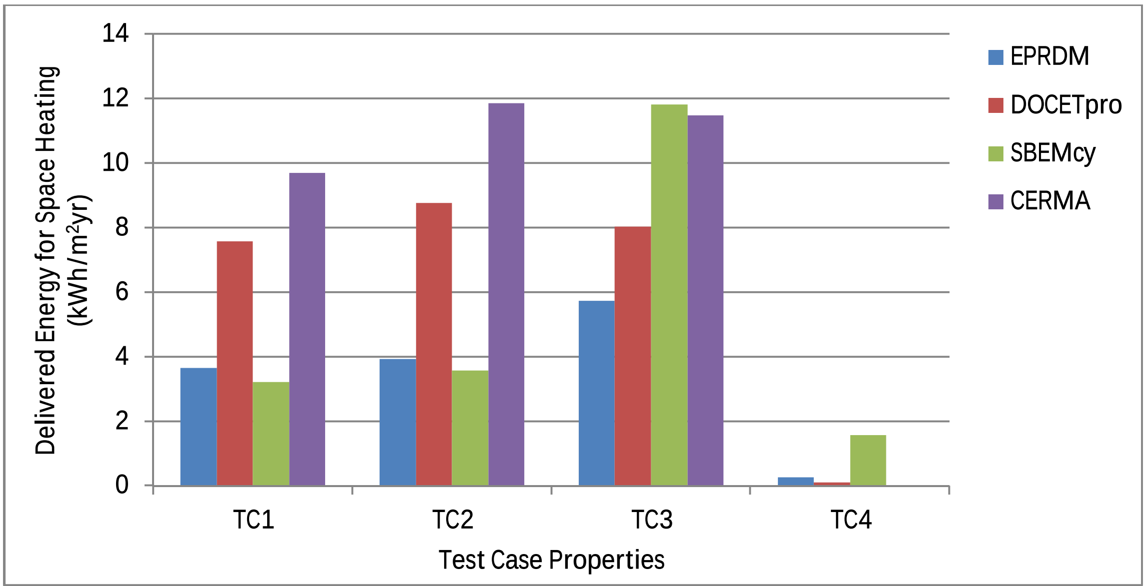

Figure 5.6 Delivered energy for space heating calculated by national EPC certification methodology.

Figure 5.6 demonstrates that the range of values for the specific delivered energy for space heating for the test case properties is much less that the range of values for space cooling displayed in Figure 5.7. Whilst there is considerable variance between the certification methodologies for the different test case properties, the difference between the highest and lowest values is limited to the order of three.

The comparative values for the delivered energy for space cooling (Figure 5.7) demonstrate that the range of values produced by the DOCETpro methodology is generally of the order of between forty to sixty times as much as those calculated using the EPRDM and CERMA methodologies, with the exception of the terraced apartment, TCI, where the values for the specific delivered energy for space cooling derived from DOCETpro are of the same order as those obtained from the EPRDM and CERMA methodologies. In the case of the SBEMcy methodology, the specific delivered energy for space cooling for the terraced apartment TC1 is fifty times higher than the values calculated by the other three methodologies, whilst for the other three test cases, the specific delivered energy for space cooling is between seventy five and one hundred and twenty times the values calculated by EPRDM and CERMA

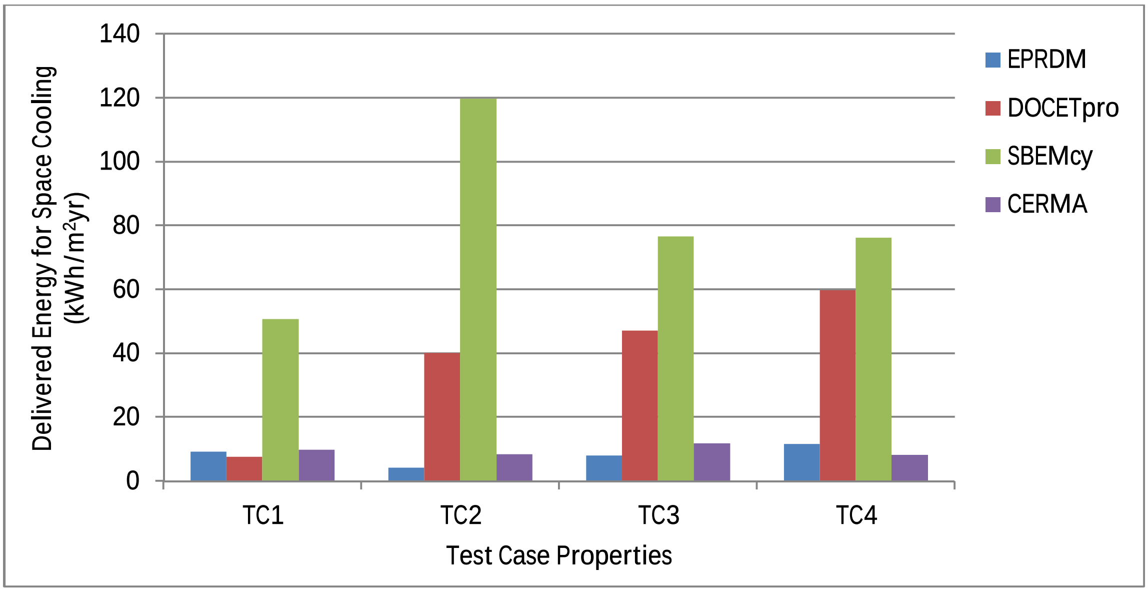

Figure 5.7 Delivered energy for space cooling calculated by national EPC certification methodology.

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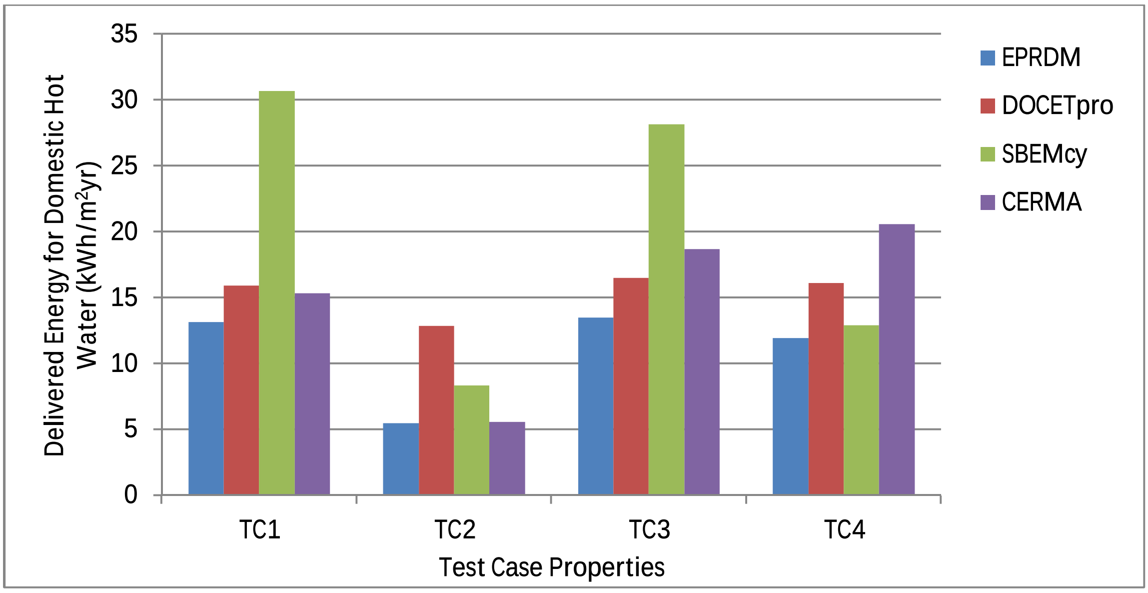


Figure 5.8 Delivered energy for domestic hot water calculated by national EPC certification methodology.

Again there is considerable variation, even, unexpectedly, in the case of domestic hot water where the relationship between hot water demand and delivered energy is often assumed to be similar between regions with the same climate and same standard of living. In the test cases TC1 and, TC3, where there is no solar thermal installation, it can be seen in Figure 5.8 that the delivered energy for domestic hot water is comparable when calculated using the EPRDM, DOCETpro and CERMA methodologies but is practically twice as high when calculated using the SBEMpro methodology. In TC2, where there is a solar thermal installation for domestic hot water, the methodologies also appear to concur in that the property has reduced domestic hot water energy requirements. However the effect of the small solar thermal installation in TC2 is negligible according to the DOCETpro methodology. For the test case TC4, all methodologies show reasonable concurrence.

Whilst the graphical depiction of the delivered energy to the test case properties for space heating, cooling, and domestic hot water appears to indicate the relationship between the different methodologies to be quite tenuous, statistical analysis of the data identifies the space cooling calculation as the primary cause of the large variance. The standard deviation for the total delivered energy for the four test cases is of the order of 33.2. The standard deviation for the space heating calculation is 2.3, and for domestic hot water the value rises to 4.7, but the standard deviation for the cooling energy calculation is 30.6. In order to obtain a better understanding of the extent of the variance, the comparison of the calculated energy values was carried out on a monthly basis.

Figure 5.9 shows the comparison of the monthly space heating energy demand for each of the four test case properties using the four certification methodologies. As predicted, the correlation between the four methodologies is quite reasonable for the space heating energy demand calculation, with the duration of the heating season and the magnitude of the monthly heating demand corresponding well between the four cases. The space heating load for TC2 and TC3 is similar, as these properties are both semi-detached houses of similar typology and dimensions, whilst the space heating load of TC1 is significantly less, since this property is a terraced mid-floor apartment which is inherently more energy efficient due to its compact dimensions and reduction in the extent of exposed surfaces for heat transfer. Whilst the configuration of TC4 should be the least energy efficient, since this is a detached property with the largest quantity of exposed areas for heat transfer, the well-insulated building elements result in the lowest calculated values for space heating energy demand out of the four test cases, with the monthly values approaching and improving upon the equivalent values for the terraced apartment TC1.

Figure 5.10 compares the monthly space cooling energy demand for each of the four test case properties. The first observation is that the duration of the cooling season varies considerably, with DOCETpro and SBEMcy displaying a cooling demand practically all the year round, whilst EPRDM and CERMA limit the cooling season between April/May and Oct/Nov. The magnitude of the cooling energy delivered to the property also displays substantial variations, with SBEMcy and DOCETpro producing values for the delivered energy for cooling of the order of between two to five times as much as the values calculated by EPRDM and CERMA. Referring back to Figures 5.2 and 5.3, it is pertinent to note that the EPRDM and CERMA methodologies estimate the energy for space heating and space cooling to be approximately of the same order on an annual basis, whilst the SBEMcy and DOCETpro methodologies suggest that the energy delivered for space cooling dominates the energy requirements of the test case properties and is approximately five to ten times more than the energy delivered for space heating. This is with the exception of the terraced apartment TC1, where DOCETpro also suggests that the space heating and space cooling delivered energy are of the same order.

Figure 5.9 Energy Demand for Space Heating in the 4 Test Cases compared on a monthly basis

The domestic hot water energy comparison in Figure 5.7 generally shows good agreement between the different methodologies for the calculation of the energy delivered for water heating, with the following minor variations. The EPRDM methodology calculates a reduction in energy delivered for water heating during the summer months whilst the other three present a relatively constant value for delivered energy for hot water on a monthly basis. The DOCETpro methodology displays a minimal reduction in delivered energy between TC2 and TC3, although TC2 has solar water heating whilst TC3 does not. The SBEMcy methodology results in a value for delivered energy for domestic hot water for TC3 (without solar water heating) that is considerably higher than the other three methodologies.

To conclude, the monthly analysis of the delivered energy for space heating, space cooling, and domestic hot water, show much better agreement between the methodologies for space heating and domestic hot water, although there are clear variations in specific circumstances for some of the test case properties. In the case of the delivered energy for space cooling, there is good agreement between two methodologies, EPRDM and CERMA, but a very pronounced difference between the results from these two methodologies and the other two, DOCETpro and SBEMcy.

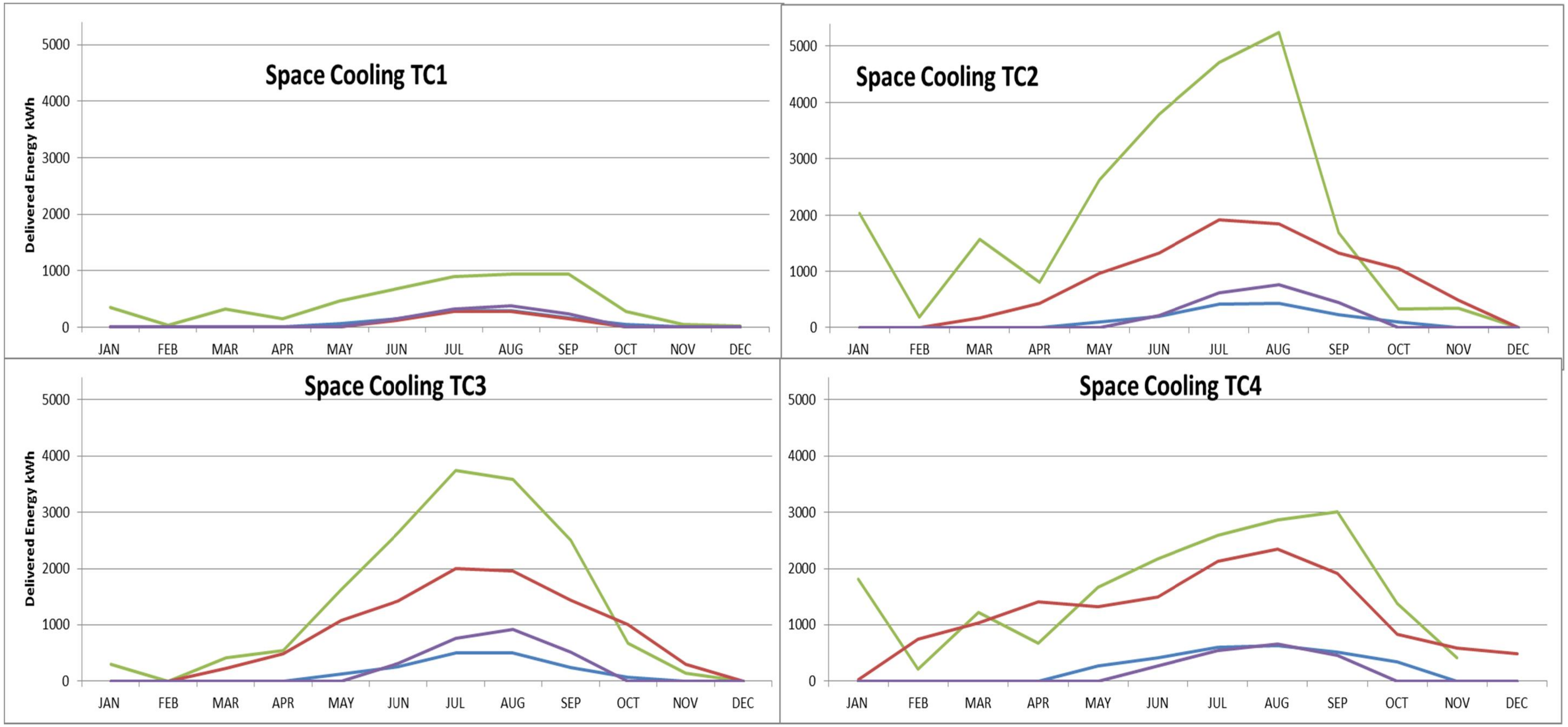


Figure 5.10 Energy Demand for Space Cooling in the 4 Test Cases compared on a monthly basis

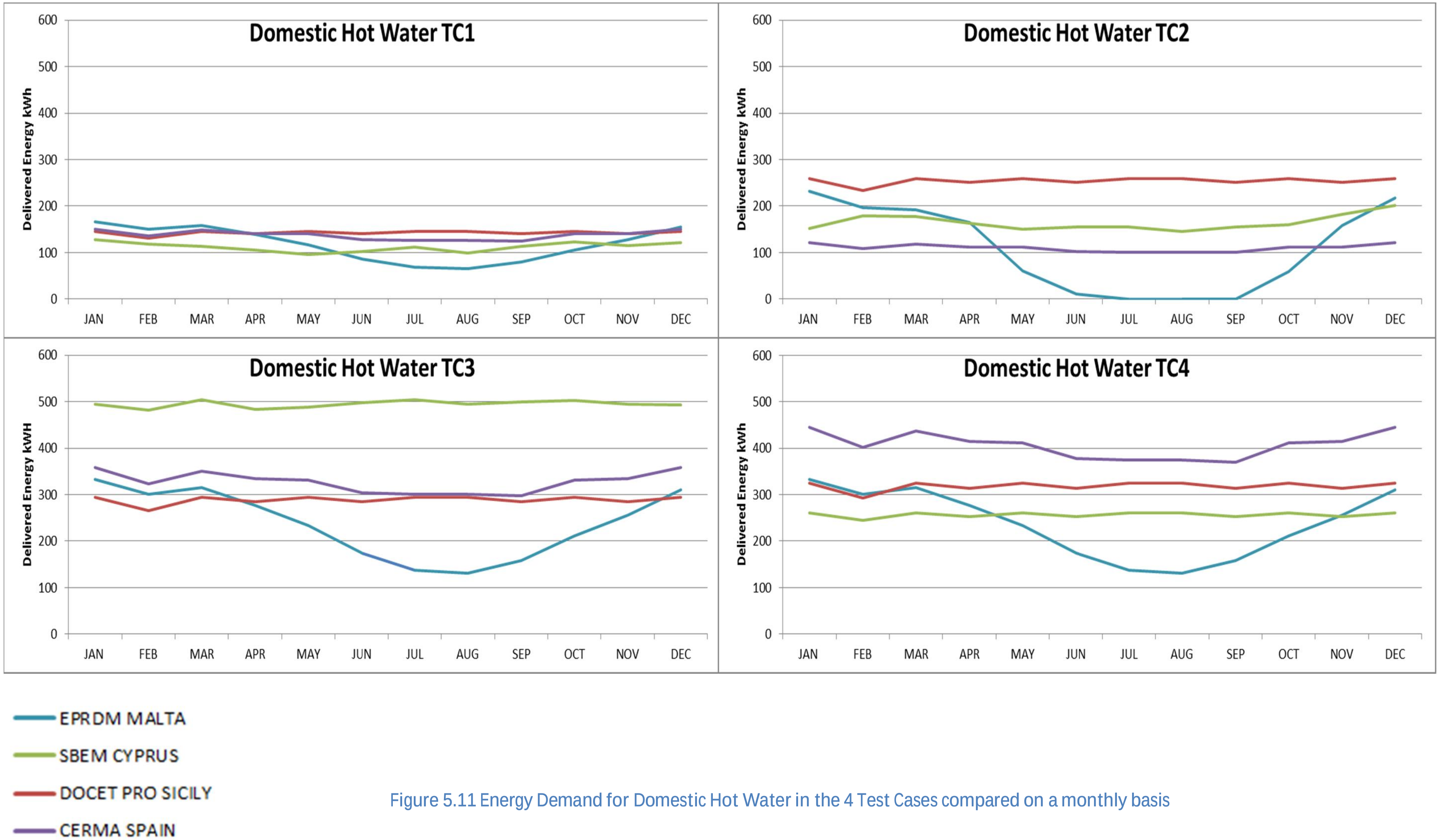


Figure 5.11 Energy Demand for Domestic Hot Water in the 4 Test Cases compared on a monthly basis

5.6. Analysis of the output

The comparative testing of the four methodologies on four test case properties has identified considerable differences between the different outputs. It is clear that the main variation between the values of the outputs can be attributed to the different valuation of the space cooling loads, where the SBEMcy and DOCETpro methodologies consistently result in a significantly higher valuation of the energy demand for space cooling than the EPRDM and CERMA methodologies. It is appropriate to note that the calculation methodology used by CERMA is the only one of the four that is not based on EN ISO 13790, whereas the other three methodologies use the simplified monthly method proposed by EN ISO 13790.

Whilst the delivered energy for space heating shows better agreement between the four methodologies, there is still some variation between the methodologies. Analysis of this data on a monthly basis shows that the difference can be attributing to differences in the length of the heating season, differences between the climate of the four zones, and other factors identified in the comparative analysis of methodologies in Comparative analysis of methodologiesTable 4.4.

The best agreement between the methodologies can be seen in the relatively straightforward calculation of the energy delivered for domestic hot water, where the main differences are the calculation of the input from the solar thermal system in Test Case 2 and the seasonality of demand displayed by the EPRDM methodology which is not reflected in the other methodologies.

When comparing the output from the four different methodologies by property type, it is clear the four methodologies correspond most accurately in the case of the terraced apartment, Test Case 1. The monthly comparison of the delivered energy for domestic hot water shows negligible variation between the methodologies for this property, whilst three out of four methodologies also show negligible variation between the monthly values for the delivered energy for space cooling, with SBEMcy being the exception. Paradoxically the main discrepancies for Test Case 1 are in the monthly calculation of the delivered energy for space heating, where the output data can be divided into two groups, with DOCETpro and SBEMcy producing results of approximately the order of double the results generated by EPRDM and CERMA.

Whilst the trends displayed by the methodology results from Test Case 1 can also be seen in the other three test cases, the discrepancies for Test Cases 2, 3, and 4 are considerably larger, with the main variation exhibited in the space cooling energy.

5.7. Summary

This chapter presents the results of the comparative testing of the four selected national methodologies on the four test case properties. In the next chapter, a dynamic simulation tool, IES VE, is used as a means of analytical verification of the national methodologies.

Chapter 6. Analytical Verification using Dynamic Simulation

6.1. Introduction

In this chapter the dynamic simulation software IES VE is used to model the behaviour of the test case properties as a means of analytic verification of the results of the energy certification methodologies.

The steady state method recommended by EN ISO 13790 and used by three of the energy certification methodologies is acknowledged as an approximation of the actual energy performance of the building, since a building in daily operation does not normally achieve steady state conditions, particularly when there is intermittent use of the building throughout the day. Furthermore, the steady state method is based on a daily average temperature and does not take into account the variation of temperature and other outdoor conditions with time. Dynamic simulation software is expected to provide a more accurate model of the building performance since the analysis is carried out over a much shorter time interval, of the order of minutes, several times over the course of one day, and therefore taking into account the changes in the external environment. In order to use the dynamic simulation tool to accurately verify the calculation methodologies, it is clearly necessary that the standardised operating conditions assumed by the methodology are the same conditions input to the dynamic simulation tool.

The contents of this chapter are outlined hereunder:

- Development of the IES VE dynamic simulation model;
- Output from the model;
- Comparison between the IES VE results and the results of the certification methodologies;
- Analysis and conclusion.

6.2. Development of the IES VE Model

The IES-VE dynamic simulation requires a geometric definition of the building with details of the construction materials used. The software includes a building template manager to define the occupancy profile, space conditioning equipment type and operating profile, ventilation rates, and various other parameters affecting the thermal behaviour of the building model. The location of the model is established in order to apply the appropriate weather data. Once the model is complete the simulation process commences with a solar shading analysis and proceeds to the Apache thermal calculation and simulation.

Since it is frequently concluded that the main variation between the results of thermal modelling and actual metering of building performance is attributable to the stochastic nature of building occupation and use, the IES-VE model was tested using an unoccupied apartment on the top floor of the same block of apartments as Test Case 1. Since this apartment was vacant, no use was made of the services during the test period, and there were no energy loads for cooling, heating, lighting, hot water, or appliances.

This top floor apartment is in a block of four apartments. The overlying roof is partially built up. The block is terraced with the façade facing west. The north, south and west facades are exposed whilst the east wall adjoins third party property. The apartment consists of three bedrooms, 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.

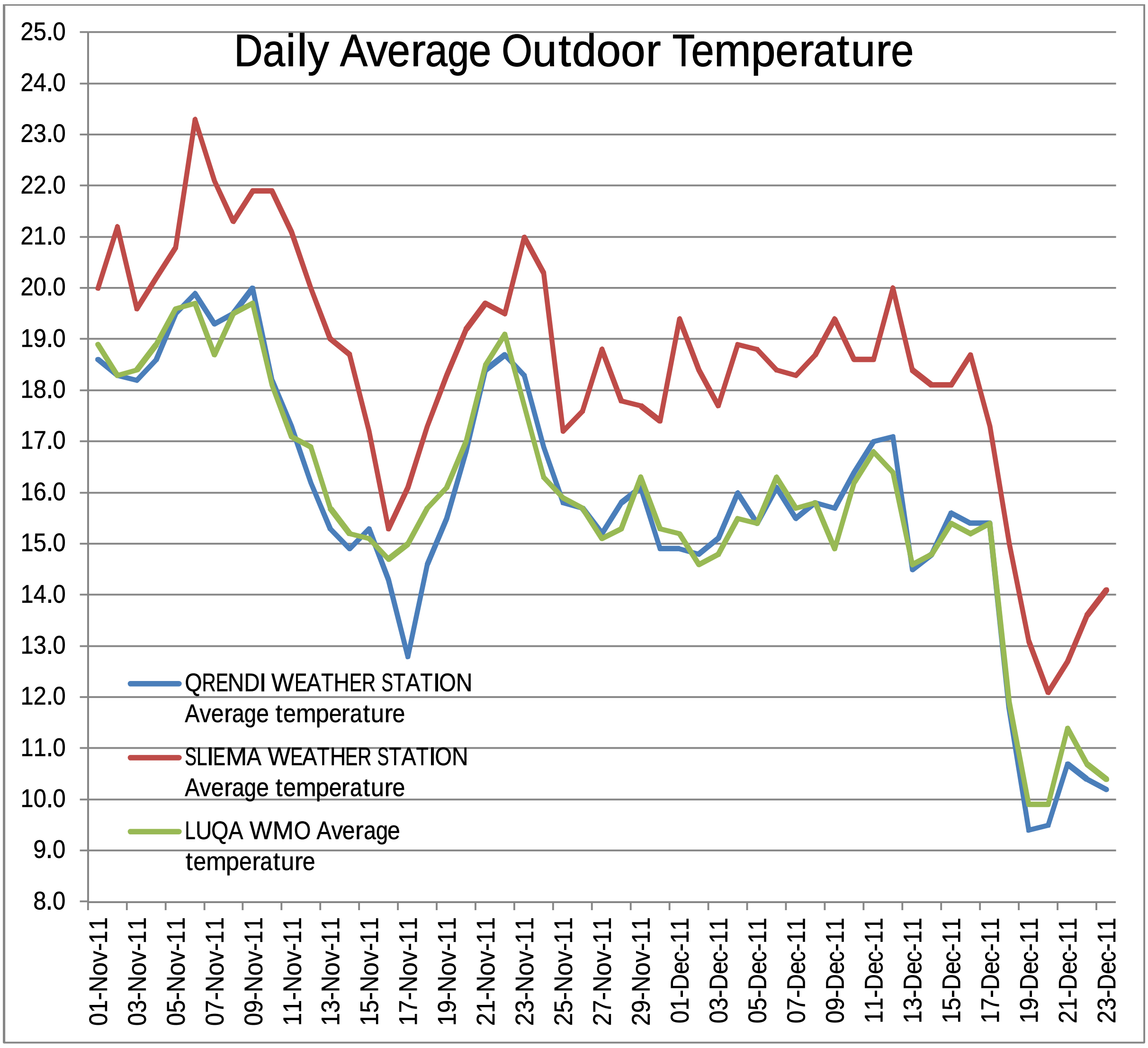


Figure 6.1 Daily Average Outdoor Temperatures Measured at Sliema Weather Station Compared to Values Recorded at Qrendi and Luqa Weather Stations between 1 Nov 2011 and 23 Dec 2012.

The apartment was monitored using three Hobo U12-012 data loggers installed in three different rooms, namely the bedroom on the west façade, the study on the east façade and the living area on the west façade. The data loggers measured and recorded temperature, humidity and light levels at 5-minute intervals. This data collection took place between the 31st October 2011 and the 1st April 2012. A Current Cost energy meter was installed to monitor the electrical consumption but this simply confirmed that no energy was supplied to the apartment during the test period. A portable weather station was installed on the roof of the apartment for measurement of the local weather conditions.

6.2.1. Weather Data

When downloading the temperature data from the weather station, a number of values were found to be missing or corrupted. Alternative sources of weather data were required and two other local weather stations in Qrendi and in Luqa (within a 10 km radius of the property) were accessed. Figure 6.1 shows a comparison of the average daily temperature data between the two weather stations and that measured on site. It can be seen that the temperature profile is identical with the the measurement from the weather station on site being consistently about 2^{o}C higher than that measured by the professional weather stations.

6.2.2. Indoor temperatures

Figure 6.2 shows the hourly average temperatures in each of the three rooms for the complete measurement period between the 1st November 2011 and the 1st April 2012. Measurements in the bedroom and study were not recorded during part of November and December. It can be seen that the temperature of the unoccupied apartment is relatively stable.

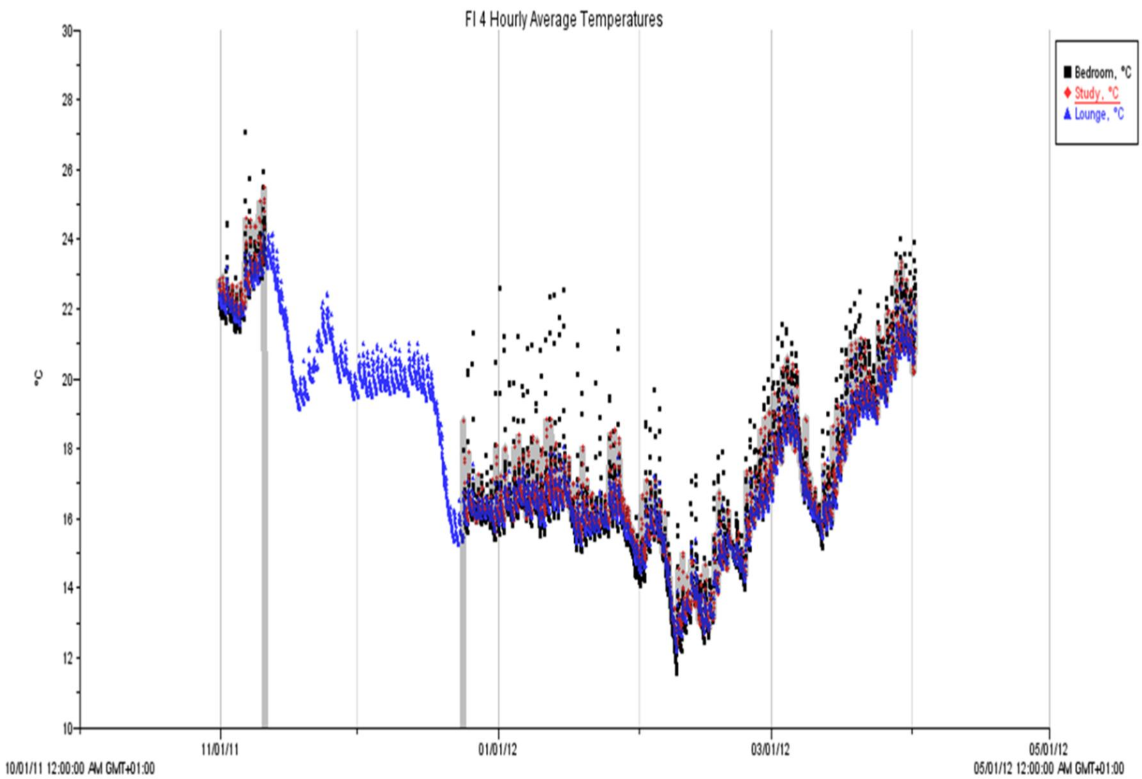


Figure 6.2 Temperature data recorded in unoccupied top floor apartment from 1 Nov 2011 to 1 Apr 2012

The IES VE model of the apartment was set up and used to generate the indoor temperatures. The model generates the air temperature for each of the rooms and the average hourly air temperature in the apartment was compared to the average hourly air temperature recorded by the HOBO loggers. Figure 6.3 displays this data for the month of March. It can be seen that the actual measured temperature is generally higher than the calculated temperature, and that the temperature profile is quite different. The standard weather data for Malta used by IES VE was the data taken from a station in Messina, Sicily. In order to reduce any error that this might produce in the model, the data from the official weather station in Luqa, Malta was input to the model. Figure 6.4 indicates that the use of the actual weather data results in better modelling of the temperature profile within the apartment, although a notable difference in the actual temperature values remained.

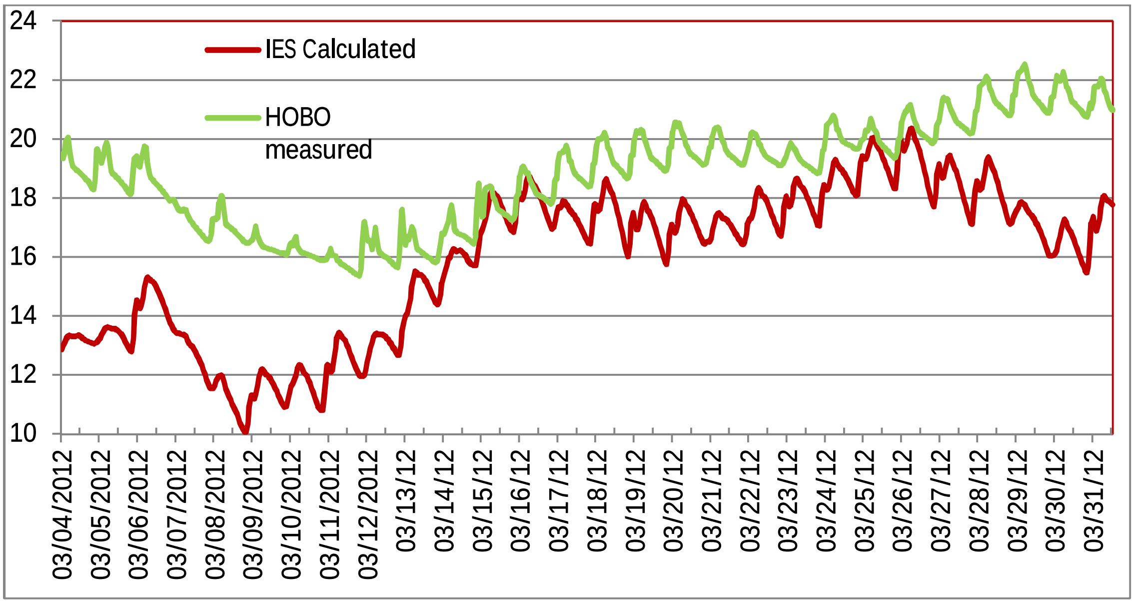


Figure 6.3 Comparison between the HOBO measured average hourly temperature and the IES VE calculated average hourly temperature using default weather data for the period 3rd to 31st March 2012

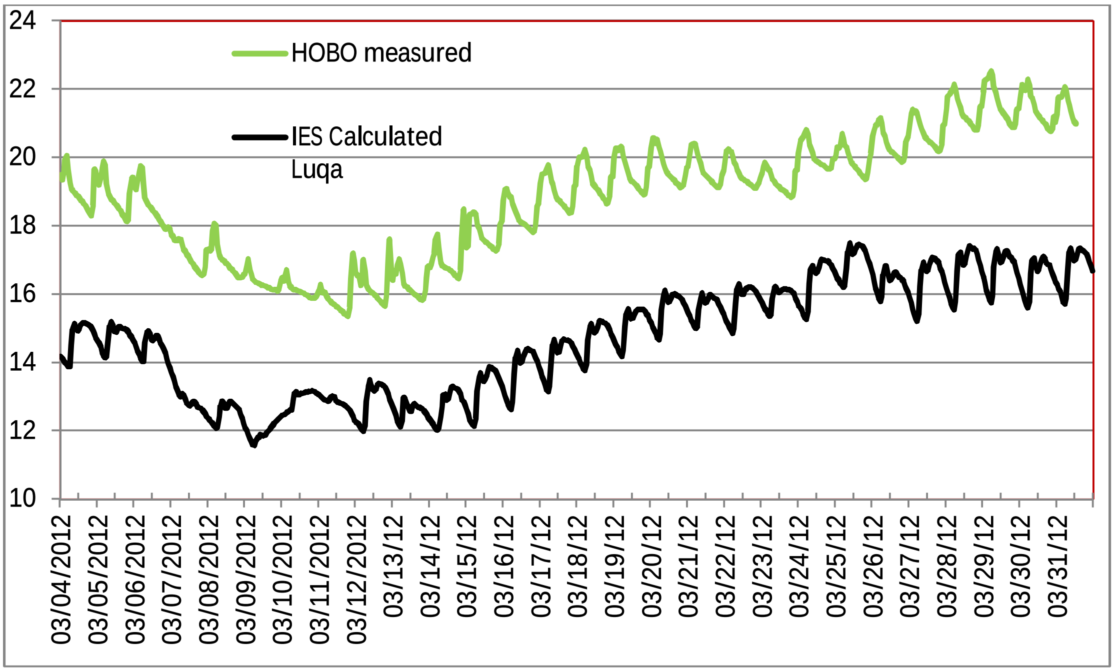


Figure 6.4 Comparison between the HOBO measured average hourly temperature and the IES VE calculated average hourly temperature using actual Maltese weather data for the period 3rd to 31st March 2012

In Figure 6.5, the graphical comparison between the measured temperature profile and the temperature profile generated by the IES VE model over a typical day shows that these two are well matched, and that the heavy thermal mass of the apartment has the effect of smoothing out the ambient temperature fluctuations. The remaining discrepancy between the model and the measured temperatures is a near-constant approximately 2°C temperature difference with the IES VE model generating a temperature which is lower than the measured values. Possible causes of this temperature difference could be:

a. heat gains from the apartment below;

b. the ability of the thermal capacity of the apartment structure to retain heat energy not being modelled precisely by the dynamic model.

The use of the unoccupied apartment to calibrate the IES VE model allowed for greater confidence in the use of the model and provided an indication of the accuracy of the results.

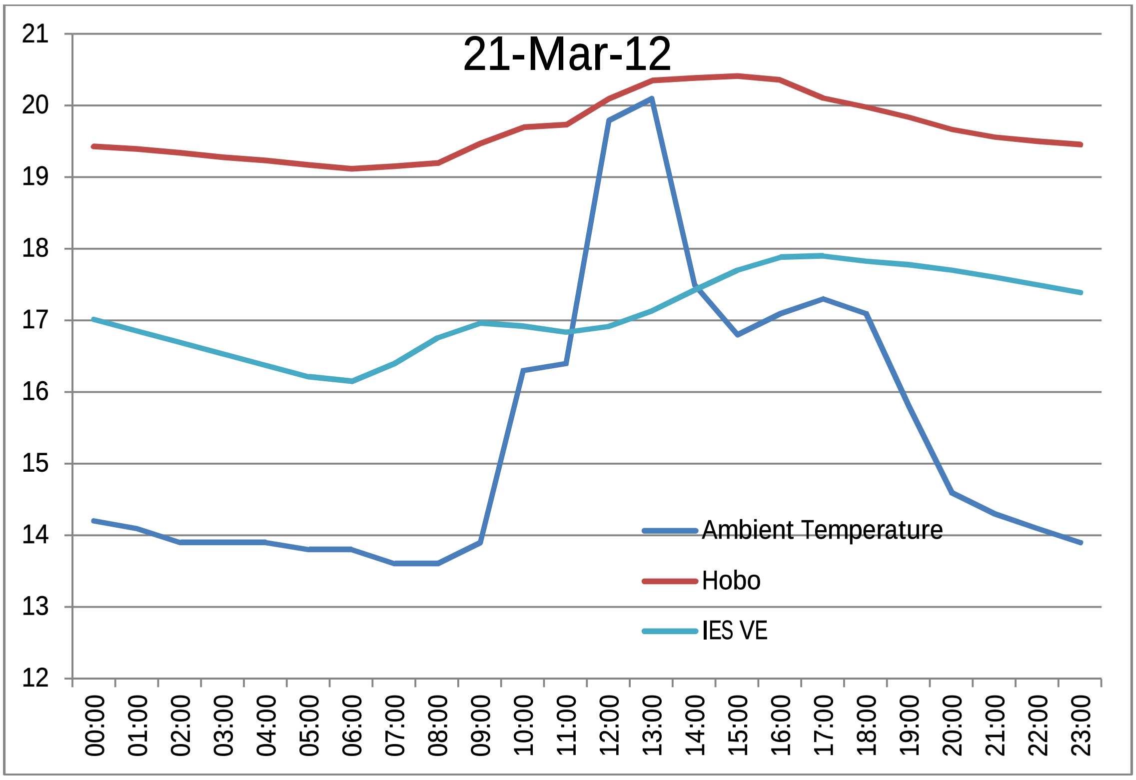


Figure 6.5 Comparison of hourly temperature profile over 24 hours for unoccupied apartment

6.3. Modelling the Test Case properties

Since the primary scope of the use of the IES VE model was the verification of the certification methodologies, it was important that that the parameters used to set up the model were similar or identical to the parameters used for the certification methodologies. Table 4.4 clearly demonstrates that a number of parameters vary considerably between the methodologies. For the purposes of this initial analysis, it was decided to use the EPRDM parameters as the framework for the IES VE model, particularly since three out of the four test case properties were located in Malta.

Table 6.1 shows that the application of the different weather files to the IES VE model has a minimal effect on the performance of the model, confirming the outcome expected from the weather data in Table 5.1 and Table 5.2.

	Delivered energy (kWh/m^2 yr) calculated using IES VE			
Climate	Malta Sliema	Cyprus Larnaca	Italy Agrigento	Spain Almeria
Test Case 1	45.09	44.67	41.53	44.58
Test Case 2	26.28	23.97	23.78	25.47
Test Case 3	46.33	42.14	41.24	46.20
Test Case 4	22.49	20.56	20.25	21.75

Table 6.1 Comparison of IES VE models for test case properties with different weather files

However, when the delivered energy is broken down into its components, the values for space heating and cooling show considerably more variation than expected.

Table 6.2 shows that the different weather files applied to the same IES VE model can result in variations of up to 60% for space cooling (Test Case 2 Malta and Spain) and 100% for space heating (Test Cases Malta and Cyprus). This differences cannot be simply explained by reference to the weather files and they illustrate the complexity of dynamic modelling. The different weather files have different effects on the different test cases, even when all other parameters defining the model have been kept constant.

	Delivered energy for cooling (kWh/m2 yr) calculated using IES VE			
Climate	Malta Sliema	Cyprus Larnaca	Italy Agrigento	Spain Almeria
Test Case 1	11.11	16.06	12.40	14.00
Test Case 2	4.63	7.14	6.30	7.38
Test Case 3	8.89	9.79	8.42	10.99
Test Case 4	4.43	5.79	5.15	6.05

	Delivered energy for heating (kWh/m2 yr) calculated using IES VE			
Climate	Malta Sliema	Cyprus Larnaca	Italy Agrigento	Spain Almeria
Test Case 1	10.67	5.30	5.83	7.27
Test Case 2	8.25	4.35	4.50	5.68
Test Case 3	17.75	12.66	13.12	15.51
Test Case 4	5.85	3.28	3.35	4.35

Table 6.2 Comparison of delivered energy for space heating and cooling from IES VE models

6.4. Comparison between the IES VE models and the Certification Methodologies

Since the effect of the weather data on the IES VE model was not negligible, the comparison between the IES VE models and the certification methodologies was performed on each of the test case properties on a country by country basis. Figures 6.6 to 6.9 show the monthly energy demand for space cooling for the test case properties, whilst figures 6.10 to 6.13 show the same comparison between IES VE and the national methodologies for space heating.

Figure 6.6 shows good correspondence between the dynamic simulation model and the Spanish methodology for the delivered energy for space cooling for three out of the four test cases, with the Spanish methodology calculating higher values for space cooling energy for Test Case 4, a detached property recently designed and built for low energy demand. Figure 6.7 shows similar results for the comparison between the dynamic simulation model and the Maltese methodology, with the Maltese methodology also resulting in higher values for space cooling for Test Case 4. Figures 6.8 and 6.9 indicate that whilst in the case of both the Italian and the Cypriot methodology the calculated values for space cooling show agreement with the values resulting from the dynamic simulation for Test Case 1, in the other three Test Cases the two methodologies produce values for the space cooling delivered energy that are markedly higher than those generated by the dynamic simulation.

Overall, it is noted that the space cooling results for Test Case 1, the terraced apartment, are congruent between all four national methodologies and the dynamic simulation models. This appears to indicate that the typology of this test case property is simple to model and not susceptible to the large variations that appear to have been generated by the modelling of the other three test cases.

In Figure 6.10 it can be seen that the delivered energy for space heating calculated by the Spanish certification methodology agrees with the dynamic simulation model for Test Cases 1 and 3, but not for Test Cases 2 and 4. In the case of the Maltese certification methodology, this consistently results in lower values for the delivered energy for space heating than those calculated by the dynamic simulation model. The Cypriot certification methodology shows good agreement with the dynamic model for the space heating calculation whilst the Italian model shows better agreement for Test Case 1 than for the other three cases.

Overall the space heating results for Test Case 1, the terraced apartment, show the best agreement between the results produced by the certification methodologies and the dynamic simulation models. However, the discrepancies between the values calculated for the other three Test Cases for the space heating delivered energy are smaller than those observed for space cooling.

6.5. Summary

The use of dynamic simulation to model the behaviour of the test case properties shows considerable divergence from the results produced by the case study certification methodologies. Whilst there is generally better agreement between the results for space heating than there is between the results for space cooling, the dynamic simulation appears to correspond more closely to the Maltese and Spanish methodologies for the cooling calculation. On the other hand, the Maltese methodology shows the most pronounced variation from the dynamic simulation when the delivered energy for space heating is calculated. This comparison was carried out on the basis of a defined set of operating parameters, eliminating the random behaviour normally exhibited by occupants of the property. In the next chapter the actual metered energy performance of the test case properties is used for the empirical validation of the certification methodologies.

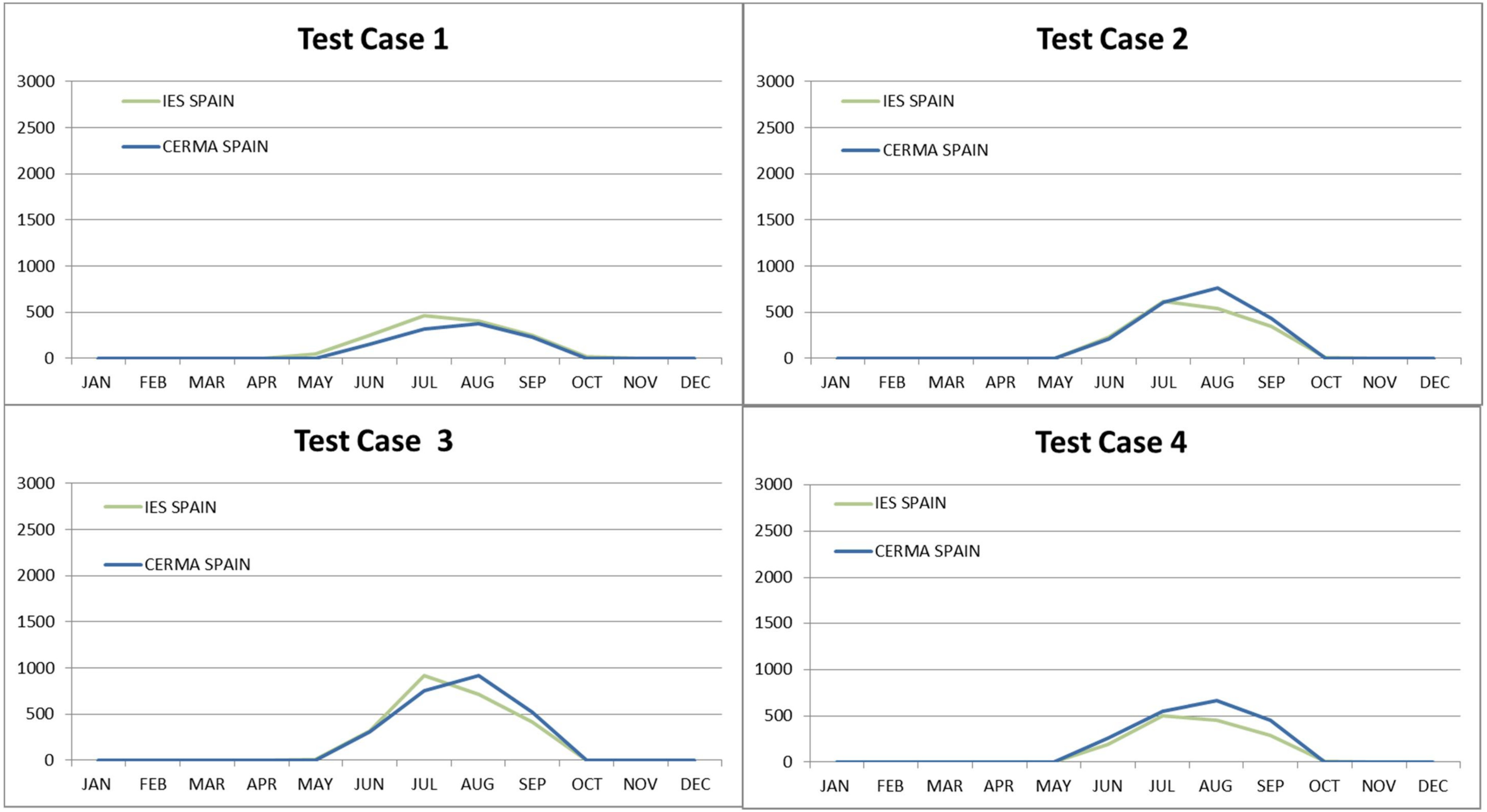


Figure 6.6 Delivered Energy (kW) for space cooling with Spanish weather file

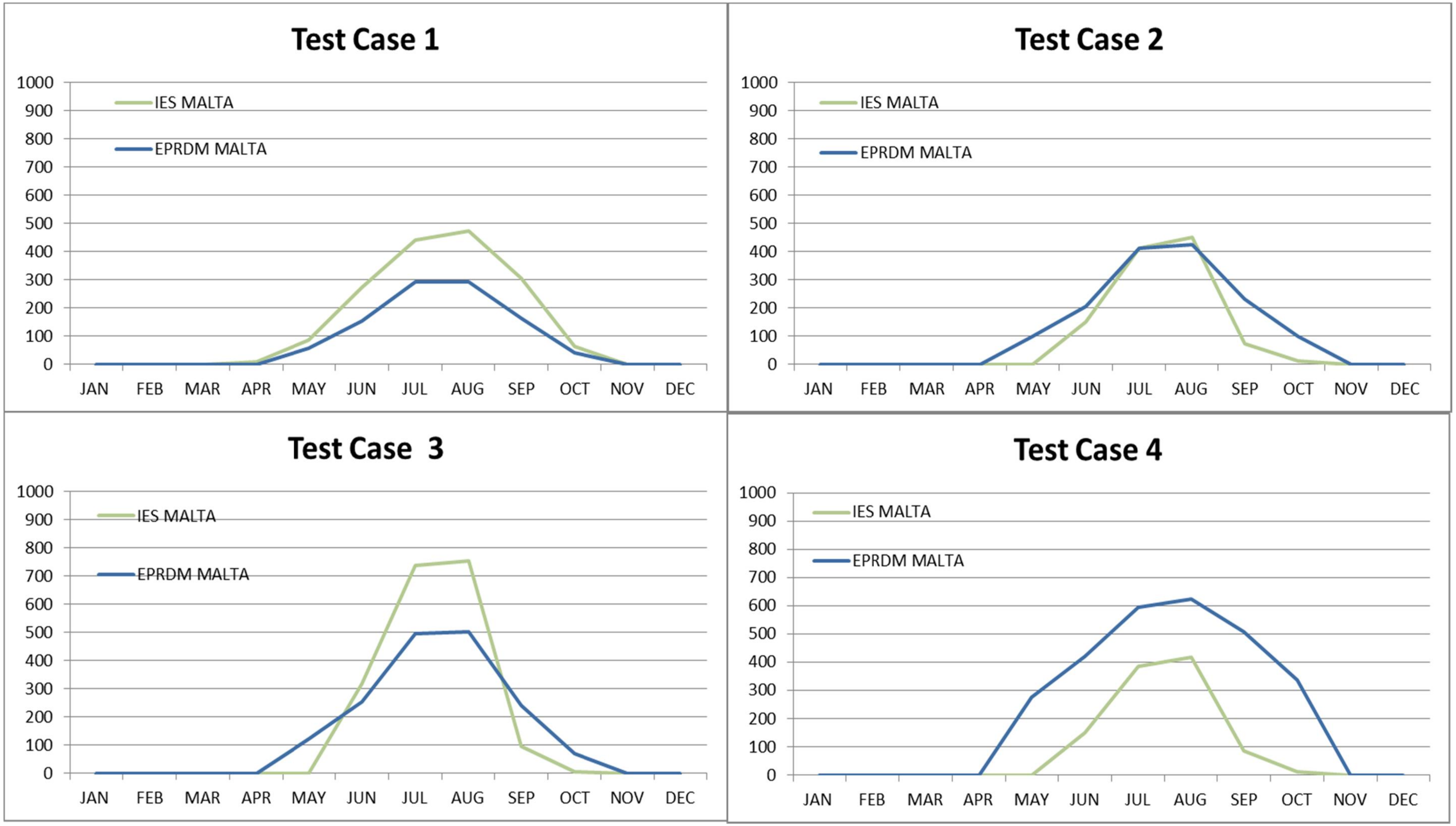


Figure 6.7 Delivered Energy (kW) for space cooling with Maltese weather file

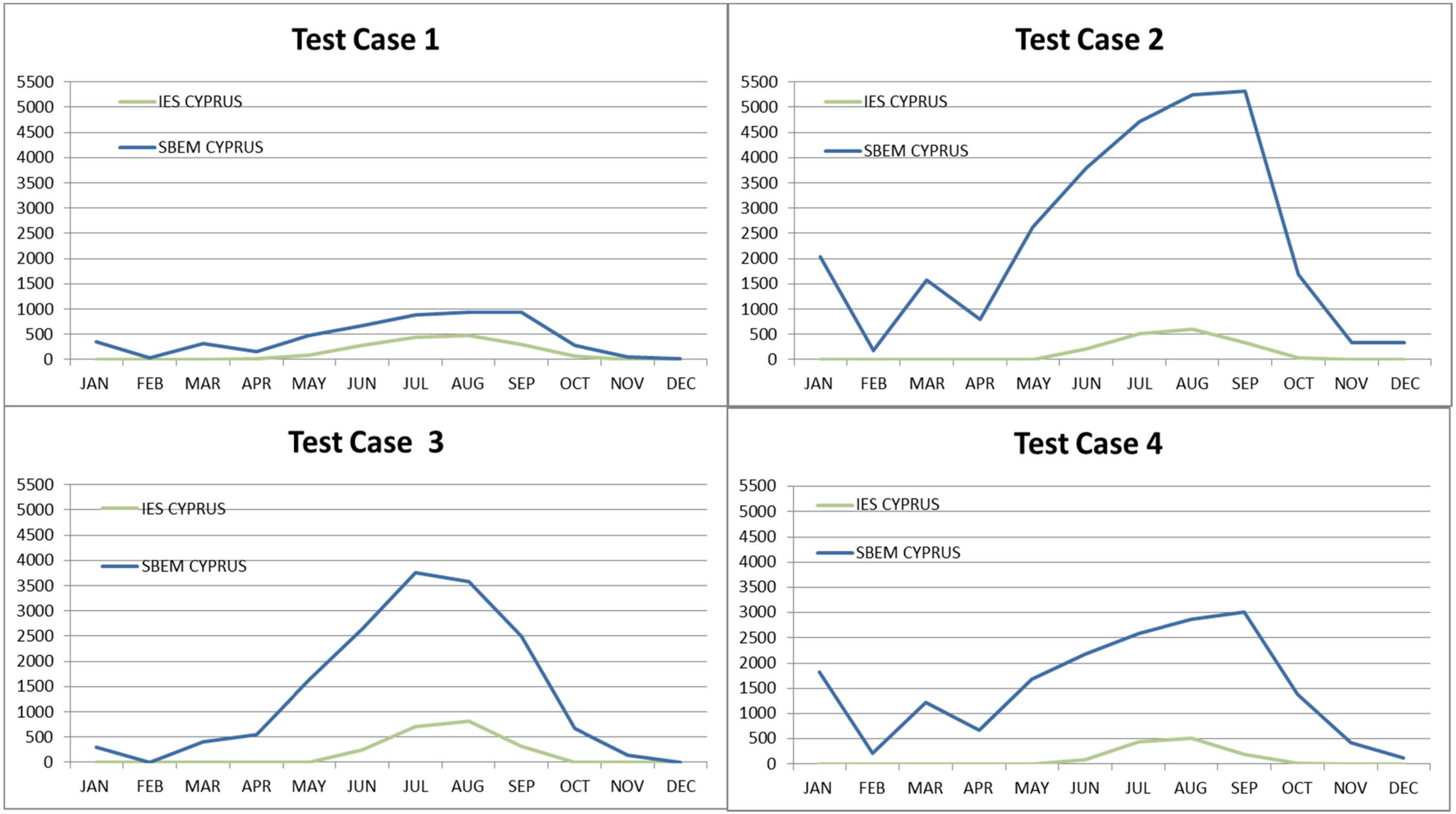


Figure 6.8 Delivered Energy (kW) for space cooling with Cypriot weather file

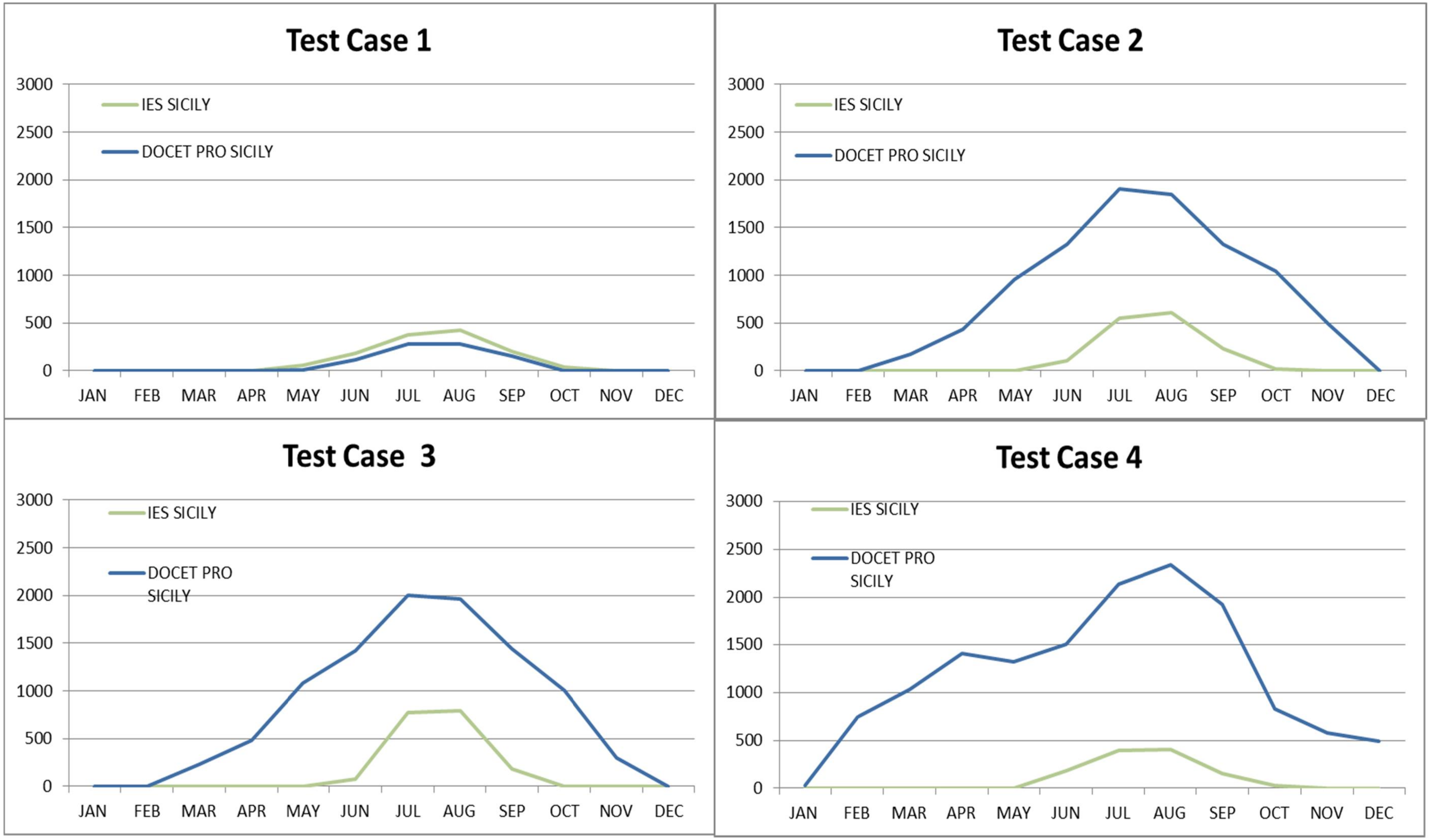


Figure 6.9 Delivered Energy (kW) for space cooling with Italian weather file

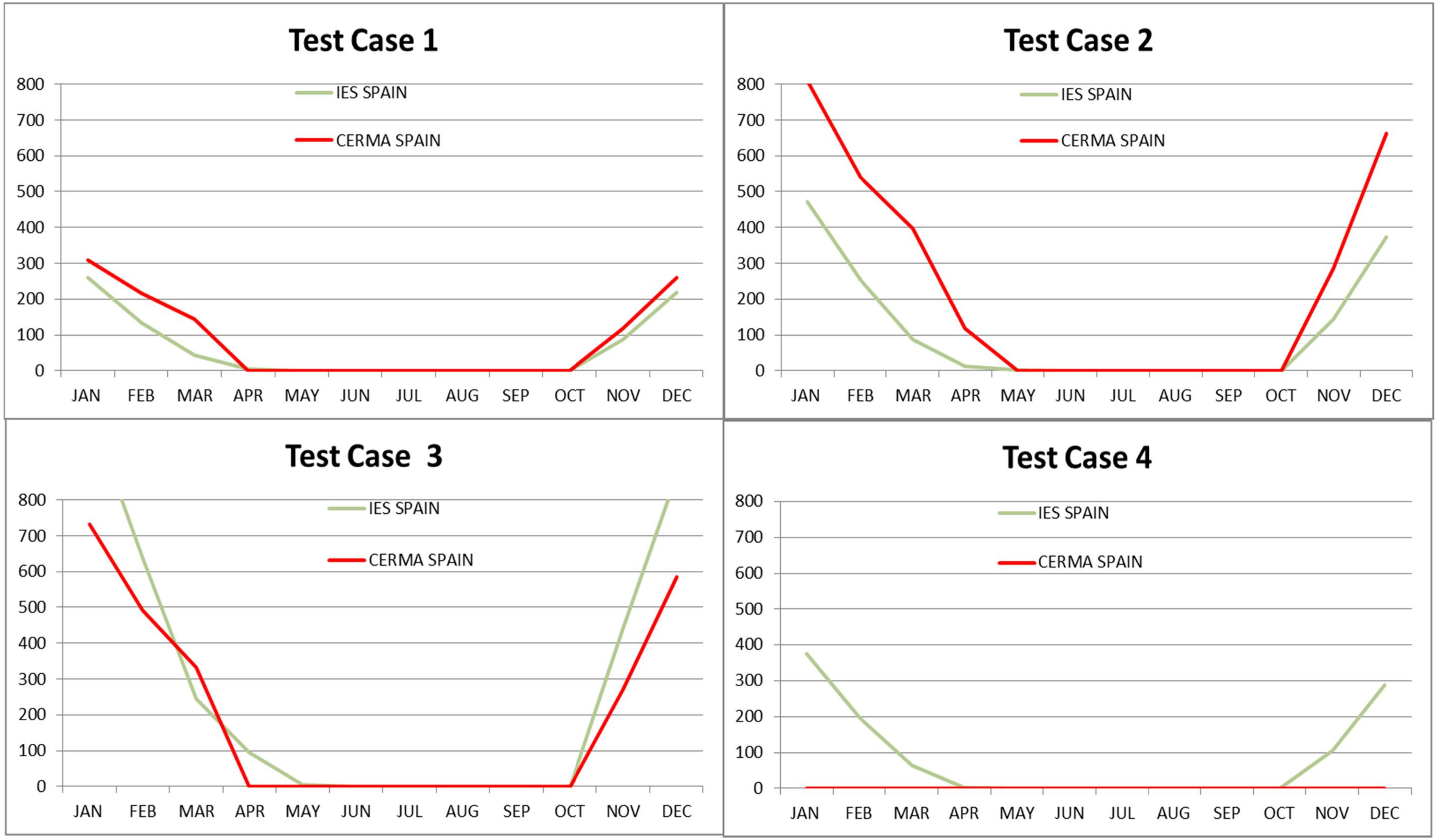


Figure 6.10 Delivered Energy (kW) for space heating with Spanish weather file

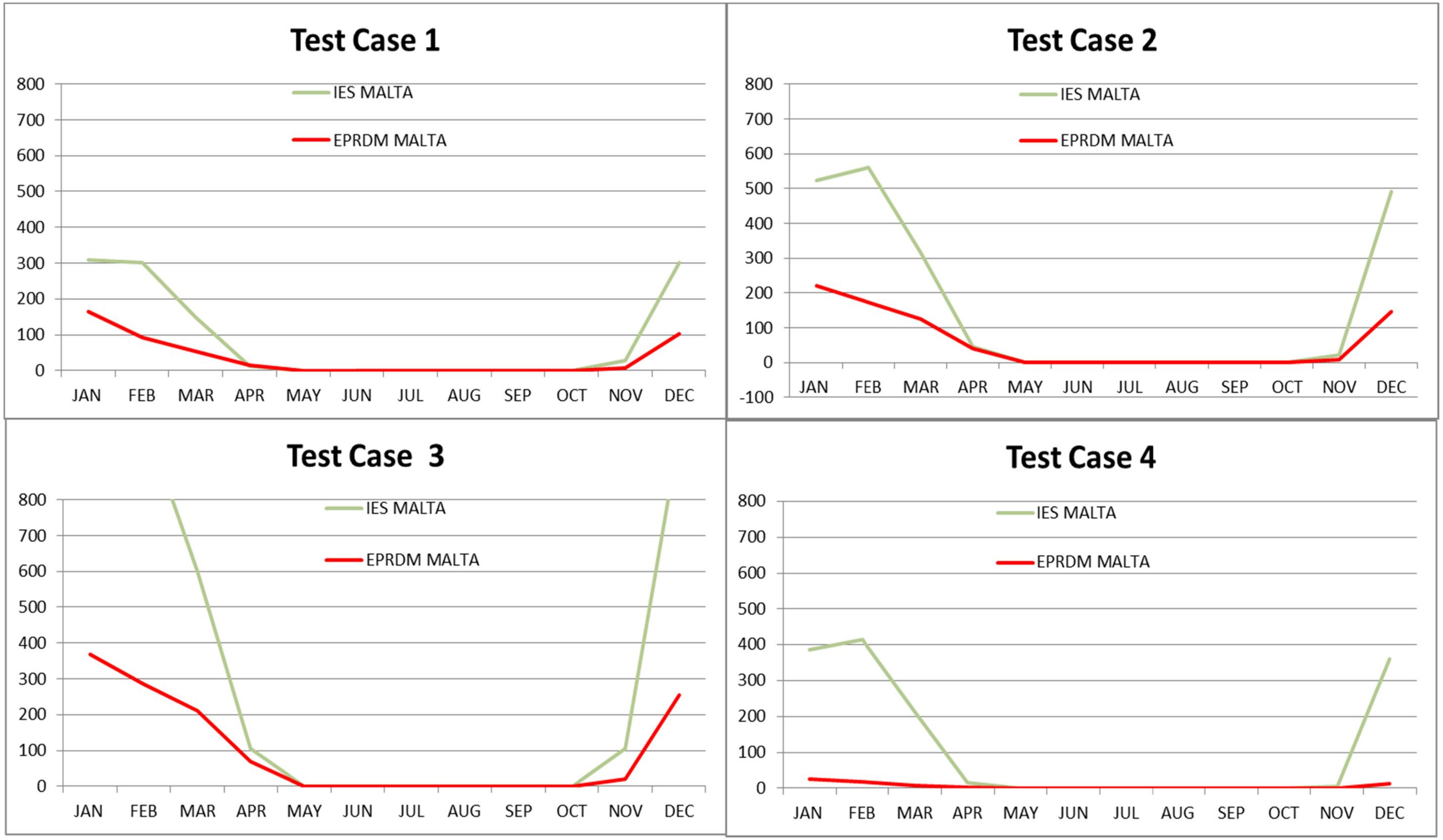


Figure 6.11 Delivered Energy (kW) for space heating with Maltese weather file

Figure 6.12 Delivered Energy (kW) for space heating with Cypriot weather file

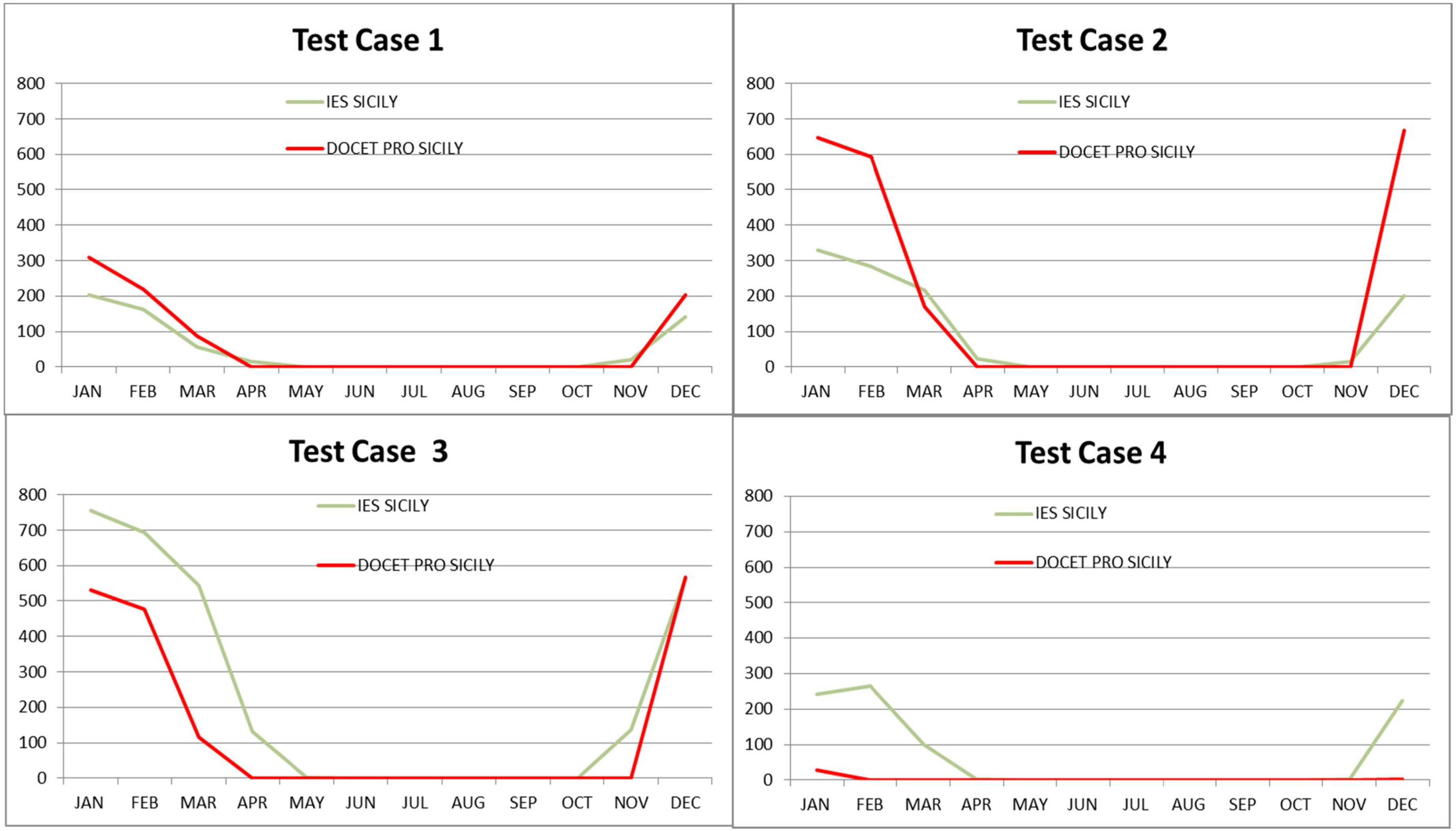


Figure 6.13 Delivered Energy (kW) for space heating with Italian weather file

Chapter 7. Empirical Validation

7.1. Introduction

This chapter presents the results of the monitoring of the energy use and thermodynamic behaviour of the actual test case properties in a Mediterranean climate. Three properties in Malta and one property in Cyprus were monitored over an eighteen month period. Additional data for properties in Italy and Spain was referred to for comparative purposes.

Since it is generally accepted that considerable variations results from the actual behaviour of the occupants (in relation to the predicted behaviour assumed by the certification methodologies), the focus of the analysis of the monitoring data is on the difference between the predicted and the actual energy performance of the test cast properties.

7.2. Monitored temperature profiles

The internal temperature has been identified as the most significant parameter in establishing the energy performance of residential property (Corrado & Mechri, 2009). The certification methodologies define the internal temperature in order to calculate the energy performance of the property to be certified. Long term monitoring of the internal temperatures of the case study properties was carried out between 2012 and 2013. In each property, measurements were taken using three Hobo U12-012 data loggers installed in three different rooms. The data loggers measured and recorded temperature, humidity and light levels at ten minute intervals. The data collected was used to establish the average daily temperature of the property as well as an hourly temperature profile for a typical day in the heating and cooling season.

Figure 7.1 displays the average indoor temperature on a monthly basis for each of the four test case properties. It is quite clear that in spite of the different property typologies, the different occupancy patterns, and the different locations, the average monthly indoor temperature profile is remarkably similar. In the same figure, for comparison purposes, the higher and lower limits of the indoor temperature profile assumed by the EPRDM methodology are also indicated. Whilst the indoor temperature profiles for the different methodologies do differ slightly, they all follow the same pattern of a single winter indoor temperature and a single summer indoor temperature, with the main variation being the value of the indoor temperature set point (See Table 4.4 Comparative analysis of methodologies for further details.). The figure immediately indicates that although there is a clear relationship between the temperature set points assumed by the methodology and the actual temperatures recorded (when these are summated and averaged over a monthly basis), the measured temperatures demonstrate lower indoor temperatures in winter and higher indoor temperatures in summer than those assumed by the certification methodology profiles. The recorded temperature data appear to suggest that the average monthly indoor temperature profile follows the average monthly outdoor ambient temperature profile. This is certainly a more energy efficient way of operation, and modifying the certification methodologies to reflect this should decrease the calculated energy requirements of the property. This is however a preliminary conclusion, and in order to have a better understanding of the relationship between the actual and the calculated energy performance, it is necessary to investigate the temperature profile over a smaller time step than one month, as well as to examine the actual energy demand of the case study properties.

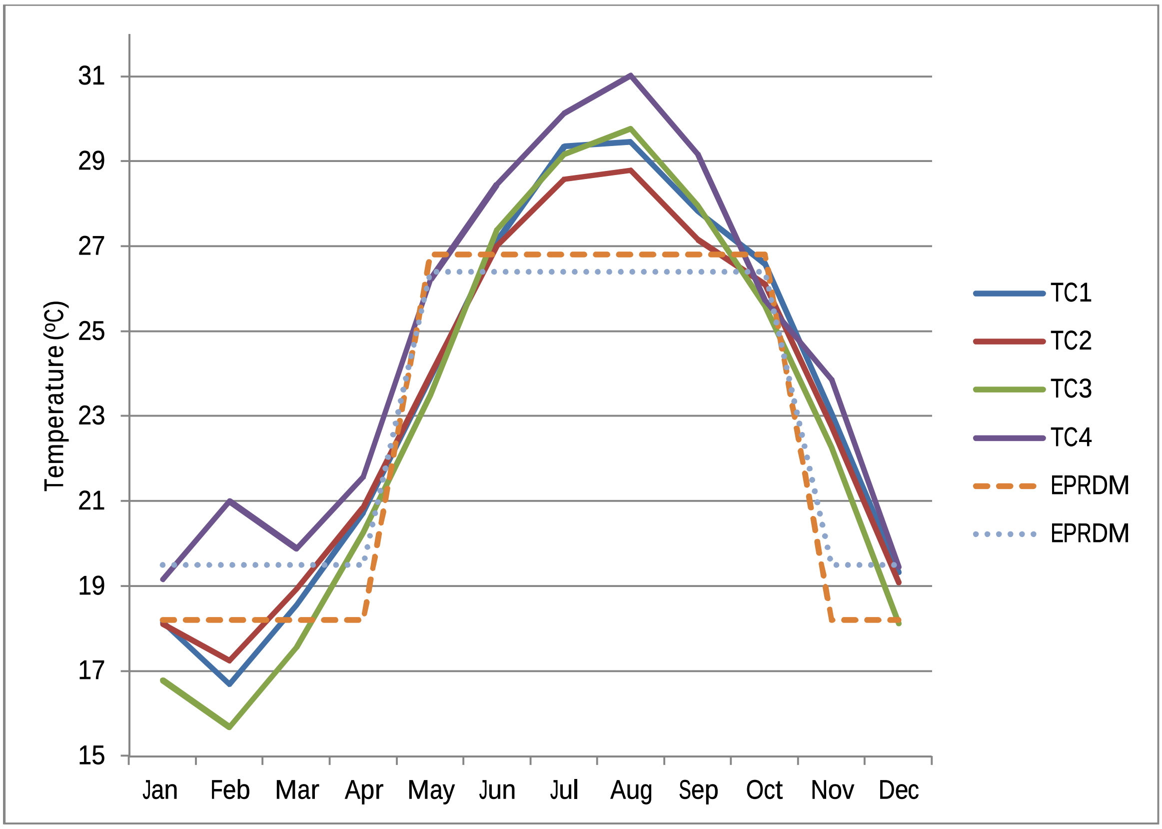


Figure 7.1 Monthly average indoor temperature for test case properties

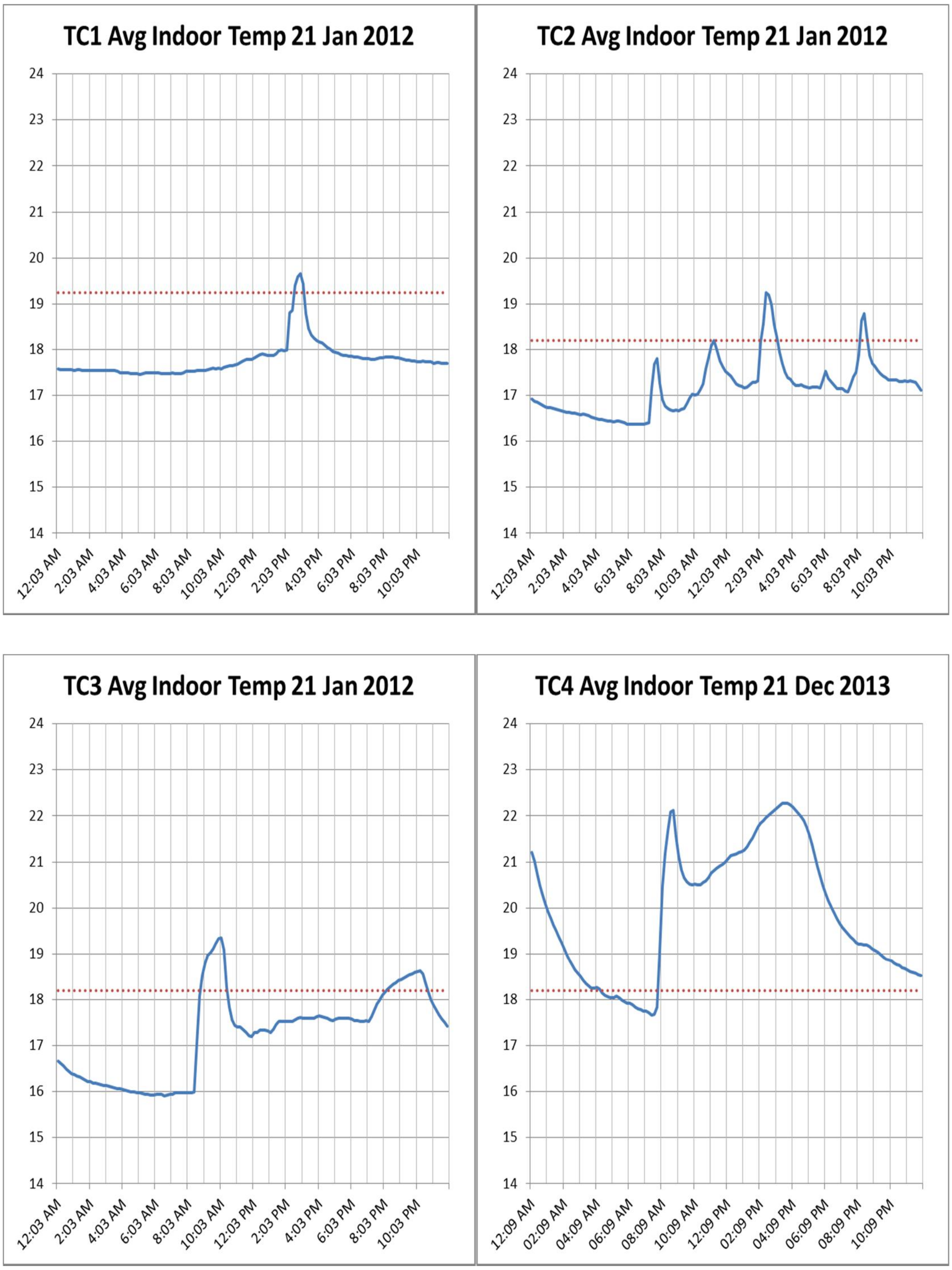


Figure 7.2 Average indoor temperature profile (°C) for typical winter day for test case properties

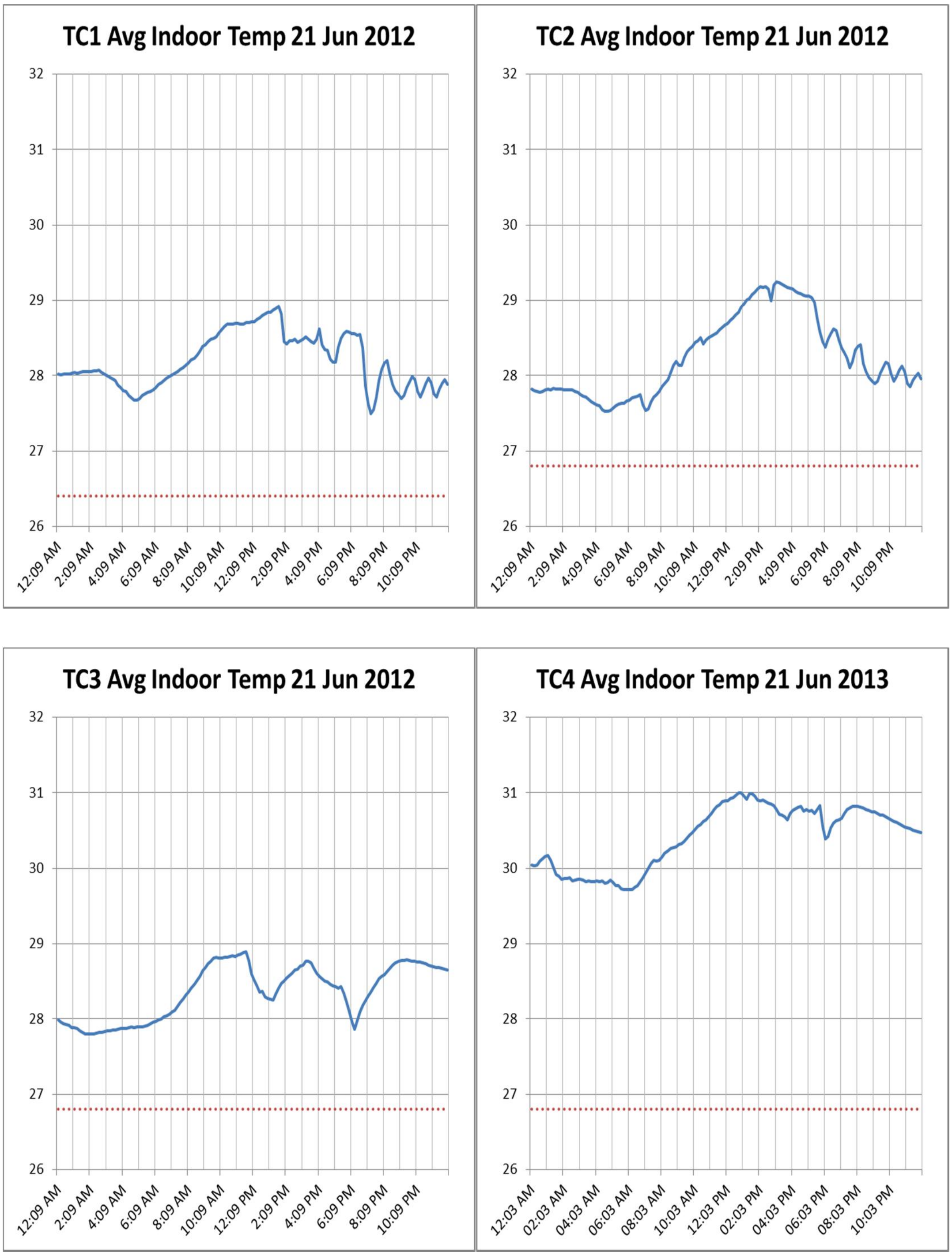


Figure 7.3 Average indoor temperature profile (°C) for typical summer day for test case properties

The actual temperature measurements taken every ten minutes for each of the test case properties were plotted to generate a temperature profile for a sample day in the winter and the summer season, and these graphs can be seen in Figure 7.2 and Figure 7.3. These graphs clearly demonstrate that the hourly temperature profile of the four properties varies considerably during the day, and this is not the case for the temperature profile assumed by the certification methodologies. However, Figure 7.2 does indicate that the heating temperature set point assumed by the certification methodologies does fall within the range of the indoor temperature profile for all four test case properties. This is not however the case for the cooling season, and Figure 7.3 highlights that the average indoor temperature in all four test case properties never actually reaches the cooling temperature set point of between 26°C and 27°C assumed by the certification methodologies. In fact, on the basis of the sample days plotted in Figure 7.3, the selection of a higher cooling temperature set point should result in a more accurate estimate of the actual conditions within the dwellings.

Figure 7.4 indicates the considerable difference between the actual temperature profile measured in the test case properties, and the temperature profile generated by the dynamic simulation model IES VE. It is appropriate to bear in mind that the IES VE temperature profile is based on the activity schedule assumed by the certification methodology. However the main differences between the two indoor temperature profiles appear to be related to the temperature set points, and not to the times of use. The IES VE model maintains the indoor temperature at the assumed temperature set point when the cooling (or heating) equipment is switched on (between 6 and 8 am and 5 and 11 pm). Furthermore, the temperature of the IES VE model in the afternoon when the cooling equipment is off, rises to higher levels than those actually measured. The measured temperatures demonstrate considerable less temperature fluctuation between the equipment on and equipment off periods. Whilst the IES VE dynamic simulation model is certainly a more precise and rigorous method for calculating the energy performance of the test case properties, the benefit of the increased accuracy of the models is neutralised by the difference between the actual indoor temperature profile and the simple assumed temperature profile input to the IES VE model.

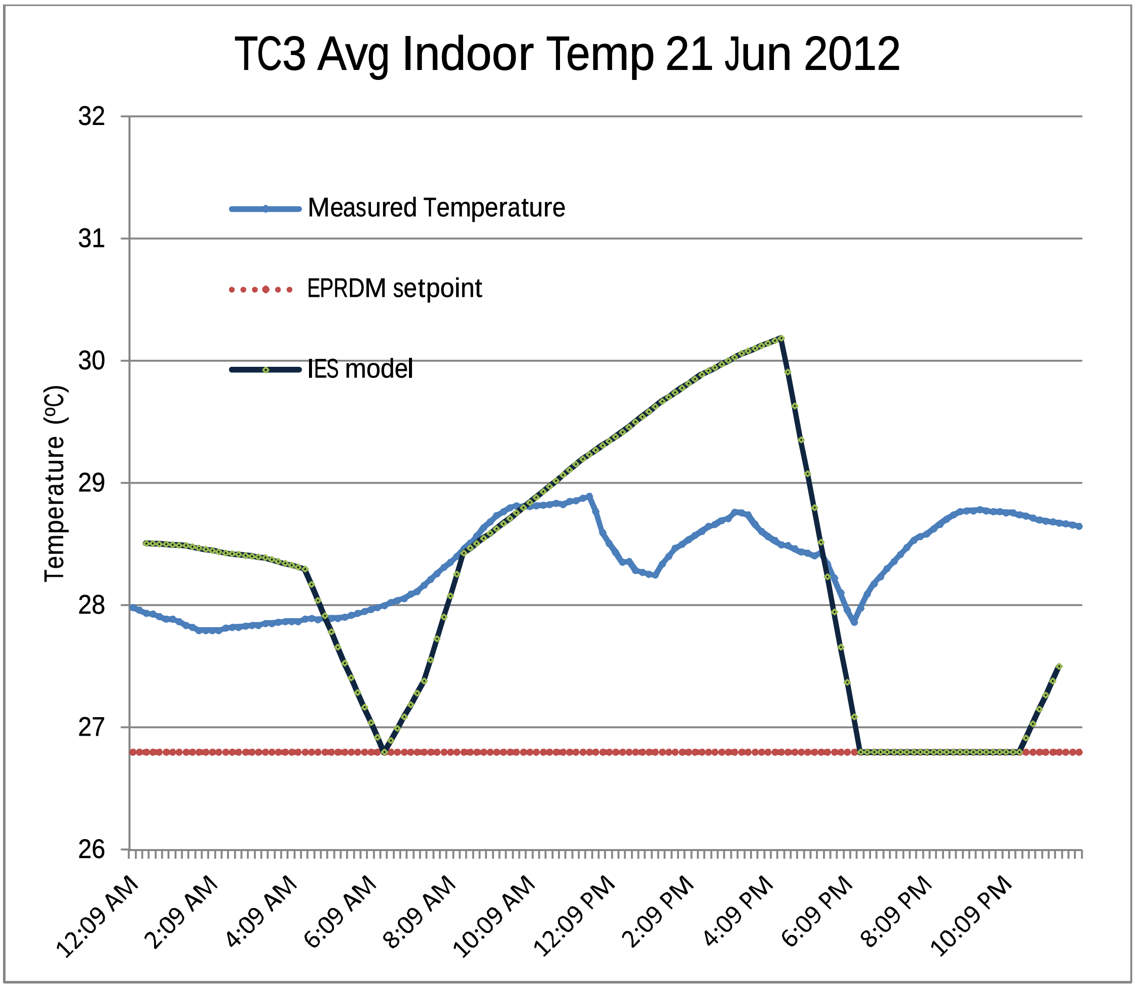
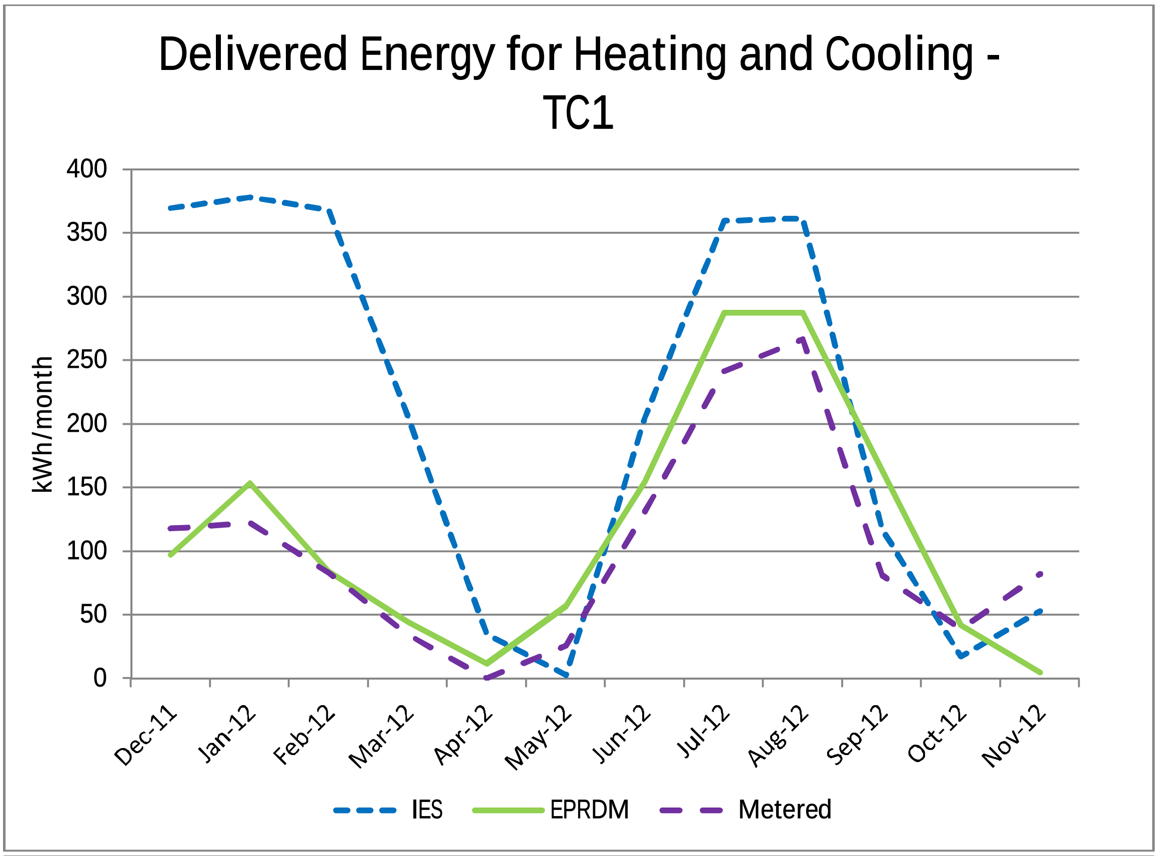


Figure 7.4 Comparison between measured and modelled indoor temperature profile for typical summer day

7.3. Metered energy for heating and cooling

Current cost meters were installed in three of the four test case properties for the monitoring of the electrical power consumption on an hourly, daily, and monthly basis. The fourth property was monitored by the occupant on a monthly basis. All four test case properties used solely electricity for space heating and cooling and domestic hot water during the monitoring period, with the use of gas being limited to cooking. The data from the current cost meters was correlated with the electricity bills for the test case properties. Figure 7.5 shows the delivered energy for space heating and cooling in each of the four test case properties on a monthly basis. The metered data provided the overall energy consumption of the properties, and the heating and cooling energy were extracted from this data by



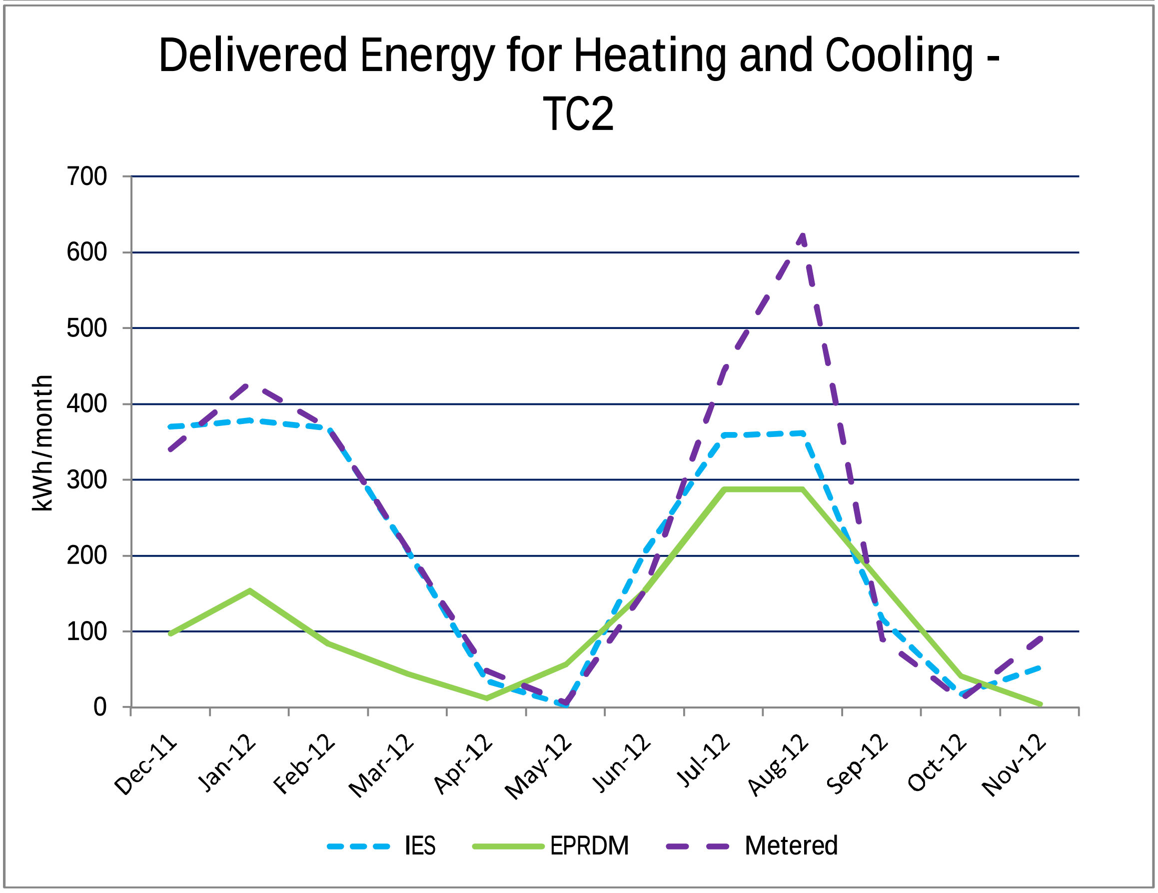
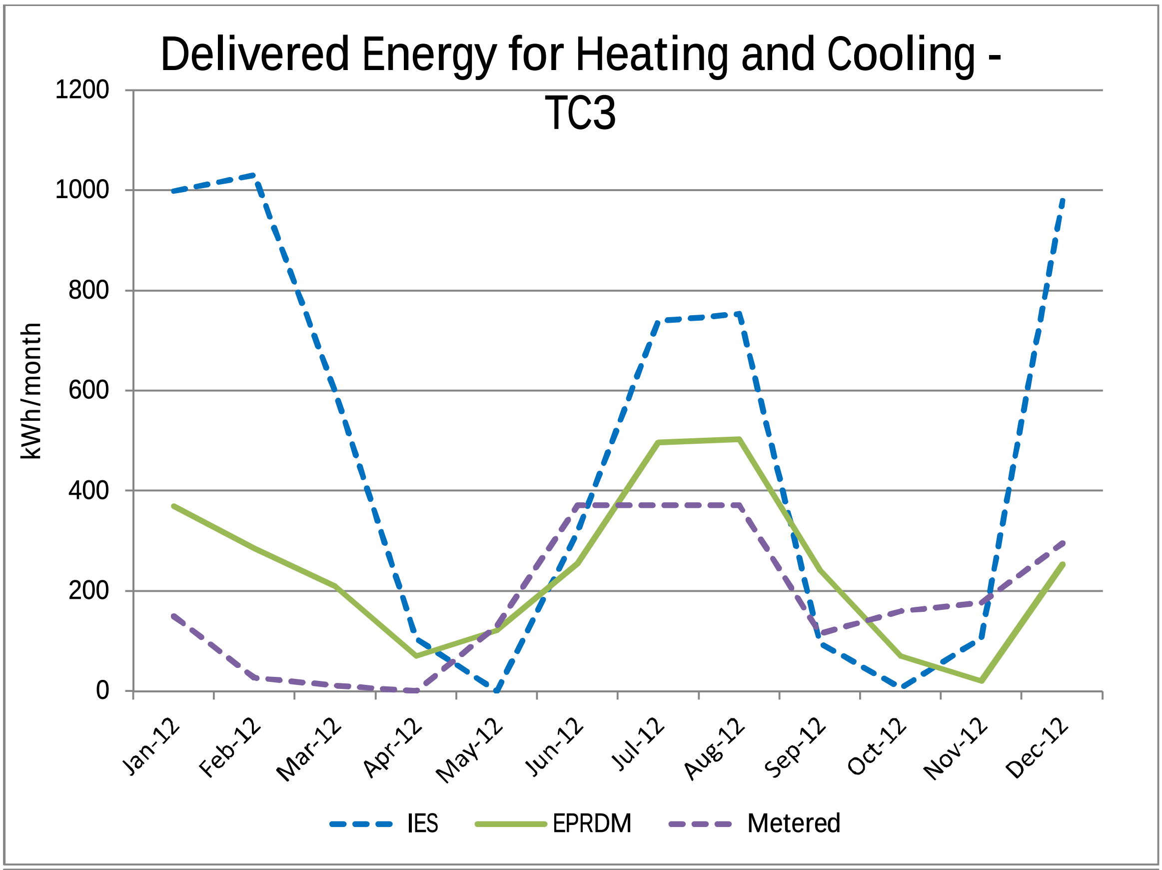


Figure 7.5 Comparison between metered energy for heating and cooling and values calculated using IES and EPRDM



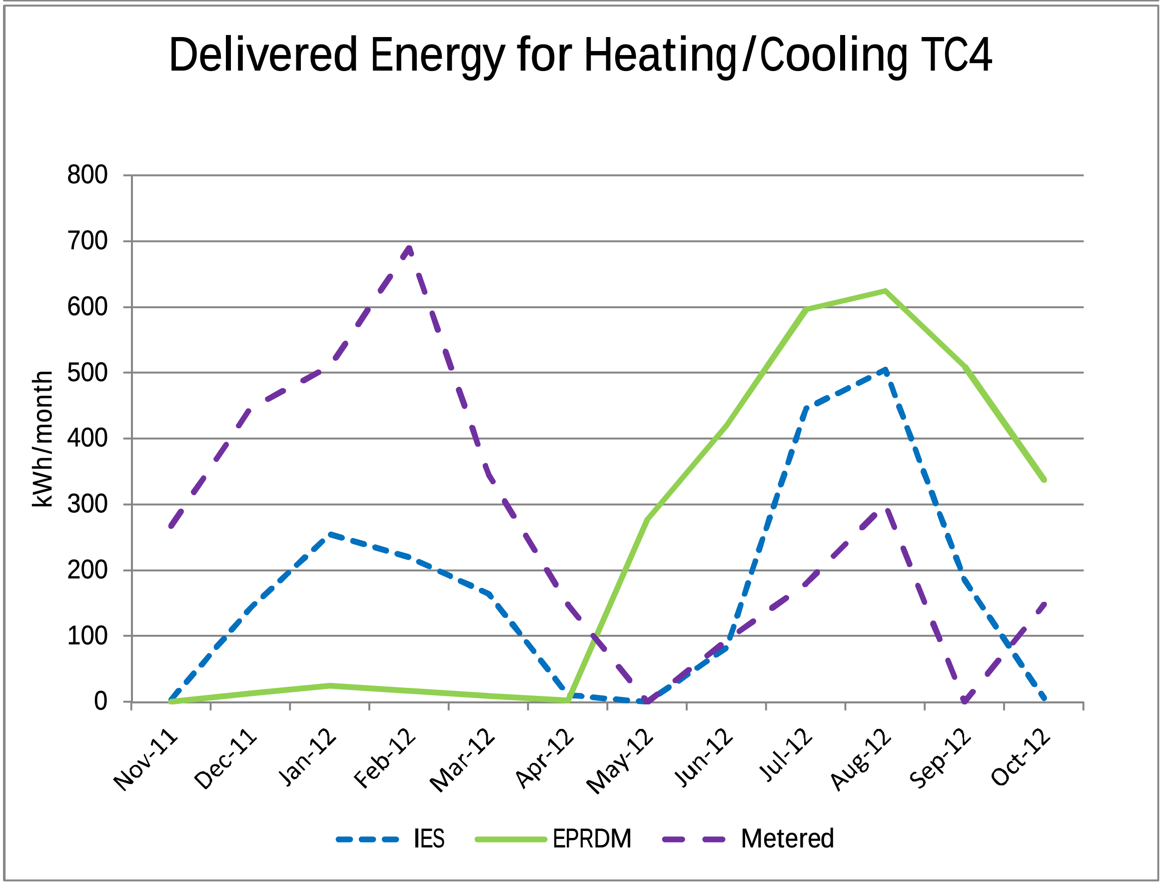


Figure 7.6 Comparison between metered energy for heating and cooling and values calculated using IES and EPRDM

subtracting the energy consumed in the seasonal transitional months (without heating and cooling) from the monthly energy. The graphs compare the metered energy with the delivered energy calculated using the IES VE dynamic model for Malta for TC, TC2, and TC3, and the model for Cyprus for TC4. A comparison is also made with the delivered energy calculated using the Maltese certification methodology EPRDM. This methodology was used for the comparison since three out of the four test case properties are located in Malta.

In the case of the terraced apartment TC1, it can clearly be seen that the energy calculated by EPRDM is very similar to the actual metered energy. It is appropriate to point out that the various methodologies tended to show similar agreement for TC1 when compared in Figures 6.6 to 6.9.

The other three test case properties, TC2, TC3, and TC4 do not demonstrate any common characteristics, with seasonal variations between the results. For example, TC2 shows good agreement between IES VE and metered energy for winter but in summer there is better agreement between IES and EPRDM.

7.4. Pressurisation Tests

In the context of the significantly more mature certification methodologies developed for housing in Northern and Central Europe, the raising of fabric insulation levels has increased the importance of the air-tightness of the building envelope, particularly in cold climatic conditions, and several studies have been carried out on the importance of building air tightness in North America and North and Central Europe. However similar data for the evaluation of the effects of infiltration on building envelope performance in Mediterranean conditions is not readily available (d'Ambrosio Alfano, et al., 2012). One study of residential houses in Greece identified a correlation between the total window perimeter and the air tightness measurements (Sfakianaki, et al., 2008) and the importance of the window frame losses was also identified as the most critical parameter in an experimental analysis of Italian residential buildings (d'Ambrosio Alfano, et al., 2012). The latter study concluded that the air leakage rate at the reference pressure difference of 50 Pa across the building envelope was quite high and significant in calculating the energy performance of the buildings.

Each of the four certification methodologies use a different approach for the calculation of the air leakage rate by infiltration of the building being certified. These are summarised in Table 7.1 below, which demonstrates that there is considerable variation between the results of the various algorithms and the choice of default values. This variation is further confirmation of the assertion made by d'Ambrosio Alfano et al(2012) that the availability of actual infiltration data for building envelope performance in the Mediterranean is indeed very limited. Consequently, a Minneapolis Blower Door Model 3 System complete with DG-700 Digital Gauge was acquired from BSRIA and pressurisation tests were carried out on the three Test Case Properties located in Malta. Table 7.2 presents the results from these tests and a considerable variation can clearly be noted. The principal reason for the variance is the different type of window framing systems used in the properties, with sliding aluminium windows giving the highest infiltration rates and tilt-and-turn windows resulting in the lower rates measured for TC2.

Certification Methodology	Method of determination of Infiltration Rate	Values Calculated for Test Case Properties				
		TC1	TC2	TC3	TC4	
EPRDM	Calculation Algorithm	0.68	0.79	0.81	0.86	ach
		5301	13399	14190	15377	m^3/day
CERMA	Calculation Algorithm	0.57	0.41	0.44	0.57	ach
		4443	6954	7708	10192	m^3/day
SBEMcy	Default value of 25 $m^3/h/m^2$ at 50 Pa					
		20736	45504	40493	45715	*m^3/day @ 50 Pa*
DOCETpro	Default value of 0.3 ach	0.3	0.3	0.3	0.3	
		777.6	1706.4	1518.48	1713.6	m^3/day

Table 7.1 Different approaches to calculation of infiltration rate by national methodologies

Blower door test	Values Measured for Test Case Properties				
	TC1	TC2	TC3	TC4	
Infiltration Rate	1.2	0.34	0.78	-	ach @ 4 Pa
	35904	24840	40848	-	m^3/day @ 50 Pa

Table 7.2 Results from Blower Door Tests on Test Case Properties

7.5. Summary

In this chapter the outcome of the monitoring of the test case properties was presented and compared to the results obtained from the calculation methodologies and the dynamic simulation.

The measurements of the internal temperature in the test case properties showed that the assumptions made by the calculation methodology in connection with this fundamental parameter would benefit from refinement. Needless to say, without accurate definition of this parameter, the expected benefits from the increased accuracy of the dynamic simulation model are completely eliminated. Figure 7.1 indicates that there is little variation in internal temperature between the test case properties, and that defining the average monthly internal temperature rather than simply having a seasonal temperature set-point could be a simple matter.

The power data did not provide the equivalent level of detail as that of the temperature data, since the data was restricted to the monthly power measurements, corrected to give space heating and cooling energy as outlined above. Nevertheless, Figures 7.5a and 7.5b demonstrate that the correlation between the EPRDM methodology, the dynamic simulation model, and the metered data, is generally better for the summer cooling season than the winter heating season. This is in contrast to the indoor temperature profiles, where the correlation between the methodology and the measured temperatures is better in winter than in summer. This appears to indicate that in the summer, the building cooling energy performance is less sensitive to indoor temperature variations than the winter heating season.

The data collected from the pressurisation tests confirmed the uncertainty of the air change rate estimation and justified the wide range of values calculated or assumed as default by the different certification methodologies.

Chapter 8. Discussion and Analysis of Results

8.1. Introduction

This chapter synthesises the various outcomes from the analytical verification, comparative testing and empirical validation of the four national certification methodologies. The results from the case study properties are also compared to the outcomes from other research, as well as to comparative data for housing in Italy and Spain, the two regions where no test case properties were available. The implementation of EN ISO 13790 in the context of the certification methodologies is assessed in the perspective of the testing outcomes. This exercise is utilised to develop improvements to the methodology of energy performance certification of housing in a Mediterranean climate. An obvious corollary is a more precise definition of occupant behaviour in a scenario that is quite alien to that found in a typical centrally heated North European home. The final section of this chapter examines the expected outcomes of the application of the suggested recommendations for improvement of the energy performance certification procedure.

8.2. Analysis of results

8.2.1. Comparative Testing

The comparative testing of the four national certification methodologies on the four selected test case properties clearly shows that in spite of the very similar climatic conditions, the methodologies result in wide variations in the calculated values for the building energy requirements. The main variation between the values of the outputs can be attributed to the different valuation of the space cooling loads (see Figure 8.1) where the SBEMcy and DOCETpro methodologies consistently result in a significantly higher valuation of the energy demand for space cooling than the EPRDM and CERMA methodologies. Figure 8.1 also indicates that the calculated specific delivered energy shows little variation between property types with similar profiles for each of the four test case properties when the same calculation methodology is used.

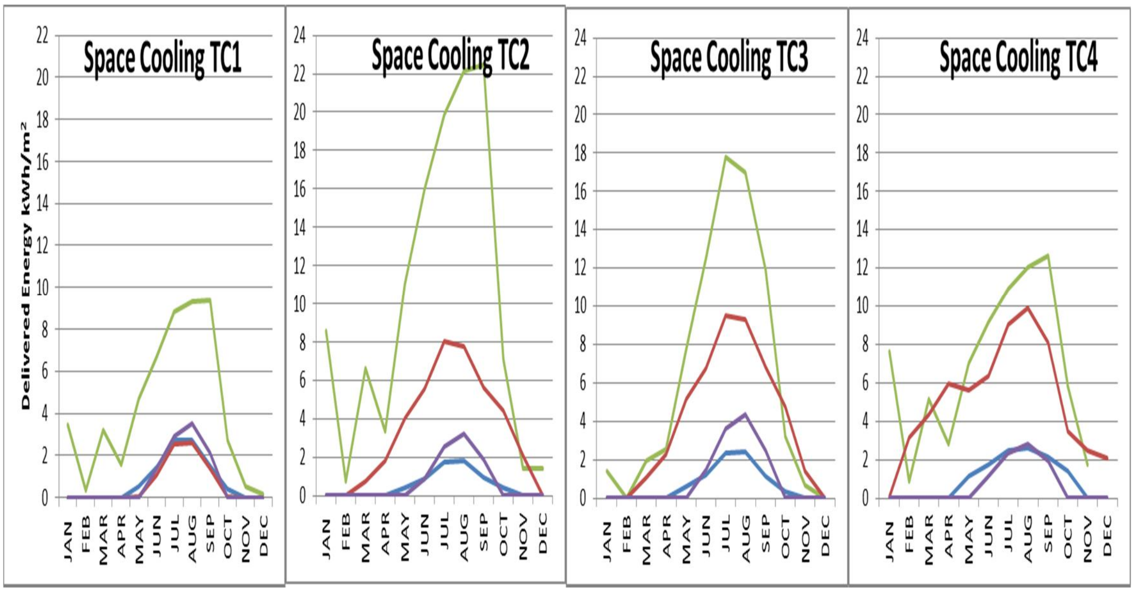


Figure 8.1 Specific Delivered Energy for Space Cooling for the four test case properties

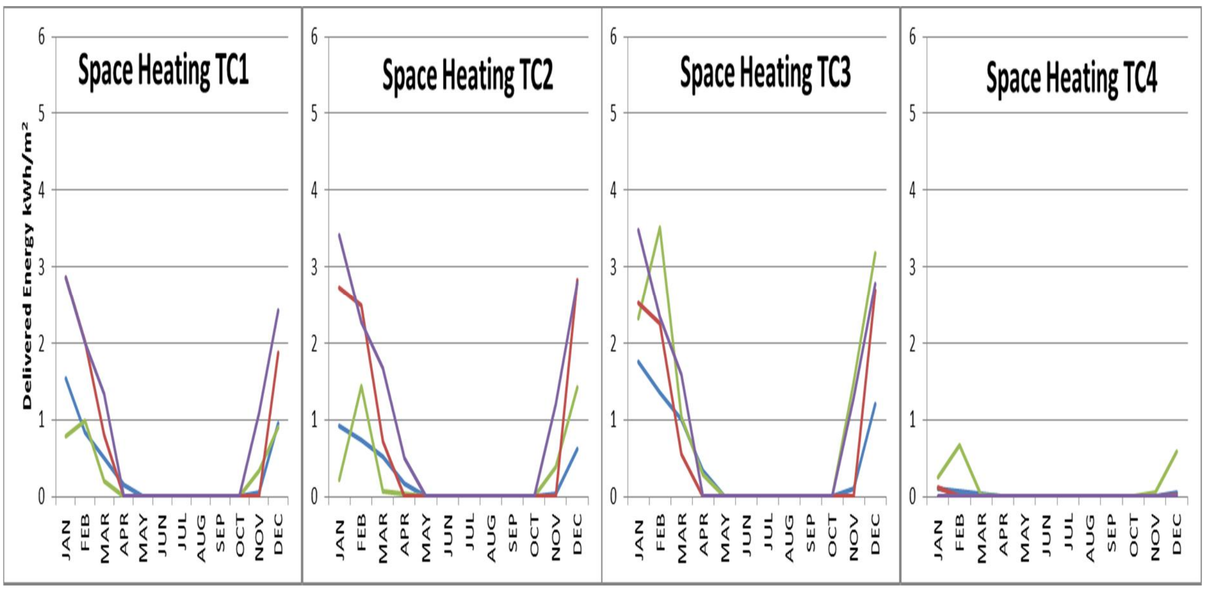


Figure 8.2 Specific Delivered Energy for Space Heating for the four test case properties

Whilst the delivered energy for space heating shows better agreement (see Figure 8.2) between the four methodologies, there is still some variation between the methodologies. Figure 8.1 and Figure 8.2 also highlight the fact that when the atypical monthly specific cooling delivered energy values generated by DOCETpro and SBEMcy are disregarded, the maximum monthly specific delivered energy for both cooling and heating for the test case properties is of the order of 4 kWh/m^2.

8.2.2. Analytical Verification

The use of the IES VE dynamic simulation model for the analytical verification of the four certification methodologies on the four test case properties documented in Chapter 7 confirmed that the energy demand for space cooling calculated by the SBEMcy and DOCETpro methodologies was overestimated. The results generated by the IES VE dynamic simulation model for the delivered energy required for space cooling of the test case properties correspond to those calculated by the EPRDM and CERMA methodologies (see Figure 8.3). The certification methodologies and the dynamic simulation model show better agreement between the calculated values of the delivered energy for space heating of the test case properties, and the magnitude of the variances between these values is considerably less than that observed for the delivered energy for space cooling (see Figure 8.4).

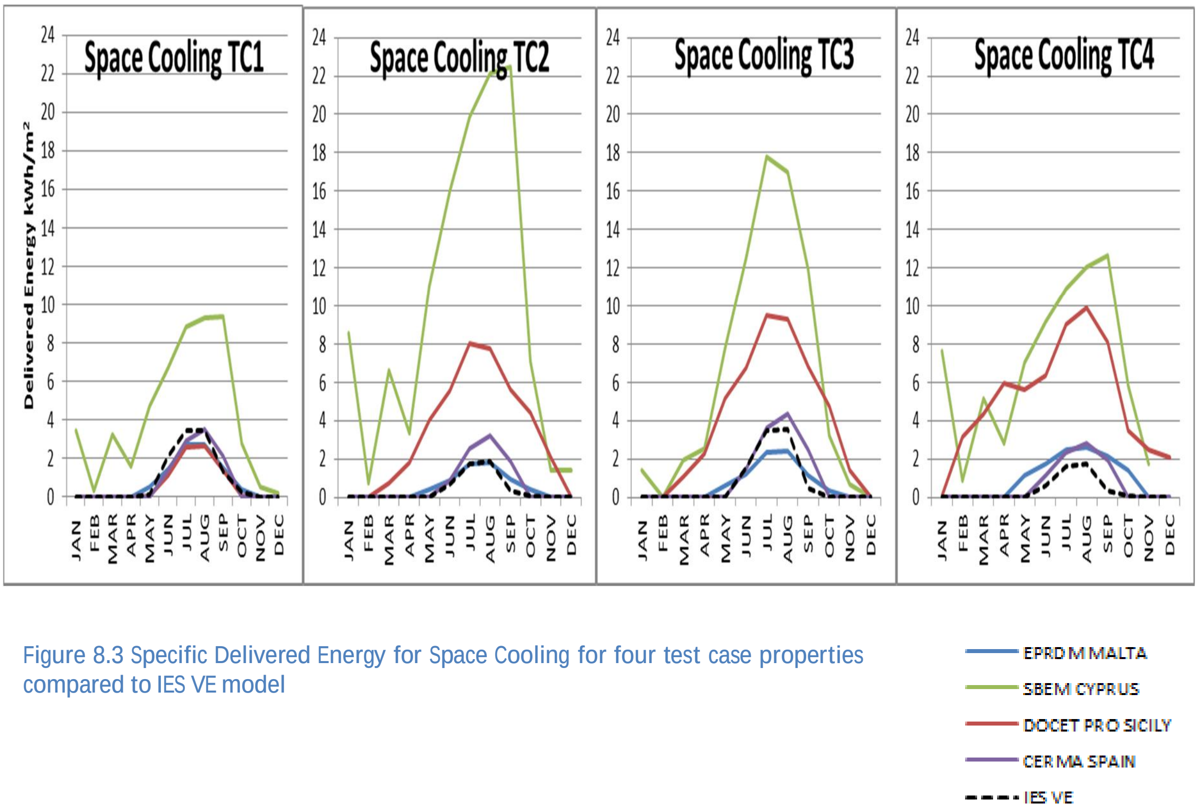


Figure 8.3 Specific Delivered Energy for Space Cooling for four test case properties compared to IES VE model

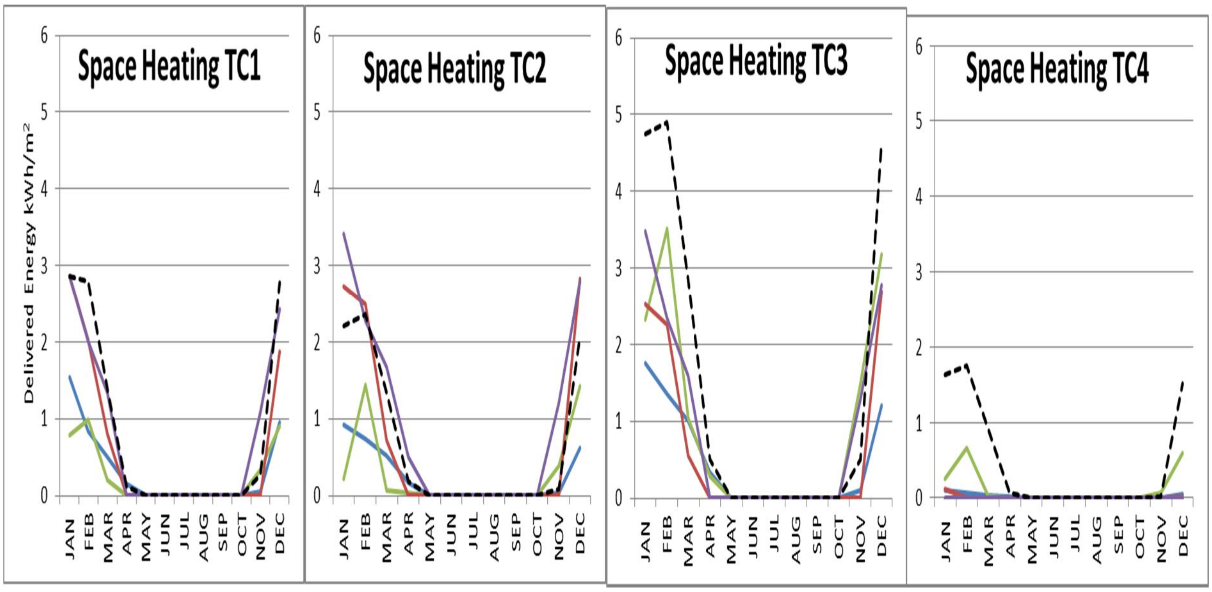


Figure 8.4 Specific Delivered Energy for Space Heating for four test case properties compared to IES VE model

8.2.3. Empirical Validation

The main finding arising from the monitoring of the test case properties was the discrepancy between the actual indoor temperature profile, and the profile assumed by both the certification methodologies and the dynamic simulation model, with a typical depiction shown in Figure 7.4. Figure 7.1 and Figure 7.2 illustrate the difficulty of applying a simple profile to define the internal temperature of the property to be used as a basis for the energy calculation. Interestingly, and to a certain extent, unexpectedly, the average internal temperature on a monthly basis were very similar amongst the test cast properties, with the maximum standard deviation on a monthly basis not exceeding 2.01^{o}C and an average monthly standard deviation over the year of 0.78^{o}C. For the case of certification methodologies using the quasi steady-state monthly method, the average monthly indoor temperature is the significant parameter and the temperature profile over the day is of little or no importance. However the measured daily temperature profiles illustrate a noteworthy difference between the temperature set-points and the actual average indoor temperature. This can be attributed to the fundamental difference in temperature control between a central heating system, where it is common practice to have a single house thermostatic control, often with thermostatic radiator valves in the individual rooms, and a reverse cycle heat pump air conditioning system, which generally has individual thermostatic control in each room. Whilst the former lends itself to a single even temperature throughout the heated residence, the latter, combined with a faster response time to user intervention, is characterised by short on/off periods and larger temperature fluctuations throughout the residence. In particular, even if the same temperature set-point is applied in this scenario, the selected temperature is only requested in a few rooms concurrently (possibly even just one), and the other rooms are left uncooled (or unheated), thus allowing the overall property temperature to fluctuate more freely and to follow the ambient temperature profile. The proportion of used (and heated or cooled) rooms is directly related to the number of rooms in the property and the number of occupants present. The higher the proportion of used rooms, the more the average property temperature approaches the indoor temperature set-point. Figure 7.4 shows that it is unrealistic to expect the actual average internal temperature to ever reach the temperature set-point. It should also be kept in mind that as far as both the methodologies and the dynamic simulation model are concerned, the internal temperature set-point is also an assumed value, and may be varied in accordance with the particular requirements of the occupant(s), possibly on a room-by-room basis.

The monitoring of the metered energy to the test case properties provides a general profile of energy use for heating and cooling in the Mediterranean climate. The accuracy of the data using an hourly and a daily time step is not sufficient to compare the energy profile on this basis to the temperature profile. However, the monthly total energy data for the test case properties, corrected to represent the delivered energy for heating and cooling (Figures 8.5 and 8.6) clearly shows that there are two peaks energy demands in the year, one for each season. In three out of the four test case properties, the peak summer demand is greater than the peak winter demand, with the detached property in Cyprus (TC4) being the exception. It is difficult to identify a relationship between the actual delivered energy, the EPC calculation methodology, and the dynamic simulation. For the terraced apartment TC1, the metered delivered energy closely follows the values calculated by the EPRDM certification methodology, and this happens to a lesser extent for one of the two semi-detached properties TC3. However in the case of the other semi-detached property TC2, the metered energy closely follows the values calculated by the IES VE model for the winter season, and does the same for the summer season with the exception of the peak values for August (Figure 7.5). The well insulated detached property TC4 shows practically no relationship between the three sets of values.

The importance of air tightness is questionable in a climate where the opening of windows was the traditional method of cooling homes during the summer period. The CERMA methodology is the only one of the four certification methodologies to take this into account during the summer period. On the other hand, the rapid introduction of air conditioning for cooling of Mediterranean homes, together with other lifestyle changes, has meant that the opening of windows for night cooling is less frequent. Whilst the calculation methodologies use different approaches to define the infiltration rates, the values calculated for the test case properties show that the infiltration rates for the different properties using the same methodology (Table 8.1) can vary from between 50% (EPRDM and CERMA) to 100% (SBEMcy). The actual blower door tests also show a variation of nearly 100% between the most and the least airtight properties (Table 8.2). It is also significant to note that although three different algorithms are used by the different certification methodologies, none of these calculate values for the test case properties that are in line with the measured results. For the case of the terraced apartment TC1, the measured infiltration rate is double the rate calculated using the EPRDM algorithm, and this would have the effect of increasing the calculated delivered energy for heating by 35%, and decreasing the delivered energy for cooling by 4%. For the semi-detached property TC2, the measured infiltration rate is half the rate calculated using the EPRDM algorithm, and this decreases the calculated delivered energy for heating by 15% and increases the delivered energy for cooling by 5%. This indicates that the energy calculation for heating is more sensitive to changes in the infiltration rate than the energy calculation for cooling, possibly because of the smaller temperature differences between the indoor and the outdoor temperatures during the cooling season.

8.3. Correlation of results with statistical data

Whilst SBEMcy is based on the simplified quasi steady state methodology proposed by EN ISO 13790 (CEN, 2008), as are both EPRDM and DOCETpro, unlike the latter two the Cypriot implementation of the standard is applicable to all buildings and not limited to residential buildings. The implication is that the calculation of energy use has not been tailored specifically to residential buildings and the results produced reflect this inherent difficulty. One major difference between SBEMcy and the other methodologies is that the length of the cooling season is not defined or limited, but cooling is available all the year round. This results in the anomalous situation of a possible residential cooling load throughout the year, with simultaneous heating and cooling in the winter months. Whilst this is often the case in multi-zone commercial buildings, in a residential context it is highly unlikely to have a requirement for both heating and cooling during the same period, particularly in a Mediterranean context where the seasonal transitional months between winter and summer are characterised by a mild climate requiring no space conditioning. Another potential inaccuracy in the implementation of SBEMcy for residential buildings is the difference in the concept of intermittent heating and cooling when compared to commercial buildings. Intermittency in commercial buildings is normally clearly defined and regulated by the working hours whereas in residential applications with individual room temperature control, intermittency is considerably more variable. Fokaides et al (2011) suggest that the cooling conditioned space in dwellings does not exceed 20% of the total area, whilst the heated space is closer to 80% of the total area. They also recommended that the daily operating schedule of the cooling equipment should be set to 60% of the daily heating schedule. Panayiotou et al (2010) found that the calculated energy using SBEMcy was double the energy consumption and attributed this to the incapability of the simulation methodology to reflect the characteristics of the local lifestyle. SBEMcy adopts the adjustment of the set-point temperature to compensate for intermittency using the procedure suggested for quasi-continuous heating and/or cooling (ibid.) whilst EPRDM (and DOCETpro) apply the corrections for intermittency recommended for the monthly method. Once again the procedure selected by SBEMcy is probably better suited to non-residential buildings than to dwellings. However it seems that the tendency for SBEMcy to overestimate cooling loads is not limited to housing since the Ministry of Commerce Industry and Tourism (2013) recommend a factor of 0.3 to be applied to the calculated values for cooling energy consumption for all building types.

In Italy over the last decade, households in the South have experienced an increase of 1.3 percentage points in the share of energy expenditure over total expenditure, driven by an increase in the demand for cooling, while those of the median household increased by 0.3 percentage points (Faiella, 2011). However in a review of the Italian residential building typology for building stock energy assessment, the types of equipment considered are those for space heating and domestic hot water, and cooling equipment is omitted (Corrado, et al., 2011). The Italian EPC is defined as including the whole energy used in the building, with separate values for heating, hot water, and cooling, but the cooling performance in only concerned with the building summer load and the performance of the cooling system does not feature (Antinucci, et al., 2011), implying that cooling is not placed on the same level as the other energy requirements. In fact the Energy Performance Index is limited to the sum of the energy performance indices for heating and domestic hot water and the legislative requirements defining the indices for cooling and lighting have not been established (Comitato Termotecnico Italiano - CTI, 2012). Paradoxically, the minimum requirements for cooling in residential buildings in climatic zones A and B (the furthest South) are set at a maximum cooling demand of 40 kWh/m^2, whilst for non-residential buildings, which would be expected to having higher internal gains and correspondingly higher cooling loads, the minimum requirements are set at a maximum of 14 kWh/m^2 (Moneta, et al., 2013).

DOCETpro does include a clear definition of the heating season (unlike SBEMcy) which varies between October/April and December/March depending on the selection of one of the six climatic zones defined by the Italian Standard UNI 10349, and by default this is also a definition of the cooling season. Again, this calculation methodology makes no allowance for intermittent operation of the heating and cooling plant but assumes constant operation throughout the respective season, with no allowance for temperature set-back or time scheduling of equipment.

An investigative study of the cooling performance of two residential blocks of apartments consisting of a total of 196 units in Milan compared the results of a summer monitoring campaign with the theoretical model used for energy calculation in the region. The block was constructed with a well-insulated thermal envelope, with U values considerably lower than the minimum legal requirements in Italy. The delivered energy for cooling of the apartments ranged between 0 and 58 kWh/m^2yr with approximately 70% of the properties having a value of below 20 kWh/m^2yr. Three of the apartments were monitored over the summer season, with specific focus on the internal temperature profiles, which were found to vary between 24 and 28^oC. In spite of the fact that both the certification methodology and the dynamic simulation for the three apartments showed considerable differences in the predicted specific cooling requirements with over 50% variance, due to one of the monitored apartments being on the top floor, the actual measured energy consumption was a lot more uniform with just a 28% variance. The mean internal temperature of the apartments varied from 24.26 to 25.67^oC, and this was for a scenario with a centralised air conditioning system scheduled for 24 hour operation (Dall'O, et al., 2012). A similar analysis during the winter months recorded mean internal temperatures between 20.25 and 23.00^oC, with a much larger variance in the actual measured specific energy consumption for heating of 96%. This was much higher than the predicted values calculated by the certification procedure, but the energy certificates are based on a constant temperature of 20^oC during the heating season (Dall'O, et al., 2012).

An analysis of the results of the application of the CERMA methodology to a typical residential single family house in the different climatic zones in Spain showed that the annual delivered energy for heating ranges from 18.0 kWh/m^2 for the A3 region in the south (Cadiz) to 122.8 kWh/m^2 for the D1 region in the north (Vitoria). The calculation for the annual delivered energy for cooling demonstrates a much smaller range from nil in C1 (Bilbao) and C1 (Vitoria) to 29.6 kWh/m^2 for B4 (Seville) (Glez-Caballin Sanchez, et al., 2013). The reference data for existing properties based on representative construction typologies and technical systems, were calculated on behalf of the Spanish Government in order to establish the range of values for the energy performance scales (Salmeron, et al., 2011). The values for the C3 climatic region (Almeria) are shown in Table 8.1 below. The average values for actual delivered energy to housing in the Mediterranean region, based on a sample size of 1,232 properties are 35.3 kWh/m^{2}yr for heating and 16.9 kWh/m^{2}yr for cooling (IDAE , 2011).

REFERENCE VALUES SPAIN

LOCATION: Almeria

Building Type	Energy demand			
	Heating	Cooling	Domestic Hot Water	Total
	kWh/m^{2}yr	kWh/m^{2}yr	kWh/m^{2}yr	kWh/m^{2}yr
Apartment	36.5	33.7	12.1	82.3
Single Family House	44.7	46.8	16.6	108.1

Table 8.1 Reference values for energy demand in Almeria Spain (Salmeron, et al., 2011)

8.4. Guidelines for the application of EN ISO 13790

In the current CEN experts group which is preparing the second generation of CEN standards to support the EPBD, it has been suggested that there are advantages to the use of a hourly calculation method where the input for the user is not more complex than for a monthly calculation procedure. However the CEN experts group is of the opinion that the usefulness of the monthly method is limited with the growing numbers of low energy buildings, with increasingly complex dynamic interactions between occupancy patterns, climate, and technical systems. The group feels that these developments require so many correction factors that the monthly method is no longer the simple and transparent method as it used to be and that this should be replaced by a simple hourly method, without adding complexity for the user (van Dijk, 2012).

There are several options or approaches recommended for the implementation of EN ISO 13790 and the standard does not provide any specific guidelines for the selection of the most appropriate option for specific applications. EN ISO 13790 covers three different types of calculation methods, a quasi-steady-state calculation method (monthly or seasonal), a simple hourly dynamic calculation method, and calculation procedures for detailed hourly simulation methods. The standard recommends that the choice of method depends on the use of the building, the complexity of the building and its systems, and the scope of the calculation. Although residential buildings make up a large proportion of the building stock, there are no specific recommendations regarding the selection of a calculation method for evaluating the energy use for space heating and cooling of homes. However it appears that the majority of EU member states have selected the quasi-steady-state calculation method for certification of the energy performance of housing. Whilst the simplicity of this method could be considered to be its most attractive feature, experience from both this and other studies of the energy performance of residential property demonstrates that schedules for occupancy and heating/cooling systems cannot be defined hourly on a global basis but differ according to the number, sociological status, and economic profile of the occupants. The results presented in Chapter 6 make evident the contradictions apparent when using a sophisticated dynamic simulation tool with a set of input data based on a very generalised occupancy profile. This challenges the current proposals from the CEN experts group to discard or give less importance to the quasi-steady-state calculation method and raises the issue whether the calculation should be defined by the reliability of the input data rather than by the calculation procedure, with a direct relationship between availability and accuracy of the input data and accuracy of output.

The difficulty of defining the occupancy profile is also significant in relation to the next issue regarding the definition of the model insofar as whether the energy calculation for a residential property is to be performed on a single-zone or a multi-zone basis. Most residential certification methodologies opt for a single-zone calculation, with exceptions such as SBEMcy which allows for zoning. The introduction of zoning makes the requirements for precise definitions of occupancy and operating conditions even more onerous. This then carries over into the definition of the set-point or internal temperature for the zone or zones. Section 7.2 clearly indicates that the prediction of a fixed winter heating and a fixed summer cooling set-point does not reflect the actual situation. In a Mediterranean context the definition of an internal temperature set-point for the residence is made more complex by the fact that houses rarely have central heating which is the norm for central and northern Europe. On the contrary the cooling systems generally consist of individual units or possibly centralised systems with individual room control, such as variable refrigerant volume or flow systems, with heating often provided through reverse cycle operation of the cooling systems. This results in an operational profile of the heating and cooling systems that is dominated by intermittency of operation on a room-by-room basis, resulting in mean dwelling temperatures which are well outside the range predicted by assuming a single internal temperature set-point for a fixed period of say, eight hours per day. The data acquired from temperature monitoring in all four test case properties clearly show that out of three rooms monitored the most frequent scenario when the cooling / heating system is in operation is that when only one of the rooms is acclimatised. This introduces the necessity for a definition of a spatial average internal temperature that falls between the heating/cooling system temperature set-point (which is not necessarily a fixed value) and the free running temperature, in the ratio of the conditioned to unconditioned areas (which also varies with time). Whilst EN ISO 13790 gives consideration to intermittency of plant operation, this is handled in a very deterministic fashion, with two options, for either an adjusted set-point temperature or a dimensionless reduction factor. The adjusted set-point temperature is recommended for setback of the temperature set-point, which is seldom the case for residential buildings. The dimensionless reduction factor for intermittent heating is defined in relation to the number of hours in the day with a normal heating set-point whilst the dimensionless reduction factor for intermittent cooling is defined in relation to the number of days in the week with a normal cooling set-point, although the standard does permit the use of a national method at national level to take into account the effect of intermittency. The strict application of the dimensionless reduction factor for intermittent cooling as proposed by EN ISO 13790 would imply that if cooling was used on a daily basis, even if for a short time period, there would be no reduction for intermittency.

One of the principal contributors to the discrepancies between results of the different national methodologies was the inconsistency of definition of the length of the cooling and heating seasons. The EN ISO 13790 standard suggests that the length of the seasons be determined at national level but also suggests a method for determining the cut-off points for the two seasons, based on the principle that the heating season includes all days when the useful portion of the heat gains do not balance the heat losses, and the cooling season includes all days when the heat losses do not balance the useful portion of the heat gains.

Whilst there are several technical requirements within the calculation methodology that require complex solutions both as regards data collection and model sophistication, the outcomes from the research highlight that the procedures defined by the standard need to be more rigorous when defining the setup parameters for the model. This is accentuated by the specific peculiarities of operation of domestic heating and cooling systems in a Mediterranean context. The refinement of data collection and the calculation procedure for improved accuracy in the handling of thermal bridges, infiltration rates, shading, thermal mass, and correction factors should only take place when the basic parameters for the model have been defined, and the model calibrated to meet the clearly specified goals of the EPC.

8.5. Improving the EPC for Residential Property in the Mediterranean

Technical requirements for the reduction of energy consumption in housing in the Mediterranean region are acknowledged to be complex due to the existence of an air-conditioning load as well as a heating load (Asdrubali, et al., 2008), and most of the mature energy certification methodologies implemented in northern and central Europe only consider winter heating. Researchers have found that the simplified methods described by the EN ISO 13790 standard are better suited for calculation of heating energy use than cooling (Kokogiannakis, et al., 2008). As recently as 2010 (eight years after the introduction of the first EPBD), it was reported that southern European countries have no form of labelling or market infrastructure for passive or low energy houses (Mlecnik, et al., 2010). The introduction of the relevant legislation for the implementation of the EPBD and the recast EPBD in the Mediterranean region has not been straightforward, and the potential of Energy Performance Certificates, both as a reliable source of information about the energy performance of building stock and as a marketing tool, has not yet been realised (Abela, et al., 2013).

8.5.1. Outcome of applying 8.3 to test cases

The variety between the results obtained from the certification methodologies, the monitored data, and the dynamic simulation demonstrates that the definition of the framework for the input parameters is significantly more important than the calculation method itself. The salient points requiring better definition are discussed hereunder.

The length of the cooling season

Figure 8.1 clearly shows the discrepancies in the length of the cooling season between the four national methodologies, and this contrasts with the close agreement shown in Figure 8.2 for the length of the heating season. Whilst Figure 8.3 shows small variations between the IES VE dynamic model and the EPRDM and CERMA methodologies, it is clear that these three calculations, although based on three completely different theoretical foundations, limit the cooling season to a maximum of six months of the year, completely ruling out the possibility of cooling between November and April. The possibility of year round cooling, or simultaneous heating and cooling, is not realistic in a residential context and the official certification methodology should include checks to ensure that this does not happen.

Definition of the internal temperature and hours of operation of the cooling plant.

The internal temperature is usually defined as the temperature set point for both the cooling and the heating season. It has been highlighted in 8.4 that whilst there is a relationship between the temperature set point and the average internal temperature, these are by no means equal. The relationship depends directly on the number of rooms that are actually heated or cooled at any one moment, as well as the intermittency of operation of the air conditioning equipment. The high cooling energy requirements calculated by the DOCETpro methodology can be attributed to the assumption of 24 hour operation. Both DOCETpro and SBEMcy make no allowance for partial heating or cooling but assume that the average internal temperature is equal to the temperature set point, further contributing to the higher cooling loads shown. The zoning requirements of SBEMcy also assume longer operating hours for the cooling plant than the eight hours considered by both EPRDM and CERMA. Whilst the actual internal temperature is very dependent on the behaviour of the occupant, the stratagem of assuming a constant internal temperature throughout the residence is acceptable for central heating installations but is not precise enough for housing with air conditioning systems controlled on a room-by-room basis. The measured temperatures charted in Figure 7.1 suggest that it is appropriate to consider an average internal temperature that varies on a monthly basis, and which follows the trend of the average external temperature. This is clearly due to the proportion of internal floor area within the property that is not being cooled (or heated), thus placing the average internal temperature somewhere between the selected temperature set-point in the conditioned rooms and the free-running temperature in the unconditioned rooms.

Zoning, occupancy, internal loads

Three out of the four methodologies assume that the property being certified consists of a single zone. This is a simpler approach than the zoning assumed by SBEMcy and allows for more rapid data entry and reduces the possibility of errors. In view of the characteristics and dimensions of the majority of residential properties, the certification methodology, particularly when a simplified calculation method is used, is better suited to a single zone approach.

The data assumed for occupancy affects both the internal loads as well as other factors such as hot water usage. While occupancy varies from property to property, as well as between regions, etc., for the certificate to be relative, the occupancy data should represent actual occupancy rates. If regional values are not available, then a standard data set should be used. It is questionable how occupancy rates can vary from one person per $60m^2$ in Malta to one person per $33m^2$ in Spain.

Similarly the data for internal loads, which reduce the heating requirements and increase the cooling requirements, need to be related to the actual average loads experienced in residential property. Whilst this data is not always accessible in published format, it is certainly available from statistics of energy usage.

8.5.2. What should be done for an improved EPC? And a more useful EPC

It is useful to recall that the EPC is intended to be a measure or indicator of the energy efficiency of property, as well as a means to suggest recommendations for the improvement of the energy performance of the certified property. In order for the EPC to have practical value, it is critical that the predicted energy performance accurately reflects the energy use attributed to both building construction and occupant behaviour. Assessing the accuracy of predicted energy use of occupied buildings poses far greater challenges than the theoretical case where comparative testing is performed using hypothetical buildings with stipulated occupancy and operational conditions (Parker, et al., 2012). Analysis of energy prediction tools has shown an extensive but sparsely documented reliance on defaults, rather than the use of actual data relating to known conditions, giving rise to a situation where increasing the number of inputs or refining the precision of the calculation method does not improve accuracy of the predicted energy use.

Determination of the accuracy of the prediction of the energy performance necessarily requires the availability of actual energy data suitably representative of the national building stock. Empirical validation of the national energy performance calculation methodology requires this statistical database which is generally unavailable in Mediterranean regions. In fact the main source of data is the recently set up database of EPCs which cannot be considered as representative of actual energy performance. Data from empirical studies has shown considerable variation in energy use, even for virtually identical buildings, with up to three times the variation in energy use for a group of ten intensively metered and highly similar homes in Florida (ibid.) and even larger variations for other studies. This emphasises the fact that a large dataset is required for the extraction of average values representative of the housing stock, which can then be used for comparative purposes against the energy performance certificate calculation. Without this statistical data, the large differences between the four methodologies examined earlier in this study, could lead to the conclusion that the predicted energy performance displayed by some of the methodologies has no relation to average energy use. In spite of the potential for large variations between individual properties, if the energy performance certificate cannot be related to the average energy performance for the housing stock, its usefulness as a baseline for potential energy improvements to certified property becomes severely limited.

It is acknowledged that the standardised methodology employed to generate an EPC cannot be related to the actual occupancy and operational characteristics of the certified property, due to the fact that in order for the EPC to be comparable, it provides a prediction of energy use under standardised conditions. However in relation to the use of the EPC for the provision of recommendations for improvement of the energy performance of the certified property, greater precision is required to make a more accurate estimate of end-use energy consumption and savings under specific operational conditions in order to relate costs to savings for suggested improvements to the property. One method of relating the projected energy savings to the actual energy performance has been implemented by Standards Norway, whereby the energy assessor has to relate the calculated energy performance to the actual utility bills as part of the exercise to propose improvements to the property and calculate projected savings. Along similar lines, the Building Research Establishment has modified their energy performance assessment tool SBEM for use in Mauritius, adding the feature to input the actual energy bills together with operational data so as to relate the calculated energy performance to the actual building behaviour and align the two before estimate the projected savings from any recommended energy performance improvements (Lewry, et al., 2012).

8.5.3. The EPC and decision making

The raison d'etre of the EPC is based on a two-pronged strategy, where the EPC has been conceived as a marketing tool to promote energy efficient dwellings and a better quality building stock, and as a stimulus to householders to improve poor energy performance of their dwellings. However, evaluation of the effectiveness of the EPC as a policy instrument has shown that whilst higher rated dwellings do obtain a market advantage, the EPC is still ineffective as a driver for the improvement of energy efficiency (Murphy, et al., 2012), or indeed as a decision making tool for energy saving refurbishment. This crucial shortcoming is directly related to the lack of confidence in the information provided by the EPC, coupled with the complete absence of any monitoring and evaluation programs to correlate the EPC data with actual energy consumption trends, particularly in the Mediterranean climate (Murphy, et al., 2012). Even in the colder north and central European climate, where the energy profile of dwellings is dominated by the space heating load, with several countries having mature energy performance calculation methodologies that have been refined over the last thirty years, the theoretical energy consumption has been shown to be questionable (Visscher, et al., 2013), with predicted energy consumption for energy-inefficient housing being much higher than actual consumption, and vice versa for energy-efficient housing. Majcen et al (2013) concluded that the use of the EPC for decision making could lead to inaccurate estimates of payback periods and misleading targets for reduction of primary energy and CO_2 emissions. This was confirmed by Laurent et al (2013), who identified that EPCs in four central European countries consistently overestimated actual heating energy demand by over 50%.

Whilst there is considerably less data available for housing in a Mediterranean climate where the building energy requirements are reasonably well distributed between summer cooling and winter heating, and although it is acknowledged that the calculation methodologies for summer cooling have not been tested as rigorously as those for winter heating, comparisons between the predicted and the actual energy performance for summer cooling in Italy (Dall'O, et al., 2012) and in Cyprus (Fokaides, et al., 2011) have also shown that EPCs in these countries overestimate actual cooling energy demand by a similar factor. At the same time, the data collected on the test case properties at the basis of this research clearly show that the substantively different results can be obtained by varying the application of a methodology that is inherently similar between the four case study certification software programs examined. This is also confirmed through the comparison with the results of the IES VE dynamic simulation model, even though the model was constrained by input parameters defined by the certification methodologies rather than the actual test case properties operation. Whilst it is has been asserted that energy efficiency in mild climates is completely dominated by occupant behaviour (Kordjamshidi, et al., 2006), it appears that the correlation between occupant behaviour and the choice of input parameters has not been carried out in sufficient depth, and this is the principle cause of inaccuracies in the certification methodologies.

8.6. Summary

Analysis of the data collected has identified a number of input parameters having considerable significance on the accuracy of the output of the energy performance calculation methodologies. The variances between these parameters on a national basis has a larger effect than differences of precision between the methods, or even differences in the detail and accuracy of data collection. The use of the EPC as a driver for the improvement of energy efficiency, or as a tool for taking and supporting decisions related to design and refurbishment for improved energy performance, has been rendered untenable due to unpredictability of the accuracy of output. This could be attributed to implementation of the EPC calculation methodologies without a mechanism to calibrate the output against the actual building stock performance, and does not necessarily imply any shortcomings in the methodologies themselves.

Chapter 9. Conclusion

9.1. Introduction

This research investigated the methodologies implemented for energy certification of housing in the Mediterranean region of Europe, specifically Cyprus, Italy, Malta, and Spain. The methodologies were applied to four test case properties, which were also modelled using the dynamic simulation software IES-VE. Actual internal conditions and energy consumption of the test case properties were metered and analysed. The predicted energy performance generated by the methodologies was compared to the dynamic simulation models generated by IES-VE and the metered data from the test case properties. The objective was to determine whether the certification methodologies provide an accurately calculated value of energy demand in Mediterranean housing. The energy certificates issued by the methodologies are one of the main outcomes of the EPBD. The certificates themselves, and the data contained therein, constitute a measure of the energy efficiency of the certified buildings. The generation of energy certificates which bear no relationship to the actual or the typical energy use of the national building stock is detrimental to both the effectiveness of the certificates and the aims of the EPBD. Whilst there are a number of mature certification schemes in north and central Europe, the concept of energy efficiency in relation to building performance, particularly in the residential sector, is relatively recent in southern Europe. Furthermore, the energy performance of housing in south Europe has to consider air-conditioning in summer and heating in winter, whereas in the north and central Europe, the focus is exclusively on winter heating. The effect of the summer air-conditioning load can be seen in Figure 1.2.

The first part of this study (Chapter 2) examines the state of existing research into the validity of the EPC as a tool to accelerate the transformation of the existing housing stock into low-energy dwellings, within the context of Mediterranean housing. It was found that the effectiveness of EPCs was restricted and that the expected impact on energy and financial savings had not been attained, mainly due to difficulties in implementation, monitoring, and quality control of the energy certification of buildings. Insofar as research into Mediterranean housing is concerned, the focus is on the differences between north and south Europe, and the increasing use of air-conditioning. Several researchers have regarded traditional housing as a reference model for energy efficient design, while others have investigated new and innovative techniques and materials for low energy housing. The main emphasis is on research into the effects of insulation, thermal mass, ventilation, and shading, but examples of the development and construction of high performance energy saving buildings in the region are clearly limited. Some work has been done on the analysis of the certification methodologies in the region, but the amount of published research which includes both cooling and heating performance is limited. The majority of residential certification methodologies are based on the quasi steady state method proposed by EN ISO 13790, and researchers have often compared the results obtained to those produced by a dynamic simulation model generated by TRNSYS, EnergyPlus, IES VE, or similar programs. Analyses of the implementation of the EN ISO 13790 steady state methodology have generally found that this required calibration in order to produce results significantly close to those obtained by dynamic simulation. The parameters requiring calibration are the utilisation factors, the building reference time constant and the numerical coefficient. Comparisons of the output from EPC calculations to the measured energy are rather less frequent, but the few published studies generally identify significant differences between the measured and the calculated cooling loads. These differences have generally been attributed to discrepancies between the assumptions made by the calculation methodology and the actual occupants' behaviour and lifestyle. In north and central European countries, where the domestic energy profile is dominated by space heating, and cooling is practically non-existent, studies comparing certificate values and actual energy use found significant differences between the two. When the EPC data is extended to calculate the projected savings from energy performance improvements to the building, it was found that the actual savings would probably not exceed 50% of the value of the calculated savings. These differences between actual and calculated energy performance are at the heart of widespread criticism of the EPC, and could also be part of the cause of general reluctance to adopt and implement the energy performance certification system for buildings.

Chapter 3 outlines the methodology adopted for this work. The research is centred in the geographical area defined by the Mediterranean regions of southern Europe, within the field of construction and the built environment. The nature of the research incorporates requirements for both quantitative and qualitative techniques, and this was the basis for the decision to opt for a mixed methodology, and to operate in the framework of the case study approach. The case studies selected consisted of four national certification calculation methodologies adopted in Malta, Cyprus, Italy and Spain. Since the methodologies are implemented through software routines, the research technique considered the three categories of software testing recommended by Judkoff (1998), namely empirical validation, analytical verification, and comparative testing. The certification calculation methodologies are expected to meet the requirements of EN ISO 13790, and three out of the four case study methodologies selected are actually based on the monthly quasi-steady-state calculation method prescribed by the standard as one of three different types of calculation method. Chapter 4 starts by examining this calculation method since it is central to the current implementation of the EPC. This is followed by an overview of the four national approaches selected as case studies, namely EPRDM (Malta), CERMA (Spain), DOCETpro (Italy), and iSBEMcy (Cyprus). Table 4.4 presents an overview of the main differences between these calculation methodologies. This chapter also includes an introduction to the IES VE dynamic thermal simulation software used for analytical verification of the building models generated by the national software programs used for generation of EPCs.

Four test case properties were used for comparative testing of the four case study methodologies. Each test case property was used to generate a model using each of the four methodologies, and after establishing that the differences in the weather data for the methodologies are minimal (See Table 5.1 and Table 5.2), the delivered energy calculated for space heating, space cooling, and domestic hot water were compared for each property in Chapter 5. This showed that the calculated values for space heating and domestic hot water for the different methodologies tended to converge, but that there were pronounced differences between the calculated values for space cooling. Two calculation methodologies, EPRDM and CERMA, displayed better agreement between the space cooling results, even though CERMA was the only case study methodology directly based on the EN ISO 13790 quasi-steady-state calculation procedure. In Chapter 6, the use of dynamic simulation to model the behaviour of the test case properties showed considerable divergence from the results produced by the case study certification methodologies. Once again the results for space heating show better agreement than the results for space cooling, and the dynamic simulation appears to correspond more closely to the Maltese (EPRDM) and Spanish (CERMA) methodologies for the cooling calculation. On the other hand, the Maltese methodology shows the most pronounced variation from the dynamic simulation when the delivered energy for space heating is calculated. This comparison was carried out on the basis of a defined set of operating parameters, eliminating the effects of the random behaviour normally exhibited by occupants of dwellings.

The outcome of the monitoring of the test case properties was presented and compared to the results obtained from the calculation methodologies and the dynamic simulation in Chapter 7.

The measurements of the internal temperature in the test case properties showed that the assumptions made by the calculation methodology in connection with this fundamental parameter would benefit from refinement. Needless to say, without accurate definition of this parameter, the expected benefits from the increased accuracy of the dynamic simulation model are completely eliminated. Figure 7.1 indicates that there is little variation in internal temperature between the test case properties, and that defining the average monthly internal temperature rather than simply having a seasonal temperature set-point could be a simple matter.

The power data did not provide the equivalent level of detail to that of the temperature data, since the data were restricted to the monthly power measurements and corrected to give space heating and cooling energy. Nevertheless, Figures 7.5a and 7.5b demonstrate that the correlation between the EPRDM methodology, the dynamic simulation model, and the metered data, is generally more precise for the summer cooling season than the winter heating season. This is in contrast to the indoor temperature profiles, where the correlation between the methodology and the measured temperatures is more accurate in winter than in summer. This appears to indicate that in the summer, the building cooling energy performance is less sensitive to indoor temperature variations than during the winter heating season.

The data collected from the pressurisation tests confirmed the uncertainty of the air change rate estimation and justified the wide range of values calculated or assumed as default by the different certification methodologies.

The analysis in Chapter 8 identified a number of input parameters having considerable significance on the accuracy of the output of the energy performance calculation methodologies. The variances between these parameters on a national basis has a larger effect than differences of precision between the methods, or even differences in the detail and accuracy of data collection. The use of the EPC as a driver for the improvement of energy efficiency, or as a tool for taking and supporting decisions related to design and refurbishment for improved energy performance, has been rendered untenable due to unpredictability of the accuracy of output. This is attributable to the implementation of the EPC calculation methodologies without a mechanism to calibrate the output against the actual building stock performance, and does not necessarily imply any shortcomings in the methodologies themselves.

The following sections present the conclusions and recommendations drawn from this research in the context of the research questions. Section 9.2 presents the contribution to knowledge whilst section 9.3 discusses recommendations for policy and practice in a Mediterranean context, as well as suggestions for future work.

9.2. Contribution to knowledge

9.2.1. Background

Prior to defining the contribution to knowledge from this research, it is appropriate to highlight the original aspects of the work. Whilst the literature review has made reference to the fact that the existing body of knowledge on the energy performance of Mediterranean housing is limited, particularly in comparison to research on the energy performance of housing in colder climates, nevertheless a number of studies have been identified and discussed in Chapter 2 of this work. However, apart from the fact that the subject area of the research is still relatively unexplored and in a developmental stage, it is perhaps the selection and application of the research technique in this area that provides a unique and original aspect to the work, whilst also establishing a solid foundation for the development of the findings arising from the contribution to knowledge of this work.

Whereas there has been similar research examining the energy performance certificate methodologies in South Europe, this work has hitherto taken the format of either comparing different methodologies amongst each other in a national context, or comparing a national methodology against one or several commercial or academic software packages, or comparing the methodology against metered data for a test case. This research is unique in that it has considered three separate approaches for verification, namely comparative testing of the methodologies with each other, analytical verification of the methodologies against an established dynamic simulation software package, and empirical validation against metered data for the test case properties, and this has all taken place across four nations or regions, providing a much larger backdrop for the work.

9.2.2. The Research Question

> "To establish whether the current certification methodologies used in South Europe (Malta, Italy, Spain, Cyprus) provide an accurately calculated value of energy demand in Mediterranean housing."

This research has found that the current certification methodologies for south European dwellings have not been tried and tested, specifically in the regions where both space heating and space cooling are required for the occupants' comfort. The use of the energy certificates without associating them with the actual energy use of the national building stock is detrimental to both the effectiveness of the certificates and the aims of the EPBD. The shortcomings appear to be twofold, in that there is no clearly defined process for associating the body of certificates representing the national building stock with a statistical database representing building typology and energy profile, and that there is no procedure to calibrate, even in the most rudimentary way, the building model used for certification against the actual building. In other words, the EPCs issued by the national methodologies appear not to have undergone any form of calibration process, neither en masse against national statistics, nor individually against the specific building being certified.

The first level of calibration is dependent on the existence of national statistics relating the average or typical energy profile of dwellings to the predominant typologies, and this research has found that these statistics are not available, or not published, in the desired format. The relatively limited variety of energy sources in south European regions should mean that the extraction of the required statistics from energy company records ought not be an arduous task. The current unavailability of these statistics contributes to an impression that the energy performance of housing in the region is not an issue of political or economic importance.

At the same time, due to the unavailability of statistical data against which the certification methodologies for Mediterranean housing could be calibrated, the output from the certification methodologies can and has been compared, in this work and by others, to the results obtained from dynamic simulation models. Whilst these models are more time consuming to create and implement, they provide the facility to model the behaviour of the dwelling more precisely. This has prompted the suggestion that replacing the quasi-steady-state monthly method for the generation of EPCs by a more precise method, similar to or aligned with a dynamic simulation model, albeit in a simplified format, would lead to greater precision in the data output by the certification process.

However this work has found that the underlying assumptions made about the use of the dwelling, particularly in relation to the heating and cooling plant, together with the indiscriminate use of default values, have a far greater influence on the outputs from the certification methodology than any inaccuracies in the calculation method itself. Several researchers have identified the indoor temperature as the most significant parameter when determining the energy performance of the dwelling. Whilst the indoor temperature is directly related to the behaviour pattern of the occupants, the measured data clearly shows a common trend for the four test case properties. Unlike the characteristic assumption of a fixed winter temperature and a fixed summer temperature, the actual indoor temperature in Mediterranean housing clearly appears to 'follow' the external temperature, in line with the principles of adaptive comfort.

Apart from the indoor temperature, both the length of the heating and cooling seasons and the operating schedule of the heating and cooling plant have a significant effect on the accuracy of the output from the certification methodology. These parameters are not user defined but are predetermined within the methodology, and when the selected values are inappropriate, the errors generated in the cooling energy calculation are significantly larger than for the heating energy calculation.

The infiltration rate, the utilisation factor, and the thermal capacity of the structure are also parameters in the certification methodology that are generally managed through the use of default values or standardised assumptions. Whilst these factors are not as significant as the above factors relating to the operation of the heating and cooling plant, there is also scope for the development of guidelines to ensure that values for these parameters are established on a national or perhaps a regional basis.

The analysis of the delivered energy for heating and cooling obtained from the four national EPC calculation methodologies, the dynamic simulation model, and the metered data, was directed towards determining the cause of the differences between actual and predicted energy consumption, and identifying the characteristics that have a major effect on discrepancies in the EPC calculation methodology. According to the results obtained, the main sources of error are inaccuracies in the application of the quasi-steady-state calculation model used. In particular, the accurate definition of the operating parameters for the heating and cooling system is particularly significant if a more precise prediction of the energy performance of the dwelling is required. It is suggested that it would be more appropriate to introduce guidelines to ensure the correct application of the existing model than to consider replacing the model with a more sophisticated method for the calculation of the dynamic thermal behaviour of the dwelling. The accuracy of the dynamic simulation model (IES VE) is counteracted by the fact that the behaviour of the occupants of the building cannot be modelled with equivalent accuracy, hence the additional time and effort required to set up the more sophisticated model are difficult to justify.

9.2.3. Subsidiary questions

a. What are the consequences of the differences in the energy performance of housing between North and South when implementing a common policy directive?

The mild Mediterranean climate is characterised by ambient temperatures that are closer to comfort levels than the colder northern climates. The dual space conditioning load that includes both summer cooling and winter heating necessitates an architectural compromise. Energy efficient building design should consider shading and ventilation for the summer season, and this does not correspond with the winter requirement for insulation, airtightness, and maximisation of solar gains. Whilst the magnitude of both the cooling and the heating load is not large, cooling is provided by air-conditioning equipment using electricity, which is mainly generated from fossil fuels, resulting in a high primary energy factor. This means that the energy supply can transform the relatively low energy requirements of Mediterranean housing into a substantial carbon footprint. The requirements of the EPBD cannot be considered to be biased in favour of property in any particular climatic region. However, the implementation of the EPBD has been most rapid in the colder regions of North and Central Europe, with the effect that South European regions and states have, in their majority, attempted to implement the EPBD in a similar manner. This has also had an effect on the concepts, materials, and techniques considered suitable for the energy efficient design of housing in the Mediterranean.

The accepted rationale for improving the energy efficiency of housing in colder climates is primarily to minimise the heating load through a well-insulated airtight envelope, and only after this is achieved is attention given to improving the efficiency of the heating plant. In terms of fuel, the generation of heat is possible using a variety of different sources, and this also lends itself to the maximisation of the use of low-carbon or alternative fuels, as well as large-scale solutions such as district heating.

The analysis of the building energy performance of the test case properties arising from the calculation methodologies, the dynamic simulation model, and the metered data demonstrates that the specific values for delivered energy for heating and cooling approach the design values for primary energy for low energy housing such as the Passive House, even though three out of the four test case properties have uninsulated building envelopes which could be considered as poor by European standards. On this basis, it is likely that the rationale for improving the energy efficiency of housing in the Mediterranean should, in complete contrast to the above, focus primarily on improving the conversion factor from delivered energy to primary energy, followed by ensuring the most efficient selection and operation of the heating and cooling plant, with improvements to the building envelope being given the lowest priority. This suggested approach should be particularly effective when evaluating cost effective methods of improving the energy efficiency of the existing building stock, since the costs of improvements to an existing building envelope are substantially higher than the cost of implementing improvements during the construction phase.

b. What techniques can be applied to ensure reliability of the energy performance certificate methodologies in a climate where heating and cooling are required for residential buildings?

Significant research directed towards improving the relationship between the energy performance certificates and actual energy consumption has been carried out for a number of north and central European countries (Laurent, et al., 2013) (Majcen, et al., 2013). This research is centred on the comparison of the calculated energy for space heating and domestic hot water with the metered consumption and it would be appropriate to apply similar techniques to compare the calculated energy for space cooling. This would be in addition to the proposal made earlier for the calibration of the certification methodologies against statistical data representative of the national or regional building stock. An additional complexity in the collection of data defining the metered consumption for space cooling is that the energy source is principally mains electricity and hence the data from meter readings include the consumption for all electrical appliances, lighting, etc., and the value for space cooling must therefore be either separately metered, or extracted in some way from the total consumption. The metered consumption for space heating and domestic hot water in colder climates is normally readily available from the metered gas consumption, which only includes a small element of consumption for cooking in addition to the main demand which is for heating and hot water.

Once the national methodology has been calibrated to correspond with the statistical data representative of the national building stock, so that the energy performance certificate becomes representative of the national stock when occupied under a standardised set of conditions which are also representative of national averages, the actual certificate can also be used to provide a set of tailored values relating to actual occupancy. These tailored values are the values to be used when estimating the projected energy savings arising from refurbishment or improvements to the property or the systems.

c. Can the differences between national methodologies applied in similar climates be justified?

The main factors contributing to the differences between the outputs from the national methodologies arose from differences in the method of application of the methodology, and not from differences in the calculation procedure. When considering that the mild Mediterranean climate reduces the significance of the thermal properties of the building envelope, and the limited variety of cooling systems and technologies suitable or available for installation in housing, it becomes difficult to justify differences in the application of national methodologies designed for use in regions with the same climate. At the same time, in larger EU states such as Spain and Italy, with significant north-south differences in climate, it is important to ensure that the standardised set of conditions defining the use and occupancy of the residences are representative of the different regions. This work has shown that the operation of heating and cooling systems in the Mediterranean region cannot be defined in the same manner as the operation of central heating systems in north and central Europe.

9.3. The EPC in a Mediterranean context – at a conceptual level

The scope of the EPBD is the reduction of the substantial energy use in buildings throughout the EU. The Mediterranean region is characterised by a mild climate which results in substantially lower heating loads in winter, but with an additional cooling load in summer. Although the climate is named after the Mediterranean sea, and is typical of the countries bordering this sea, the EU member states on the Mediterranean coast fall into a number of different categories. There are the island states, such as Malta and Cyprus, the island regions, such as Sicily and Crete, and the coastal regions of larger countries such as Spain, Italy and Greece. This variety is reflected in the implementation of the EPBD but there are a number of common attributes. Collectively, these states and regions do not have a long tradition in the field of energy saving in buildings and have not established or defined models for low-energy buildings (Fokaides, et al., 2014). The diversity of the different regions makes it hard to collect comparable statistics, particularly since these are generally available on an national basis. However, Panayiotou et al (2010) defined the average primary energy consumption of dwellings in Cyprus at 129 kWh/m^{2}yr, on the basis of measurements taken of 500 dwellings. This value is based on a primary energy conversion factor of 2.7, which implies an actual metered energy consumption of 47.8 kWh/m^{2}yr. A remarkably similar figure of 55.3 kWh/m^{2}yr has been established as the average metered energy consumption for Malta (Abela, et al., 2010), although the higher primary energy conversion factor applied in Malta of 3.45 results in an average primary energy for dwellings of 190.7 kWh/m^{2}yr. The primary energy conversion factor is related to the choice of fuel and the efficiency of generation and distribution of energy, and has no direct relationship to the actual efficiency of the buildings. Clearly the metered energy consumption for dwellings in Malta and Cyprus is of the same order (47.8 and 55.3 kWh/m^{2}yr), and with the introduction of more efficient generating plant in Malta, the average primary energy consumption in Malta and Cyprus is in the region of 120 kWh/m^{2}yr, which is actually the defined maximum required by the PASSIVHAUS standard (Ford, et al., 2007). This implies that the average Mediterranean house, in a region without a long tradition of energy-saving regulations in buildings, meets the maximum energy requirements established in design guidelines for comfortable low energy homes, without any energy-saving interventions.

In the light of the above, it is useful to revisit the functions of the EPC, namely its dual purposes as a marketing tool and as a stimulus to encourage home owners to improve the energy efficiency of their property. As discussed in 9.2.2, the usefulness of the EPC as a marketing tool is enhanced by its accuracy in reflecting the energy performance of the certified property in relation to the national building stock. When, however, the use of the EPC as a stimulus to home owners is considered, the EPC has to incorporate additional data to enable the home owner to understand how the improvements considered could affect the actual energy performance of the property. The energy saving improvements generated by the EPC must take into consideration the potential for realistic savings, a potential which is limited by the inherently energy-efficient nature of the buildings in a mild climate. From a national or societal viewpoint, investment in more efficient means of the production and distribution of energy have the potential to be more cost effective in the reduction of primary energy and the carbon footprint of the Mediterranean residential building stock.

9.4. Research limitations and recommendations for future work

This research has identified the need for national or regional calibration of the EPC methodology for homes, specifically in the context of a climate where both heating and cooling are required. It questions the current trend of moving towards more complex calculation models and methods for the EPC and indicates that better definition of the simple quasi-steady-state method produces results that are more representative of actual energy performance.

Three research limitations have been identified. Firstly, since the research focussed on the four different test case properties which were used to validate the four case study methodologies at the basis of this study, the research is constrained by the window of opportunity provided by both the test case properties and the case study methodologies. Secondly, the availability of detailed monthly statistical data on the energy performance of housing in Mediterranean states and regions would have lent additional weight to the findings and conclusions. Finally the analysis of energy performance of housing is generally related to the occupants and their behaviour. This research only considered the occupants' behaviour insofar as the definition of the internal temperature was concerned, this being the most significant parameter in relation to both energy performance and comfort.

Following completion of this work, the following areas with scope for further exploration for the expansion and refinement of the findings are suggested:

9.4.1. Behavioural aspects of energy performance of Mediterranean housing

This work has identified that there are clear differences between the definition of the indoor temperature between air-conditioned and centrally heated properties. These differences arise from the more frequent usage of individual room on/off and temperature control in air-conditioned properties, as opposed to the more typical centralised thermostat in centrally heated properties, albeit with increasing usage of thermostatic radiator valves. The implications of the rebound effect in a Mediterranean context, and the changes in occupants' expectations resulting from the shift from naturally ventilated minimally heated housing to air conditioned residences over the past few decades. There is scope for further work in analysing this and other possible behavioural differences and possibly identifying regional and cultural behaviour and its effect on energy performance.

9.4.2. A cost optimal strategy in a Mediterranean context

The recast EPBD has introduced a requirement for the cost optimisation of the minimum requirements for the energy performance of buildings. This exercise has increased the focus on the effect of improving the energy performance of components. There is scope for research comparing the effectiveness of improvements in the production and distribution of energy, improvements in technical systems, and changes in behaviour, all in the context of a mild climate. Whilst the requirement for cost optimisation is of both practical and economic value, the application of this requirement has manifest as an extension of the existing movement towards energy efficient housing in colder climates. The principles for the definition of cost optimisation in a Mediterranean context need to be re-examined, and defined within the parameters of both the climate and the behavioural characteristics of the region.

9.5. Summary

At the commencement of this research, the EPBD was introduced as a legal instrument to achieve the great unrealised potential for energy savings in the building sector in the European Union. Labelling and certification schemes such as the EPC have been identified by the International Energy Agency as one of the main policy instruments to reduce energy demand in the building sector. Implementation of the EPBD and the dissemination of EPCs in south Europe has lagged behind both legislation and policy for building energy efficiency in north and central Europe. In relation to the EPC calculation methodologies for housing in the Mediterranean region, this has had a number of implications, namely that the methodologies are based on or adapted from methodologies from other regions where cooling is not a consideration in the housing sector; that information on the effect of space cooling on the energy performance of housing is limited and guidelines on the implementation of the relevant European Standards for the sector are too generic to be of specific use; that the methodologies themselves have not been tested or calibrated against statistical or actual data; that the effect of behavioural differences arising from the Mediterranean climate, building typology, and socio-economic framework have not been taken into account. This has manifest itself in the wide variety of results obtained from the certification methodologies, the monitored data, and the dynamic simulation, with the largest discrepancies arising from variations in the application of methodology rather than in the calculation methods. Whilst it is possible to fine tune the certification methodology in order for EPCs to provide a more accurate overview of the energy performance of Mediterranean housing, the inherently low energy demand of the sector, driven by the mild climate, challenges the cost effectiveness of the EPBD driven strategies which appear to be dominated by the high space heating loads characteristic of northern Europe. There can be no question that the Energy Performance Certificate has the potential to function both as a marketing tool and as a performance indicator for Mediterranean housing, but it is clearly not in a position to meet these requirements in its current format. Whilst it is technically possible for EPCs to provide a more accurate performance indication of Mediterranean housing, specifically when the certification methodologies are calibrated as shown by this research, the measures promoted by the recast EPBD for the reduction of energy consumption in buildings would benefit from conceptual analysis and prioritisation in accordance with the specific characteristics of the region. This research has shown that the application of methods and standards without due consideration of the regional context, and with the use of default assumptions that are not based on statistical data, produce EPC results which do not represent the actual energy performance of Mediterranean housing. Since national and regional governments are increasingly looking at their EPC databases to assess the current state of energy use in housing and the measure of its improvement, it becomes even more urgent to ensure that both the strategy and the implementation of energy efficiency in housing are tailored to the particular climatic and behavioural aspects of the Mediterranean region.

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List of Appendices