Actual & Calculated Heating Energy Consumption in Hellenic Dwellings Using Data from EPCs and Field Studies

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Abstract
This paper presents the results from the work carried out in Greece in order to quantify the differences of calculated and actual heating energy use in Hellenic residential buildings. The approach is based on the exploitation of data from thousands of energy performance certificates (EPC) to derive empirical adaptation factors, defined as a ratio of actual to calculated energy use that could then be used to adjust predictions for large building stocks. The work is complemented by evidence from field surveys on occupant behaviour and the actual energy use before and after the implementation of energy efficiency measures in dwellings.

Data from the EPCs reveals that the average actual primary energy use is 44% lower than the normative calculations. Findings from the field surveys of occupant behavioural changes in the operation of space heating systems confirm the deviations of calculation assumptions from actual operating conditions. For example, only 17% of single-family and 10% of multi-family houses have operating hours close to the assumed 18-hours used in the calculations, while the heated floor area is only 33% and 43% respectively, compared with the total heated floor area considered in the calculations. Field data on actual energy use before and after common retrofit actions provide additional insight. For example, weather adjusted actual primary heating energy savings are about 16% by installing double glazed windows and 18% by replacing an oil-fired boiler with a new natural gas unit and 33% with a heat pump.

Keywords – actual-calculated energy use, occupant behaviour, residential buildings

1. Introduction

Hellenic buildings accounted for 36.6% of the total final energy in Greece and reached 5.6 million tonnes of oil equivalent (Mtoe) in 2013 according to the latest officially-reported data [1]. About 3.2 million exclusive use residential buildings or 79.2% of the building stock [2] used 3.8 Mtoe or 24.8% of the total final energy use in 2013, as illustrated in Fig. 1a. The recently observed dropping trend is due to milder winters (lower heating degree days) and the deep economic recession experienced in the country since 2008 that drives the occupants’ efforts to reduce the
operational energy costs of their dwellings, even at the expense of proper indoor thermal conditions. Heating oil was the main energy carrier for space heating [3] although there is a notable drop over the past few years as a result of the imposed fuel tax on heating oil and financial crisis (Fig. 1b). Apartment buildings have turned-off central heating systems, since some residents cannot afford it and overall occupants have reduced heating hours and switched to alternative local heating (e.g. wood for open fire places).

![Fig. 1. a) Evolution of the total and residential sector final energy consumption in Greece [1] and average heating degree days (secondary y-axis). b) Evolution of average monthly energy consumption of main residences in Greece [3].](image)

Space heating is the main end-use in residential buildings accounting for 64%, followed by 17% for cooking, 10% for appliances and equipment, 6% for domestic hot water (DHW), 2% for lighting and 1% for cooling [4]. Accordingly, the annual average thermal energy use averages 10,244 kWh per household, of which 85.9% for space heating and 4.4% for DHW. Heating oil (63.8%) has been the main fuel source for space heating, despite the steep decline over the past few years. The annual average electrical energy use per household is 3,750 kWh, which is mainly used for cooking and white appliances (67%), DHW (9.4%), lighting (6.4%), cooling (4.9%) and space heating (3.0%).

Refurbishment can extend the lifespan and operation of the existing building stock, while energy upgrades can improve living conditions and lower energy bills. Along these lines, several studies have been performed to assess the potential of energy efficiency measures (EEM) in Hellenic residential buildings [5-6], and the recent national energy efficiency action plans [7-8] in compliance with the EU Directive on energy efficiency (2012/27/EU). Their main findings concur that there are significant energy savings in the buildings sector that remain untapped. Accordingly, most EEMs target the building sector for reaching the national targets for energy savings and the abatement of CO₂ emissions.

Since 2011, in line with the mandates of the national transposition of the European Directive on the energy performance of buildings (EPBD) and its recast (2010/31/EC), about 670,000 energy performance certificates (EPC) have been issued in Greece. The available data from the national EPC registry (buildingcert) constitutes a valuable resource for gaining an insight
on the energy performance and other characteristics of the building stock. Dwellings account for ~85% of the issued EPCs. The average calculated total primary energy use is 261.6 kWh/m², while the CO₂ emissions reach 70.3 kgCO₂/m² [9]. However, it has long been recognized that there may be significant deviations amongst calculated versus actual energy use that may exceed 100% in some cases [10]. This may be due to a multitude of reasons including the role of occupants’ [10-11] and deviations from the assumptions of normative calculations [12].

Beyond the well prescribed methods on how to calibrate software predictions for detailed analysis at building level, the challenge remains on how to adapt the estimations from official calculation tools and facilitate the process of handling the diversities in building stock modeling. A multinational effort within EPISCOPE [13] paved the way by developing a conceptual framework for assessing refurbishment processes of European residential buildings in a transparent and effective way. The project motivated a number of national pilot actions targeting regional or national residential building stocks, considering different approaches. This paper presents some of the findings from the Hellenic pilot project. It focuses on the findings from a streamline approach that was derived in an effort to close the gap of actual and calculated heating energy consumption and improve the knowledge base for performing more realistic energy performance assessments of a residential building stock.

2. Methodology

Previous investigations have demonstrated that there may be significant deviations of calculated and actual energy use in buildings. The challenge of closing this gap when addressing millions of cases in national building stock analysis mandates an easy to implement generic approach. In an effort to quantify these discrepancies for Hellenic residential buildings the approach followed in this work exploits relevant data from EPCs in order to derive simple empirical adaptation factors (defined as a ratio of actual to calculated energy use). These factors could then be used as multipliers for correcting the calculated values to obtain a more realistic actual energy use for representative building types in building stock models.

Complementary data were also collected from a field survey that documents recent behavioral changes of occupants and the role of the human factor in the operation of residential space heating systems. This new insight reflects common practices that deviate from normative calculation assumptions according to national regulations. The data are used to derive similar correction factors for adapting calculations to more conservative estimates of the actual energy use. Finally, field surveys were also performed in order to quantify the actual effectiveness of some popular EEMs applied in Hellenic dwellings. Energy bills were collected and analyzed to also derive normalized energy use intensity (EUI) values (i.e. a commonly used...
metric expressed as the annual energy use per unit floor area), before and after the implementation of EEMs.

3. Insight from EPCs

National EPCs provide valuable data on existing buildings that progressively reflect the building stock. The Hellenic EPC is a two-page document [14] that includes general building data, the building’s energy class label (using asset rating compared against a reference building), annual calculated (and sometimes the actual thermal and electrical) final and primary energy consumption and CO₂ emissions, along with a breakdown of energy carriers for the different end-uses, among others. The normative calculations are performed using the official national software [14], assuming for residential buildings an 18-hour daily operation for the entire heating season, for achieving indoor thermal comfort conditions set at 20°C for the entire conditioned floor area, in compliance with the national technical guidelines. The primary energy is estimated using national conversion factors for different energy carriers, i.e. 2.9 for electricity, 1.1 for heating oil and 1.05 for natural gas.

The valid EPCs that include data on actual thermal and/or electrical energy consumption account for only 3.5% of the total (i.e. ~16,000 cases), since this information is provided on a voluntary basis. The first stage analysis used the “raw data” of unique EPCs from dwellings that use only one energy carrier for space and DHW heating, and depending on the installed heating systems they included both actual thermal and electrical energy consumption. The raw data includes 11,824 cases, of which about 15% are for single-family houses (SFH) and 85% for multi-family houses (MFH). The available data were then screened with some intuitive data quality controls, e.g. excluding erroneous or questionable values of thermal or electrical energy consumption (i.e. organized in bins and censoring top outliers). This constitutes the “screened data” composed of ~8,500 cases, of which about 17% are for SFH. The following analysis focuses on space heating and DHW. The available data for the primary energy use intensity (EUIₚ) are illustrated in Fig. 2. The data exhibit large variations as a result of the unique building characteristics or prevailing weather conditions (since the normative calculations are performed using standard weather files) and occupant behavior.

Overall, the higher calculated EUIs correspond to lower actual energy use, which is more evident for dwellings with a poor energy performance. This is known as the “prebound” effect ranging in European households from 30% to 40% less than the calculated values [15]. The opposite phenomenon is identified as the “rebound” effect [16], which is most notable for low-EUI dwellings (i.e. dwellings with a good energy performance), when actual energy use is higher than the calculated EUI. Studies in European dwellings quantify the rebound effect of 20% up to 68% [17].
Fig. 2. Scatter plots of raw (left) and screened (right) data for the calculated and actual primary energy use intensity (kWh/m²) for space heating and DHW in Hellenic dwellings. The least-square regression lines correspond to SFH and MFH. The 45-degree line (i.e. x=y) identifies the case when the calculated and actual energy consumption values are in perfect agreement.

Considering the primary energy use, the empirical adaptation factors, i.e. f(actual/calcualted), average 1.35 for the raw data (i.e. 35% higher energy use than calculated) and 0.56 for the screened data (i.e. 44% lower than calculated). Looking at the final energy use, the corresponding ratios average 1.57 using the raw data (i.e. 57% higher) and 0.65 for the screened data (i.e. 35% lower). Apparently, the observed differences among the raw and screened data underline the need for implementing proper data quality controls. This would have been possible if one had access to the relevant input data entered by the energy auditor for generating the EPC, which was not possible during this study.

A similar analysis could also be performed for deriving specific empirical adaptation factors for different groups of data that correspond to Hellenic residential typology, i.e. aggregating and analyzing data in terms of building size (i.e. SFH and MFH), construction period (e.g. pre-1980 to reflect the time that the first national thermal regulation code was introduced, 1981-2010 for partially or fully insulated buildings and post-2011 for buildings constructed in compliance with the new code) and location based on the four national climate zones. The details for the different building types are elaborated in [18]. Representative results from the analysis of SFH and MFH building types using the empirical adaptation factors derived from the screened data, are illustrated in Fig. 3. The ratios should be comparable to the slope obtained from a linear regression on the same set of data, with zero intercept. The data are organized for the different construction periods and climate zones (e.g. zone A in the south and zone D in the north of the country). The cloud data is the actual primary energy use retrieved from the corresponding EPCs. The estimated values are the product of the calculated data with the corresponding adaptation factors.
Fig. 3. Correlations of actual (bullets) and calculated (triangles) EUI$_p$ for SFH and MFH types using the screened data. Dashed lines represent the best-fit linear regression to the corresponding actual EUI$_p$ data (bullets) from the EPCs. Solid regression lines are fitted to the calculated EUI$_p$ data (triangles) using the corresponding adaptation factors.
Apparently, the estimated values line-up and each time the resulting best-fit linear regression (solid line in Fig. 3) has a slope that is equal to the corresponding empirical adaptation factor for the specific building type. For example, considering the case of a pre-1980 SFH and MFH in Zone D, the slope (i.e. adaptation factor) is 0.44 and 0.54, respectively. Specific building types do not include sufficient number of cases (i.e. no EPCs are currently available that include the actual energy consumption data) and especially for recent constructions. As the EPC database is progressively enriched with more certificates that include the actual energy use, the process could be repeated to periodically update adaptation factors to capture current trends and complete the bands of building types that have a very small number of cases (e.g. new construction periods).

4. Insight from Field Surveys

Homeowner field surveys, reaching out to 211 dwellings, were performed in order to identify current trends in the use and operation of heating systems in Hellenic dwellings. The actual operating conditions deviate from the assumed operating conditions used in the normative calculations and thus explain some variations of the actual energy use. Additional information was also collected from field surveys that targeted buildings which have implemented popular EEMs in order to collect energy bills before and after the measures.

4.1 Actual vs Assumed Operating Conditions

Occupants are usually forced to reduce the heating operating hours, lower indoor temperature and isolate rooms in their dwellings (i.e. reducing the heated floor area) in order to reduce heating bills. The field survey revealed that only 17% of SFH and 10% of MFH have operating hours close to the assumed continuous heating hours of the normative calculations, while only 33% of SFH and 43% of MFH heat their entire dwelling. Lowering the indoor temperature is another common occupant (re)action in an effort to reduce heating costs, even at the expense of thermal comfort. According to the collected data, only 28% of the occupants in SFH and 27% in MFH reported that their average indoor temperature is set at 20°C that resembles the specified indoor set-point in the normative calculations. The weighted average temperature reported by the occupants is 19.6°C during the day, with a temperature night set-back at 16.9°C. Individually or collectively, one can derive a series of similar empirical adaptation factors for adjusting the calculated values and account for deviations from the standard operating conditions. Although the available data from this limited campaign does not currently cover all building types, the representative results were 0.39 for the heating operating hours, 0.88 for the heated floor area and 0.91 for indoor temperature deviations.
As anticipated and confirmed by the collected data, the most notable impact of these recent developments is on the overall assessment of the prevailing indoor thermal conditions in Hellenic dwellings. Only 56% of the occupants in SFH and 45% in MFH manage to feel comfortable in their homes. The overall findings are in agreement with results from the annual national survey of dwellings [4].

4.2 EUIs Before vs After EEMs

Findings from over 80 field surveys of actual energy consumption “before” and “after” the implementation of popular EEMs revealed relevant energy performance indicators for documenting the effectiveness of different measures under real operating conditions. The analysis was based on energy bills for at least one heating season for dwellings with most of the times comparable operating conditions “before” and “after”. The data was also used to derive empirical correction factors, i.e. ratios of f(after/before) that reflect actual energy savings as a result of specific EEMs. When necessary, the analysis accounted for the deviations of the seasonal on/off periods, the prevailing weather conditions (i.e. normalizing the data using the ratio of reference heating degree days HDD\( _R \) (i.e. 947) to the local HDD\( _P \) for the period of energy use), adjusting the heated floor area in case of MFH with vacant apartments that are not heated, etc.

Although the available data from this limited campaign does not currently cover all building types, the representative results provide some practical yardsticks and trends. The variations of the weather adjusted EUI\(_P\) “before” and “after” some popular EEMs are summarized in Fig. 4.

![Fig. 4. Weather adjusted primary energy use intensity in dwellings “before” vs “after” the installation of double glazing (left), the replacement of oil-boiler to natural gas boiler (center) or heat pump (right). The 45-degree line (i.e. x=y) identifies a case when the actual energy use “before” and “after” is identical, i.e. there are no savings.](image)

The most popular building envelope refurbishment measure is the replacement of windows with double glazing, resulting to average actual savings of 21%. Specific variations for some building types are summarized in Table 1. For the heating systems, replacing oil-fired boilers with new natural gas units (especially in MFH) or with high temperature efficient heat pumps are some of the most common measures. Overall, some of the large observed variations after the EEMs are also strengthened by occupant
behavioural changes and altering operating conditions as a result of the economic crisis that are reflected in the more recently collected data.

Table 1. Weather adjusted primary energy performance indicators and empirical adaptation factors f(after/before) as a result of some popular EEMs.

<table>
<thead>
<tr>
<th>Building type</th>
<th>Before EUI_p kWh/m² (HDD_90/HDD_p)</th>
<th>After EUI_p kWh/m² (HDD_90/HDD_p)</th>
<th>Avg f</th>
</tr>
</thead>
<tbody>
<tr>
<td>(number of cases)</td>
<td>Min</td>
<td>Max</td>
<td>Avg</td>
</tr>
<tr>
<td>EEM: Install double glazing</td>
<td>ALL (N=10)</td>
<td>90.5</td>
<td>76.6</td>
</tr>
<tr>
<td></td>
<td>SFH pre-1980 (N=6)</td>
<td>89.2</td>
<td>108.2</td>
</tr>
<tr>
<td></td>
<td>MFH pre-1980 (N=1)</td>
<td>120.5</td>
<td>100.6</td>
</tr>
<tr>
<td></td>
<td>MFH post-1980 (N=3)</td>
<td>36.0</td>
<td>71.7</td>
</tr>
<tr>
<td>EEM: Replace oil boiler with natural gas</td>
<td>ALL (N=49)</td>
<td>68.5</td>
<td>56.6</td>
</tr>
<tr>
<td></td>
<td>MFH pre-1980 (N=14)</td>
<td>42.3</td>
<td>96.6</td>
</tr>
<tr>
<td></td>
<td>MFH post-1980 (N=35)</td>
<td>35.4</td>
<td>95.2</td>
</tr>
<tr>
<td>EEM: Replace oil boiler with heat pump</td>
<td>ALL (N=15)</td>
<td>97.0</td>
<td>63.0</td>
</tr>
<tr>
<td></td>
<td>SFH pre-1980 (N=1)</td>
<td>147.9</td>
<td>73.0</td>
</tr>
<tr>
<td></td>
<td>SFH post-1980 (N=9)</td>
<td>68.6</td>
<td>135.9</td>
</tr>
<tr>
<td></td>
<td>MFH post-1980 (N=5)</td>
<td>54.9</td>
<td>112.5</td>
</tr>
</tbody>
</table>

5. Conclusions

Efforts to close the gap between actual and calculated energy consumption beyond a single building analysis, can benefit building stock modeling for making more realistic projections. This study presented an easily reproducible and updatable approach for exploiting readily available data from EPCs and data from short field studies to account for the role of occupants and the actual performance of EEMs.

Data analysis of actual heating energy consumption revealed that the ratio of actual to calculated primary energy use intensity averages 1.35 (i.e. 35% higher than calculated) and 0.56 (i.e. 44% lower). The screened data for deriving the adaptation ratios provide results with a slope that is close to the least-square linear regression for the different building types. This is a more realistic description of the actual energy use trends. Field studies have also revealed the effectiveness of some popular EEMs. Savings may vary widely for specific applications in different building types, depending on occupant behaviors. The weather adjusted actual EUI_p results to average savings of 16% for double glazing, 18% replacing oil-fired boilers with natural gas and 33% with heat pumps.

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