CALIBRATING RESIDENTIAL BUILDINGS FOR IMPROVED HEATING ENERGY DEMAND FORECASTING AND CONTINUOUS PERFORMANCE MONITORING.

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LEGAL FRAMEWORK

• There has been a growing interest in Europe in the evaluation of the energy demand for building heating and cooling mainly caused by the issue of **European Directive 2002/91/CE** of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings.

The objectives of the named **Energy Performance in Buildings Directive (EPBD)** are:

(a) Establishing a calculation method for the integrated energy performance of buildings.

(b) Application of minimum requirements on the energy performance of new buildings.

(c) Energy certification of buildings.

(d) Energy audits in large buildings.

(e) Regular inspection of boilers and air conditioning systems.
EPBD Directive specifies that some **building energy performance index** must be shown together with an indoor environment comfort quality index.

**Energy certification** is mainly a market mechanism whose main objective is to promote higher energy performance standards than those already regulated.

To achieve this objective:

Energy certification must provide **clear and detailed information** about the buildings’ energy performance (energy labeling), **allowing for direct comparison among different buildings**.

Buildings are usually evaluated according to a quantitative indicator (metric) of the amount of energy required by the building and therefore expressed in terms of **kWh/m² per year** consumed and these consumptions are used for rating buildings performance from bad to excellent in the final label.
The above quantitative metric of kWh/m² per year, although it has been widely adopted for the energy rating of buildings, seems to be inadequate for such an application.

This is due to the fact that it is a non-generic index or performance metric since it presents building size and type as well as strong weather dependency.

This is a problem that calls for some further special classification and other adjustments for its wider application (e.g. with the introduction of additional correction factors) based on buildings’ type and size as well as weather conditions.
Many software are available like DOE-2, BLAST, ENERGYPLUS etc. which are all based in a model representation of the building for the evaluation of its energy performance.

Various sources of uncertainty exist in the analysis of such buildings models mainly due to a lack of information on the exact characteristics of every building.

*There is a well proven strong link between domestic heating demand and climatic conditions.*

However, different distributors throughout Europe have developed models which differ to some extent.
The most common models take into account the heating degrees-days while others take into account temperatures of the preceding days, the wind and the sunlight. Still others retain only the part of consumption which is susceptible to climatic conditions or weight the degrees-days (the weight factor is less in summer and higher in winter) allowing the entirety of the consumption to be corrected.

Apart from the weather data,
• historical consumption adjusted to the demand that would be expected in seasonal normal conditions,
• indices of retail energy prices relative to GDP deflator,
• indices of real price of fuel oil and
• a variety of commercial census sources or economic indicators such as household numbers, household disposable income, employment index, fuel price forecasts etc. are also employed.
In the end, the question raised was:

How much effort and resources are necessary to produce a satisfactory building’s energy demand model?

The development of simple and more generic building energy calibration metrics and methods appears more as a necessity.
Figure 1. A simplified building heating energy model.
Thermal balance of a Building

\[ \Phi_H = (\Phi_{cond} + \Phi_{inf}) - (\Phi_{Sol} + \Phi_{int}) \]

- Building’s thermal load in Watt
- \( \Phi_{cond} + \Phi_{inf} \) = \( \Phi_{loss} \) Thermal losses
- \( \Phi_{Sol} + \Phi_{int} \) = \( \Phi_{gain} \) Thermal gains

- \( \Phi_{cond} \): Conductance losses through building’s envelope (walls, windows, doors etc.)
- \( \Phi_{inf} \): Infiltration (air) losses
- \( \Phi_{Sol} \): Solar thermal gains
- \( \Phi_{int} \): Internal thermal gains (human, lights, operating equipment)
A building in thermal equilibrium practically means that:

\[ \mathcal{Q}_{\text{loss}} = \mathcal{Q}_{\text{gain}} \]

or else its thermal load is:

\[ \mathcal{Q}_H = 0 \]

All losses depend on \((\Delta T = T_i - T_o)\) or internal \((T_i)\) – external \((T_o)\).

When \( \mathcal{Q}_{\text{loss}} > \mathcal{Q}_{\text{gain}} \) (during the winter \(\Delta T >>\) then \( \mathcal{Q}_H > 0 \)

and it expresses the necessary thermal load of a building in Watt needed in order to return to its thermal equilibrium state, defining so the thermal energy demand of the building.
Thermal Load of a building.

\[ \phi_H = \phi_{\text{loss}} - \phi_{\text{gain}} = BLC \cdot (T_i - T_o) - \phi_{\text{gain}} \]

\( \phi_H \)  Thermal load in Watt

\( T_i \)  is the necessary internal temperature of the building (or even the design temperature of the building in °C)

\( T_o \)  is the outside (environmental) temperature

BLC is the Building’s total thermal Loss Coefficient in Watt/K, which is normally calculated for every building as:
\[ BLC = \sum_{n=1}^{N} \left( U_{T,i} \ast A_i + m_{inf} \ast c_{pa} \right) \]

\( U_{T,j} \) = thermal conductance in Watt/(m\(^2\)*K) of the building components (outside walls, floors, doors, windows etc.)

\( A_j \) = the respective components’ areas in m\(^2\)

\( m_{inf} \) = Infiltration air flow in kg/sec

\( c_{pa} \) = Specific heat capacity of air in KJ/(Kg*K)
Balance Temperature of a Building ($T_{bal}$)

\[
\Phi_H = BLC \times (T_i - T_o) - \Phi_{gain} = BLC \times \left( T_i - \frac{\Phi_{gain}}{BLC} \right) - T_o = BLC \times (T_{bal} - T_o)
\]

\[\Phi_H = BLC \times (T_i - T_o) - \Phi_{gain} = BLC \times \left( T_i - \frac{\Phi_{gain}}{BLC} \right) - T_o = BLC \times (T_{bal} - T_o)\]

\[\Phi_{gain} = \text{Total heat gains of a building in Watt}\]

\[BLC = \text{Total building loss coefficient in Watt/K}\]

The balance temperature would be an excellent calibration metric of any building, however its calculation difficulties makes it impractical for it application as a performance monitoring index.
Any correlation that can be obtained between buildings’ energy demand (heating oil) and the HDDs is always useful for forecasting of its future energy demand as well as for buildings’ performance monitoring purposes.

A simple calibration metric that can be obtained from measured heating oil consumption and weather related data is the specific heating oil consumption index given as:

\[ \varepsilon = \frac{Q_H}{A \times HDD} \text{ in KWh/m}^2\text{K} \]

A is the heated area in m\(^2\) of the building (alternatively it can be used the heated Volume, V).

It can be a very useful calibration metric and used either for the future demand forecasting as well as for the heating energy performance monitoring of a single building or a whole residential building’s area.

Its advantage over the normally used index of KWh/m\(^2\) is that performs significant stability under the same operating conditions of a building while for longer time periods and wider buildings areas its stability is even better.
Table 1 – 5 Years averages of Heating Oil Consumption in KWh/m².

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Monthly average heating oil consumption (5 years mean 2001-2006) (KWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCT</td>
<td>14.6</td>
</tr>
<tr>
<td>NOV</td>
<td>19.0</td>
</tr>
<tr>
<td>DEC</td>
<td>24.8</td>
</tr>
<tr>
<td>JAN</td>
<td>25.4</td>
</tr>
<tr>
<td>FEB</td>
<td>19.5</td>
</tr>
<tr>
<td>MAR</td>
<td>17.8</td>
</tr>
<tr>
<td>APR</td>
<td>12.7</td>
</tr>
<tr>
<td>YEARLY TOTALS</td>
<td>133.9</td>
</tr>
</tbody>
</table>
Daily Mean HDDs (base temperature 18.3 °C) developed based on the daily measured HDDs between 2005-2008.

HDDs (2005-6) = \(-0.00000107\times DN^4 - 0.00005345\times DN^3 + 0.09972735\times DN^2 + 1.65484803\times DN + 11.91908223\)
\[R^2 = 0.99943183\]

HDDs (2006-7) = \(0.00000132\times DN^4 - 0.00087215\times DN^3 + 0.17230255\times DN^2 - 0.58385619\times DN + 8.51936344\)
\[R^2 = 0.99959305\]

HDDs (2007-8) = \(0.00000175\times DN^4 - 0.00119624\times DN^3 + 0.23635648\times DN^2 - 3.47219947\times DN + 38.05623489\)
\[R^2 = 0.99945395\]

Figure 2 - Daily Mean HDDs (base temperature 18.3 °C) developed based on the daily measured HDDs between 2005-2008.
Observed Transposition of Cold Development & Peakedness (max HDDs) between years 2006-7 & 2007-8 compared with the coldest year 2005-06.

Figure 3 – Observed Time shift of Cold Development & Peakedness (max HDDs) between years 2006-7 & 2007-8 compared with the coldest year 2005-06.
Figure 4 - Measured Monthly HDDs for the months October to April of years 2005-2008.
Figure 5 - % Monthly differences (per year based on the colder minus the milder year) from the measured HDDs between 2005-2008.
Figure 6 - Distribution and Cumulative Distribution of Daily HDDS recorded for the years 2005 to 2008.
<table>
<thead>
<tr>
<th></th>
<th>October</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>Σύνολο</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erbs et.al</td>
<td>109</td>
<td>276</td>
<td>413</td>
<td>447</td>
<td>340</td>
<td>273</td>
<td>137</td>
<td>1995</td>
</tr>
<tr>
<td>Measured (2005-6)</td>
<td>146</td>
<td>315</td>
<td>405</td>
<td>510</td>
<td>417</td>
<td>304</td>
<td>147</td>
<td>2243</td>
</tr>
<tr>
<td>Measured (2006-7)</td>
<td>109</td>
<td>293</td>
<td>437</td>
<td>357</td>
<td>330</td>
<td>280</td>
<td>159</td>
<td>1965</td>
</tr>
<tr>
<td>Measured (2007-8)</td>
<td>135</td>
<td>303</td>
<td>459</td>
<td>454</td>
<td>352</td>
<td>230</td>
<td>149</td>
<td>2082</td>
</tr>
</tbody>
</table>

Table 2 – Measured and calculated (from the model of Erbs, et. al.) HDDs for the specific buildings area.
### Table 3 - Calculated Mean Specific Index of Heating Oil Consumption (ε) in KWh/(m²K) of city's buildings.

<table>
<thead>
<tr>
<th>Month</th>
<th>October</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Erbs et al</td>
<td>0.049</td>
<td>0.058</td>
<td>0.061</td>
<td>0.050</td>
<td>0.044</td>
<td>0.059</td>
<td>0.070</td>
<td>0.060</td>
</tr>
<tr>
<td>Measured (2005-6)</td>
<td>0.065</td>
<td>0.063</td>
<td>0.057</td>
<td>0.071</td>
<td>0.055</td>
<td>0.063</td>
<td>0.064</td>
<td>0.068</td>
</tr>
<tr>
<td>Measured (2006-7)</td>
<td>0.053</td>
<td>0.061</td>
<td>0.054</td>
<td>0.056</td>
<td>0.052</td>
<td>0.077</td>
<td>0.069</td>
<td>0.064</td>
</tr>
<tr>
<td>Measured (2007-8)</td>
<td>0.065</td>
<td>0.067</td>
<td>0.060</td>
<td>0.057</td>
<td>0.054</td>
<td>0.065</td>
<td>0.075</td>
<td>0.067</td>
</tr>
<tr>
<td>Average</td>
<td>0.058</td>
<td>0.062</td>
<td>0.058</td>
<td>0.059</td>
<td>0.051</td>
<td>0.066</td>
<td>0.069</td>
<td>0.065</td>
</tr>
</tbody>
</table>
Figure 7 - Correlation of mean heating oil consumption with HDDs.
Figure 8 - Correlation of mean heating oil consumption with mean outside temperature.

\[ KWh = 6.56 \times T_{mean}^2 - 223.45 \times T_{mean} + 3197.17 \]

\[ R^2 = 0.92 \]
The calculated reduction is about 0.8 kWh/m²/years after construction.
By employing relevant heating oil price data for the afore mentioned period and correlating them with the actual heating oil consumption of the buildings it was revealed the fact that since most domestic heat end users in Greece are essentially captive in the short term since they have no immediate alternative to using heating oil.

**The overall residential heating oil demand was almost totally price inelastic for this period.**

The calibration metrics developed, although they appeared to be heating oil price inelastic, they can be affected and invalidated by:

- significant differences in **occupants behaviour** and especially by
- any **energy conservation measures** or **energy efficiency improvements** (improvements in buildings insulation, heating equipment etc.).
Calibrating Residential buildings by employing **proper calibration metrics** can offer, on the one hand,

*enhanced possibilities to the occupants for a continuous building energy performance monitoring, evaluation and improvement in terms of potential energy and subsequent economic savings,*

and on the other hand

*enhanced demand forecasting and demand side management possibilities to any domestic heating supplier utility.*

In addition, **modern smart domestic metering services** can utilise and further improve such calibration metrics, offering even more opportunities for substantial energy savings.