I J E M Volume 6, Number 2, July-December 2014
pp. 73-90

Household Energy Savings

J. Jantzen[*] and M. Kristensen
Samso Energy Academy, Samso, Denmark, Email: jj@energiakademiet.dk

Abstract: For savings on heating or cooling, our approach is based on temperature measurements in the household, and we have defined saving factors that estimate the potential savings as a fraction of the observed energy consumption. The approach considers local climate data, to make the saving advices more relevant to the visited households. We have found energy savings of 1000 – 8200 kilowatt-hours per household, depending on the local climate, or 5 – 20% savings per household. The first 5% result from inexpensive behaviour related changes, while larger savings result from improvements to the building envelope.

Keywords: end-use efficiency; individual action; local actions; energy performance; energy use; home energy check

INTRODUCTION

Households can find many saving advices on the World Wide Web, and an energy adviser can straightforwardly compose a list of saving advices that are relevant to a given household. One example of an advice is, 'Keep the indoor temperature low during the heating season'. It is not straightforward, however, to quantify the advices, such that the household will know how much energy and money the advice saves.

The European directive for energy efficiency, which aims at 20% energy efficiency by 2020, defines *energy savings* as, 'an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of an energy efficiency improvement measure' (Council of the European Union and European Parliament 2012). An energy advice should thus be accompanied by at least an estimate of the savings in order to be able to check the effect against the 20% target. Energy savings in households are congruent with the EU policies and regulations for energy efficiency (European Commission 2010a, b, c; 2012a, b), and the pursuit of energy savings is a business opportunity for energy agencies, among others.

Many *folk wisdom* advices arise from experience and common sense. For example, 'turn your heating system down', 'remember to turn off lights and appliances when not in use', 'set your washing machine to wash at 30°C' or 'wash only when the machine is full'. An *energy check*, performed by an energy adviser, is a quick walk-through of the dwelling that results in a list of advices relevant to the particular household. There are even checklists for households that wish to check their home by themselves (Energy Neighbourhoods 2013). The advices are useful, because they are educational, and they are believed to affect the behaviour of the household. However, we wish to deliver more accurate advices, which rest on assumptions that can be documented, and we wish to allow for differences in the local climate.

The Danish Energy Agency refers to a long list of standard saving values (Teknologisk Institut 2013). For example, replacing a three-speed circulator pump by a continuously controlled 'class A' pump saves a standard amount, namely 280 kilowatt-hours per year. The standard amount may differ from the actual savings, as it is a nominal value based on specified assumptions. The list contains similar saving values concerning lights, district heating, gas boilers, the building envelope, coolers/freezers, office equipment, cooking, oil boilers, photovoltaic panels, solar hot water panels, heat pumps, and washing devices. It is straightforward to use, and the saving values are officially approved. The list is limited, however, to equipment replacements mostly, and many of the saving values are inapplicable in other climate zones.

An *energy audit*, performed by an energy auditor, is a longer, detailed analysis with professional equipment, which results in accurate estimates of the saved kilowatt-hours and the saved money. According to the energy directive, the audit is 'a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile (...), identifying and quantifying cost-effective energy savings opportunities, and reporting the findings.' The energy audit provides accurate results, based on computer simulation, but that level of detail usually requires a component analysis of the house lasting several hours or days. The results are based on the calculated consumption of the building, not the observed consumption. Furthermore, an energy audit does not consider changes of behaviour.

In this study, we have developed a home energy check, which is conceptually positioned between folk wisdom and energy audits regarding accuracy and time consumption. The following requirements specify the scope of our home energy check.

- It should be simple enough that an energy adviser will be able to perform an energy check after a little practice.
- The result should be presented quickly to the household showing an estimate of the savings in terms of energy (kilowatt-hours) and money (euro or the local currency).
- The energy check should be over in about one hour. The energy check provides a first estimate of the savings potential.

- The calculations must be as relevant as possible, allowing for the local climate and local prices.

Our objective is to form advices based on physics. It is a challenging task, but physics is a more solid foundation than folk wisdom, the advices will have broader scope, and they will be quantifiable.

RET Screen is an admirable software package, which is built on physical equations, and it can fetch climate data from satellites and weather stations. It is freely available from the World Wide Web (RETScreen 2005). However, in order to estimate energy savings in a building, it is necessary to measure components of the building, such as wall area, wall resistance, window area, and heated floor area. Again, the results depend on calculated energy consumption, in the style of an energy audit.

From the viewpoint of physics, the heat flow in a building starts with the fuel input, which is converted by a heating (cooling) unit into end-use energy (Figure 1).

Figure 1: Overview of the heat flow in a building

The figure suggests the following three main saving advices when moving against the flow, from right to left, in the figure:

(1) Reduce the end-use consumption.

(2) Improve the efficiency of the energy conversion.

(3) Increase the share of renewable energy in the fuel.

Advice (1) is associated with behaviour, and spending less energy is a costless or at least inexpensive action. Advice (2) is related to the efficiency rate of the energy conversion unit, and also the reduction of losses in the building envelope. Advice (3) is related to renewable energy, which is free, but the installation is costly. The three items even form steps of a Swedish procedure for discovering energy savings (Energimyndigheten 2010). We focus on behaviour, and we propose the following working definition of behaviour-related savings based on the main advice (1):

Definition. Behaviour-related savings are costless or inexpensive reductions in end-use energy as opposed to improving efficiency ratios or installing renewable energy.

Nevertheless, when consulting the households we do include the replacement of equipment, changes to the building, as well as renewable energy, because they are common topics of discussion and the potential savings are large. We cannot advise how to change the building, and we do not know the cost of refurbishment, but we can estimate how much energy will be saved, as long as it only depends on physics.

We have validated our approach in widespread geographic locations in Europe, representing diverse climates. Intermediate results were presented at conferences in order to reach a wider audience and seek reviews and feedback (Klaesener et al. 2013a, b).

SAVING FACTOR METHOD

The energy consumption of a household depends, among other things, on the heated floor space of the dwelling, the surface of the building, whether it is an apartment or a house, the number of occupants, the climate, and the habits of the occupants. Regarding heating and cooling, we express the savings as a percentage of the actual (observed) consumption.

Suppose that an advice saves x kilowatt-hours on heating (or cooling), thus the *saving factor* is the fraction $f = x/X$, where X is the household's energy consumption for heating (cooling). Conversely, given an estimate $\hat{f}$ of the saving factor, we multiply by the observed (possibly estimated) energy demand in order to find $\hat{x} = \hat{f}X$, which is our estimate of the savings.

In this manner, we mitigate the risk of giving advices that save more than the household actually consumes. Furthermore, we base the estimate on the observed consumption rather than a calculated nominal consumption, as in energy audits. Even the EU goal is given in relative terms, that is, a percentage of the projected consumption in 2020.

The physical relationship between the heat flow through a wall and the outdoor temperature is simple, because it is a linear relationship.

Figure 2 illustrates a heated house with indoor temperature T_i, heat flow Q, and outdoor temperature T_o, which is assumed lower than the indoor temperature

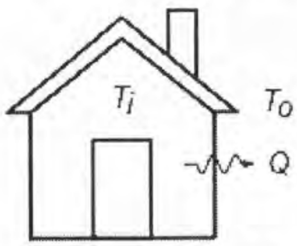

Figure 2: Heat transfer in a building. Definition of symbols

for the sake of illustration, but the following is also valid in the case of cooling ($T_o > T_i$). To be precise, Q is the *heat flux,* measured in Watt per square meter (W/m^2). One model is to view the wall as a resistor, that is, the higher the resistance, the less heat flows out of the house.

The following differential equation governs the rate of heat transfer (Fourier's law)

$$\dot{q} = -\lambda A \frac{\Delta T}{\Delta x} \tag{1}$$

where

$\dot{q}$ is the *heat transfer rate* [W]

λ is the wall's *conductivity* [W/m·K]

A is the area of the wall [m^2]

ΔT is the temperature difference across the wall [K]

Δx is the thickness of the wall [m]

We measure temperatures in degrees Celsius (°C), but use the convention that temperature differences are in Kelvin (K). The minus sign in Equation (1) is necessary, because the heat flows from the higher temperature to the lower temperature. If we substitute the variable R for $\Delta x/\lambda$ in the equation, then we have that

$$\frac{\dot{q}}{A} = -\frac{1}{R}\Delta T \tag{2}$$

The left hand side is the heat flux, previously named Q. We can now rewrite the equation to the following more convenient form (analogous to Ohm's law),

$$Q = \frac{T_i - T_o}{R} \tag{3}$$

The equation shows that the heat flux is proportional to the temperature difference across the wall, and inversely proportional to the *resistance* R. We can say that a given temperature difference drives the heat to flow through the wall at a rate depending on the resistance of the wall. The resistance in turn depends on the λ-value of the material and the thickness Δx of the wall. The heat flow accumulated (integrated) over a time interval is the energy loss corresponding to that time interval. The inverse of the resistance, $1/R = U$ is the *heat transfer coefficient* of the wall measured in W/m^2·K, the so-called U-value. The term $U \times A$ is thus the rate of heat loss, in Watt, resulting from a one degree temperature difference.

All the above is standard knowledge, but it is important for us to straighten out the physics in order to create a solid foundation. We thus note that the relationship in Equation (3) between temperature difference and heat flow is linear, and this observation is fundamental to all of what follows.

Saving Factors

Equation (3) indicates two ways to reduce the heat flux: (1) To decrease the difference between the indoor and outdoor temperatures by adjusting the indoor temperature, and (2) to increase the resistance R by adding more insulation. As a bonus, the same reasoning can be applied to a refrigerator, a freezer, an oven, or a hot water tank.

We assume that the indoor temperature is steady, but adjustable. The outdoor temperature T_o depends on the weather, but if we use the *average* outdoor temperature during the heating (cooling) season, then T_o can be regarded as steady. Consequently, the resulting heat flux Q is the average heat flux, and we do not have to worry about solving the differential Equation (3). The average outdoor temperature is available from weather stations or satellite data (RETScreen 2005).

In the first case, assume the indoor temperature is adjusted from T_i to T_i'. That causes a new heat flux Q', governed by the new temperature difference as follows:

$$Q' = \frac{T_i' - T_o}{R} \tag{4}$$

The saved heat flow is the difference $Q - Q'$ between the original flow and the new flow. The saving factor f is the saved flow relative to the original consumption. Using Equations (3) and (4),

$$f = \frac{Q - Q'}{Q} = \frac{\frac{T_i - T_o}{R} - \frac{T_i' - T_o}{R}}{\frac{T_i - T_o}{R}} = \frac{T_i - T_i'}{T_i - T_o} \tag{5}$$

The equation shows that the saving factor is equivalent to the relative temperature saving, that is, the ratio of the temperature adjustment $T_i - T'$ in the numerator to the maximal range $T_i - T_o$ in the denominator. For a one-degree adjustment, the corresponding *unit saving factor* follows from Equation (5) by setting $T_i - T_i' = 1$, that is,

$$f(1) = \frac{1}{T_i - T_o} \tag{6}$$

The unit saving factor $f(1)$ can also be applied to energy, since energy is just $E = \bar{Q} \times t$, where t is the length of the considered time interval, and $\bar{Q}$ is the *average* heat flux.

Since the outdoor temperature T_o depends on the climate, we deduce that the unit saving factor in Equation (6) depends on the climate, through T_o, but not on the resistance of the wall.

Example. The average outdoor temperature during the heating season in the airport of Rhodes is approximately T_o = 14 °C (RETScreen 2005). According to Equation (6), a decrease of the indoor temperature by 1 degree results in the unit saving factor $f(1) = 1/(T_i - T_o) = 1 / (22–14) = 0.125$. In other words, lowering the indoor temperature 1 degree saves 12.5% of the current energy consumption for heating. If the home is heated by an oil furnace, then 12.5% oil is saved.

On the island of Grimsey, Iceland, the average outdoor temperature is approximately 3 °C. Here the unit saving factor is $f(1) = 1/(22–3) = 0.053$. Thus, on Grimsey, only 5.3% is saved compared to 12.5% in Rhodes, for every degree. *End of example*.

In the second case, assume instead that the resistance is adjusted from R to R'. That causes a new heat flux Q', and consequently,

$$Q' = \frac{T_i - T_o}{R'} \tag{7}$$

By a procedure analogous to the previous one for temperatures, we find that the heat flow saved, in terms of the original flow, is the following expression:

$$Q - Q' = \left(1 - \frac{R}{R'}\right)Q \tag{8}$$

In this case, we deduce that the saving factor, in parentheses, depends on the insulation, through the resistance R, but not on the climate. Again, the same saving factor can be applied to energy, as explained previously. We can even estimate how much there is to gain from added insulation (Appendix).

Example. Assume that the household adds extra insulation, such that the new resistance is $R' = 2.5R$. Then the saving factor is $f = 1 - R/2.5R = 0.6$. In other words, if the insulation is improved 2.5 times, then 60% is saved. If the walls are responsible for a fraction, say, $w = 0.15$ of the losses of the whole building, then the saving factor corresponding to insulating the walls is $f(w) = f \times w = 0.6 \times 0.15 = 0.09$, or 9% of the heating expenses. *End of example*.

Summarizing the two cases, it is only the saving factors related to changing the target indoor temperature that depend on the climate.

Heat losses from a hot water tank behave in a similar manner. Thus, the saving factor related to lowering the temperature T_h in the hot water tank depends on the temperature of the surroundings, which is the indoor temperature T_i when the tank is placed inside the home. The unit saving factor when lowering the target tank temperature by one degree is consequently $f(1) = 1/(T_h - T_i)$. If the owner adds extra insulation to the hot water tank, or buys a new and better tank, Equation (8) applies. The saving factor owing to additional insulation does not depend on temperature.

There is a similar saving factor in connection with a shower-bath, when lowering the temperature of the water, which is a mixture of cold and hot water. Suppose that the shower outflow is held constant by a thermostatic mixing valve. The shower temperature T_s depends linearly on the hot water temperature T_h and the cold water temperature T_c, as follows,

$$T_S = wT_h + (1 - w)T_c \tag{9}$$

The weight w is the fraction of the flow owing to the hot water ($0 \le w \le 1$). Solving the equation yields $w = (T_s - T_c)/(T_h - T_c)$. If we now adjust the shower temperature from T_s to T_s', the new flow fraction becomes $w' = (T_s' - T_c)/(T_h - T_c)$. The saving factor for hot water is thus

$$f = \frac{w - w'}{w} = \frac{\dfrac{T_s - T_c - (T_s' - T_c)}{T_h - T_c}}{\dfrac{T_s - T_c}{T_h - T_c}} = \frac{T_s - T_s'}{T_s - T_c} \tag{10}$$

The equation confirms that even when hot water is mixed with cold water, the unit saving factor for a one-degree adjustment of the shower temperature is $f(1) = 1/(T_s - T_c)$. It has the familiar form, where the temperature range from the lowest temperature to the current temperature (the denominator) determines the effect of a one-degree change. The local average cold water temperature T_c is available as the *ground temperature* in RETScreen (2005).

Similar reasoning can be applied to refrigerators and freezers. It is sufficient to keep the refrigerator at 5 °C, and if the actual temperature is lower, energy can be saved in accordance with the saving factor. It is also sufficient to keep the freezer at -18 °C, and if the actual temperature is lower, energy can be saved in accordance with its saving factor.

Heating Value and Efficiency

For comparisons, such as energy performance certificates, it is relevant to speak in terms of a building's end-use energy demand, that is, after the heating unit; but for the household owner, it is relevant to speak in terms of fuel consumption, that is, before the heating unit.

The energy content in a fuel amount F depends on its *heating value* H. The energy available for end-use depends on H as well as on the *efficiency ratio* η of the heating unit. In combination, the energy available for end-use is the following:

$$E = H\eta F \quad (11)$$

Since the heating value and the efficiency ratio enter the right-hand side as factors, a relative saving (in percent) of end-use energy E corresponds to the same relative saving of fuel F. The same saving factor can thus be applied to both end-use energy and fuel consumption.

In practice, we thus avoid having to consider heating values and efficiency ratios.

RESULTS AND DISCUSSION

Table 1 shows our basic advices related to heating and cooling. Each advice is associated with a saving factor, which is to be multiplied by the fuel consumption observed by the household or estimated by the energy advisor. Furthermore, the result must be multiplied by the number of saving items agreed upon. We have used a handheld infrared thermometer (Testo 810) to quickly measure temperatures around the dwelling, including the indoor temperature, the temperatures in the refrigerator and freezer, the hot water temperature, and the cold water temperature.

Example. A household agrees to lower the indoor temperature by two degrees. The first advice in Table 1 must then be multiplied by a factor of two. If the household instead agrees to set the temperature back by 1 degree on average during the night, that is, for 8 hours rather than 24 hours, the savings must be multiplied by 8/24. *End of example.*

Table 2 shows the advices related to electricity. These are not percentages, because the electricity consumption of the electric appliances, such as light bulbs, is assumed independent of climate; the numbers are thus absolute savings in kilowatt-hours (kWh).

The advices have been inserted into a spreadsheet program (Excel) that the adviser takes to the household on a portable computer. As an example, changing the indoor temperature is associated with the saving factor $f = (T_i - T_i') f(1)$. The expression illustrates the principle that underlies the spreadsheet calculations: The quantity $T_i - T_i'$ is the temperature adjustment that we negotiate with the household; the spreadsheet multiplies by $f(1)$, which is pre-calculated based on the observed indoor temperature and the average outdoor temperature; and finally the spreadsheet multiplies by E, which is the actual energy consumption as observed by the household. During the consulting phase, the adviser enters the negotiated items to be saved, and the result is immediately available to the household. The spreadsheet program is publicly available[1].

Figure 3 shows the temperature variation in a building on the island of Samso (the Community Centre) before and after the introduction of nightly temperature setback. The temperature was logged during the winter time, when the heating unit was running. The average indoor temperature was 20.6 °C before the action.

Table 1
Relative saving factors [%] related to heating and cooling advices.

Advice	*Saving factor*
Lower the indoor temperature by 1 °C (heating)	The unit saving factor is $1/(T_i - T_o)$ where T_i is the current indoor temperature and T_o the average outdoor temperature.
Raise the indoor temperature by 1 °C (cooling)	Same as above, but relative to the energy spent on cooling.
Upgrade to energy windows	Assume that the windows are responsible for 15% of the heat losses. The new resistance is assumed 2.5 times better ($R' = 2.5R$). Thus the saving factor is $0.15\times(1 - 1/2.5) = 0.09$.
Same for cooling	Same as above, but relative to the energy spent on cooling.
Improve the wall insulation 2.5 times	Assume that the walls are responsible for 15% of the heat losses. The new resistance is assumed 2.5 times better ($R' = 2.5R$). Thus the saving factor is $0.15\times(1 - 1/2.5) = 0.09$.
Same for cooling	Same as above, but relative to the energy spent on cooling.
Improve the loft insulation 2.5 times	Assume that the roof is responsible for 30% of the heat losses. The new resistance is assumed 2.5 times better ($R' = 2.5R$). Thus the saving factor is $0.30\times(1 - 1/2.5) = 0.18$.
Same for cooling	Same as above, but relative to the energy spent on cooling.
Seal air leaks around doors and windows	Assume that the advice allows lowering the target indoor temperature by one degree. The unit saving factor is thus $1/(T_i - T_o)$, where T_i is the current indoor temperature and T_o the average outdoor temperature.
Same for cooling	Same as above, but relative to the energy spent on cooling.
Improve heating unit: lower thermostat, lower pump speed, insulate boiler, service checks, renew burner	Assume that the adjustments improve the efficiency by 1%.
Lower the temperature in the hot water tank one degree	The unit saving factor on heat losses is $1/(T_h - T_i)$, where T_h is the current hot water temperature and T_i is the temperature of the room where the tank is. The heat flow from a medium quality tank (100 litres) is $1.5\ \text{W} \times (T_h - T_i)$.
Lower the temperature of your shower 1 degree	The unit saving factor is $1/(T_s - T_c)$, where T_s is the current temperature of the shower and T_c the temperature of the cold water supply.
Shower 1 minute less	The unit saving factor is $1/t$, where t is the current shower time (default value is 7 minutes).
Install a solar hot water heater	Requires a separate calculation depending on climate. Solar fractions are between 33 % (Iceland) and 78% (Tenerife), or, equivalently, $1.5 < COP < 5$.

Table 2
Absolute savings [kWh] related to electricity advices

Advice	*Savings [kWh]*	*Explanation*
Avoid standby mode	40	Assume 40 W average power per device, and standby time 1000 h/y.
Raise the temperature in the refrigerator by 1 degree	33	The unit saving factor is $1/(T_i - T_c)$, where T_i is the room temperature and T_c the temperature inside the refrigerator (max 5 °C). Assume a standard average energy consumption E = 563 kWh (0.335 m^3, category 6, European Commission 2010b).
Raise the temperature in the freezer by 1 degree	10	The unit saving factor is $1/(T_i - T_c)$, where T_i is the room temperature and T_c the temperature inside the freezer (max -18 °C). Assume a standard average energy consumption E = 420 kWh (chest freezer, 0.283 m^3, category 9, European Commission 2010b).
Lower the temperature in 1 washing device (dishwasher from 60 to 30 °C, washer from 90 to 60 °C or from 60 deg to 30 °C)	152	Dishwasher and washer are treated as equal. The standard annual energy consumption for a washing machine is $S = 47 \times c + 51.7$, where c is the rated capacity in kilograms (European Commission 2010c). Assume size c = 6 kg. Multiply by energy efficiency index EEI = 0.82 (class C). Use saving factor 0.56 corresponding to 60 °C before / 40 °C after, and 15 °C inlet temperature.
Upgrade a washing device from class C to A++	110	Dishwasher and washer are treated equal. Energy efficiency index before upgrade is EEI_0 = 82, and after it is EEI_1 = 49 (European Commission 2010c). The saving factor is $1 - EEI_1/EEI_0$. Annual energy consumption as in the previous advice.
Upgrade a tumble dryer from class C to A++	311	The standard annual energy consumption is $S = 140*c^{0.8}$, where c is the rated capacity in kilograms (European Commission 2012b). Assume size c = 6 kg. Energy efficiency index before upgrade is EEI_0 = 81, and after it is EEI_1 = 28 (European Commission 2012b). The saving factor is EEI_1/EEI_0. The annual energy consumption is $0.81 \times S$.
Replace an old light bulb by a CFL	45	Current wattage w_0 = 60 W. New wattage w_1 = 15 W. Burning hours per year b = 1000 h. Saving is $(w_0 - w_1) \times b$
Upgrade a refrigerating device from class C to A++	414	We use a refrigerator-freezer as an example (category 7) (European Commission 2010b). The fridge compartment is 251 litres and the

contd. table 2

Advice	*Savings [kWh]*	*Explanation*
		freezer is 137 litres. The equivalent volume is $V = 251 + 137 \times (25+18)/20$. The standard annual energy consumption $S = V \times 0.777 + 303$ (category 7). The energy efficiency index before is $EEI_0 = 85$, and after it is $EEI_1 = 28$. The saving factor is EEI_1/EEI_0. The annual energy consumption is $EEI_0 \times S$.
Replace an old circulation pump by a class A pump	280	According to the official Danish standard value (Teknologisk Institut 2013).
Install PV panels		Requires a separate calculation depending on climate. Yields are between 100 kWh/m^2 (Iceland) and 240 kWh/m^2 (Tenerife).

The average outdoor temperature is 6.7 °C. From Equation 6, the unit saving factor is then $f(1) = 1/(20.6 - 6.7) = 0.072$ or 7.2%. From the plot, the average temperature dropped 1.7 K, therefore the saving factor is $f = 1.7 \times 0.072 = 0.12$ or 12%.

The example shows that we gained 12% merely by adjusting the controller for the heating unit, and this action is costless. Furthermore, the figure provides valuable documentation of actual savings.

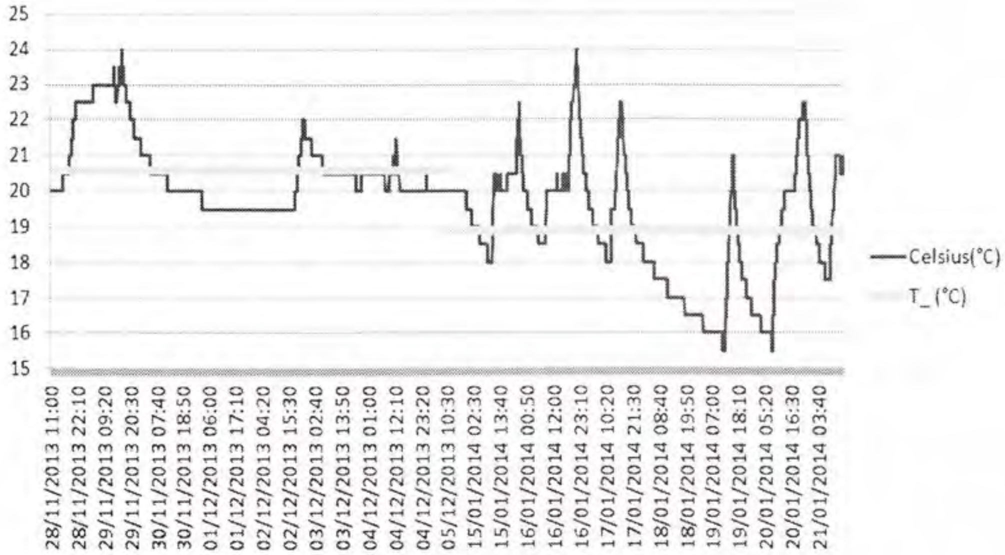

Figure 3: Temperature log before and after the introduction of nightly setback (Community Centre, Samso). The average indoor temperature T_ dropped from 20.6 °C to 18.9 °C.

Energy Savings

Based on more than 175 home energy checks we have found savings ranging from 1300 kWh (Tenerife) to 8200 kWh (Grimsey, Iceland) per household (Klasener *et al.* 2013a). As a rough indicator for the island of Samso, we find savings of 1000 kWh per household related to behaviour, but if we include changes to the building envelope and the heating unit, then we find 4000 kWh per household on average. The numbers correspond to 5 - 20% savings of the household fuel energy. In Rhodes, the numbers are as follows: 430 kWh of annual savings per household are related to behaviour, and if measures requiring an investment are added, we found at least 2000 kWh annual savings per household. In these two cases, the savings related to behaviour account for the first 5% of the savings.

In all cases the electricity bills are complex and loaded with details. The energy agency from each island must therefore decipher the energy bills, in order to discover the *incremental* cost of one kilowatt-hour, disregarding fixed costs such as the subscription fee. This is the price to use, because we start saving from the top of the stack, that is, the last kilowatt-hour spent is the first one saved. If there are several tariffs, for instance night and day, the calculation of the price becomes more difficult, and some judgement must be made to estimate an average cost. Electricity savings are especially valuable since the generation of one kilowatt-hour of electricity requires 2.5 kilowatt-hours of fossil fuel, as a general rule-of-thumb (IEE 2013).

Accuracy of the Method

Since we use a mathematical expression to calculate a saving factor, the saved energy, and the saved amount of money, we can estimate the accuracy of the method. In fact, we can even find a symbolic expression for the uncertainty.

Suppose we wish to calculate the saved money resulting from an advice. Furthermore, suppose we are applying an advice for lowering the indoor temperature, such that the unit saving factor is $f(1) = 1/(T_i - T_o)$. The saved amount for one unit saved is the product of the saving factor and two other factors, namely,

$$M = \frac{1}{T_i - T_o} \times E \times P \tag{13}$$

Here, E is the observed energy consumption, and P is the price of one energy unit in, say, euro/kWh. Each of the three factors on the right-hand side of Equation (13) is associated with uncertainty, which we represent by an *error* ϵ; it is the distance of our value from the true value. In the case of temperatures, we have a measurement error from the thermometer, and the average outdoor temperature may be off from the future average outdoor temperature. In the case of the energy E, we have to estimate the energy for heating as a fraction of the total energy; the estimate is especially prone to error when all energy is paid on one electricity bill. Even the electricity price P is uncertain, owing to the complexity of the bill. If we include the uncertainties, the expression for the saved money is the following,

$$M(\epsilon) = \left(\frac{1}{T_i - T_o + \epsilon_T} \right) \times (E + \epsilon_E) \times (P + \epsilon_P) \tag{14}$$

$$\frac{M(\epsilon) - M}{M} = \frac{M(\epsilon)}{M} - 1 = \frac{\left(\frac{1}{T_i - T_o + \epsilon_T} \right) \times (E + \epsilon_E) \times (P + \epsilon_P)}{\frac{1}{T_i - T_o} \times E \times P} - 1 = \frac{T_i - T_o}{T_i - T_o + \epsilon_T} \times \frac{E + \epsilon_E}{E} \times \frac{P + \epsilon_P}{P} - 1 \tag{15}$$

This equation shows that the overall error factor depends on the individual errors in a manner which is meaningful, because it is a combination of three distinct error terms. The equation shows also that the worst case scenario, which results in the largest overall error factor, is to underestimate the temperature difference while at the same time overestimating E and P.

Equation (15) thus provides the error sensitivity, which can be used to determine the accuracy of the approach.

Example. Take the previous case of Rhodes with an average outdoor temperature $T_o = 14$ °C. What is the worst case error using realistic numbers?

Suppose the average indoor temperature is $T_i = 23$ °C, such that the temperature difference $T_i - T_o = 23 - 14 = 9$. However, the thermometer measures two degrees too low, that is 21 °C. The first fraction in Equation (15) is thus 9/7. The energy could be overestimated by, say, 15% or 1.15 times the true value. The price could be overestimated by 5 %, or 1.05 times the true value. The calculation involves the product of the three factors, that is,

$$\frac{M(\epsilon) - M}{M} = \frac{T_i - T_o}{T_i - T_o + \epsilon_T} \times \frac{E + \epsilon_E}{E} \times \frac{P + \epsilon_P}{P} - 1 = \frac{9}{7} \times 1.15 \times 1.05 - 1 = 0.55 \tag{16}$$

The committed error is thus 55% of the true value, or in other words, the estimate is 1.55 times the true savings. *End of example.*

The example shows, that the error margin can be ± 55% in a worst case scenario. On the other hand, in a normal scenario the individual errors would cancel each other to some extent, resulting in a better accuracy. Equation (15) further shows, that the temperature error appears in the denominator, which makes the expression sensitive when the denominator is small, that is, in mild climates. One way to eliminate some of the error is to use a good datalogger and take measurements over a period of time.

CONCLUSIONS

In summary, the developed approach to an energy check is better than qualitative advices based on folk wisdom, because the energy check results in quantified savings of energy and money. The energy check is less accurate than an energy audit, but it does have four distinct advantages over an energy audit, as follows.

- An energy adviser can relatively quickly perform an energy check, as opposed to measuring the components of a building and entering them in a software package that calculates the result.
- Simple equations document the results of the energy check, as opposed to a larger set of coupled equations embedded inside a commercial software package.
- The energy check savings are based on the observed energy consumption, as opposed to a calculated nominal consumption.
- The energy check considers behaviour-related savings, the energy audit does not.

The energy check can be regarded as a forerunner, and an inspiration to perform an energy audit; it is not a competitor.

Approaching and involving the local population from the beginning improves the chances of their acceptance of an energy saving campaign. An interactive and tailor-made workshop — involving households, multiplier organisations, and stakeholders — is an efficient way to involve the locals. In this connection, the home energy check is an effective means to get acquainted with the households; it is an 'ice breaker'.

Naturally, an island in a mild climate, such as Tenerife, spends less energy on heating and cooling, and, consequently, we harvest fewer savings in terms of kilowatt-hours. However, the relative savings, in percent of the actual consumption, can be high anyway. Conversely, in a cold climate, such as Iceland, the saving factor is small, but the absolute savings in kilowatt-hours are high.

Acknowledgement

The work is a result of EU projects, co-funded by the Intelligent Energy Europe programme of the European Commission (Energy Ambassadors, grant agreement IEE/08/446/812.528576; PROMISE, grant agreement IEE/10/312/SI2.589421; Night Hawks, grant agreement IEE/12/671/SI2.644734) as well as work performed under the Danish organisation Energitjenesten (Energy Service Denmark), which is funded by Energifonden.

Note

1. *www.ieepromise.eu*

References

[1] Council of the European Union and European Parliament. (2012), "Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency." *Official Journal of the European Union*, L 315: 1–56.

[2] Energimyndigheten. (2010), *Energikoll i små och medelstora företag* [Energy checks in small and medium size enterprises]. Eskilstuna, Sweden: Energimyndigheten. *http://www.energimyndigheten.se*

[3] Energy Neighbourhoods. (2013), "Do it Yourself Home Energy Check." Energy Neighbourhoods. Accessed 17 Jul 2013. *http://www.energyneighbourhoods.eu/en_uk/top-tips*

[4] European Commission. (2010a), "Delegated regulation (EU) 1059/2010 on energy labelling of household dishwashers." *Official Journal of the European Union*, L 258: 1–20.

[5] European Commission. (2010b), "Delegated regulation (EU) 1060/2010 on energy labelling of household refrigeration appliances." *Official Journal of the European Union*, L 314: 17–46.

[6] European Commission. (2010c), "Delegated regulation (EU) 1061/2010 on energy labelling of household washing machines." *Official Journal of the European Union*, L 314: 47–63.

[7] European Commission. (2012a), "Delegated regulation (EU) 874/2012 on energy labelling of electrical lamps and luminaires." *Official Journal of the European Union*, L 258: 1–20.

[8] European Commission. (2012b), "Delegated regulation (EU) 392/2012 on energy labelling of household tumble driers." *Official Journal of the European Union*, L 123: 1–26.

[9] EN. (2007), *Building components and building elements - Thermal resistance and thermal transmittance - Calculation method (ISO 6946:2007)*. European Committee for Standardization, CEN.

[10] IEE. (2013), *Guide for proposers*. Brussels: Intelligent Energy Europe. Version 1.1, *http://ec.europa.eu/energy/intelligent*

[11] Klaesener, A., J. Jantzen, S.I. Fridleifsson, A. Chatzimpiros, K. Komninos, E. Lopez Suarez and S. Carlier-Wiart. (2013a), "Energy Efficiency in Households: A Case Study from Four European Islands." In *Proc. 4th Int. Conf. on Renewable Energy Sources and Energy Efficiency, 6–7 Jun 2013, Nicosia, Cyprus*, edited by I. Michaelides, A. Papadopoulos and A. Poullikkas, 278–286. Nicosia, Cyprus: MSE Congress Plus.

[12] Klaesener, A., J. Jantzen, S.I. Fridleifsson, A. Chatzimpiros, K. Komninos, E. Lopez Suarez and S. Carlier-Wiart. (2013b), "Household Energy Saved by Changing Behaviour: A Case Study from Four Islands." In *Proc. 7th Int. Conf. on Energy Efficiency in Domestic Appliances and Lighting EEDAL'13, 11–13 Sep 2013, Coimbra, Portugal*.

[13] RETScreen International. (2005), *Clean Energy Project Analysis*. 3rd ed. Canada: Natural Resources Canada. *http://www.retscreen.net*

[14] Teknologisk Institut. (2013), *Standardværdikatalog for energibesparelser* [Catalogue of standard values for energy savings]. Version 2.7. http://svk.teknologisk.dk/.

Appendix: The Potential for Additional Insulation

One advice concerns added wall insulation (Table 1). If the indoor surface of a wall is 4-5 degrees colder than the indoor air temperature, then the occupants may notice it and even feel uncomfortable. Intuitively, a poorly insulated wall will have a relatively cold indoor surface temperature, and the temperature drop from the indoor air to the wall's surface indicates the degree of insulation. With just three temperature measurements we can estimate the resistance of the wall.

Figure A1 shows the variation of the temperature through a wall. There is an air film on both sides of the wall, and it is common practice to let the resistance R of the wall include the resistance of the exterior film and the resistance R_{si} of the interior air film. With the variables defined in the figure, the heat flux $(T_i - T_1)/R_{si}$ through the interior air film is the same as the heat flux $(T_i - T_o)/R$. Equating the two and rearranging, we find that the ratio A/B of the line segments A and B on the figure, is

$$\frac{T_i - T_1}{T_i - T_o} = \frac{R_{si}}{R} \tag{12}$$

Given the three temperature measurements on the left-hand side, we can estimate the resistance R of the wall, assuming that R_{si} = 0.13 m^2K/W (the internal air film resistance for horizontal heat flow, EN 2007). Conversely, given typical values of R we can find typical values of the ratio A/B.

Table 3 shows, for instance, that for a wall with a high energy loss, corresponding to U = 1.30 (W/m^2K), the indoor temperature drop $T_i - T_1$ to the surface of the wall is 17% of the temperature difference $T_i - T_o$ between the indoor and outdoor temperatures. If the house owner insulates a wall having a high energy loss to the level of a medium loss wall, the resistance is improved by approximately a factor of 3, and going from medium to low, the improvement is approximately a factor of 2. The energy adviser can quickly estimate the saving factor by making the three temperature measurements on the site. If, for example, the advisor measures the indoor temperature drop to 17% of the whole, and it is feasible to reach 5% by adding insulation, then the saving factor is f = 1 - 5/17 = 0.71 or 71% saved.

There are sources of uncertainty, however, such as the following three: (1) The indoor temperature drop $T_i - T_1$ may be so small that it is comparable to the inaccuracy interval of the thermometer (± 2 °C for Testo 810), in which case the calculation becomes susceptible to measurement errors; (2) the measured temperatures may be in a transient state, rather than steady state, due to solar heating, nightly cooling, evaporation from a wet outdoor surface, or wind; and (3) the interior wall temperature T_1 may be affected by a radiator mounted on the wall. It is recommended to take the measurements at night-time in cold weather, when the difference is largest. It is also recommended to take all temperatures at the same height above the floor level.

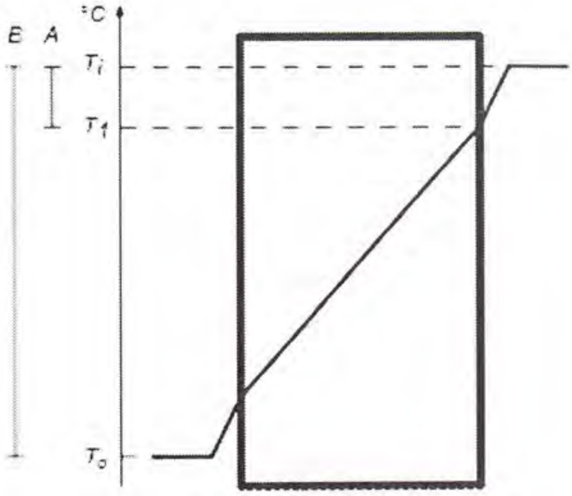

Figure A1: Temperature profile in a wall, including an interior air film (right side) and an exterior air film (left side)

Table 3
Interior air film proportion of temperature difference between indoor and outdoor.

Component	*Energy loss*	*U*	*R = 1/U*	R_{si}/R *[%]*
Wall	High	1.3	0.77	17
Wall	Medium	0.4	2.50	5
Wall	Low	0.2	5.00	3
Window	High	5.1	0.20	66
Window	Medium	2.8	0.36	36
Window	Low	1.1	0.91	14

ISSN : 0975-4490

International Journal of ENGINEERING AND MANAGEMENT

Volume 6 Number 2 July-December 2014

RESEARCH SCIENCE PRESS
New Delhi (INDIA)

I J E M

International Journal of Engineering and Management

Editor-in-Chief
Prof. Constantin Zopounidis
Technical University of Crete, Dept. of Production Engineering and Management
Financial Engineering Laboratory, University Campus, 73100 Chania, Greece
Tel: +30-28210-37236, Fax: +30-28210-69410
E-mail: ijem@dpem.tuc.gr

Managing Editor
Prof. George Dounias
University of the Aegean, Department of Financial and Management Engineering
31 Fostini Street, 82100 Chios, Greece
Email: g.dounias@aegean.gr

Annual Subscription Price Per Volume : ₹ 3000 (India) US$ 150 (Foreign) • Price for Single Issue : ₹ 2000

RESEARCH SCIENCE PRESS (INDIA)
4830/24, Ansari Road, Darya Ganj, New Delhi-110 002
Phone: 2324 5225, 2327 2135 • E-mail: *researchsciencespress@gmail.com*

ENG
VOLUME 6

Household

Intelligent T

Investigatio
Doping usin

A Review of
the Calculati
Allocation in