



THE EUROPEAN GREENBUILDING PROGRAMME

A Benchmarking Guide adapted to Air Conditioning based on
Electricity Bills

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1 Objectives of the guide

The objectives of that guide are mainly to help building owners detecting drifts in energy consumptions of their air-conditioning plant. However, building owners have to be conscious of energy consumptions of their plants and even require reference indicators allowing them to launch actions. These actions can then be of several kinds: behavioural changes, operational changes (adjustments), investments in punctual replacements or in a complete retrofit. Finally, as soon as actions have been carried out, checking energy savings generated can be useful to judge about the payback time of these investments.

2 Pre-requisite

Energy uses having effect on the electricity bill of a building

Any building owner must be aware that, for more accuracy, direct measurements on one equipment (chiller for example) or one energy use (lighting for example) should be preferred to overall energy bills. Indeed, on the one hand several energy consumptions of numerous uses are often mixed in a same energy bill and on the other hand, it is the energy supplier who defines the billing frequency.

An electricity bill mainly includes consumptions of lighting, ventilating and small power appliances (kitchen or office equipments, HI-FI etc...) and finally large process appliances (air compressors, pumps, fans etc...) for which that energy is most of the time not substitutable. Thermal uses of electricity like air-conditioning, when existing, are also often included because only few AC processes operates with another primary energy. Building heating and domestic water heating can also be done by the Joule effect or even through thermodynamics with a heat pump but an important share of these two activities uses fossil fuels and are then accounted in a separate bill.

That tool requires listing all or each group of electrical appliances, the consumptions of which are included in the energy bill. When possible, try to evaluate the electrical power they absorb in operation by looking at their electrical plate or documentation. It is important also to estimate the time they operate during the time period considered. Absorbed power and time of operation allow together to approximately calculate their energy consumptions on the time period considered. Keep in mind the analysis of air-conditioning performances using global energy bills would be accurate only if the share of air-conditioning energy consumptions in the bill is important. If energy consumptions for cooling are dissolved among them from a lot of other energy uses, it is better to measure only the power absorbed by the air conditioning system.

Parameters having effects on air-conditioning energy consumptions

Several parameters have effects on air-conditioning energy consumptions and more generally on all thermal energy consumptions. It is possible to distinguish four types:

- Building parameters are intrinsic to the construction of the building. The building shell thermal characteristics, the glazing surface, heated/cooled surfaces or the location are part of them. They were fixed by the first owner of the building and can hardly be changed by following building owners because of the costs induced by a retrofit and its payback time.
- Policy parameters depend only on the current building owner choices and his will to save energy. Equipment choices and investments, operational parameters such as temperature and humidity set points (if building centralized), the time of operation or maintenance and follow-up policies are among them. The sensibility of energy consumptions to these parameters is really important. However, actions are neither natural nor frequent because they often follow an audit from a professional.
- Behavioural parameters depend on the occupants' choices. Operational parameters such as temperature and humidity set points (if room localized) or the natural wasting

behavior of occupants are part of them. Their influence on energy consumptions can be great although the duration of the “good practice” behavior can be short.

- Activity parameters depend mostly on the market in the activity sector. The building owner has only little effects on them. They have a great influence on energy consumptions of the building and a building owner cannot change them without affecting the turnover of its building.

That tool requires listing main parameters that have strong effects on energy consumptions of each use. Special attention must be paid to causes that might be improved by the building owner.

3 Basic benchmarking of energy consumptions

With such numerous parameters, one understands well that energy consumptions of buildings can differ strongly. The first part of that guide is hence dedicated to the simple follow-up of energy consumptions of a building from one time period to another. Although it seems evident, it is often underestimated by most building owners in practice. Most of them only focus on energy bills at the building level looking almost only at the amount of money they pay, independently of energy prices. Think about energy uses can bring however a lot of additional information.

After listing energy uses and influent parameters, it is important for a building owner to determine the optimal measurement frequency (<hourly, hourly, daily, weekly, monthly, yearly etc...). The objective is to maximize the information available while minimizing the quantity of measurements and associated costs. Again, when certain parameters (climate for example) vary a lot, it is relevant to reduce the time period to get more accuracy. Prefer therefore monthly billing to yearly billing for thermal uses. If it is not possible, try to make your own measurement using additional metrology (general meter, sub-meter, portable metrology).

As soon as consumptions of at least two time periods for the same building are available, you can begin the comparison. The objective of such a follow-up is not only to be aware of variations in energy consumptions but also to look for parameters responsible of such variations. Logically if thermal uses (pure cooling system, joule effect heating or reversible heat-pump) are not negligible in the bill in comparison to process uses, electricity consumptions must be maximal in summer (July or August) and in winter (December, January or February). Therefore, detect possible problems on energy consumption magnitudes and variations with time by trying to explain the bill through the main influent parameters you found previously. Once the responsible parameters were underlined, think to possible actions that would allow optimizing energy consumptions or call a professional to assist you (energy supplier, ESCO etc...) thank to an energy audit.

Observe for example the variations of annual electricity consumptions in the banking sector (figure). Electricity uses (office equipments, money distributors, lighting, HVAC) are known and unlikely to change unless in terms of quantity especially for money distributors. Opening hours are constant from one year to another in a bank agency so that electrical appliances operate for the same duration each year. On these examples, the area of bank agencies and the staff are unchanged from one year to another. The only parameters that can explain such variations could be: activity variations of the agency (customers?), process changes (quantity, type?), operational changes (temperature set-points, operating hours?) or climate variations (winter, summer or both?). In that case, the agency manager is finally the best person able to determine the origins of these variations, to know if they are normal or not and to decide to carry out actions.

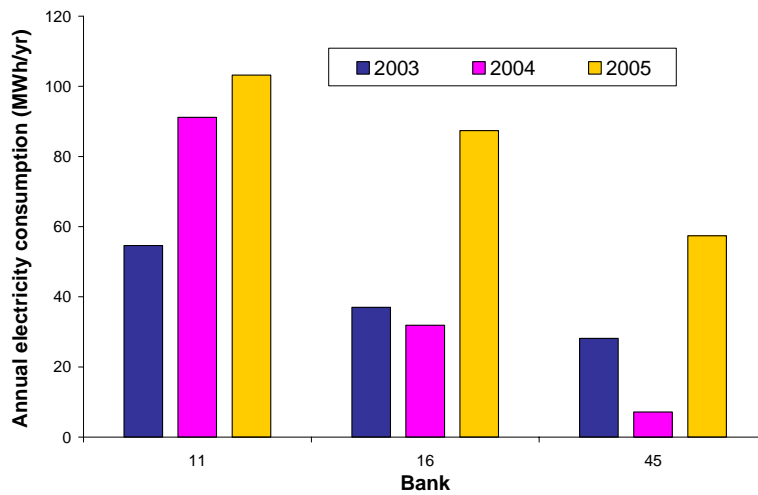


Figure 1: examples of variations in annual electricity consumptions in the banking sector

Table 1: action plan for the basic benchmarking of energy consumptions

| ACTION PLAN |
|---|
| Determine the electricity uses included in the bill in general |
| Determine parameters having effect on electricity consumptions in general |
| Collect activity indicators that might justify variations in electricity consumptions |
| Note any changes other than climate (process, adjustments) from one time period to another |
| Collect electricity bills (prefer monthly to annual basis to get more accuracy) |
| Draw the diagram: time period on the X-axis and kWh/time period on the Y-axis |
| Try to explain variations in consumptions thanks to previous changes or activity indicators |
| If variations are unexplainable, call a professional (energy supplier, ESCO etc.) for an energy audit |
| Try to continue that follow-up of energy consumptions even if no problem is detected |

4 Benchmark typical energy ratios

The lack of reference often leads us to think that all is OK. The objectives of the second part of that guide are to allow building owners to compare their energy consumptions. Although it is vain, the idea of benchmarking is then to try to build “universal” indicators that can be compared in the same activity sector whatever the building. To reach that independency from the activity level, the best way is to calculate energy ratios (kWh/activity parameter/time period) by dividing energy consumptions of a system (building, energy use, equipment) during a certain time period by one or more activity indicators.

The first task is to choose the best time period on which you will calculate energy ratios. Unless you want to regularly follow-up your energy consumptions because your activity parameters vary strongly and frequently, it is useless to consider short time periods such as a week or a month. Indeed, such reference value will hardly be available and results become much more climate-dependent. Prefer typical time periods such as a year or a season in case of distinction between heating and cooling.

There exist an obvious relationship between the number of energy uses, their size and power and the area of the building so that the most common indicator is the cooled area (in square-meters). It can be used in every air-conditioned spaces especially buildings with no direct production (office or residential buildings) and then no other indicators.

Another obvious relationship exists between the area of the building and its occupancy especially for constant occupancy buildings (no or limited numbers of external visitors) so that the use of that indicator should then be equivalent to the use of square-meters. In practice, it is not as clear (Figure 2) and the distinction between the two indicators allows sometimes to maximize the information.

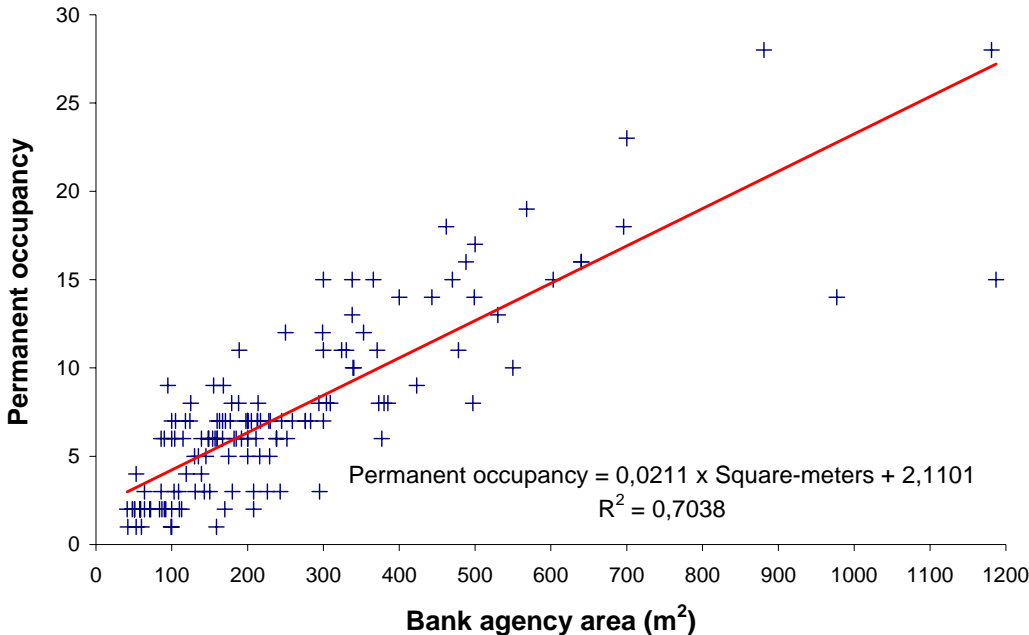


Figure 2: relationship between area and permanent occupancy in the banking sector

Everybody knows that the more the activity level of a building, the higher its energy consumptions. Thermal uses are not an exception and energy consumptions are correlated to occupancy. For example, heat and humidity productions and inlets due to temporary occupancy have to be fought against by air-conditioning systems. As it is often difficult to count visitors of a building during a time period, it is better use other indicators that are necessarily such as: occupied beds in a hospitals, occupied bedrooms in hotels, students in schools, meals in restaurants, tickets sold in museums or concert-halls etc... In case of variable occupancy, these indicators should be used in addition to kWh/m² ratios.

Keep in mind that benchmarking only provides valid results (Figure 4) for the same building on several time periods or at least for the same category of buildings. Two buildings from the same activity sector may have totally different energy ratios because of their different sizes. Indeed, most processes, their intrinsic efficiencies and their control systems are often better in large-scale buildings. Moreover, these ratios do not take into account the climate influence (outdoor temperature, sun, wind etc...) on energy consumptions so that comparisons of buildings in too different locations may be analyzed carefully.

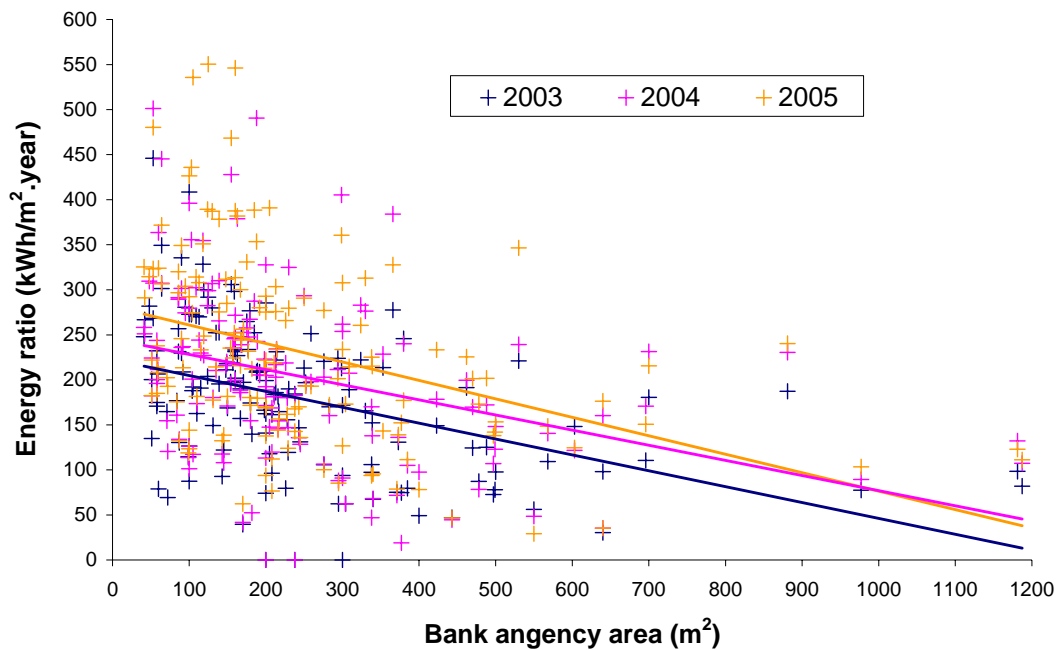


Figure 3: ratio decreases with the surface in the banking sector

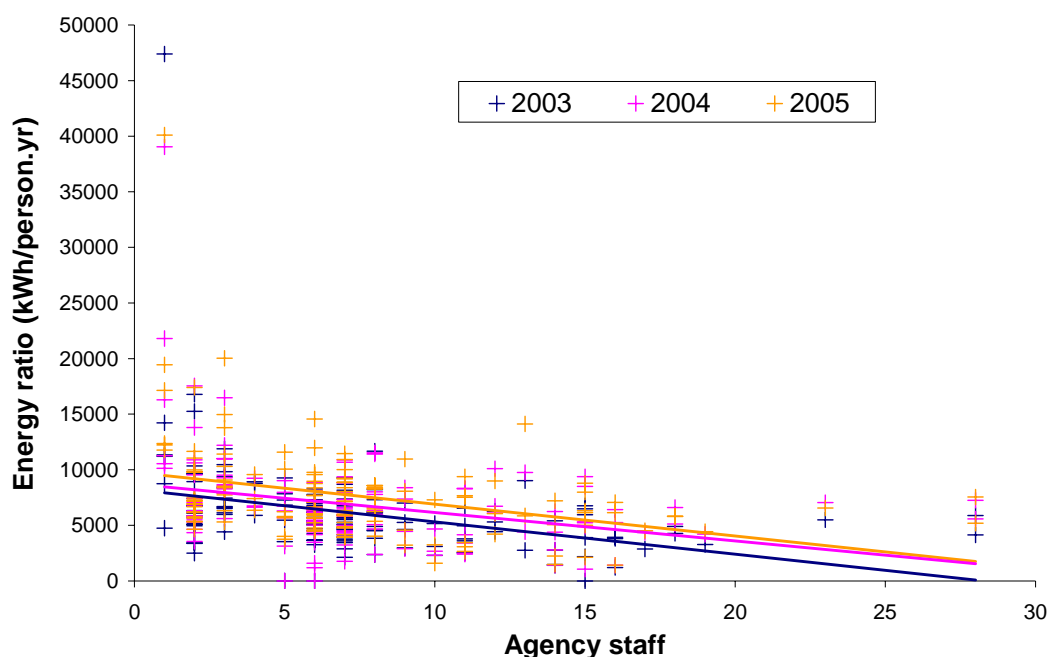


Figure 4: ratio decreases with the staff in the banking sector

If your ratios (compare several ones) are lower than other building ratios or statistics, your building seems energy-efficient and you have probably no action to carry out or investment to make. Continue however to regularly follow-up your indicators to anticipate problems. In the other case, you should probably contact a professional to consider some ways of improvements.

Table 2: Action plan for the benchmarking of energy ratios

| ACTION PLAN |
|---|
| Determine the electricity uses included in the bill in general |
| Determine parameters having effect on electricity consumptions in general |
| Choose main activity indicators that justify variations in electricity consumptions |
| Calculate electricity consumptions on the time period (the same as the one used in statistics) |
| For each activity indicator and the same time period, divide energy consumptions by the indicator |
| Compare each ratio from one time period to another |
| Try to explain possible variations (climate, adjustments etc...) |
| Compare each ratio to statistics |
| Try to explain possible differences (size, climate, adjustments etc...) |
| If variations/differences are unexplainable, call a professional (energy supplier, ESCO etc.) for an energy audit |
| Try to continue that benchmarking of energy ratios even if no problem is detected |

5 Establish the climate based energy signature of the building

Previous energy ratios are climate dependent so that only statistical ranges are published. Several climatic parameters (sun, wind, outdoor temperature, outdoor humidity) play important roles in energy consumptions of thermal uses. The objective of that paragraph is then to determine the sensibility of energy consumptions to climate parameters. It is focused especially on the outdoor temperature because that parameter is easier to feel and measure for a building owner.

The particular interest of such a method is to distinguish between climate dependent energy consumptions (variable part) and them that are not (constant part). However, find a correlation between energy consumptions and outdoor temperature necessarily requires a representative dot scattering, in other words much more dots. Therefore, monthly energy bills or weekly measurements should be preferred to annual energy bills. There are three possibilities concerning the temperature: either measure it, or get free daily-averaged measurements (can be found on the internet¹) or pay for local hourly measurements (to national weather forecast institute).

Two climate indicators can be used in the energy signature. The first one is directly the averaged outdoor temperature of the time period. As a consequence, the correlation function is growing for cooling in summer and decreasing for heating in winter. The second indicator is degree-days that can be calculated for heating (HDD) in winter and cooling (CDD) in summer. HDD (respectively CDD) is the sum on the chosen time period (higher than a day) of the product of “the number of days during the time period for which the outdoor temperature is lower (respectively higher) than a reference value” by “the difference between the daily averaged outdoor temperature and that reference value”. HDD (respectively CDD) represent how cold (respectively hot) is a winter (respectively summer) time period.

The main difficulty of using degree-days is to choose the good reference temperature. In theory, that value is the averaged temperature ensured only by the building shell without any additional heating (or cooling) system. Logically, the balance temperature in winter is different from the one in summer. For heating, the reference temperature is usually taken equal to 18°C in Europe. As heat gains can contribute to about 3°C in buildings and due to the averaged decrease of building shell thermal conductivity, the reference temperature for heating tends to rise. For cooling, the same problem exist so that in large office buildings, air-conditioning system may start for an outdoor temperature of 14°C whereas in residential buildings, accounting less heat gains, the reference temperature may reach 24°C.

Once you got enough dots for your energy signature, you are able to detect rapidly drifts in energy consumptions due to some defaults compared to the past normal operation. It is thus better to apply this method as soon as the start-up of a new thermal process in order to have reference (without default) dots. Figure 5 sums-up some of the typical defaults that can be detected from an energy signature analysis.

¹ For example, a French website centralizes several climate data in a lot of locations in the country <http://www.meteociel.fr/climatologie/climato.php>

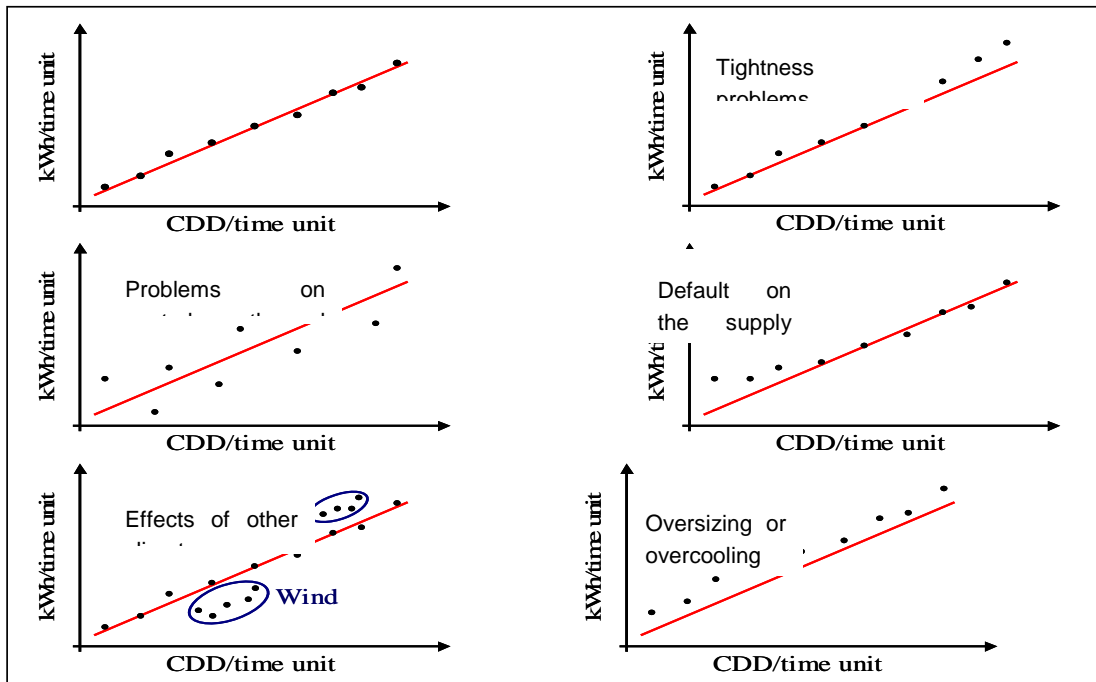


Figure 5: few problems that can be detected by the climate-based energy signature of a building

That method works almost perfectly for heating and is often used in operation and maintenance contracts with guarantee of results. However, it is not as accurate for cooling because of the higher number and power of electrical auxiliaries, the stronger influence of humidity on air-conditioning and the non-uniformity of temperature and humidity set points in buildings due to a lack of regulation. As a consequence, take care to the conclusions you make.

Once the correlation between energy consumptions and degree-days or average temperature is established, climate independent energy ratios are directly available calculating the slope of the curve. It is then possible to compare your building ratios with those from any other building whatever their locations. Remember that measuring only the power absorbed by the considered thermal use (an air-conditioning system for example) allows to strongly limit the offset magnitude of the curve and to better underline the effect of climate (slope) on energy consumptions. Energy bills are a mix of consumptions from different uses attenuating the visibility of pure thermal uses. Thus, always take care to the framework to compare ratios with statistics or between buildings.

Table 3: Action plan for establishment and the use of the climate based energy signature of the building

| ACTION PLAN |
|---|
| Determine the electricity uses included in the bill in general |
| Determine parameters having effect on electricity consumptions in general |
| Choose main activity indicators that justify variations in electricity consumptions |
| Determine the best time period (monthly/weekly for DD, daily for average temperature) |

| |
|---|
| Determine the best temperature reference for your building (usually 18°C in winter, from 14°C to 24°C in summer) |
| Measure/get average daily temperature or calculate/get degree-days for each time period |
| Separate cooling degree-days from heating degree-days |
| Measure or get from the bills electricity consumptions on each time period |
| Draw the diagram for each time period: average temperature or DD on the X-axis and kWh on the Y-axis |
| As soon as a season/year is complete, determine the (linear) regression between consumptions and climate parameters |
| Try to find the reasons why a new dot is outside the scatter – If differences are too important, too frequent and unexplainable, call a professional (energy supplier, ESCO etc.) for an energy audit |
| Calculate climate independent energy ratios (slope of the regression curve) in kWh/m ² .DD |
| Compare to statistics – Try to explain possible differences (size, activity, adjustments etc...) |
| Try to continue the energy signature even if no problem is detected |

6 Establish the multi-parameter energy signature of the building

We showed that energy consumptions were due to a lot of parameters and underlined especially the influences of building parameters (area, staff), activity parameters (occupancy, production) and climate. However, it is impossible to analyze one parameter independently of the others. Concerning air conditioning for example, a more temperate climate than forecasts can be compensated by a much higher occupancy than in normal conditions so that the only climate or activity analysis will provide biased results. As all of these parameters have a common influence on energy consumptions, it is important to analyze their effects simultaneously. The idea of that paragraph is then to find the energy signature of the building by considering not only the climate but also main activity parameters (pure occupancy, indirect occupancy, production etc...). Building parameters (surface, staff etc...) can be added in order to determine the energy signature of several similar buildings of the same activity sector (see next example).

This method is exactly the same as the previous one but additional parameters are this time included into the linear regression. As for climate parameters, building and activity parameters must be measured precisely for each time period so that specific metrologies or procedures should be set-up. Again, time periods must be short in order to get more dots and then accuracy. Finally, to be able to find a correlation between consumptions and all the parameters, you will need at least as many time periods as parameters. For example, if the main parameters having effects on your building energy consumptions E are the degree-days DD and the occupancy O , the regression method requires at least two time periods on which the coordinates (E, DD, O) . However, to reach higher levels of representativeness, it is better to scan a large range for every parameter.

For example, in the banking sector the information available for each agency is: area S , staff N_{wkr} , the annual electricity consumptions for three years and finally the location allowing to calculate both cooling (CDD) and heating (HDD) annual degree-days. As building parameters (area and staff) are constant for one agency in the time, they only intervene into the magnitude of consumptions but not in their variations with time. On the opposite, variations of cooling and heating degree-days lead to variations in annual electricity consumptions for one agency. As only three dots were available for each agency, the results of each energy signature were neither accurate nor representative. Although the approach is strictly the same, the energy signature was applied not to each agency but to the whole banking sector including every agencies in order to determine a general profile of electricity consumptions. Several models were tested: influence of the area (S), of the winter climate (HDD), of the summer climate (CDD), of both winter and summer climates (H&CDD) depending on the type of heating system (joule or reversible heat-pump), of the staff (N_{wkr}). The **Fehler! Verweisquelle konnte nicht gefunden werden.** presents both results and accuracy (R^2) obtained by such models. Again, the more the parameters, the more accurate.

Table 4: Modeling of electricity consumptions in the banking sector in France using a linear regression method

| Model kWh/yr= | a | b | c | R ² |
|--|--------|-------|------|----------------|
| a.HDD.S+b | 0,101 | 11677 | | 0,67 |
| a.HDD.S+b.N_{wkr}+c | 0,0471 | 3822 | 4652 | 0,772 |
| a.CDD.S+b | 0,411 | 27170 | | 0,273 |
| a.CDD.S+b .N_{wkr}+c | 0,139 | 4000 | 1766 | 0,64 |
| a.H&CDD.S+b (Joule) | 0,099 | 11481 | | 0,667 |
| a.H&CDD.S+b.N_{wkr}+c (Joule) | 0,0461 | 3813 | 4700 | 0,770 |
| a.H&CDD.S+b (HP) | 0,099 | 11174 | | 0,678 |
| a.H&CDD.S+b.N_{wkr}+c (HP) | 0,0479 | 3700 | 4740 | 0,772 |

Once the multi-parameter energy signature of the building is established, drifts in energy consumptions generated by defaults may be detected as soon as new dots deviate from the scatter. As for the simple climate base energy signature, energy ratios relative to each parameter may be deduced from the correlation function calculated by extracting multiplier coefficient before each variable.

Table 5: Action plan for establishment and the use of the multi-parameter energy signature of the building.

| ACTION PLAN |
|---|
| Determine the electricity uses included in the bill in general |
| Determine parameters having effect on electricity consumptions in general |
| Choose main activity and climate indicators that justify variations in electricity consumptions |
| Determine the best time period (monthly, weekly, daily) |
| Measure/get every chosen indicators for each time period |
| Measure or get from bills the electricity consumptions of each time period |
| As soon as enough dots are available, establish the linear regression ($E = \sum a_i \cdot P_i + b$) between electricity consumptions E and every parameters P_i |
| Try to find the reasons why a new dot is outside the scatter – If differences are too important, too frequent and unexplainable, call a professional (energy supplier, ESCO etc.) for an energy audit |
| Calculate energy ratios by extracting multiplier coefficients a_i |
| Compare to statistics – Try to explain possible differences (size, activity, adjustments etc...) |
| Try to continue the energy signature even if no problem is detected |



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