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An approach to evaluate the energy performance of buildings based on incomplete monthly data

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Abstract

The energy performance of buildings has become increasingly important in the general strive to reduce the overall energy use, which is manifested in the Energy Performance of Buildings Directive launched by the European Union. An important first step is of course to identify and address buildings that have an energy saving potential. In order to achieve this, robust methods for evaluation as well as reliable energy key figures are needed.

For a large majority of multifamily buildings in Sweden the available data of the energy use originates from the property holder. Unfortunately, the data is often limited to the energy that the property holder is responsible for. Thus, information from the tenants about their household electricity use, indoor temperatures, number of residents, etc., is missing.

In this paper an evaluation was conducted on monthly consumption data registered by the property holders for over 100 multifamily buildings/real estates in Sweden. The used approach, based on the energy signature method, was developed for evaluating the energy performance of multifamily buildings in terms of the overall heat loss coefficient, K_{tot}. To compensate for the missing data, different assumed consumption profiles have been used.

The results shows that although the obtained value of K_{tot} for an individual building is rather sensitive to the assumed consumption profiles of household electricity, the sensitivity is reduced if the evaluation is made in relative and not absolute terms. Thus, the use of consumption profiles could be a successful way to circumvent the present lack of a detailed knowledge of a buildings total energy use. In addition, an evaluation in relative terms instead of absolute values is also more correct, since available data in almost all cases does not support the determination of the true value of K_{tot}. The use of an average consumption profile instead of a detailed knowledge is of course not desirable, but for fairly large buildings such an approach could be successful.

Keywords: Energy performance; Overall heat loss coefficient; Energy signature; Household electricity; Benchmarking

1. Introduction

The Energy Performance of Buildings Directive, 2002/91/EG [1] has been launched in order to reduce the use of energy in the building sector in the European Union. In order to achieve this goal, robust methods for evaluation as well as reliable energy key figures are needed and these methods and energy key figures must probably also be adapted to the different prerequisites in different EU-countries. For finding energy key figures of a building, there are a number of different approaches. These approaches could be categorized according to primary reliance on:

Design data.
Data from short-term, in situ measurements.
Aggregated consumption data, such as utility bills, meter readings and building energy management systems (BEMS).

A brief overview of work related to these categories; and a discussion of drawbacks and strengths can be found in [2,3].

In this work aggregated performance data has been used. With access to aggregated data it is possible to, e.g. compare the energy use between different periods, evaluate trends and outliers based on simple base lining (with or without degree-day compensation) [4,5]. For more qualitative investigations of the energy performance, system identification methods are needed. System identification can be based on inverse modelling using, e.g. neural networks, see for example [6–8] or

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Nomenclature

A	coefficient
c_p	specific heat capacity of water (J kg^{-1} K^{-1})
CP	consumption profile
E	energy per square meter area to let (J m^{-2})
f_{DHW}	fraction of the water that becomes domestic hot water
K_{tot}	overall heat loss coefficient per square meter area to let (W K^{-1} m^{-2})
MFB	multifamily building
P	power per square meter area to let (W m^{-2})
Q	volume per square meter area to let (m)
T	temperature (°C)

Subscripts

BE	building electricity
dyn	dynamic
DCW	domestic cold water
DH	district heating
DHW	domestic hot water
e	external
EL	building and household electricity
G	gained
H	heating
HE	household electricity
i	internal
L	losses
P	people
S	sun
tot	total

Greek letters

η	gain factor
ρ	density of water (kg m^{-3})

parametric studies based on statistical models, which is more widely used [9,10]. In the literature a variety of methods can be found. A method with parametric studies based on linear regression using aggregated data in combination with DOE-2 simulations was introduced by [11]. In [12–14] linear regression models was used based on collected design and performance data for investigation of the strongest determinants of energy use. A frequently used system identification method is the energy signature. It can be used for evaluating the energy performance of a building in terms of the overall heat loss coefficient [3,15–18]. The analysis introduced in this paper is based on the energy signature and is applied on monthly consumption data from 114 Swedish multifamily buildings/real estates. Data, that has been collected by the property holder and entered into a database.

One hurdle when confronting the problem of estimating the performance of buildings, based on aggregated consumption data collected by the property holder, is the information that is missing. The problem is mainly three folded.

The aggregation level is often on an annual basis but in some cases (mostly for larger property holders) data exists on monthly basis and in very rare cases with an even higher time resolution.

In Sweden, as in many other countries, the property holder is generally charged for the energy supplied to the space heating system, cold water and hot water preparation and electricity used for the technical systems of the building. But for the electricity used in each individual flat, the energy supplier generally charges each tenant and thus, vital information is missing for the property holder. The information of the tenants energy use is not available without their permission. Further more, tenants in the same building may have different suppliers of electricity, which complicates larger surveys.

Other important parameters, such as indoor temperature and for most cases also the domestic hot water consumption, are usually not available.

As a consequence, an energy performance analysis in Sweden to day, based on measured data, is often based on the energy used for space heating, E_{H}, and in many cases (especially for district heated buildings) of $E_{\mathrm{H}} + E_{\mathrm{DHW}}$, where E_{DHW} is the energy used for domestic hot water preparation. If only annual data is available a comparison is normally done by simply comparing the E_{H} or $E_{\mathrm{H}} + E_{\mathrm{DHW}}$ per square meter between different buildings. Even if monthly data is available, methods like the energy signature, is very sparsely used outside the academic world and in practice the monthly data is aggregated to an annual consumption per square meter, based on degree-days correction and assumed fractions of domestic hot water.

In these approaches vital information about for example the household electricity and indoor temperature is missing. The obtained results reflect thus more the behavior of the tenants and the management of the building than the buildings energy performance.

The aim of this work is to investigate the possibility, based on monthly data from the property holder, to evaluate the energy performance of the buildings. As measure of the energy performance the overall heat loss coefficient, K_{tot}, is used, which takes into account the total transmission and ventilation heat losses of the building. In order to determine K_{tot} we have used the available monthly energy use and outdoor climate data together with different assumptions for the missing data of indoor temperature, household electricity and domestic hot water preparation.

The robustness of this approach is then investigated in terms of the assumed consumption patterns and also the possibility to use the K_{tot}-values as a basis for estimating the relative position for energy performance of an individual building within the group of studied buildings. The results are also compared with the frequently used energy key figure of the energy per square meter paid by the property holder.

2. Data

2.1. The database

In order to create an improved environment for estimating the energy performance of residential and commercial buildings in Sweden a project was started in 2000 and was financed by the Swedish Energy Agency (STEM). The aim was to establish a database, where property holders could enter data of the physical and technical features of the buildings and data of used energy and water consumption. This project is called ''Enyckeln''(Energy Key), www.enyckeln.se and up to this date 360 real estates, where each real estate consists of one or more buildings with a total of 3,500,000 m^2, has been reported during 2001.

Data for all buildings was collected in the same way and the database contains information of about 50 energy related parameters per building. The parameters concern the HVAC-system, building design, type of maintenance organization, type of owner, actions taken to reduce energy consumption, etc. These data were entered to the database by each buildings maintenance organization after an inventory under the supervision of the project leader of Energy-Key project.

All buildings in the database used the same building energy maintenance system, for energy control, and consumption data were reported monthly, i.e. electricity for heating and operation of the building, oil, gas, district heating, district cooling, domestic hot and cold water.

After the initial test period the web-based Energy-Key system has been exposed to a major overview and a new version will be released during 2006.

2.2. Choice of building type

Since the number of multifamily buildings (MFB) was the largest in the database compared to the number of commercial buildings, the decision was to focus on the MFB where more than 90% of the area to let was used for apartments. The commercial buildings also have a more complex technical structure that where not fully reflected in the information in the database. district heating (DH) heated the vast majority of these MFB and a few used gas or oil boilers. Since the efficiency of the gas and oil boilers was unknown, these MFB were excluded together with those that used heat pumps (performance unknown), which reduced the available number of MFB from 118 to 114. No MFB were equipped with comfort cooling.

2.3. Limitations and some comments

The area entered in the database is that of the area to let, and thus the area of basement corridors, stairwells, technical spaces, etc., is unknown. The remaining area normally represents on average about 15% of the total building floor area according for this type of Swedish buildings PROFU [19]. In Fig. 1 below, the distribution of the investigated MFB in terms of area to let is displayed.

The year of construction ranges from year 1900 to 1995 with a total area to let of 1,147,000 m^2. The average number of apartments is 128 per real estate and the average area to let is 10,060 m^2. In some cases the size of the real estates indicates that there are two or more separate buildings attached to the same DH-substation, but they are treated as one MFB. Since the buildings are fairly large the use of different consumption

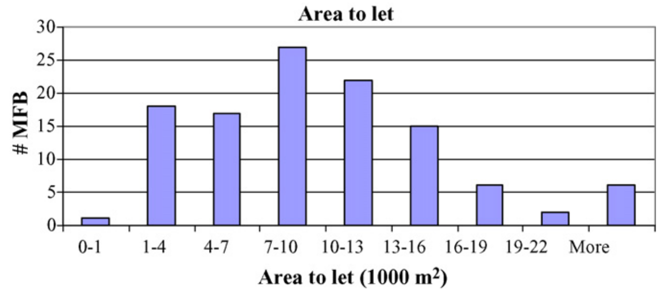

Fig. 1. Distribution of the investigated MFB in terms of area to let.

profiles that are based on an average description is assumed to be fairly good.

3. Method

In this article, energy, power, etc., of the MFB refers to the energy, power, etc., per square meter of area to let.

The energy balance for a building is in a lumped description given by

$$E_{\text{trans}} + E_{\text{vent}} + E_{\text{dyn}} = E_{\text{H}} + E_{\text{G}} \tag{1}$$

where E_{trans} and E_{vent} are the energy losses through the building envelope trough transmission and ventilation, respectively, E_{dyn} the dynamically stored/released energy, E_{H} the energy supplied to the heating system and E_{G} is the energy gained from sources that are not primarily designed for heating. With a time resolution of 1 month, the dynamic term may be neglected since the time constant of the buildings are of the magnitude of days. With E_{dyn} equal to zero Eq. (1) reduces to a static description which in terms of power may be rewritten as

$$K_{\text{tot}}(T_{\text{i}} - T_{\text{e}}) = P_{\text{H}} + P_{\text{G}} = P_{\text{tot}} \tag{2}$$

where K_{tot} is the overall heat loss coefficient which includes both transmission and ventilation and where and T_{i} and T_{e} are the internal and external temperatures of the building. K_{tot} is thus a measure of the buildings thermal efficiency, in terms of required power to maintain an internal/external temperature difference of 1 °C/m^2 area to let and thus a measure of the buildings thermal performance.

The gained power (P_{G}) represents contributions from a number of sources such as electricity used for household equipment (P_{HE}), domestic hot water (P_{DHW}), electricity used for the buildings technical systems (P_{BE}), solar irradiation (P_{sun}), etc., to heating. In general we have

$$P_{\text{G}} = \sum P_{\text{G},j} = \sum \eta_j \times P_j \tag{3}$$

where $\eta_j \times P_j$ is the utilized power for heating from source P_j with a gain factor η_j.

This means that in order to determine P_{tot}, data from all different sources, P_j, and there individual gain factor, η_j, together with the data from the heating system is required and finally also T_{i} and T_{e} in order to determine K_{tot}.

In the existing database, the only available information is energy supplied by district heating, domestic cold water consumption, electricity used by the property holder and consumption of domestic hot water, which has been reported by the property owner.

3.1. Energy primarily used for heating

Since all investigated buildings were attached to district heating, the energy supplied to the buildings (E_{DH}) was used for heating, domestic hot water preparation (E_{DHW}) and losses (E_L). The energy used in the heating system is thus given by

$$E_H = E_{DH} - E_{DHW} - E_L \quad (4)$$

and in terms of power we have

$$P_H = P_{DH} - P_{DHW} - P_L \quad (5)$$

By introducing the domestic hot water fraction, f_{DHW}, the power for hot water preparation (P_{DHW}) is given by

$$P_{DHW} = f_{DHW} \times Q_{DCW} \times (T_{DHW} - T_{DCW}) \times c_p \times \rho \quad (6)$$

with $f_{DHW} = Q_{DHW}/Q_{DCW}$ and where T_{DHW} and T_{DCW} are the domestic hot and cold water temperatures and Q_{DHW} and Q_{DCW} are the domestic hot and cold water consumptions.

The monthly cold water consumption was measured in all buildings, but data of the domestic hot water consumption was only available from 11 MFB.

In Fig. 2 the average monthly values of f_{DHW}, for these 11 MFB's is displayed. Based on these data, two annual consumption profiles are constructed. One profile is taken equal to the average behavior (Fig. 2) of the 11 MFB and a second profile from the building with the largest f_{DHW}. These two consumption profiles have then been used for all buildings in our simulations together with data of the average monthly cold water temperature T_{DCW} (based on data from the local water supplier) [20] and with two levels of T_{DHW}, 55 or 60 °C.

The term P_L is difficult to estimate, since detailed knowledge of where the eventual losses take place is not available. If the losses are mainly in pipes that are within the building envelop they contribute to the heating and thus $P_L = 0$. If on the other hand the main part of the losses takes place outside the building envelop they have to be considered which is the situation for some of our registered MFB which based on the reported area to let must consist of two or more MFB.

In the simulations two cases have been considered

$$P_L = 0$$

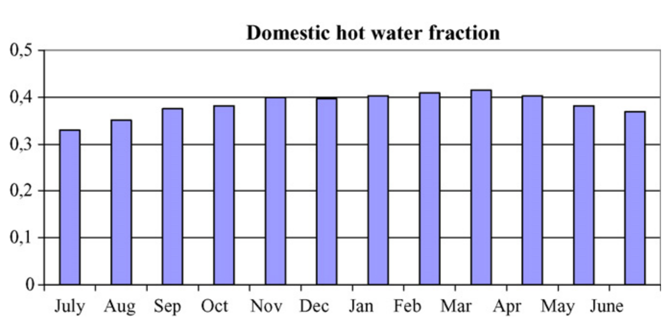

Fig. 2. Average fraction, f_{DHW}, from 11 measured MFB.

The losses have been estimated from the 2 summer month, July and August when the heating demand basically is zero. Based on the data of P_{DH} for the 2 month, the losses have been estimated as the difference between P_{DH} and calculated P_{DHW}. The average losses during these 2 months have then been used for the entire year, i.e. P_L is constant for each MFB.

3.2. Gained free heat

3.2.1. Gained heat from hot water

Heat is of course gained from the domestic hot water but at the same time heat is also transferred to the cold water that is used in the building. The net result from these two processes is difficult to estimate but we have assumed that they are of equal magnitude and thus used a gain factor equal to zero ($\eta_{DHW} = 0$) for the domestic hot water.

3.2.2. Solar irradiation

The solar irradiation is not easy to estimated, even if in depth data for the individual buildings in terms of location, orientation and shape, etc., were available. Since such detailed data is lacking, the evaluation of this study was limited to the period October–March, a period for which the solar irradiation is fairly small in Sweden and for which the relative contribution to the monthly heating demand can approximately be neglected, i.e. $\eta_{sun} = 0$.

3.2.3. Household and building electricity

For the electricity used by the buildings technical systems, E_{BE}, data is available for all MFB but for the household electricity, E_{HE}, no data is available. Since the contribution to the heating of the buildings from E_{HE} may be substantial, simulations for four different household electricity (electricity used in the apartment) consumption profiles, CP_{HE} on a monthly basis (corrected for the number of days) are used.

Information about the consumption profile for the electricity use in apartments is limited. We have found and used data that mainly has been presented in different non-scientific publications. The first profile CP_{HE}(PS) was taken from a pre-study on behalf of STEM [21] from measurements in 39 apartments. The second profile is used by the local electricity company in Umeå, Umeå Energi, CP_{HE}(UE) [22] for billing their costumers that only use electricity for household purpose. The third profile is taken from a survey done on behalf of The Swedish Consumer Electricity Advice Bureau and referred to as Gothenburg, CP_{HE}(GBG) [23], and finally CP_{HE}(CON) is the assumption of a constant use of household electricity for each day. The four profiles are displayed in Fig. 3 together with the average measured consumption profile E_{BE}. The scale on the y-axis is arbitrary.

As seen in Fig. 3 the used profiles from Umeå Energi (UE) and Gothenburg (GBG), are similar and agrees fairly well with the measured average of E_{BE}. The PS-profile exhibits a surprisingly high peak in February followed by an almost corresponding drop in March. If this is a true feature or due to some error in dating the readings will be revealed when the study has been completed and then also is based on a larger number of apartments.

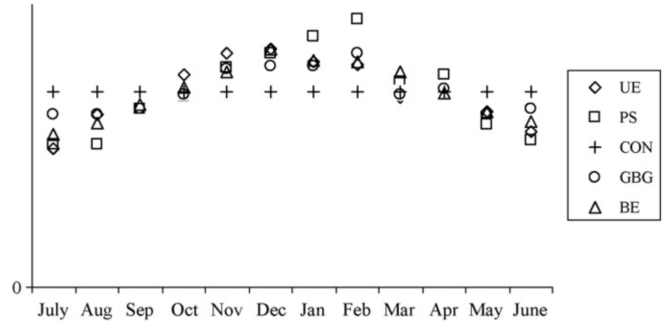

Fig. 3. Different used consumption profiles for the daily household electricity together with the measured average building electricity of all 114 MFB.

Since the profile of E_{BE} is fairly similar to that of E_{HE}, CP_{HE} has been taken to represent both E_{BE} and E_{HE}. This is done mainly in order to reduce the number of parameters to be determined (since we have only six data points for our regression), but also from the fact that the gain factor of E_{BE} is expected to be smaller than the gain factor of E_{HE} since not all technical systems are indoors.

Assuming that the gain factor is constant during October–March in each building the total gain from electricity, $P_{G,EL}$, from both P_{BE} and P_{HE} with a lumped gain factor η_E is given by

$$P_{G,EL} = P_{G,HE} + P_{G,BE} = \eta_{HE} \times P_{HE} + \eta_{BE} \times P_{BE} \approx \eta_{EL} \times P_{HE} = A \times CP_{HE} \tag{7}$$

where A is a coefficient with a specific value for each building.

3.2.4. Heat from people

Data for the number of persons and their living pattern are not available in our database. But based on official statistics (SCB, Statistics Sweden) [24] the average rented area per person is 40 m^2 in multifamily buildings in Sweden.

In 1996 SCB also initiated an investigation where members of 179 households were asked to keep a diary where they kept track of their whereabouts. The results from this survey are published [25] in terms of different age groups. Based on those data and the assumption that the age-distribution of the tenants are the same as that of the whole country Sweden, the time spent in the apartments are on average 16 h during a work-day and 19 h during weekends/holidays. Since no data were available for children under 10 years we assumed the same presence in the apartment as that of their plausible parental generation (26–45 years) and finally that the time spent at home had the following content [26] (in terms of energy)

Working days: 12 h with a low activity of 71 W and 4 h with a higher activity of 119 W.
Weekends/holidays: The corresponding assumptions are 14 h at a low activity and 5 h with the higher level of activity.

With a gain equal to 1 our assumption gives a fairly constant value of the gained heat from people per square meter ($P_{G,P} = P_P$) with a small peak for December. These assumptions give at hand that the heat from people corresponds to an increased temperature of approximately 1.1 °C (average value for all MFB).

3.3. Final model

The power balance given by Eq. (2), may now be written as

$$K_{tot} \times (T_i - T_e) = P_{DH} - P_{DHW} - P_L + P_{G,EL} + P_P \tag{8}$$

or as

$$K_{tot} \times (T_i - T_e) = P_{DH} - f_{DHW} \times Q_{DCW} \times (T_{DHW} - T_{DCW}) \times c_p \times \rho - P_L + A \times CP_{HE} + P_P \tag{9}$$

Using the assumptions discussed earlier together with measured monthly data of T_e, T_{DCW}, Q_{DCW}, the only unknown parameters are K_{tot}, T_i and A. Based on the monthly data from the period October–March, the value of K_{tot} for each MFB is then determined by linear regression. This is done by finding the value of the constant A that yields an intercept ($K_{tot} \times T_i$) that corresponds to the desired indoor temperature for each building. This means that based on the measured P_{DH}, the demanded gain from P_{EL} to obtain the desired average indoor temperature is determined together with K_{tot} and P_{GP}. This is done for all combinations of T_i, T_{DHW}, f_{DHW}, P_L and CP_{HE}.

4. Results and discussion

A total of 96 simulations has thus been performed for each building based on the different combinations of the parameters T_i, T_{DHW}, f_{DHW}, P_L and CP_{HE} as shown in Table 1.

4.1. Dependency of T_i and P_{EL} on K_{tot}

For some MFB the linear regression gave a negative value of A, which can be interpreted as if cooling was required to obtain the assumed indoor temperature. For the case of an average indoor temperature of 24 °C, 93–98% (depending on the other assumptions) of the buildings gave a solution with $A > 0$, for T_i = 22 °C the corresponding range was 79–93% and for T_i = 20 °C, 45–79% of the buildings. These results indicate that the actual indoor temperatures of buildings normally are higher than 20 °C. In Fig. 4 the obtained values of K_{tot} are compiled for the different assumptions of T_i and CP_{HE}. The values in Fig. 4 are thus the average values of eight simulations for different

Table 1
Used assumptions for the different parameters

Parameter	Different values	#
f_{DHW}	Average, maximum	2
CP_{HE}	CON, UE, GBG, PS	4
T_{DHW}	+55°, +60°	2
P_L	Yes/no	2
T_i	20°, 22°, 24°	3
P_{People}	See Section 3.2.4	1

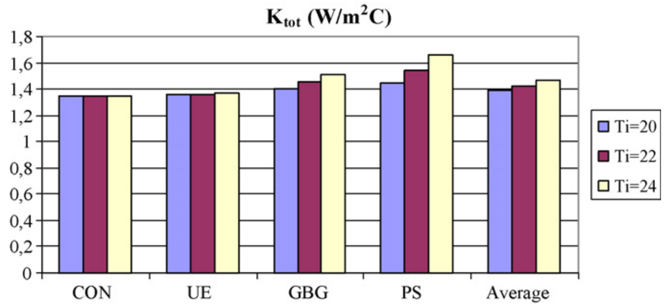

Fig. 4. The average value of K_{tot} m^{-2} of area to let. The values are based on the MFB that gave a $A > 0$ for all eight combinations.

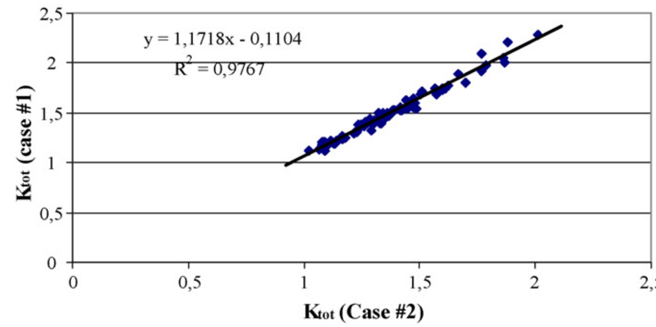

Fig. 6. K_{tot} of case #1 vs. K_{tot} of case #2.

combinations of f_{DHW}, P_L and T_{DHW} according to Table 1 and calculated for the MFB that gave a $A > 0$ for all combinations.

As seen from Fig. 4, the indoor temperature affects the obtained value of K_{tot} in most cases. With increasing T_i, the necessary contribution to heating from P_{EL} increases. Based on the assumption of a constant gain factor (October–March), the gained energy for heating from P_{EL} has the same monthly distribution as CP_{HE} of Fig. 2. In the case of a constant CP_{HE} there is no indirect dependency of T_e which results in a constant value of K_{tot}. The CP_{HE}(GBG) and CP_{HE}(PS) have on the other hand the largest values during the coldest months (February was the coldest month, followed by December, March and January) and thus an indirect dependency of T_e which results in an increasing K_{tot} with increasing T_i. The displayed T_i-dependency shown in Fig. 4 is thus connected to the profile, CP_{HE}.

4.2. Dependency of f_{DHW}, T_{DHW} and P_L on K_{tot}

In order to describe the impact from the assumption for f_{DHW}, T_{DHW} and P_L on the obtained values of K_{tot} for a specific building (#14) is shown in Fig. 5. The calculations are performed for $T_i = 22$ °C and CP_{HE} according to GBG.

In the case of losses, the required gain from P_{EL} increases and following the same line of reasoning as earlier, the result is higher K_{tot}-values compared to the case of no losses. This is also true when increasing T_{DHW} or f_{DHW}, since it means that the buildings heating system uses a smaller part of P_{DH} and that a larger gain from P_{EL} is required.

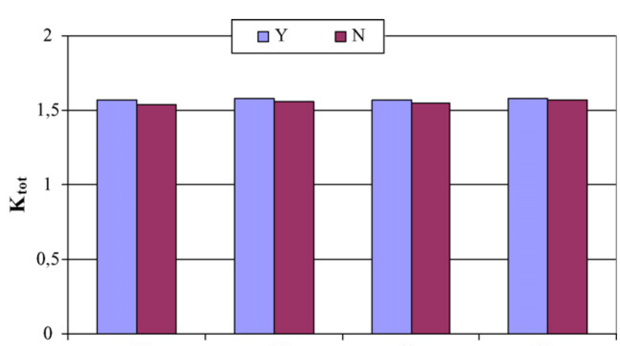

Fig. 5. K_{tot} for building #14, for different combinations of f_{DHW} (average/maximum), P_L (Y/N) and T_{DHW} (55 °C/60 °C).

The used assumptions, has been based on measured data and available information and hopefully they cover a fairly large part of existing variations. Some of the parameters such as P_P and P_L have been given a fairly simple treatment in the sense that P_P has been taken to be the same per square meter for all MFB, whereas P_L has been taken to zero or constant. The buildings are fairly large which favours a general treatment of P_P although the distribution of activities may be questioned together with the assumption that the numbers of hours spent indoors are the same during the whole period (October–March). For P_L the assumption that the losses are constant during the same period is not correct since the temperatures of both ground and the secondary supply system are not constant during October–March. These simplifications are thus questionable but have a minor influence on K_{tot} than the assumption of CP_{HE} and T_i, as seen in Figs. 4 and 5. The used P_{EL} can also be questioned from many perspectives. We assumed that P_{BE} and P_{HE} has the same profile (see Fig. 3), which for the case of UE and GBG is fairly accurate, whereas it is a more questionable assumption for constant CP_{HE} or according to the pre-study. The same profile has also been used for all buildings disregarding their size. For buildings with many tenants an aggregated consumption profile may be expected to be fairly representative, but for buildings with few tenants the consumption profile might deviate considerably from the used profiles which influences the obtained value of K_{tot} (see Fig. 4).

The obtained values of K_{tot} are as discussed dependent on the used assumptions of f_{DHW}, T_{DHW}, P_{BE} and P_{HE}. This is illustrated in Fig. 6, where the calculated K_{tot} for all buildings for the two cases from Table 2 is plotted versus each other. Each dot represents an MFB with the value of K_{tot} calculated according to cases #1 and #2. If the calculated values of K_{tot} was independent of the used assumptions, the intercept of the linear fit (which is shown in the graph) would be zero with a slope equal to unity. In order to decrease the shown uncertainty the main focus should be to obtain data of P_{HE} and T_i as stated before.

Table 2
Values of modelled parameters

	T_i	CP_{HE}	T_{DHW}	f_{DHW}	P_L
Case #1	24°	GBG	55°	Average	No
Case #2	20°	CON	60°	Maximum	

4.3. Relative energy performance

When evaluating an individual building, the energy performance in comparison with similar buildings are often more interesting, than an absolute estimate. In Fig. 7 the distribution of the calculated K_{tot} is shown for the set of parameters in Table 2 (case 2). The distribution is fairly Gaussian and quite similar for all investigated 96 combinations of the different parameters. For the case of a Gaussian (normal) distribution we can calculate the cumulative distribution function, and use as a measure of the buildings relative position (RP) within the group of MFB.

If we return to the data behind Fig. 6, and calculates the RP-values of each MFB (value of the cumulative distribution function) for cases #1 and #2, respectively, the results in Fig. 8 is obtained. On the *y*-axis we have the relative position in the group of each building for the assumptions according to case 1 and on the *x*-axis the buildings relative position based on the assumption according to case 2. As seen from Fig. 8, the relative position of an individual building is almost invariant. The solid line corresponds to the situation of RP1 = RP2 and represents an unchanged relative position of each building.

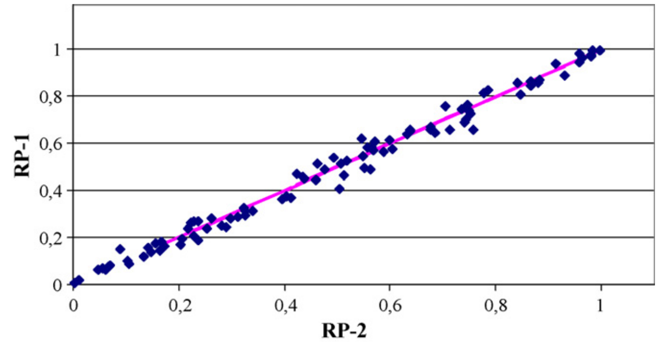

Fig. 8. The relative position (in terms of the cumulative normal distribution function) of case #1 vs. case #2.

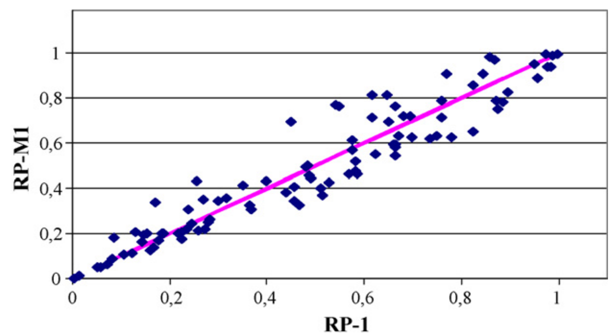

Fig. 9. The relative position (in terms of the cumulative normal distribution function) of set M1 vs. case #1.

As stated many times, we have no access to the actual consumption patterns of all individual buildings. The actual profiles for P_{HE}, P_P, etc., of each individual MFB can differ more or less from any of the assumed cases but since the MFB are fairly large, an average behavior should be fairly accurate in most cases. One way to simulate a possible reality, would be to assume that our 96 combinations reflects the real situation, but we do not know what specific combination of T_{DHW}, P_{HE}, etc., that each MFB operates under. Therefore, a new set of K_{tot}-values was created, where K_{tot} for each MFB was determined for a specific combination of assumptions that was randomly (uniform distribution) selected among the 96 combinations. In this way K_{tot}-values for every building was calculated, but with randomly distributed assumptions of P_L, f_{DHW}, T_i, T_{DHW} and CP_{HE}. This new set (M1) of K_{tot}-values could thus illustrate some plausible reality. In Fig. 8 the relative position of each building in the randomly generated set Mix1 is plotted versus RP1 (the relative position of each MFB when K_{tot} of all MFB have been calculated according to case #1). A similar guideline as in Fig. 8 is also included.

As seen in Fig. 9, the relative position is not as invariant as in Fig. 8. This is of course dependent on the influence from T_i and CP_{HE} on K_{tot} and thus on the relative position of each building. The buildings that deviates the most from the guideline are those buildings that in the random distribution of assumptions in set M1 were allotted a CP_{HE} according to PS. This fact is illustrated in Fig. 10 where a new set of randomly distributed assumptions was created (M2) but where a CP_{HE} according to PS was omitted.

The relative position of an MFB is thus fairly invariant to the made assumptions (PS excluded), i.e. if K_{tot} is calculated for the same assumptions for all buildings or with a random choice of assumptions. This indicates that with access to a fair description of the CP_{HE} the relative position of an individual MFB could be determined fairly accurately. Additional improvements would of course be reached if the indoor temperature also were

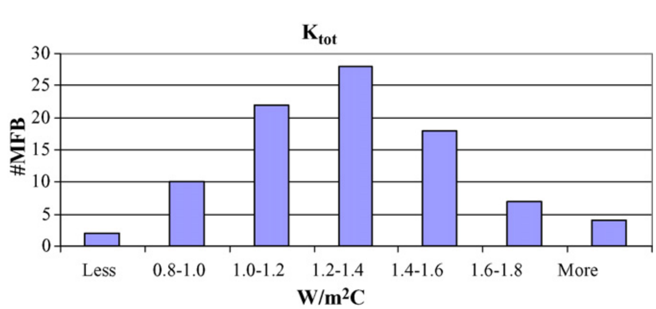

Fig. 7. Distribution of K_{tot}-values under the assumptions of case #2 of Table 2.

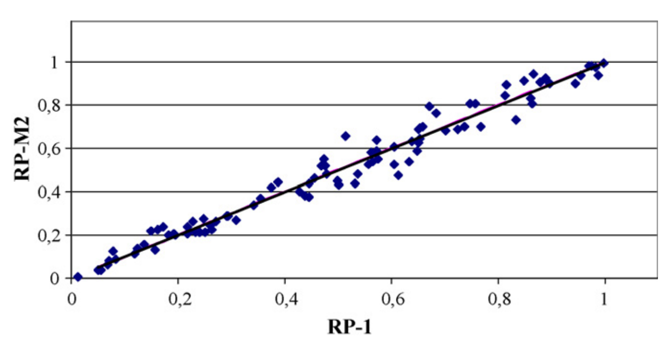

Fig. 10. The relative position (in terms of the cumulative normal distribution function) of set M2 vs. case #1.

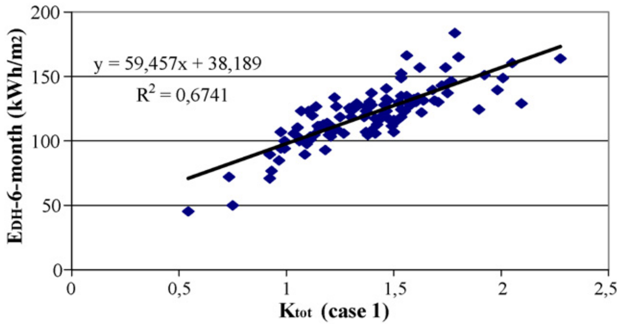

Fig. 11. Measured E_{DH} from the period October–March vs. K_{tot} of case #1.

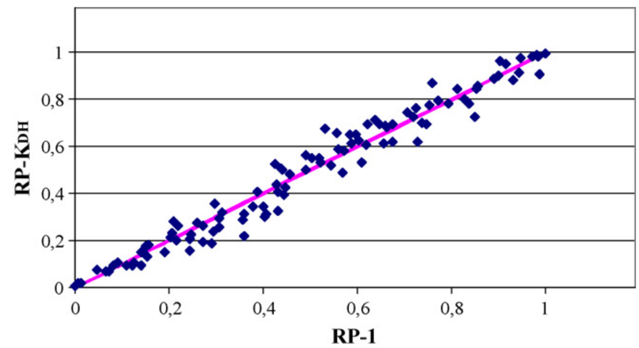

Fig. 13. The relative position based on K_{DH} (determined from P_{DH}) vs. relative position of K_{tot} of case #1.

available. But in practise T_i would be difficult to obtain, since T_i should represent the average temperature inside the building. But for CP_{HE} it is plausible to assume that the profile is fairly similar between different MFB if they are fairly large. And finally, since the absolute value of K_{tot} demands a full knowledge of all parameters the concept of the relative position is more correct to use than K_{tot}-values.

Today most estimates of the energy performance of an individual building in Sweden, is based on the annual energy supplied by DH or by other sources for heating. A similar representation of the accumulated value of E_{DH} (in kWh/m^2) for October–March and K_{tot} (W/m^2 °C) and the relative position based on E_{DH} and K_{tot} is shown in Figs. 11 and 12.

Since E_{DH} more reflects the management of the building and the tenants behavior than that of the buildings energy performance, contradictory evaluations are obtained as seen in Figs. 11 and 12. This feature is also reinforced if the annual E_{DH} is used instead of E_{DH} from the period October–March.

Instead of using the accumulated value of E_{DH}, K_{tot}, based on the use of district heating, $K_{tot,DH}$ is determined from a simple linear regression of the monthly values of E_{DH} versus T_e. The results are shown in Fig. 13. The solid line represents as before the invariant case. The reason why this simple approach yields such good agreement is due to the fact that only using the measured monthly, E_{DH}, corresponds to the assumption that the sum of P_G, P_L and P_{DHW} is constant for all months.

But if $K_{tot,DH}$, determined from a linear regression of the monthly values of E_{DH} versus T_e, is used instead of the

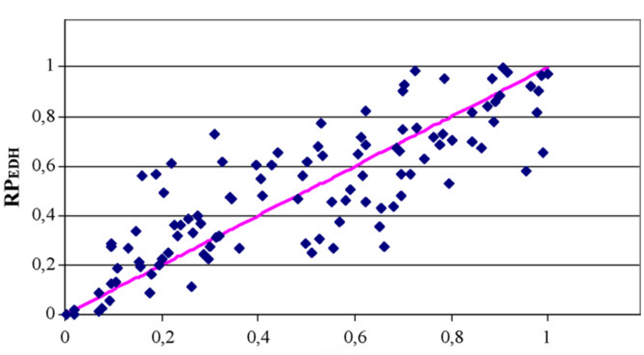

Fig. 12. The relative position based on E_{DH} (October–March) vs. relative position based on K_{tot} (case #1).

accumulated E_{DH} we get the results of Fig. 13. The solid line represents as before the invariant case. The reason why this simple approach yields such good agreement is due to the fact that only using the measured monthly, E_{DH}, corresponds to the assumption that the sum of P_G, P_L and P_{DHW} is constant for all months.

5. Conclusions

The thermal property K_{tot} is a good measure of the energy performance of a building. Based on our analysis we conclude that in order to obtain the absolute value of K_{tot} it is most important to have data for the household electricity use together with the indoor temperature. Of minor importance are the domestic hot water consumption and temperature levels. When comparing the energy performance of individual buildings in a larger set an alternative could be to compare the buildings relative performance. For this comparison the absolute values of the house hold electricity is not necessary, but the household electricity consumption profile (CP_{HE}) is sufficient. For buildings that are fairly large, CP_{HE} from the local energy company could be used without introducing any larger errors in the relative position of an individual building and the same applies to the indoor temperature. With access to data for a number of years P_{HE} and P_{BE} can also be treated separately when using an energy signature approach, if necessary.

We also conclude that the annual energy use per square meter (used for space heating and domestic hot water, paid by the property holder) is a very questionable energy key figure. This is due to the fact that the used energy just represents a part of the total energy for heating and more reflects the management of the building and the behavior of its tenants than the energy performance of the building.

The ultimate question if a building is energy efficient is not simply answered by the energy performance of the building but involves also the question: is the building operated in an efficient way?

In order to answer the second question the absolute value of the gained heat from sources such as household electricity, solar radiation, etc., is required in combination with the indoor temperatures to estimate the different gain factors. But based on the values of the demanded energy gain, $A \times CP_{HE}$, obtained from the linear regression, a similar analysis of $A \times CP_{HE}$ in terms of a buildings relative position could also be made. For this case the relative position is however strongly influenced by the indoor temperature, which thus becomes crucial for this kind of evaluation.

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