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Utilizing a Regression Approach for Troubleshooting Energy Performance of Swedish Buildings

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Abstract

The follow-up of calculated and actual energy performance for new buildings is important to enable a learning process. Performance verification is however not a trivial task since the traditional energy use intensity indicator (EUI) can display large variations even for buildings with similar design and HVAC systems. Hence, there exists a risk for confusion between building owners and developers when predicted and actual outcome are compared using only this indicator.

In this paper, simple methods, based on area normalization and regression analysis are investigated for interpretation of wide discrepancies in measured EUIs within four similar, newly built multifamily buildings in Umeå, Sweden. It was found that the discrepancies in specific annual energy demand were dependent on the area used for normalization but did not fully explain the variation in the EUIs.

The utilization of linear regression for identification and comparison of the buildings heat-loss factor, (ventilation and transmission), and effective solar aperture provided further insights. The regression analysis indicated that the differences in EUIs were due to a combination of chosen area for normalization and solar gain and not the consequence of variations in actual U-values and HVAC systems. Due to the regression methods robustness against influence from the users, it was concluded that the method works well as a complement to the EUI indicator since it provides insights of the buildings thermal performance. This is often of interest to verify for the developer and the property owner since the thermal performance can be controlled in the construction process.

Keywords – Performance verification; regression; shape factor; energy.

1. Introduction

Benchmarking systems are important for promoting energy efficiency and to provide transparency of energy use in the building sector. Energy use intensity (EUI) is a type of benchmark indicator that is often used [1] and is calculated by summing up energy use over a year and normalizing with the floor area. Climate adjustment of calculated EUIs is easily performed if degree–days information is available. By normalizing the annual energy demand with the floor area, the hope is that wide differences between building EUIs will indicate inefficient buildings where improvements can be made. But since EUIs is subject to a lot of uncertainties e.g. climate corrections, user behavior, solar gain etc. it is well known that EUIs can show large variations even between similar buildings [2] and [3].

In Sweden the household electricity is excluded in the calculation of EUI and the hot water use can be replaced with a standardized value if the consumption is unusually high, as an attempt to normalize the influence of the users [4]. Despite the Swedish building regulations attempt normalize the influence of the users the problem still exists with varying EUIs for similar buildings as showed in the study by Danielski [2]. Hence, there exists a risk of confusion between building owners and developers when predicted and actual outcome is compared using only this performance indicator.

Discrepancies between measured and calculated EUIs will in most cases exist, regardless if the measured EUI is lower or higher than predicted, an analysis is needed to indicate the reason for the difference. Much research effort has been put on developing alternative benchmark approaches for a review see for instance [1]. One of the alternative methods is regression analysis, for instance, Sjögren et al [5] used a regression method to evaluate the energy performance of 100 multifamily buildings in Sweden. In the analysis the buildings heat-loss factor (K_{tot}) was identified and compared with the frequently used EUI indicator. The study suggested that K_{tot} could be used as a good complementary benchmark tool.

The aim of this work is to investigate if regression models could be used to gain more insights and knowledge in the verification process compared to what is possible with the EUI indicator. As case studies, four newly built multifamily buildings in Umeå Sweden were chosen with high similarities in design but with surprisingly large variations in measured EUIs. The results are hoped to be valuable for owners and developers in the performance verification stage of new multifamily buildings in subarctic climate.

2. Building descriptions and measurements

The four studied multifamily buildings were constructed during 2011 in close proximity to each other for the social housing company, AB Bostaden in Umeå, Sweden. The buildings are designed with approximately the same overall U-value ranging between 0.27 W/m^{2}K to 0.30 W/m^{2}K, according to the developer. The ventilation systems are equipped with air heat exchangers, (enthalpy wheels with design thermal efficiencies of 80%). The buildings have high airtightness with an average air-leakage of 0.13 l/sm^2 ext. surface area, according to fan pressurization tests [6]. The number of floors varies from three to five, thus the size difference between the buildings is quite significant, noticeable in Table. 1. In Fig. 1 a photograph of one of the studied buildings (building A) is shown.

Fig. 1 Photograph of building A

Each building has separate meters for monitoring supplied district heat (DH) for space heating and domestic hot water use. The DH and building electricity demand was monitored at a building level whereas household electricity and indoor temperatures (T_i) were measured in the apartments and subsequently aggregated. All measurements were done via the property holders own metering system, installed in the construction process. The values were logged and stored at a daily resolution. An exception was the outdoor temperature (T_o). It was monitored with a manufacturer-calibrated RTR-505 tiny-logger, with higher resolution of 15 min, mounted onsite for this particular study.

3. Energy performance analysis

In the following sections the energy performance of the buildings are discussed. Calculations during the design stage are compared with the measured performance in terms of EUIs. Finally, a more detailed regression analysis of the measured data is conducted for further diagnosis.

3.1 Traditional energy evaluation

As described previously the buildings have approximately the same design overall U-values and HVAC systems. Hence, given the same operating conditions they are expected to perform similarly. This is shown in Table. 1, where the predicted EUIs based on calculations made by the building developer is introduced. If these calculations are compared with the measured, (weather-normalized), EUIs, two things can be noticed: firstly, the buildings have less good performance than predicted and secondly, that the building EUIs varies significantly. As it is usually the case that predicted and actual outcome differ this will not be the focus of further analysis. However the variation in measured EUIs is of interest since the buildings are very similar.

Table 1. Measured (weather-normalized) EUIs, calculated EUIs and building areas.

Building no.	Total floor area m^2	Living area m^2	Total surface area m^2	Air-to-air surface area m^2	Design EUI $kWh/m^2/a.$	Measured EUI $kWh/m^2/a.$
A	1521	1037	1855	1492	65	87.2
B	2366	1587	2540	2072	63	68.3
CD	2776	1792	2621	2077	64	76.8
E	1450	932	1972	1518	64	87.6

3.2 Analysis of possible causes of variations in measured EUIs

Danielski [2] identified three main causes that could contribute to variations in measured EUIs in newly built multifamily buildings in Sweden: first: the time interval between the completion of construction work and the energy measurements, secondly: the relative size of the common area and lastly: the shape factor of the building (ratio of envelope surface area to inner volume of the building). Since these buildings were built during approximately the same time period (only months differ in completion date) the first cause is unlikely to explain the measured variation of EUIs in this study. The second and third cause is more likely, as the energy use in the common areas is typically lower, compared to apartment areas. The size of the common area relative to the total floor area will have an impact on the variation of EUIs. Also, the positive effect of a compact building design (low shape factor) is fairly well documented.

In addition to the study by Danielski, Beusker et al [7] and Depecker et al [8] also found, that the shape factor design had a significant impact on the investigated buildings heat demand. The positive effect of low shape factor can be illustrated by the following example, suppose one single floor building is extended with an additional equal sized floor. The buildings heated floor area is in that case doubled but the heat-loss has in contrary not been doubled, (since the vertical heat losses, through the ground and roof is unaffected). In the previous example the ratio of envelope surface area to floor area was decreased. Consequently, the shape factor also decreases, since only the floor height differs between the ratio envelope surface area to floor area and the definition of shape factor.

To investigate the impact of used floor area for normalization, the measured EUIs in Table. 1 was compared with the cases when the annual energy demand was normalized against living area and envelope surface area, referred to as EUI* and EUI**. The results can be observed in Fig. 2.

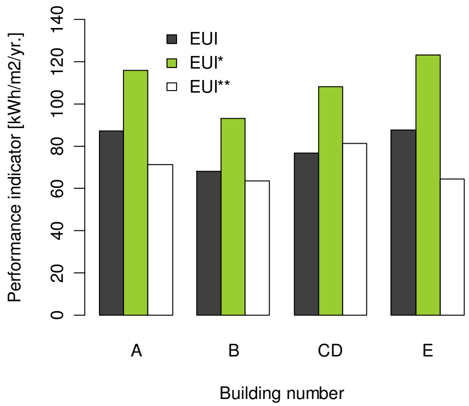

Fig. 2 Supplied annual energy use from the grid (except household elec.) to buildings A-E normalized with total heated floor area (EUI), with apartment floor area (EUI*) and with envelope surface area (EUI**).

It can be seen in Fig. 2 that the EUI indicators increases when the normalization is done with living area (EUI*), simply due to that the living area is smaller compared to the total floor area. But, the relative differences remains fairly unchanged between the EUIs and EUI*s suggesting that the variation is quite insensitive to the used floor areas for normalization. The ranking of the indicators changes when the effect of different shape factor designs is considered in the EUI** cases and the variation between the buildings decreases somewhat.

To quantify the spread, the standard deviation (Sd) was calculated for the indicators. It resulted in Sd's of 8.0, 11.0 and 7.1 (kWh/m^2, yr) for the EUI, EUI* and EUI** cases respectively. Since the buildings demand for space heating is related to the size of the envelope area it is expected that the differences between the buildings will decrease in the EUI** cases. However as other factors are influencing the annual EUI**s such as domestic hot water usage, solar gains etc. differences will continue to exists. To better understand the variation in the measured EUIs the focus shifted to the thermal performance of the buildings.

3.3 Impact of heat-loss factors on EUIs

A benefit with subarctic climate, in terms of evaluating building thermal performance, is that the global solar radiation (S) is typically very low close to the winter solstice. That makes it possible to use heating data from this period to identify the buildings heat-loss factors (K_{tot}) with little bias due to solar gain. K_{tot} denotes the sum of the transmission (air-to-air) and ventilation losses, of which the ventilation losses are small part in this study due to heat recovery on the exhaust air. The buildings K_{tot} were determined by a least square fit to the equation

$$P_h + \alpha P_{elec} + P_p = K_{tot}(T_i - T_o) + G. \qquad (1)$$

Where, P_h and αP_{elec} are the separately metered whole building use of DH and electricity for space heating. G and P_p denotes the average ground heat loss and gained heat due to occupancy respectively. In (1) the contributions to heating from the sun were neglected since the data was collected during a time period of low S, (22th of Nov 2013 through 21th of Jan 2014). Also, the contributions to heating from water usage were assumed negligible. That is, the gained heat from the domestic hot water usage was assumed to equal the heat loss due to cold water usage.

Further assumptions relate to the terms P_p and the electrical heat gain factor α. P_p was calculated based standardized values of number of tenants in the buildings, and assuming a daily occupancy schedule of 14 hours and 80 W per person of emitted heat as recommended in [9]. Also in line with this guideline a standardized value of 0.7 for the electrical heat gain factor α was assumed. Lastly, the dynamic effects were minimized by averaging the data of four days before least square fits were conducted.

Since K_{tot} mainly consists of transmission losses (air-to-air) which are governed by the envelope areas above ground and associated U-values, a good control of the quality of the building construction (and air handling units) would be to compare the buildings K_{tot} when normalized against air-to-air envelope area. These can be seen in Fig. 3 (left) and for comparison K_{tot} normalized against heated floor area is also shown in Fig. 3 (right). Each regressed estimate is shown with an error bar representing a confidence interval (CI) of 95%.

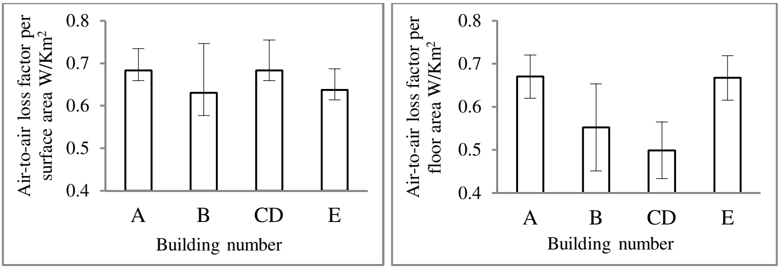

Fig.3 Regressed heat-loss factor (K_{tot}) normalized against building envelope area above ground (left) and normalized against floor area (right). The error bars are 95% confidence intervals for the estimates.

It can be observed in Fig. 3 (right) that the CIs for the regressed estimate of K_{tot} per floor area for the larger building CD do not overlap the same estimates for the smaller buildings E and A, indicating a statistical significant difference. This was confirmed with a conventional two sided t-test of parallelism, assuming equal variance, during which the hypothesis of parallelism (i.e. equal slopes) was rejected at 95% confidence level.

Due to relatively poor model fit to building B data, the tested hypothesis of equal K_{tot} per floor area could not be rejected in the case of building B relative to the smaller buildings E and A. Nevertheless, it is apparent that the larger buildings B and CD has considerable lower point estimates of K_{tot} per floor area compared to the smaller buildings E and A.

In Fig. 3 (left) it can be seen that these differences are dampened when the estimates of K_{tot} are instead normalized against air-to-air envelope area to the extent that all CIs overlap. In fact, tests of parallelism in this case could not be rejected at the 95% confidence level for all buildings. Thus, we could not conclude that there is a significant difference in thermal performance between the buildings if the normalization is done with respect to air-to-air envelope area. This affirmed our expectations since the buildings have approximately the same design overall U-values.

If K_{tot} normalized against floor area, Fig. 3 (right) is compared with the variation of EUIs in Fig. 2 the same rankings between small (A and E) and large (B and CD) buildings can be seen. But the variation in K_{tot} per floor area do not completely explain the EUIs, since building B has a larger K_{tot} per floor area than building CD, but building B nonetheless scores the best EUI of the two. This indicated a need to proceed to examine the buildings conditions to receive solar heat for further insights.

3.4 Impact of solar gain on EUIs

The differences in solar gain between the buildings can be considerable and it is dependent on the buildings orientation, design and internal and external shading etc., thus difficult to calculate in the design stage. To investigate if differences in received solar gain would further clarify differences in EUIs, eq. 1 was extended with a solar term, $\eta A_e S$ to the following form

$$P_h + P_p + \alpha P_{elec} = K_{tot}(T_i - T_o) - \eta A_e S + G. \quad (2)$$

The ηA_e factor in eq. 2 is sometimes termed solar aperture and is the equivalent solar collecting area (A_e) multiplied by a utilization factor (η) as defined in the standard [10]. In order to quantify both K_{tot} and ηA_e, the analysed period must provide a reasonable large variation in both the independent parameters S and T_i-T_o. Thus, the analyzed period was extended to cover the whole heating season 1/10-2013 through 30/4-2014 during which S was significant.

The results are listed in Table. 2 when eq. 2 was fitted to whole heating season data and for comparison the results when eq. 1 was fitted to short-term data measured during low S is also shown.

Table 2. Result of parameter identification with linear regression, with different datasets. The associated standard errors are shown in parenthesis.

Building no.	Using whole heating season data (eq. 2)			Using data collected during low S (eq. 1)	
	K_{tot} [kW/K]	ηA_e [m^2]	G [kW]	K_{tot} [kW/K]	G [kW]
A	1.04(0.03)	16.0(3.0)	-1.7(0.8)	1.02(0.04)	-0.8(1.0)
B	1.29(0.10)	24.9(7.8)	-2.4(2.2)	1.27(0.11)	-0.5(2.6)
CD	1.38(0.05)	12.7(4.1)	1.9(1.1)	1.34(0.05)	2.8(1.6)
E	0.97(0.03)	15.6(2.4)	-1.2(0.6)	0.96(0.03)	-0.7(0.9)

It can be seen in Table. 2 that the differences in the estimates of K_{tot} from eq. 1 and eq. 2 is small indicating that the additional solar term in eq. 2 has worked well of capturing the introduced variance in the dependent variable due to solar gain. It is apparent from Table. 2 that building B received the largest amount of solar gain during the heating season (due to the highest ηA_e factor) and the ηA_e factor is fairly equal for the other buildings. This can be explained by the fact that building B is orientated with its long side façades towards north/south, the large glazed surface area in the south direction is reflected in the higher estimate of ηA_e. The other buildings have their smaller gable walls in the south direction and thus have smaller solar apertures in that direction. The negative G values are not physical plausible however, and a consequence of larger uncertainties, both statistical (standard errors) and physical, due to coarse information of P_p and α. For instance, if P_p is raised by 25% and α from 0.7 to 0.9, (which is equally probable), the negative estimations of G during the analysed period of low S, in Table. 2 would be raised into the interval [0.9:1.5] kW which would correspond better with theoretical expectations. Uncertainties of P_p increase with the number of tenants and similarly the impact of α on the results increase with electricity usage. For a stringent treatment of G with the presented regression methods requires careful handling of P_p and α. In addition, measured data of emitted heat from circulation of domestic hot water would be necessary.

It should however be stressed that uncertainties in P_p and α have a small impact on the estimation accuracy of the buildings K_{tot}, due to that P_p and αP_{elec} is relatively small and poorly correlated with T_i-T_o, the same holds for the emitted heat from circulation of domestic hot water. Fortunately in this study, differences in G is not the main interest since they are believed to be small in practice, due to that the buildings are built next to each other (thus similar ground properties) and have the same designed floor U-value.

Despite of large uncertainties in the models intercept the overall model fits in Table. 2 were good, with R^2: s larger than 90% for model (1) and adjusted R^2: s larger than 85% for model (2). Equation (2) was subsequently used for prediction of the buildings heat demand during the heating season. This resulted in a good overall agreement between predicted and measured heat demand, with mean bias errors less than 1%. The rankings of the predicted heat demand were the same as the EUIs in Fig. 2 which were found reasonable since the heat demand dominates the EUIs. The other part consists of domestic hot water usage but these were fairly equal in the buildings. With the results from the regression analysis we are now able to understand the EUIs better and can summarize.

Building B had the second lowest estimate of K_{tot} per floor area and the largest ηA_e factor leading to scoring the lowest heat demand per floor area of the studied buildings (and also EUI). Building CD had the lowest K_{tot} per floor area, but also the lowest solar aperture (roughly half compared to building B) leading to the second place in heat demand per floor area. For the smaller buildings A and E strikingly equal estimates of K_{tot} per floor area and solar aperture were found, thus scoring similar heat demand per floor area (and EUIs).

4. Summary and concluding remarks

A comparison between measured and calculated EUIs will in most cases differ. Regardless if the measured EUI is lower or higher than predicted an analysis is needed to understand the reason for the differences. This study was designed to investigate simple methods to be used to explain wide differences in measured EUIs in four similar, newly built multifamily buildings in subarctic climate. It was found that the discrepancies in specific annual energy demand were dependent on the area used for normalization but did not fully explain the variation in the EUIs.

The utilization of linear regression models for identification and comparison of the buildings heat-loss factor, (ventilation and transmission), and effective solar aperture provided further insights. The regression analysis indicated that the differences in EUIs were due to a combination of chosen area for normalization and solar gain and not the consequence of variations in actual U-values and HVAC systems.

Due to the regression methods focus on thermal performance and minimization of the influence from the users, we conclude that the method works well as a complement to the EUI indicator. Buildings heat-loss factor is a good indicator to verify for both the developer and the property owner since this can be controlled to a larger extent, than the EUI indicator.

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References

[1] W. Chung, Review of building energy-use performance benchmarking methodologies. Applied Energy. 88(5) (2011) 1470-1479.

[2] I. Danielski, Large variations in specific final energy use in Swedish apartment buildings: Causes and solutions. Energy and Buildings, 49 (2012) 276-285.

[3] T. Sharp, Energy benchmarking in commercial office buildings, Proceedings of the 1996 ACEEE Summer Study of Energy Efficiency in Buildings, 4 (1996) 321–329.

[4] Swedish National Board of Housing, Building and Planning, Energihushållning enligt Boverkets byggregler- utgåva två, Karlskrona, 2012.

[5] J.-U. Sjögren, S. Andersson and T. Olofsson. An approach to evaluate the energy performance of buildings based on incomplete monthly data. Energy and Buildings. 39 (2007) 945–953.

[6] SS-EN 13829. Thermal performance of buildings-Determination of air permeability of buildings-Fan pressurization method, SIS förlag, Stockholm, 2000.

[7] E. Beusker, C. Stoy and S. N. Pollalis. Estimation model and benchmarks for heating energy consumption of schools and sport facilities in Germany. Building and Environment. 49 (2012) 324-335.

[8] P. Depecker, C. Menezo, J. Virgone and S. Lepers. Design of buildings shape and energetic consumption. Building and Environment. 36(5) (2001) 627-635.

[9] SVEBY. Brukarindata för energiberäkningar i bostäder. 2012. (In Swedish)

[10] SS-EN 15603. Energy performance of buildings-Overall energy use and definition of energy ratings, SIS förlag, Stockholm, 2008.