# LOAD ALLOCATION THROUGH DETAILED SIMULATION CALIBRATED WITH MONITORED DATA

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## ABSTRACT

Detailed simulation programs can be used to enable the comparison of the energy performance of a building with average performance of similar buildings, and to evaluate the energy savings of energy conservation measures. For the simulations to be meaningful, they should be calibrated with actual data. Utility bills are not sufficient to produce a "calibrated simulation" since they can only capture seasonal changes in the energy use. In order to capture the diurnal and hourly changes, hourly monitored data is required. Another limitation that often exists with utility bills is that institutional buildings (campus buildings) usually share utility bills, and therefore utility bills can not be used to calibrate the simulation of a specific building. Measured data in this instance can solve the load allocation problem. A study is conducted on a campus building that addresses the limitation of utility bills, and illustrates the importance of using monitored data to calibrate the building energy simulations. While this paper addresses the limitation of utility bills, a future paper will discuss the calibration procedure of the energy simulation.

## INTRODUCTION

Building energy simulation programs have been improving during the last twenty years to address more realistic details related to the dynamic energy balance of the building structure and systems, in the design stage. However when a simulation is developed for an existing building to base-model its energy use and study the effects of different energy conservation measures, one needs to calibrate the simulation with real data. Usually analysts resort to utility bills that may be sufficient to capture the seasonal changes in the energy use. However, if one needs to capture the hourly and diurnal changes, the only solution would be to monitor the energy channels within the buildings (monitoring the main building meters as a minimum).

A real problem that is often associated with institutional buildings (university and hospital campuses) is that two or more buildings usually share one utility bill. The use of such bills to calibrate the energy simulation of a separate building does not offer the required information. Monitoring the energy channels in an individual building helps allocating the loads to individual buildings, and also helps obtaining meaningful calibrated simulations. This paper focuses on the monitoring operations of a dormitory building and the findings. A future paper will discuss the calibration of the energy simulation and the savings potentials of appropriate energy conservation measures.

## BUILDING DESCRIPTION

The building under study is a university dormitory and comprises a total of 103,470 $ft^2$ of conditioned floor space: twelve floors of dormitory rooms, a main floor for management and security, a cafeteria, a kitchen facility, a small area for shipping/receiving, and a basement used mainly as electrical and mechanical rooms. The dormitory rooms are not cooled; they are heated and ventilated only, since very few summer classes are offered, and the weather in the location (Southeast Wisconsin) is not extremely hot during the beginning and the end of the school year, September and May, although students usually complain that the rooms are not very comfortable during these mentioned periods. The building is a brick-clad heavy construction with a 19.4% window-wall ratio. All the windows are facing east and west.

Since only the main area (management and cafeteria) has mechanical cooling, the building is equipped with three screw-type chillers of 30 Tons capacity, each with two 15-Ton stages (90 Tons Totals). Two chillers normally run on a hot day, with the third serving as a stand-by unit. There are two passenger elevators, 37.5 hp each, and a 15 hp freight elevator, totaling 90 hp (67kW).

The lighting in the building is all provided with T-12 fluorescent tubes.

## BUILDING ENERGY MONITORING

The project was initiated as a study aiming at analyzing the building energy performance of an urban university campus. A dormitory building was chosen as a pilot project. A walk-through survey was conducted, and a questionnaire was completed by the building manager and energy operator. The blue prints of the building (built in the late 60's) were also

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checked – some modifications in the partitioning and the mechanical equipment took place and can't be seen on the floor plans. A base-case simulation was developed (using a DOE2-based software). In order to calibrate the simulation, one-year worth of utility bills (gas and electricity) were collected. This generated a challenge. There are three adjacent dormitory buildings on campus. The local utility company bills each building for gas separately, while it bills all three buildings with one electricity bill. The university officials, based on information from the utility company, assume that the building under study uses 65% of the total billed electricity.

A monitoring project was initiated in order to substantiate the "65%" claim, as a load allocation question, and also to be able to disaggregate the total electricity consumption of the building itself.

Disaggregation of Total Energy Use (constant speed vs. variable speed equipment)

Since three buildings are billed together by the utility company, it would be difficult to assume that that a simple fraction could be used to "split" the bill. While the suggested fraction might be accurate in term of energy consumption, it could be less than accurate in terms of demand, even though all three buildings are dormitories (same function). For instance, the building under study has a large kitchen facility with a lot of exhaust fans and electrical cooking equipment, while the other two buildings do not. Taking into consideration the schedules in the operation (hours of operation) of various equipment, it would be difficult to know which building contributed in the peak demand value and to what percentage.

Furthermore, the correct answer to the load allocation can only be answered by monitoring every energy channel in the building which proves to be very costly. A cost-effective solution was used where the monitoring plan covers the main three meters in the building under study:

- Meter-1: feeds the chiller and the motor control center (MCC) load (480 Volts).
- Meter-2: feeds the kitchen, elevators and fresh air fans (480 Volts).
- Meter-3: feeds the lighting and receptacles (208 Volts).

Since all the fans and pumps are constant-speed type, one-time measurements (kW) together with the schedules of operation, are enough to enable a complete energy disaggregation of the total load on the meters. A complete disaggregated load makes an accurate calibration of the energy simulation possible. In addition the load allocation question would be answered. If some of the fans and pumps were variable-speed type, the load allocation would

be more complicated and would require more detailed monitoring (submetering), and thus more costly. Figures 1, 2, and 3 show the 480 Volts bus (Meter-1), the 480 Volts bus (Meter-2), and the 208 Volts bus (Meter-3), hooked with the three-phase 300 Amps, 1600 Amps, and 2400 Amps power transducers, respectively. Figure 4 shows a complete connection with the current transducers and the voltage wiring (tapping). Figure 5 shows the transformer cores (13,200 Volts to 480, 277 and 208/120 Volts) with the incoming high voltage lines. Figure 6 shows the data acquisition system connected to the power transducers and producing initial readings. The readings showed very low power factor values on two meters (1 and 2).
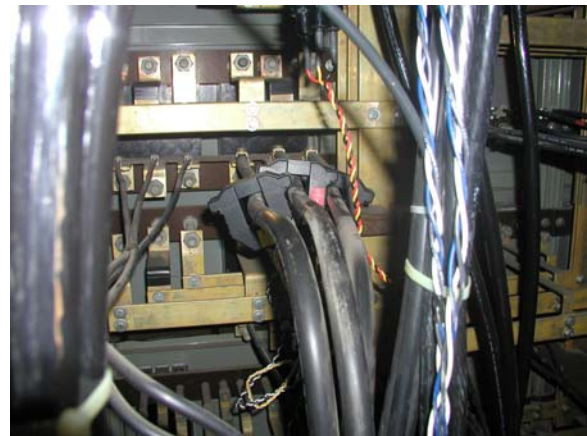


Figure 1. Three-phase power transducer installed on the 480 Volts bus, feeding the chiller and the motor control center.



Figure 2. Three-phase power transducer installed on the 480 Volts bus, feeding the kitchen, elevators and the fresh air fans.

Power Quality

An additional advantage of monitoring the energy performance of the building was discovering

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that the power factor on the 480 Volts feeds is very low (around 0.4). The initial low readings were suspicious and required a verification. First, the



Figure 3. Three-phase power transducer installed on the 208 Volts bus, feeding the lighting and receptacles loads.
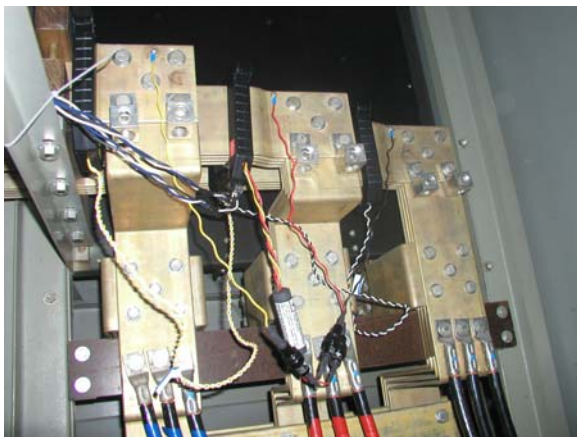


Figure 4. Complete connection with the current transducers and the voltage attachments.



Figure 5. Cores of the transformer (13,200 to 480, 277 and 208/120 Volts) feeding three adjacent buildings.
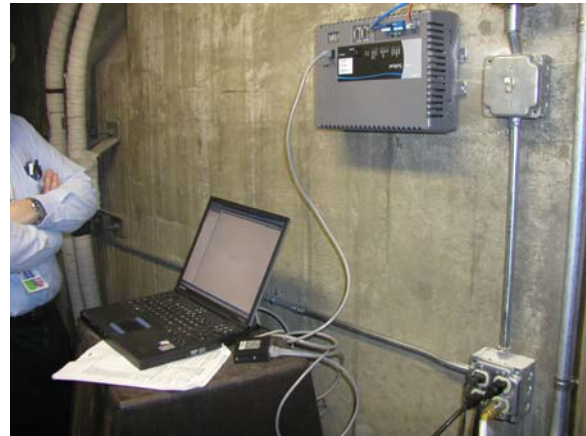


Figure 6. Testing the initial readings of the data acquisition system.

power transducers installation was checked, and they were found to be installed properly. Then, a power quality meter (shown in Figure 7) was installed for one week to provide a reality check for the problematic power factor. The values obtained confirmed the values shown by the data acquisition system; a value around 0.4.



Figure 7. The power quality meter used to verify the power factor values.

The power factor reflects the magnitude of the reactive power, which is a wasted magnetic load. The bigger the power factor, the bigger the waste, thus the utility companies penalize the customer for a poor power factor using Equation 1 (the value between the parenthesis is the penalty):

$$kW_{Billed} = kW_{Measured}\left(1 - 0.5\left(PF - 0.85\right)\right) \qquad (1)$$

For any power factor value less than 0.85, the customer would pay more for the demand. A solution to improve the power factor is to install
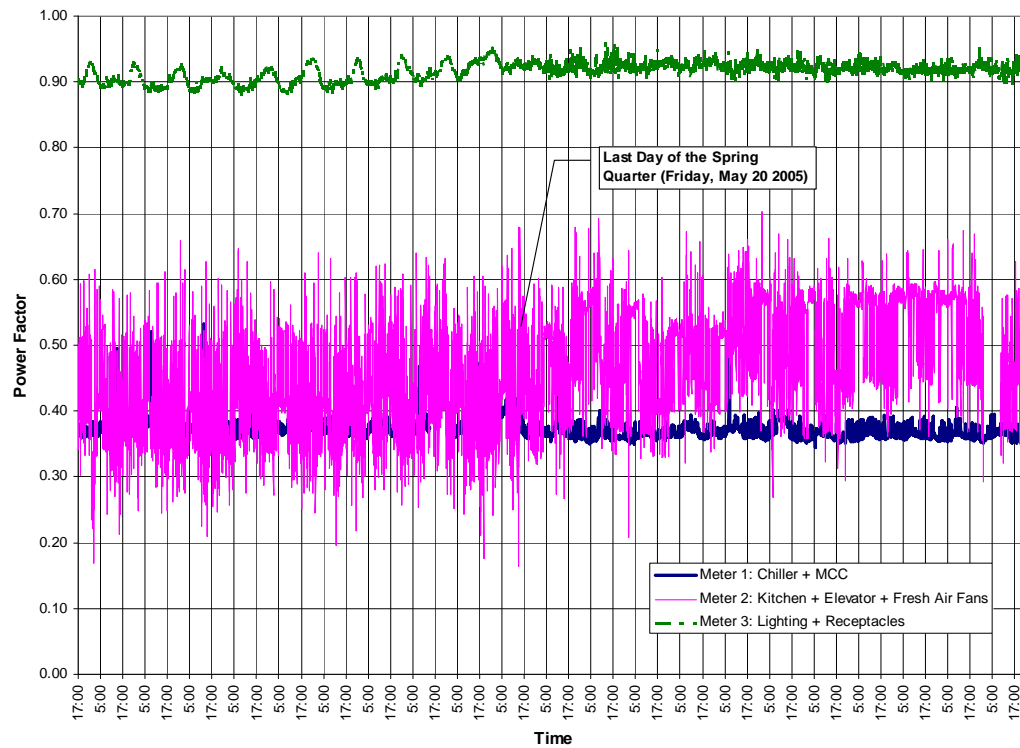
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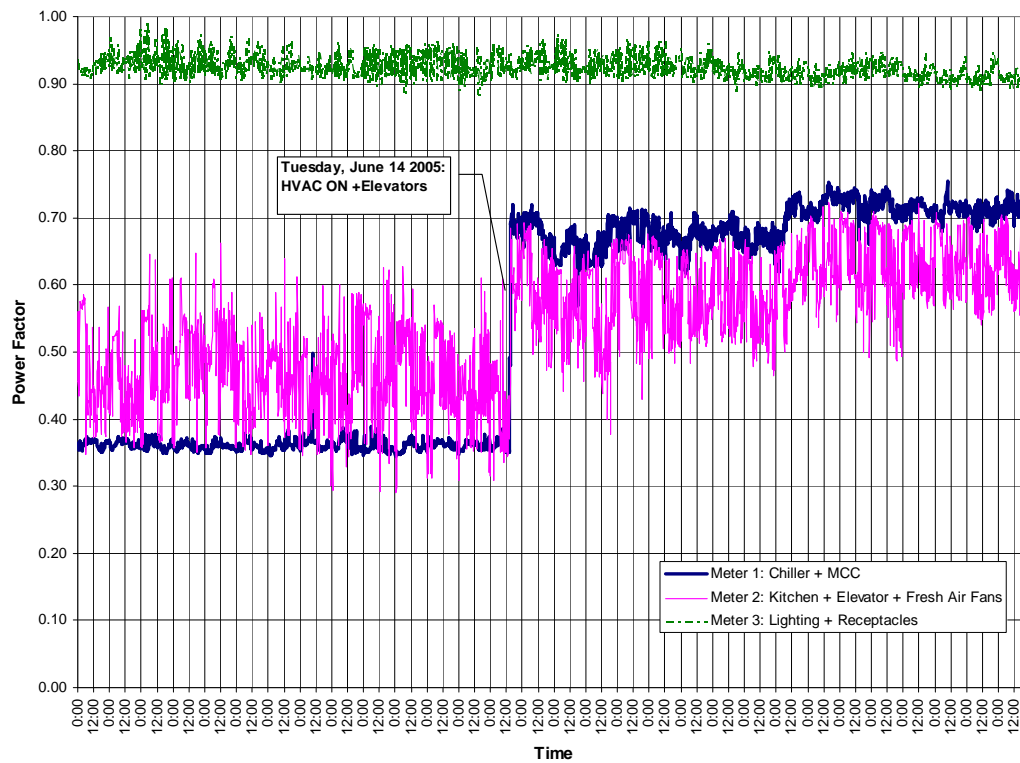Figure 8.  5-minute power factor values from three meters for May 10-31 2005.



Figure 9.  15-minute power factor values from three meters for June 1-30 2005.

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power factor correction capacitors, but this does not come without a cost and has to be justified. A power factor correction capacitor costs around $7,000 and can guarantee a value around 0.98, and usually has a one-year payback period, from generating the savings in the billing.

It should be noted that when the HVAC system started operating (June 14), the power factor improved and reached a value around 0.7. Figures 8 and 9 show respectively the power factor values of three meters during the last week of the spring quarter (the final exams week), and the month of June when there are very few classes given on campus (thus very few students) and only moving out of the dormitory activities taking place, in addition to the operation of the cooling system in the middle of the month.

**RESULTS AND INITIAL ANALYSIS**

At the time this paper was written, only two months of monitored data were collected. One full year of monitored data would shed more information. However, this short-term period of monitoring provided valuable information that otherwise would be completely hidden.

Figure 10 shows the submetered whole building electricity use for the period of May 10-31 2005. This period captures the last week of the spring quarter, which is the final exams week. During that week, the consumption looks decreasing everyday till it levels off after the weekend. Figure 11 shows the submetered whole building electricity use for the month of June 2005. The summer session starts the last week of May and covers the whole month of June. A survey of the registrar data showed that around 13% of the student residents would occupy the dorm during the summer (55 students down from 408 during the spring). In the kitchen, half of the staff would be available (6 persons compared to 12 during the spring). It is assumed that the kitchen would operate at half capacity during the summer. The maintenance, the public safety, the housekeeping and the housing personnel remain the same during the summer.

The monitored data showed that the 65% factor suggested for the contribution of the building under study is not accurate. The monitored data for the month of June showed a consumption value of 70,147 kWh and a demand value of 228 kW. The utility bills for the month of June 2003 showed a total consumption value (three buildings) of 147,538 kWh, and a demand value of the 928 kW. It should be noted that these values have to normalized for

weather changes from year to year, while the deterministic nature of the internal loads (schedule-driven) remains unchanged.

Following the utility company suggestion that the building under study uses 65% of the total electricity bill, the resulting numbers should have been 603 kW and 95,893 kWh. In fact, the monitored data showed rather a 47.5% value of the total billed consumption, and a 24.5% value of the billed demand. Using Equation 1, above, the penalty for each meter, for the month of June, is shown in Table 1 below.

| | Average Measured Power Factor | $kW_{Billed}/kW_{Measured}$ (penalty) |
|---|---|---|
| Meter-1 | 0.542 | 1.154 |
| Meter-2 | 0.542 | 1.154 |
| Meter-3 | 0.924 | 0.963 |

Table 1. Power factor and resulting penalties on each meter.

In order to come up with the "real" percentage of the demand (demand allocated to the building under study from the total demand measured by the utility company before applying the penalty), a weighted-average of the penalty can be calculated using Equation 2, below, giving a value of 1.13, resulting in a percentage of 27.7%. Therefore the suggested 65% value is not correct.

Annual Energy Use Index

In order to compare the current energy performance of the building under study with similar buildings in the U.S., CBECS (1999) data were used for the "dormitory/fraternity/sorority" category. Table 2 shows the comparison. The projected EUI calculated from the monitored data during the month of June compared well with the national mean. The projected electricity consumption was found by multiplying the June consumption by 12. Two years of utility bills show that the monthly electricity consumption is almost constant with a coefficient of variation of 13.6%. This is explained by the fact that 75% of the building is not cooled (summer), compensated by elevated levels of internal loads during the academic year (September – May). A true EUI value can be calculated after collecting monitored data for the whole year.

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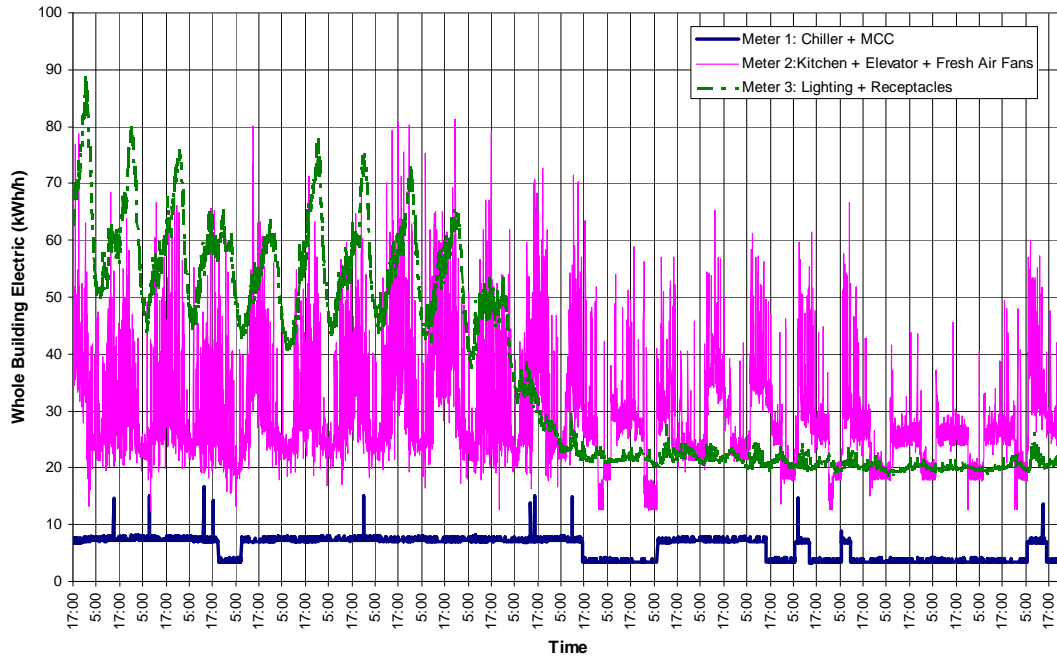
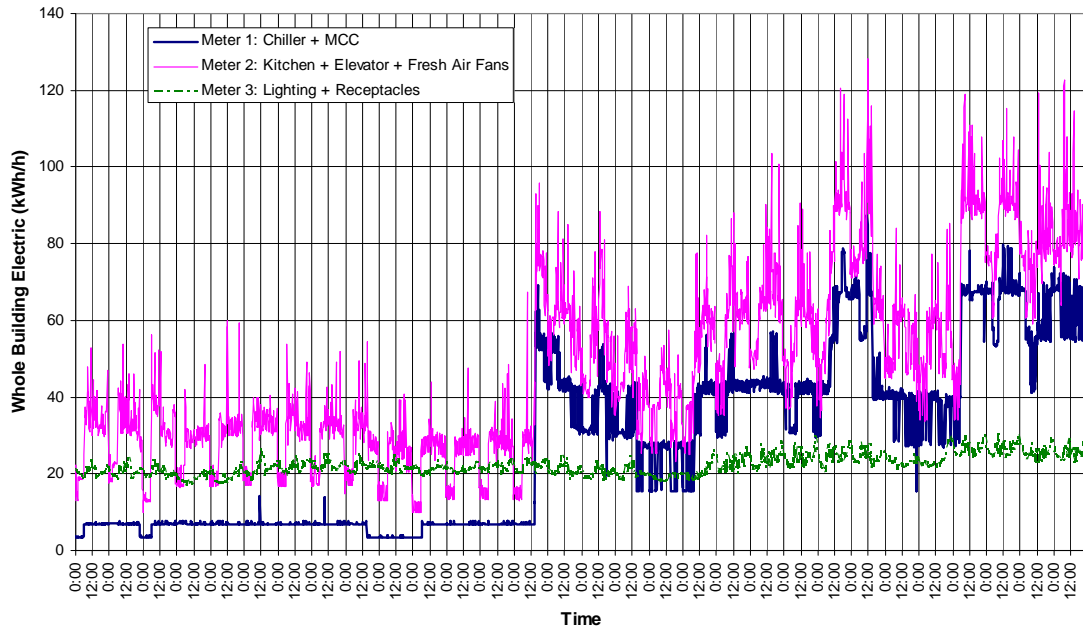Figure 10.  5-minute submetered whole building electricity use for May 10-31 2005.



Figure 11.  15-minute submetered whole building electricity use for June 1-30 2005.

$$Penalty = \frac{\left( Penalty_{Meter1}\left(kW_{Meter1}\right) + Penalty_{Meter2}\left(kW_{Meter2}\right) + Penalty_{Meter3}\left(kW_{Meter3}\right)\right)}{\left(kW_{Meter1} + kW_{Meter2} + kW_{Meter3}\right)} \tag{2}$$

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| | |
|---|---|
| Total Conditioned Square Footage | 103,470 ft$^2$ |
| Projected Yearly Electricity Consumption | 841,769 kWh |
| Projected EUI | 8.135 kWh/yr.ft2 |
| National EUI | 8.650 kWh/yr.ft2 |

Table 2. Projected EUI compared with the national value.

## CONCLUSION

Monitoring the electricity use of a university campus building with minimum submetering proved to be very valuable for the following reasons:

- Providing a true load allocation rather than relying on an estimated percentage of the total (shared) electricity bill.
- While an estimated percentage of the total bill might be accurate in term of electricity consumption (kWh), it would not be necessary accurate in term of demand, since the electricity-consuming equipment do not necessarily operate on the same schedule; the recorded (therefore billed) demand value does not have to be evenly split among the buildings sharing a single utility bill.
- Evaluating the power quality, and the possibility of generating potential savings from correcting the poor power factor problem.
- Enabling meaningful calibration of the energy simulation of an individual building, when the utility bills are shared by two or more buildings.

Since all the fans and pumps in the building are constant-speed type, one-time measurements (kW) together with the schedules of operation, are enough to enable a complete energy disaggregation of the total load on the meters. A complete disaggregated load makes an accurate calibration of the energy simulation possible. A future paper will discuss the calibration procedure of the building energy simulation.

## REFERENCES

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## ACKNOWLEDGMENT

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