A Method for Calibration of DOE Models: Annualizing and Normalizing Short-Term Hourly Metered Data

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ABSTRACT

This paper presents a method for the "partial calibration" of a prototype DOE whole building model. The partial calibration demonstrated here matches the modeled whole building hourly cooling end use energy to the metered hourly energy of an air conditioner or packaged unit that serves the building. Such a partial calibration can be achieved at much less cost and effort than a full calibration and still achieve the essential impact evaluation measurements, which are (1) an estimate of the "Normalized Annual Consumption, NAC" of a metered cooling unit, and (2) an estimate of the grid and site demand of the metered unit.

The work reported here includes comparisons of NACs derived with this partial calibration approach to NACs derived by other statistical means on five residential and five commercial sites. These comparisons showed good agreement in terms of NAC estimates, and more significantly, showed that a very simple calibration approach can reconcile metered and modeled hourly cumulative cooling energy within the RMS error and bias error criteria described in the "California Energy Efficiency Evaluation Protocols."

The key simplifications involve using existing DOE-2 prototype building models with a minimum of alterations. This is achieved by the use of cumulative hourly energy as the metric for calibration. This smoothes out the highly variable metered hourly energy, and obviates the need to change many of the detailed model inputs.

Introduction and Background

This paper details work using a DOE prototype whole building model (DEER prototype) as a tool for annualizing and normalizing short-term metered energy use from cooling equipment. The central problem is to use metered cooling data from a limited time span (about 1-2 months) to estimate cooling energy for an entire year, under normal weather conditions: the annualization and normalization problem.

Established methods extrapolate short-term monitoring data to normal annual usage. The extrapolation describes energy use as a function of outside air temperature and occupancy and other factors as derived by regression analysis of individual or pooled data sets. This effort examines whether a DOE prototype model could be a reasonable approach to annualize and normalize metered data, as an alternative to regression methods typically used in evaluations.

The benefit of using a DOE prototype model in this way is that it aligns the empirical evaluation work with these models which are broadly used tools for energy planning. The evaluation work may then be leveraged toward refinement of the models, and as modeling competence and capability improves, the models may be used in suitable cases in lieu of metering to lower evaluation costs. At its best, that is the vision underlying this work.

But a DOE prototype model has literally hundreds of inputs, and the rigorous calibration of such a model is a significant effort. Extensive site and unit characteristic data and often end use measurements are typically collected in order to calibrate the DOE whole building model. This complexity usually leads to costs more typical of research projects, which are beyond the cost horizon of program evaluation and quality assurance work. By contrast, the challenge to developing this partial calibration process has been to keep it simple enough to use economically in an evaluation context.

A brief review conducted at the outset of this effort sought to find and build upon simplified approaches for calibrating a DOE prototype model to metering data. This review did not find any simple approaches for such calibration, but it did find related work using DOE prototype models from the DEER database. We found that these models had been calibrated to the demographic circumstances found in the Residential Appliance Saturation Study (RASS) and Commercial End Use Study (CEUS). These calibrations were not relative to particular site metered data, but to broad demographic measurements such as average residential floor area, or average appliance or light load. Calibrated to broad demographics, these models were suitable for efficiency planning purposes, i.e., for utility program planning and statewide efficiency planning. There is an explicit intention in the DEER process to reconcile models to hourly metered data, but demographic calibrations occurred first, and that calibration to specific metered sites had not yet been done.

Relevant to this work also is The California Protocols (TecMarket Works, 2006), prepared for the CPUC April 2006 (Protocols, final adopted 2006). This extensive reference puts forth the general requirements of EM&V measurements applied to California evaluations. These protocols include a section discussing calibration targets which stipulates that a whole building model (IPMVP Option D) should be calibrated to whole building utility bills spanning at least one year, a sound and established evaluation practice. By contrast, this work does not use whole building utility bills as a calibration target, instead using hourly measurements of the cooling end use as the calibration target. However, the discussion of calibration targets also includes useful criteria, in terms of RMS error and Bias error, as a benchmark for a satisfactory calibration to hourly data.

Earlier work by the authors and others has used hourly metered data in impact evaluations of efficient air conditioning systems, and of packaged unit retrocommissioning programs. These applications and analytic process have been documented (ADM 2009; Balcolm 1993; Haberl 1992; Hile 2010; KEMA/Cadmus 2010; Subbarao 1990; West 2010). These prior applications align closest to this work because they were undertaken in an impact evaluation context, and because they use and describe a methodology for annualizing and normalizing the monitoring data. However, this prior work is significantly different than the current effort described in this paper because it uses simple statistical models which apply only to the metered piece of equipment and not to the whole building. The challenge of this work requires that a whole building model be calibrated to hourly measurements of a small sub-system of the whole building, in essence, a hybrid of IPMVP options B (equipment calibration) and option D (whole building calibration).

The foregoing review made clear that a rigorous calibration of hourly metering data to a DOE whole building prototype model would not be possible at a reasonable cost. But in the course of this work, it was evident that a very simplified calibration to a single end use only, a "partial calibration," could be done using very limited site data and using DOE whole building prototype models with minimal adjustment. Such a true-up to a single end use would serve the fundamental evaluation objectives, which are: (1) the accurate annualization and normalization of the metered data, and (2) the measurement of site and distributed demand.

Specifically, only the cooling end use energy (and ventilation end use in commercial buildings) from a whole building model is compared to the hourly metered energy of the cooling system, or a portion of the cooling system, such as one packaged unit on a building with five packaged units. No other aspects of the modeled building are metered or noted.

Methodology

This description of the methodology includes a summary of the selected test sites and site metering as well as a brief discussion of the analytical approach for a partial calibration of a DOE prototype model.

Selection of Ten Test Sites

This partial calibration approach was tested and refined on ten sites - five residential and five commercial – that were selected from sites included and analyzed in an earlier evaluation conducted for the CPUC, focusing on high impact measures including AC replacement. Ultimately the Normalized Annual Consumption, NAC, estimated for these sites by the partial calibration approach is compared to the NAC estimated in the earlier evaluation from the same data set.

These sites were selected for climate diversity, and all sites were assumed to have regular occupancy (no long vacancies). All sites had installed efficient new units either as an early replacement or as replacement of a failed unit (often referred to as replacement on burnout).

Table 1. Selected Residential Sites

Site	Conditioned Area (sq.ft.)	Climate Zone	Nominal Capacity (Tons)	SEER/EER
Agora	2,800	9	4.0	14
Chula Vista	1,250	7	2.5	14
Highland	1,200	10	3.5	14
Pomona	1,372	9	4.0 (2 stage)	16
San Diego	1,750	7	3.5	14

Table 2. Selected Commercial Sites

Site	Conditioned Area (sq.ft.)	Climate Zone	Nominal Capacity (Tons)	SEER/EER
Office 1	10,000	10	3.5	14
Office 2	10,000	7	4	13
Office 3	8,000	10	5	14.5
Office 4	8,000	10	3	18.6
Restaurant 1	2,000	10	6	11 (EER)

For the five residential sites, the cooling end use is limited to the energy required by the outdoor unit, compressor and condenser fan, and does not include the power of the indoor supply air fan. The commercial packaged unit metered data and analysis does include power to the supply fan.

Metering at Test Sites. Each selected site had at least one month of detailed monitored data. Metered parameters included key measurements, as shown in Table 3. Preparation for analysis requires aggregating the temperature and power data into hourly averages and calculated maximum power for each hour, as explained in the *Notes* column in this table.

The key data in Table 3 is the power and temperature data for all sites. The last three items in the table are not metering per se, but are site observations that are required for partial calibration at commercial sites that show timed fan and/or economizer activity.

Table 3. Required Metered Parameters

Logged or Calculated Variable	Interval	Notes
Outside air temperature and relative humidity	Hourly for full duration of monitoring (4+ weeks)	Outdoor air temperature needs to be measured in a shaded and vented enclosure. Nearby weather station data could be used in as alternative to this measurement.
Outdoor unit or package unit power	1-3 minute for full duration of monitoring	A short monitoring interval is important because accurate maximum power measurements are needed. It is also important to calculate maximum power, defined as the higher power reading in each metered hour.
Supply fan power (commercial sites)	One time measurement	Can often be determined by inspection of metered data if fan has a timed mode but not if the fan is in auto mode.
Supply fan timed cycle (commercial sites)		Determined by inspection of metered data
Functional economizer (commercial sites)	Site observation	Also requires inspection of metered data to determine if economizer is operating

Partial Calibration Methodology. Briefly, a partial calibration proceeds in five steps: (1) preparation of prototype model, (2) true up to maximum demand, (3) true up to cumulative energy, (4) derivation of occupancy factor, and (5) energy estimate for a normal year. Each of these steps is discussed below.

Prototype Model Preparation

The partial calibration for a particular site begins with a DOE residential prototype model selected to be similar to the metered site. This partial calibration approach does not require that the DOE prototype building physical configuration (for example, box- or L-shaped) match the building configuration at the metered site. In fact, in this work the same building configuration (box-shaped) was used for all residential models, and the same default conditioned area was also used, even though actual site building size could vary by +/- 50%. Experimentation with residential sites found that no further adjustments to the model, such as changing floor area or redistributing glazing or occupancy loads, were needed to obtain a good fit between modeled and metered data. However, once selected, the same prototype model must be used in the successive stages of the partial calibration process.

The weather input file for the prototype model for the metered site should be for the same year as the metered data, and derived from data for the closest weather station to the site. It is then modified by substituting in the hourly metered temperature and humidity data for the full metering duration of several weeks. It may be possible to omit this data substitution step if the weather station temperature and humidity data is close enough to the same site metered data.

Beyond the choice and set up of the weather input file, there are only two inputs required to run a prototype model for a particular site: (1) nominal HVAC unit capacity (tonnage), and (2) nominal efficiency (SEER). Typically, these variables are input through a set up wizard. The prototype model set up for the commercial sector is slightly more complicated because of timed fan schedules and economizer operation, discussed with the commercial site results below.

The output of interest from the DOE prototype model is the hourly cooling and ventilation end use which are itemized for the 8,760 annual hours. For the partial calibration, this output is examined during the metered data period to compare the metered hourly cooling energy use to the model's predicted energy usage for the same hours.

In the following discussions, the DOE prototype model hourly output will be designated as *Model hr*. In general, the hourly output of the DOE prototype model will not agree exactly with the corresponding hourly metered cooling energy. The partial calibration process will ultimately construct a trued up hourly output designated as *Mod2 hr*. The objectives of a partial calibration require that the trued up hourly output meet two calibration objectives: (1) it should match (and not exceed) the peak power observed in the metering period, and (2) it should match the cumulative cooling energy of the metered period. These two calibration targets require true-ups for demand as well as energy, as discussed and illustrated in separate sections below.

This work found that the DOE model is inherently responsive enough to temperature and occupancy that calibration can be done with a simple constant multiplier. This multiplier is called a usage factor, *UF*, of the hourly DOE prototype model output, and it modifies the hourly output for each of the 8,760 DOE model hourly outputs.

$$Mod2\ hr = Model\ hr * UF$$

Matching Demand and Peak Power

It is important to note that the term "demand" as used in the DOE prototype model refers to grid demand, which is distributed demand, essentially, the average energy for the hour. The grid demand should be distinguished from site demand which is the peak power within the hour. The metering captures the peak demand which figures prominently in this analysis, as well as the grid demand.

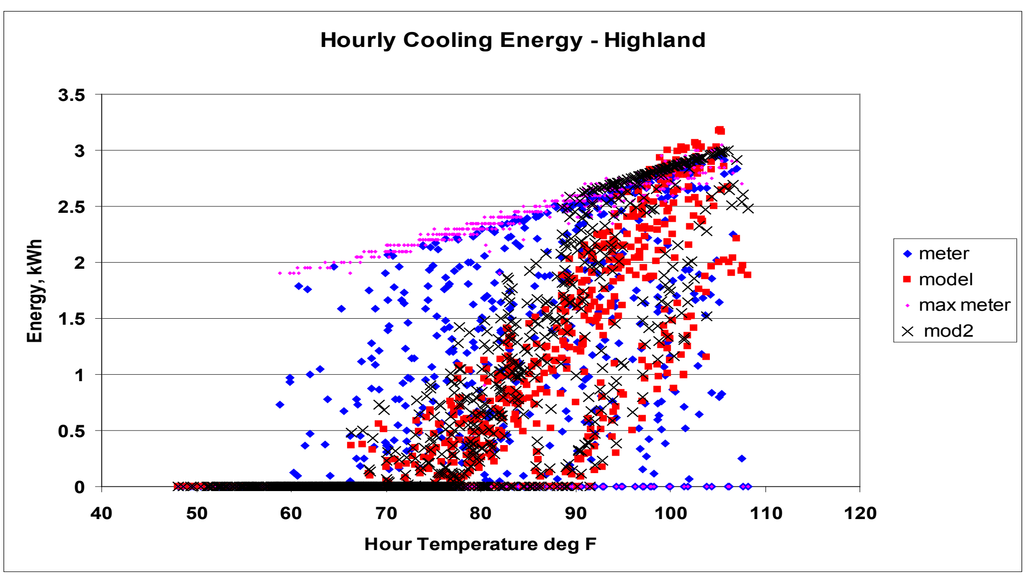

Figure 1. Cooling Energy vs. Temperature

Mod2 hr is reasonable in most cases, but it has been found that during the hottest periods there are many circumstances where *Model hr*UF* can significantly exceed the maximum metered kW observed for that hour, thereby violating the requirement to predict accurate hourly demand. Therefore, in order to preserve the demand functionality, *Mod2 hr* is constrained so that it does not exceed the metered hourly maximum kW. Fortunately, the metered data shows that there is a reasonably precise measurement of maximum kW as function of temperature. The metered maximum kW is derived from the metered energy, presented in Figure 1.

Figure 1 is based on only two metered variables: hourly average temperature; and, hourly energy. It provides a great deal of information on the performance of the real building and the performance of the DOE prototype model. In this figure, the red points are the hourly estimates of cooling energy from the DOE model, and the blue points are the metered performance for the same set of metered hours. The metered maximum kW is defined by the violet points. These are the maximum one minute power readings for each hour, and they form the well defined function of system maximum operating power versus temperature which will be used as the upper bound for *Mod2 hr*UF*.

The maximum kW function is a function of hourly temperature and is defined as:

*Max kW(T) = Max kW @80 +(hour T-80)*kW/deg*

The key parameters are derived by inspection or regression from the data presented in Figure 1.

- *Max kW @ 80* is the value of the max kW function at 80 ºF, (e.g., 2.35 kW in Figure 1)
- *kW/deg* is the slope of the max kW function with respect to temperature (e.g., 0.025 kW/deg in Figure 1)
- *hour T* is the hourly outdoor temperature

The *Max kW(T)* function is then used as an upper bound for *Mod2 hr* as follows.

- *Mod2 hr = Model hr * UF*   *if Model hr* UF < Max kW(T)*
- *Mod2 hr = Max kW(T)*   *if Model hr * UF > Max kW(T)*

In practice, this upper bound is evident only at the highest temperatures, as denoted by the black X marks in Figure 1. At two of the sites, there are clusters of metered points along the upper bound. These points all indicate continuous duty for the full hour, and most likely they also represent a circumstance where the system was not meeting cooling load.

This failure to meet load appears to be a reasonably common real world circumstance that reduces cooling energy use by supplying less cooling than required. This failure to meet load is a potential dissonance between the metering and the DOE prototype model outputs because the DOE prototype model will always estimate the higher cooling energy necessary to meet load, while the metered real world may be more complicated. The use of this upper bound also serves to limit the excess cooling energy estimated by the DOE prototype model in the event that the label tons is specified too high, which is also common. This use of an empirical upper bound produces reasonable estimates of demand during the hottest midday hours, when the demand estimate is most important.

Usage Factor, Matching Cumulative Cooling Energy

The metered cooling energy is trued up to the modeled energy by selecting an appropriate usage factor, *UF*. Figure 1 shows that a principal challenge is how to deal with an apparent very wide spread in the metered energy compared to the modeled energy. Part of this wide spread is undoubtedly due to some difference in the real and assumed building occupancies, but it is important to recognize that a significant portion of this wide point spread is an artifact of differences in how the model computes hourly energy and how the meter tallies hourly energy. For the DOE model, each hour is treated as a separate entity and the total energy needed to meet load is calculated and assumed to occur entirely in that hour. The metered energy, however, does not fit so neatly in hourly compartments since a real world cooling cycle may begin in one hour and end in the next. Typical hourly metered energy has many instances of low readings for one hour compensated by high readings in the next hour. The real physical situation is essentially a cumulative use of energy rather than totally independent hourly events.

A much more orderly way to view this same data is in a cumulative energy graph, as in Figure 2. This particular graph compares about 37 days of metered data to the same 37 days of hourly cooling energy as estimated by the trued-up DOE prototype model. This figure is intended to show how such simple adjustments can be used to match the meter to the model very closely in terms of cumulative cooling energy. In this figure the hourly cooling energy from the DOE prototype model is multiplied by 1.32, (the usage factor, *UF*), for this site, and the maximum kW has been limited to the maximum metered kW observed at this site.

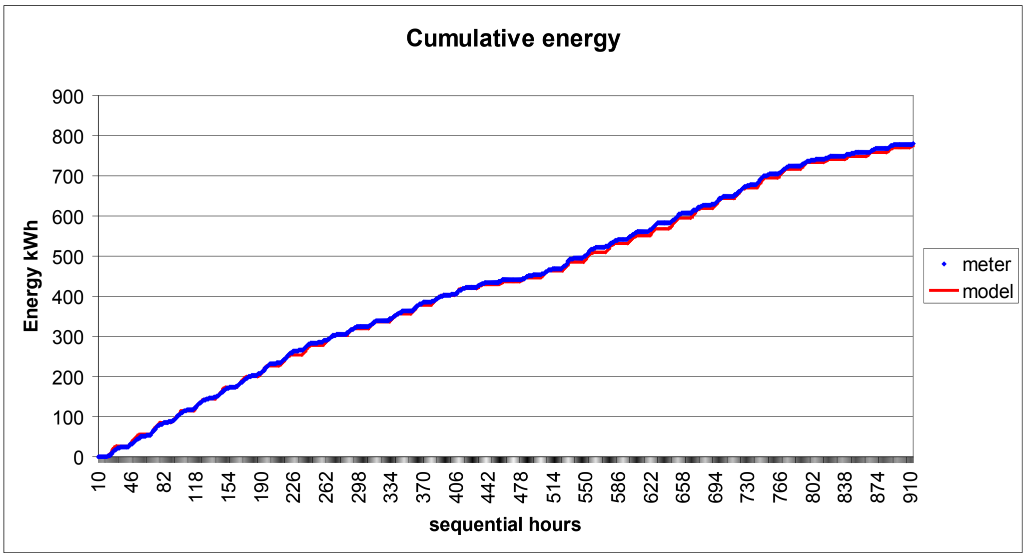

Figure 2. Cumulative Cooling Energy – Modified vs. Metered

Occupancy Factor

A common challenge for finding a reasonable *UF* will be at sites where there may be irregular operation, such as from extensive lapses in occupancy or from higher than expected cooling due to lack of proper economizer operation. It is entirely possible to derive some average *UF* from the full monitoring period of this data, but it will seem unreasonably low (or high), and physically unreasonable. In cases of this sort, a physically reasonable *UF* should be derived from a shorter but typically occupied period as shown up to line 2877 in Figure 3. The period beyond line 2877 is an occupancy lapse.

The effect of actual occupancy lapses or excessive energy use may be simulated by a ratio between the typical occupied usage/day and the average usage/day for the whole metering period. This ratio is referred to here as the Occupancy Factor, *OF*. It has been found that a complete and workable partial calibration requires both the utilization factor *UF*, and the Occupancy factor, *OF*.

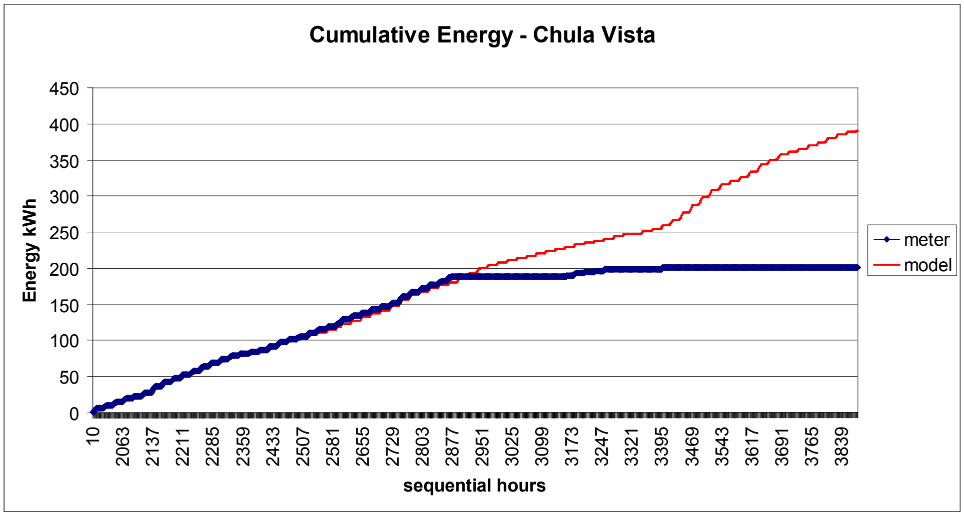

Figure 3. Cumulative Cooling Energy for Selected Occupied Period

A Normalized Annual Energy Estimate from a Partially Calibrated DOE Model

When the DOE prototype model has been trued-up with an appropriate usage factor, and the metered demand limits, it will produce the annual hourly sequence *Mod2 hr*. This is the partially calibrated DOE model; it is intended to represent the energy use and demand for the metered site for the full range of conditions specified by DOE prototype model weather inputs. To get the normalized and annualized cooling energy, the DOE prototype model is driven by weather inputs for a Typical Meterological Year, TMY, for the site climate zone. In theory it should be possible to use the partially calibrated model with other climate zones than the site climate zone.

Figure 4 is shows the cooling estimates from a partially calibrated DOE model compared to the metered data and raw data from the DOE prototype model.

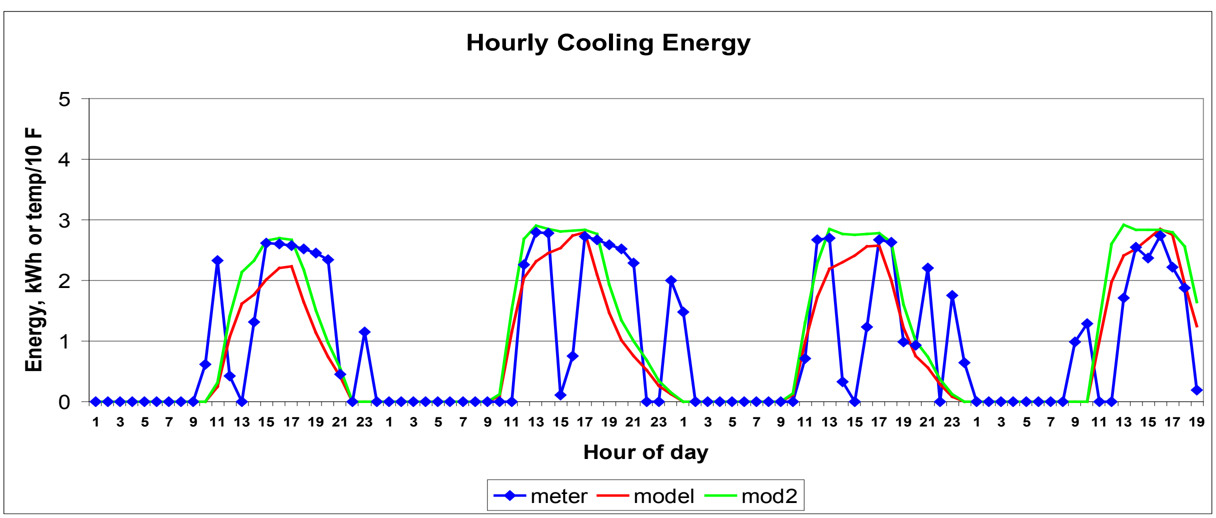

Figure 4. Comparison of Metered and Modeled Data in Time-Based Format

Note in Figure 4 that, for this site, the raw unadjusted DOE prototype model cooling estimates, the red line, were generally lower than the metered observations, the blue line. The raw DOE estimates were also quite different than the metered data in the all-important peak hours of 12 PM to 6 PM. The cooling energy estimates from the partially calibrated model, the green line, show a reasonable fit to the metered demand in the peak hours, and these hourly estimates will also accumulate to a long term energy sum that is very close to the metered total cooling energy.

Results

The results of this pilot are presented separately for the five residential sites and the five commercial sites. The principal distinction between commercial and residential sites is that the commercial sites have packaged units which house the supply fan and therefore metered energy includes the supply fan energy. The residential units were split systems, and the indoor supply fan energy was not metered.

Residential Results

A summary of the partial calibration efforts applied to residential buildings is presented in Table 4. The first three columns list the calibration factors applied to the basic DOE prototype model output in the course of the partial calibration. The *UF* in the first column is used to true up the hourly cooling energy estimated by the basic DOE model. The *OF* in column two is used to adjust the basic calibration model's predicted full occupancy cooling energy to the observed energy when sites had irregular occupancy. The maximum power function in columns three and four is a measure of site demand, and limits maximum hourly power as explained earlier. The RMSE in column five is the goodness of fit indicator. It shows the root mean square difference between the metered cumulative hourly energy and the cumulative hourly energy from the calibrated model. The last two columns show the ultimate results of this effort, the NAC derived by partial calibration, and the NAC derived by statistical means in earlier work based on the same data.[1]

Table 4. Residential Summary Results

Location	Utilization Factor	Occupancy Factor	Max kW Recorded at 80°F	kW/deg	RMSE	Partial Calibration NAC (kWh/yr)	Prior Analysis NAC[2] (kWh/yr)
Agora	1.58	1.003	3.70	.0275	.018	1,791	1,403
Chula Vista	.71	.46	1.80	.0225	.039	245	214
Highland	1.32	.99	2.35	.0250	.016	2,454	1,867
Pomona	.89	.73	2.75	.0300	.033	1,273	1,313
San Diego	1.7	.94	2.40	.0225	.017	1,253	1,168

In all cases, a close correlation was achieved between the partial calibration and the metered data as shown by the relatively low RMSE evident in Table 4. This shows that these fits are all within the goodness of fit criteria stipulated in the California Evaluator's Protocols.

[1] These results from the partially calibrated model are annualized and normalized to the weather station with metered data. Typically these would be normalized to a TMY year of data, but as a time and budget saving measure, these sites were normalized to the actual weather year. For this process, it does not matter what year of weather station data is selected to annualize the data. In order to compare results to the previous metered data analysis for these same units, prior NAC values were recalculated using the same weather files as used for normalizing the partial calibration.

[2] See footnote 1.

As it evident from the *UF*, the basic DOE prototype model estimated lower energy than the metered cooling energy in three cases (Agora, Highland and San Diego) and higher in two cases (Chula Vista and Pomona). This suggests that the DOE prototype model could be successfully used at sites with a range of cooling energy from as much as 30% less than, to 170% more than, the DOE prototype model output.

Three sites had reasonably regular occupancy on all days, but at two sites, Chula Vista and Pomona, there were significant occupancy lapses, as is evidenced for these sites by the *OF* that is much lower than 1 for these sites (see Table 4).

The most significant differences between the partial calibration NAC and the earlier NAC are for the Agora and Highland sites where the partial calibration shows a significantly higher NAC than the earlier NAC, and the difference was not attributable to irregular occupancy. Detailed review of these cases showed that the higher NACs included mechanical cooling for the DOE prototype model at generally low outdoor temperatures in the 67-72ºF range. Since the calibrated model is basically a simple multiple of the DOE prototype model, the calibrated model also showed cooling at these relatively low outdoor temperatures.

The metered data did not show cooling activity at these temperatures, and engineering judgment suggests that cooling at these lower temperatures is unlikely if there is any reasonable natural ventilation in the building. In the prior metered analysis and NAC, the statistical model required a test that zeroed out these low temperature cooling events with a test of a three day moving average outside air temperature against a threshold temperature. Most of the difference between the partial calibration NAC and the NAC from the prior metered analysis was due to this difference in cooling at low temperatures. This points to a requirement in the use of a DOE prototype model as an annualizing and normalizing tool: The DOE model must be reasonably accurate over the full annual range of temperatures, especially during the unmetered portion of the year. In this event it appears that the DOE residential prototype model is inaccurate in the 65-75 ºF temperature range. Refinements to this model should be based on metered data that includes measurements in this lower temperature range.

Commercial Results

A summary of the partial calibration results tested at the five commercial sites is shown in Table 5. Analytically, the principal distinction between commercial and residential sites is that the DOE model assumes a timed fan at all commercial sites, and an economizer in units over 5 tons.

This sample of metered commercial package units had four units of four tons or less with no timed fans, including one unit with an economizer. The fifth metered unit, Restaurant 1, had an economizer and a timed fan. These sites include two basic occupancy types: office/retail and restaurant. Accordingly, two basic DOE models of appropriate vintage were selected and used in the annualization and normalization process. As with the residential DOE prototype models, the model inputs consisted of unit cooling capacity (tonnage), efficiency (SEER/EER), and in addition, the building conditioned square feet, and the fan schedule if applicable. For commercial sites, the metered data needs to be reviewed for evidence of a timed fan, if such is found the fan schedule in the DOE model needs to be adjusted to the observed schedule. Also in cases of a timed fan the actual measured fan power must be used in the calibration and normalization. This is because in commercial units the fan energy is typically more than half of the annual energy, and the DOE prototype model will use a default fan power than could seriously bias the annual energy estimate. The crux of a partial calibration for a commercial site is fan power and schedule.

Table 5. Commercial Summary Results

Building	Utilization Factor	Occupancy Factor	Max kW @80	kW/deg	RMSE	Partial Calibration NAC (kWh/yr)	Prior Analysis NAC (kWh/yr)
Office 1	.22	.58	4.0	.0300	.064	5,325	5,603
Office 2	.16	.71	3.63	.0275	.053	5,088	2,475
Office 3	.25	.55	3.25	.0475	.112	4,059	3,414
Office 4	.155	1.02	2.30	.0250	.091	2,755	2,741
Restaurant 1	1.10	1.20	6.00	.0500	.053	21,951	21,693

The columns of the summary of commercial results in Table 5 are defined the same as those in Table 4 for the residential results. It is notable that the RMSE for all sites showed a good fit to the metered data.

It is important to note that some of the *UF* in the first column have very small values, much less than 1. This is because the DOE prototype model had assumed by auto-sizing that several units serve the whole building; this factor expresses the ratio of the energy of the single metered unit to the aggregate energy of all units serving the building. The low occupancy factors for the first three offices shows that there were changes in occupancy for these sites in the course of the monitoring period.

Commercial site calibration is different and more complicated than residential calibration because the default set up for DOE prototype models for units smaller than five tons assumes commercial system characteristics including 12 hour occupancy, seven days a week, with no off days, a timed fan, and no economizer. For units larger than 5 tons, the DOE prototype model assumes the timed fan and an economizer. The partial calibrations must include the aggregate effects of economizers, timed fan schedules, and weekend set backs. These various differences in the assumed model conditions and the observed conditions are corrected by the *OF* and *UF*. No adjustments to thermostat schedules were made in the set up of the DOE prototype model.

At two sites, Office 1 and Office 2, significant changes in operation midway in the cooling season lowered cooling energy. This is not an unusual event at commercial sites, as sites often adjust cooling controls or thermostat schedules partway into the cooling season.

Another site, Office 4, had about 60 days of occupied data and an obvious difference between cumulative metered energy and the cumulative model energy. This difference depended on the nighttime minimum temperature, which could reasonably indicate the operation of an economizer, night venting, or a thermal mass effect. Further review of this site showed that it was an unusual case of a small unit with an economizer; the difference between the metered and DOE model data was due to the fact that the DOE model was not assuming an economizer. The results for this site from the partial calibration in Table 5 include an adjustment for this difference through the *UF* and the *OF*.

Restaurant 1 was a commercial unit with a timed fan and a functional economizer. This site was an important test of the annualization and normalization process with respect to fan energy. In general, at sites with timed fans, most of the annual cooling system energy is comprised of fan energy. Restaurant 1 shows an unusual high *OF* of 1.2. This indicates that the metered site used more energy than expected in its fully occupied state. This is because the DOE prototype model assumed an operating economizer while the functional economizer at the site did not operate as assumed and led to the increased cooling energy as metered.

In the last two columns of Table 5, NACs calculated through this partial calibration process were compared to NACs derived from regression and reported in the prior metered analysis work. The NACs showed unexpectedly good agreement, considering that these commercial buildings may have had four or five package units, and the metered data was from only one of the units.

For the commercial sites, the building conditioned area (sq. ft.) is input, and the basic calibration model auto-sizes the HVAC system so that it is large enough to meet the load for the entire building, i.e. the system cannot be undersized. The data generally did show periods when the metered unit was operating at full load, suggesting that that the unit was either carrying a disproportionately large fraction of the whole building cooling load or that it was undersized for the space it served. This work on the commercial sites demonstrates that this partial calibration method can accommodate the more complex commercial operating schedules with very limited inputs of detailed site descriptive data.

Conclusions

1. The hourly cooling end use of a DOE prototype whole building model (residential or commercial) can be calibrated to hourly metered cooling energy. The metered cooling energy can be from only one unit among many serving the modeled building. A good calibration can be achieved by a simple multiplier of the cooling end use output of a minimally altered DOE prototype model. This partially calibrated model approach can be used to estimate the normalized annual consumption (NAC) and the maximum hourly site demand of metered cooling unit. It is not expected that the calibrated DOE prototype whole building model will match metered data perfectly, but hourly power and cumulative hourly energy use predicted by the calibrated model were found to be good enough to use for annualizing and normalizing limited metered data and estimating annual peak site demand as long as the DOE model itself was accurate over the full annual range of temperatures.
2. Future work may be simplified by using nearby weather station data, if the station is close enough in climate, instead of using spliced metered weather data.
3. Residential buildings served by a single HVAC system have metered cooling data for the whole building such that there is a possibility of using a calibrated model to estimate changes in NAC due to changes in cooling related whole building parameters, such as EER and unit size. However, this possibility was not tested.
4. A partially calibrated commercial model may be reliably used to estimate NAC and site demand, but the estimate applies only to the metered unit for a building that may share the full cooling load unequally among several other packaged units. For this reason, a calibrated DOE prototype whole building model may not be a reliable indicator of effects on NAC as a result of changes to other cooling related whole building parameters.
5. A timed fan is the predominant driver for annual energy use in a packaged unit and requires special attention when annualizing and normalizing energy usage. A reasonable reconciliation between metered and modeled cooling energy for timed fan cycles requires using metered estimates of both fan power and fan schedule.
6. DOE prototype modeled cooling energy in the 67-72ºF range is generally higher than observed. This modeled cooling energy at low temperatures occurs in spring and late fall and is the principal difference between the NAC estimated with the calibrated DOE prototype model, and the metered cooling energy and the NAC estimated with the regression model used in previous analysis for the same sites. An accurate annualization and normalization using DOE prototype models requires that the DOE prototype model be accurate for the full range of annual temperatures. Therefore, the DOE prototype models should be reexamined and adjusted for this effect by a calibration exercise that includes at least one month with outdoor temperatures in the 65-75ºF range.

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