1 INTRODUCTION

This informal report has the following objectives: (1) to illustrate the concept of the linear response model and explain how these building models will be implemented in the Rooftop Unit Comparison Calculator (RTUCC), (2) to demonstrate how this response data can be extracted from EnergyPlus runs, (3) to justify a simplified representation method, and (4) to document the supporting EnergyPlus runs and post-processing analysis.

The RTUCC uses a binned-weather analysis to estimate building loads and predict a corresponding air conditioning system's energy use. A fundamental part of this analysis is a linear model (see Figure 1-1) that is used to represent the building's thermal response to outdoor temperature and its internal loads.

The linear-response model predicts the thermal load on a building's cooling system as affected by the temperature differential between the outdoor and indoor temperature. This response reflects the nature of the physical building and its internal loads.

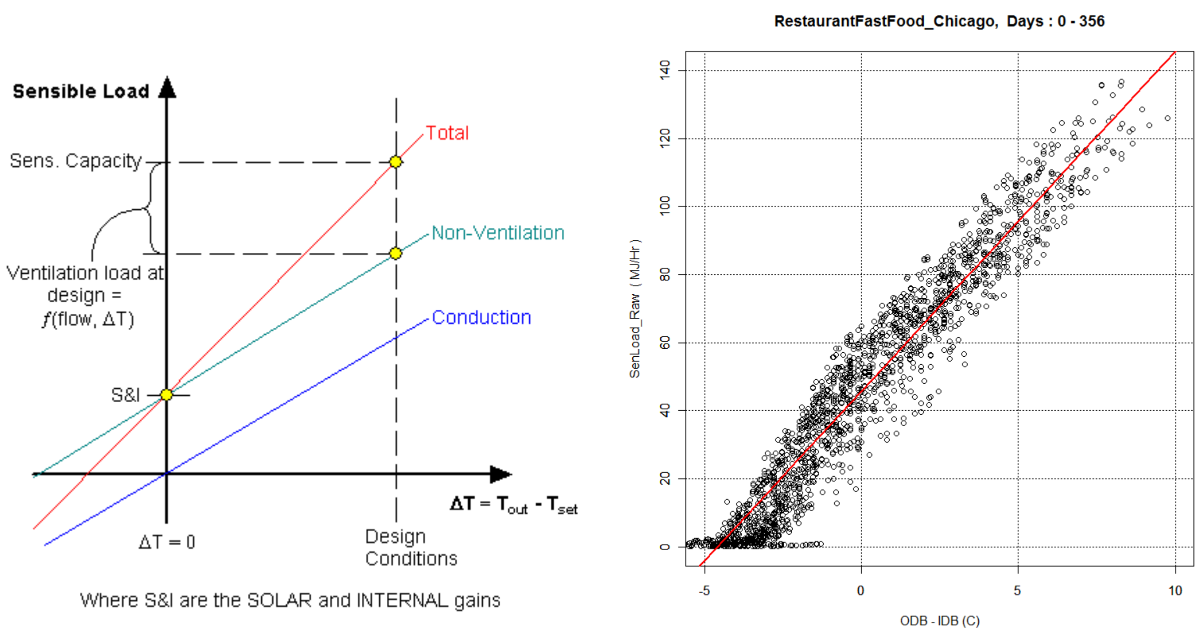


Figure 1-1 *Left*: Load-line concept drawing. *Right*: Corresponding example of load data from an EnergyPlus simulation.

The analysis in this report serves to establish the slope and intercept of the load line (see red lines in Figure 1-1). This is done by modeling the aggregate sensible load as a linear function of the indoor-outdoor temperature differential.

These response models are shown in this report to be approximately independent of the weather data driving the EnergyPlus runs. This means that one response model can be used to represent one building type at a variety of locations. Hotter climates will have more operation hours at higher delta-T, but the slope and the intercept will be similar to those seen in cooler climates.

A simple numeric indicator of the interaction between building type and climate can be determined from a calculation of the S&I fraction. This fraction, as affected by the city's design temperature, is defined in the RTUCC as follows:

$$F_{S\&I} \equiv \frac{TSL(\Delta T = 0)}{TSL(\Delta T = T_{design} - T_{set})} \quad (1)$$

Equation 1 states that the S&I fraction is defined to be the ratio of the total sensible load (TSL) at neutral conditions, i.e. when outdoor temperature equals the indoor setpoint, to the TSL at design conditions. This can be visualized in Figure 1-1 as the ratio of the loads at the two yellow dots on the red total-sensible-load line.

At neutral conditions, the load is primarily caused by solar and internal effects (this is the motivation for the S&I name). A particular building design operating in a cooler climate will have a higher S&I fraction than the same building running in a hot climate. One response model, for one building type, predicts a different S&I fraction for each climate, depending on its design temperature. As expected, internal loads are a larger fraction of the design load in cooler climates.

The S&I fraction and the unit's sensible capacity at design are two numbers from which a city-specific total-sensible load line can be formed. This calculation effectively scales the response model to match the sensible capacity of the RTU at the city's design conditions. This scaling process preserves the ratio between the slope and intercept of the response model. (Note that this use of the S&I fraction in the scaling process comes from earlier versions of the RTUCC which required the user to enter an S&I fraction to specify the building load characteristics. This scaling process, which uses the S&I factor as an intermediate step, is completely equivalent to directly scaling the load model to match capacity at design. This equivalence can be verified in the RTUCC by comparing a non-ventilation version of the load model on the *Controls* page with the non-ventilation load line that is reported on the *Results* page. The two slopes and the two intercepts are related by a simple scaling factor.)

An implicit assumption in this approach is that the response model scales simply with building size. "Simple scaling" means that the two parameters in the model, the slope and the intercept, both scale at the same rate as the building size increases or decreases. Improvements on this "simple scaling" assumption could possibly be incorporated by considering that internal loads and ventilation loads may scale with floor area and that the conduction loads may scale with external envelope area. The geometry of the building could be used to establish different scaling factors for the two model parameters.

This "simple scaling" assumption means that the total (including ventilation) sensible-load behavior of the building can be captured or represented by the ratio of the intercept and slope values of each linear model. This "I/S" ratio is reported below in Table 2-1. This single "I/S" number is sufficient representation; however, for clarity both the slope and the intercept values are used and displayed in the RTUCC.

An additional characterization of the building is done by modeling the ventilation-sensible-load line. The slope of this line can be compared to the slope of the total-sensible-load line. The ratio of the two slopes (ventilation-sensible-load slope / total-sensible-load slope) is a good indicator of the factional contribution of ventilation in the load line. If this ratio is 0.6, it means 60% of the temperature-dependent response is attributable to ventilation. This ratio is the third parameter that will be used to characterize a building type. This parameter (for a type of building) and a city's design conditions are used in the RTUCC to establish default ventilation rates.

Ideally a sensible-load model is preferred. Sensible models best reflect how a direct expansion (DX) system works to remove sensible loads as dictated by a sensible thermostat. It will be shown in this report that total-load models make reasonable substitutes for the preferred sensible models, especially with building simulations where the sensible loads are not available.

2 SUMMARY OF FINDINGS

- Variation between response models, by building type, is strong enough to justify a representative model for each building type.
- A building response model developed in Chicago is sufficient for representing similar buildings in different climate zones.
- Total (latent + sensible) and sensible load data produce similar results when developing load models.
- Models can be developed without turning off setback or ventilation in the building. IDF input modifications are only needed to change reporting variables.

Table 2-1 Summary of Run Results: "Slope" and "Intercept" columns are shown in both metric (columns 3-5) and English units (columns 6-8). The "I/S" columns are the ratio of the intercept to the slope and are an indicator of the degree of internal loading in the structure (high for hospital, low for warehouse). The "Ventilation Fraction" column is the fraction of the slope in the load model that is attributable to ventilation. The "Assumed VF" column indicates an assumed ventilation-fraction value that is currently being used in substitution of the run result.

	Building Type	Slope (MJ/HrC)	Intercept (MJ/Hr)	I/S (C)	Slope (KBTU/HrF)	Intercept (KBTU/Hr)	I/S (F)	Ventilation Fraction	Assumed VF
1	Apartment-Mid-Rise	12.3	128.3	10.4	6.5	121.6	18.7	NA	0.30
2	Apartment-High-Rise	NA	NA	NA	NA	NA	NA	NA	------
3	Health Care-Hospital	55.8	1370.0	24.6	29.4	1298.5	44.2	NA	0.80
4	Health Care-Outpatient	41.8	704.0	16.8	22.0	667.3	30.3	0.05	0.25
5	Hotel-Small	NA	NA	NA	NA	NA	NA	NA	------
6	Hotel-Large	149.5	1313.0	8.8	78.7	1244.5	15.8	0.96	0.60
7	Office-Small	3.5	43.4	12.5	1.8	41.1	22.6	0.32	------
8	Office-Medium	33.7	382.0	11.3	17.7	362.1	20.4	0.50	------
9	Office-Large	410.0	4250.0	10.4	215.9	4028.2	18.7	0.69	------
10	Restaurant-Fast Food	10.0	45.8	4.6	5.2	43.4	8.3	0.76	------
11	Restaurant-Sit Down	17.7	98.0	5.6	9.3	92.9	10.0	0.79	------
12	Retail-Stand Alone	26.5	245.4	9.3	14.0	232.6	16.7	0.63	------
13	Retail-Strip Mall	35.4	187.2	5.3	18.6	177.4	9.5	0.40	------
14	School-Primary	63.5	718.0	11.3	33.4	680.5	20.4	0.61	------
15	School-Secondary	95.0	779.0	8.2	50.0	738.4	14.8	0.13	0.40
16	Warehouse	7.1	5.7	0.8	3.7	5.4	1.4	0.21	------

Five of the ventilation levels are intended for future review (see rows with an "Assumed VF" value). These values were either not extractable from this initial EnergyPlus analysis or the determined values were considered significantly different from intuitively expected levels. The RTUCC is not critically sensitive to the ventilation-fraction values. The load slope and load intercept are more critical.

3 EnergyPlus Output and Post-Processing Approach

The hourly report (the CSV file produced by EnergyPlus) is post processed using R, a statistics analysis language. R scripts are run for each building to scan in the CSV file and analyze the hourly record.

3.1 IDF (Input Data Files)

In support of the ASHRAE Standard 90.1 Committee, PNNL developed a suite of 16 prototype building models in EnergyPlus. There are 17 different models for each of the building types. Each model complies with the prescriptive requirements of Standard 90.1, 2004 in each of the 17 DOE climate zones.

The 2004 versions of the IDF files, representing various building types, were obtained from this PNNL network location:

\\korea\comstd\ASHRAE189.1

Here is an example folder path to a specific building type (OfficeMedium):
\\korea\comstd\ASHRAE189.1\OfficeMedium\189.1.std2009\input.nobackup

Example filename: ASHRAE30pct_OfficeMedium_STD2004_Chicago.idf

(Note: the restaurant IDF file was unintentionally a 2010 version.)

3.2 Output Variables

The following variables are among those recorded in the CSV output files and were the basis for much of the post-processing analysis:

Loads

DXCOIL.DX.Coil.Sensible.Cooling.Energy.J..Hourly. (DX only, gross sensible cooling by system)
DXCOIL.DX.Coil.Total.Cooling.Energy.J..Hourly. (DX only, gross total (=S+L) cooling)
Air.Loop.Total.Cooling.Coil.Energy.J..Hourly. (Includes both DX and Chiller, gross total (=S+L) cooling)

Zone.Sys.Sensible.Cooling.Energy..J..Hourly. (Net sensible cooling, after economizer and reheat, delivered to zones. Includes sensible cooling delivered to zone when coils are off, such as economizer.)

Air.Loop.Total.Heating.Coil.Energy.J..Hourly. (Heating done by system. Includes reheat.)

Ventilation

Zone.Mechanical.Ventilation.Mass.Flow.Rate..kg.s..Hourly.
Zone.Mechanical.Ventilation.Volume.Flow.Rate.Current.Density..m3.s..Hourly.
Zone.Mechanical.Ventilation.Cooling.Load.Increase..J..Hourly.

Indoor Air

Zone.Mean.Air.Temperature..C..Hourly.
Zone.Mean.Air.Humidity.Ratio....Hourly.

Outdoor Air
Environment.Outdoor.Dry.Bulb..C..Hourly.
Environment.Outdoor.Wet.Bulb..C..Hourly.
Environment.Outdoor.Barometric.Pressure..Pa..Hourly.
Environment.Outdoor.Air.Density..kg.m3..Hourly.

Electricity Consumption
Air Loop DX Cooling Coil Electric Consumption (compressor and condenser fan)
Air Loop Fan Electric Consumption (fans: not sure if this is all fans or just the evaporator)

3.3 Post Processing in R

The two plots in Figure 3-1 contrast the two sensible-load report variables. In the left plot, DXCOIL.DX.Coil.Sensible is an aggregate (sum) of all the air-loop (system) sensible coil loads (energy removed by coils). The right, Zone.Sys.Sensible, is an aggregate of all the sensible cooling delivered to the zones. The zone result (right) includes all sensible cooling delivered to the zone, even when the compressor is off. There is likely economizer cooling (compressor off) in the zone aggregate.

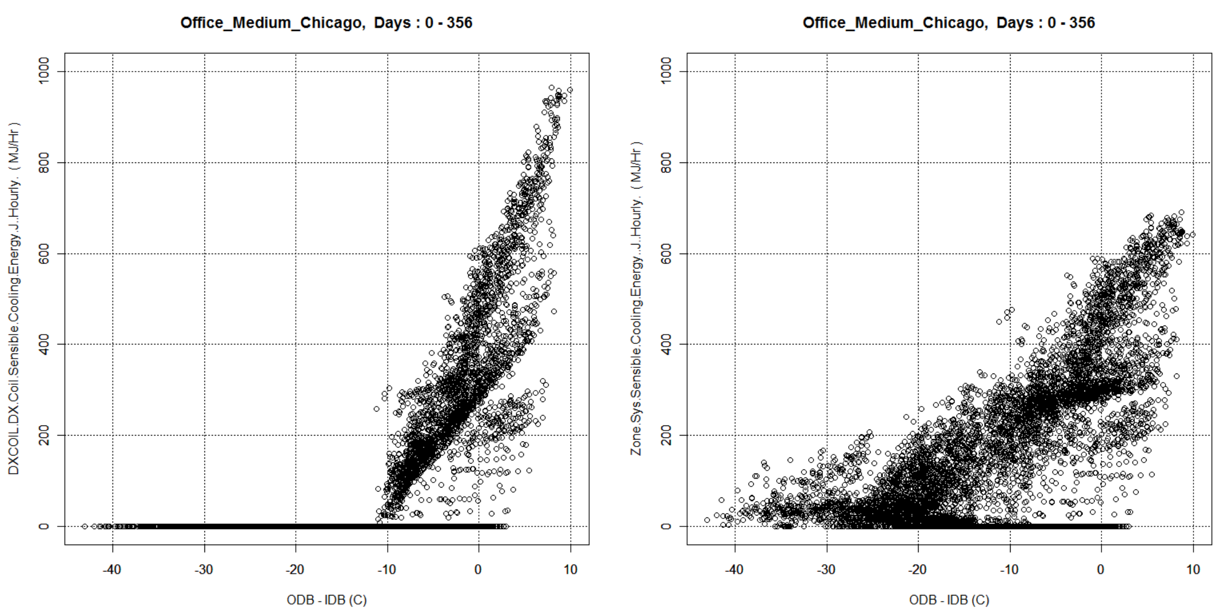


Figure 3-1 Sensible Cooling Loads. *Left*: DX coil loads. *Right*: Aggregate of zone loads.

It is difficult to determine with certainty if these loads are net after the reheat. However, descriptions in the EnergyPlus Input/Output reference lead the reader to assume the zone report (right plot) is a net effect (net cooling delivered to the zone, after reheat and economizing). The air-loop report (left plot) is strictly the output of the cooling coil (gross) needed to satisfy the thermostatic control. The air-loop cooling is the gross coil cooling needed to satisfy all sensible loads, including reheat. The two plots above support this interpretation; the right plot shows lower peak values in hot weather (because they are net) and more cooling in cool weather (because of economizing).

Annual sums for two plots in Figure 3-1: Coil Loads = 9.13654e+11 (J), Zone Cooling = 1.208048e+12 (J)

The air-loop (or system) variable best reflects how hard the system has to work to satisfy all the loads. For this reason, this or related system variables will be the basis for developing response models.

In the analysis that follows, load variables are used as described here:

DXCOIL.DX.Coil.Sensible.Cooling.Energy is used whenever there is only DX cooling. Note that sensible coil load analysis is not possible in EnergyPlus if there is no DX cooling. System (Air.Loop) variables, such as Air.Loop.Total.Cooling.Coil, only have total (=S+L) versions.

DXCOIL.DX.Coil.Total.Cooling.Energy and Air.Loop.Total.Cooling.Coil.Energy are equivalent if there is only DX cooling. If there are both DX and chiller, the DXCOIL.DX.Coil.Total will provide the DX portion of the total (=S+L) cooling. If there are both DX and chiller, the Air.Loop.Total variable will provide a sum of the DX and chiller coil cooling.

In the R modeling of the loads, a "bottom scraping" approach is used to subset the hourly data. This removes zero-value or near-zero value loads before regression is done. (Zero-level loads are clearly visible in the raw load plot on the previous page.) The idea is that zeros should not contribute to the regression; the model should reflect the loads presented to and processed by the system. Including zeros in the regressions inappropriately lowers the predictions of the load model. The default scraping mode (**GEZ**), is used to **E**xclude **Z**ero-value loads and any load data occurring at temperatures lower than the lowest **G**reater-than-**Z**ero load. An alternate approach (**GM**) is used on some buildings that produce a large number of near-zero loads. The GM approach accepts all data that is **G**reater than a minimum value as established as a fraction of the **M**aximum hourly load. In this approach, the tolerance for ground clutter (near-zero values) can be varied to see at what level their effect stops. The lowest tolerance that eliminates the effect is used.

Loads are aggregated (summed) with similar systems or zones. For example, the Medium Office building has three DX systems supporting three air loops. These are summed to produce an aggregate DX load.

Indoor temperature is calculated as an average of the zone temperatures. These are not weighted by zone size and use only a simple average. For some buildings, unconditioned zones may be excluded from the average. For example, the Fast Food Restaurant building has an unconditioned attic zone that basically floats at the outdoor temperature; this is excluded from the temperature average.

Ventilation loads are calculated (in R post processing) for any zone reporting mechanical ventilation. Standard ASHRAE algorithms are used to calculate sensible and total ventilation loads. The calculation uses indoor and outdoor psychrometric conditions and reported hourly air-mass flows. Ventilation loads are calculated at the zone level and then aggregated to produce a building sum.

The option of producing daily average loads was considered. Figure 3-2 shows daily average loads for the DXCOIL.DX plot above in Figure 3-1. This plot includes the zero-value points in the daily average; this inclusion reduces the slope. This approach was not used in the end because the hourly approach offered more control over excluding the near-zero value points. Also, with the hourly approach, it is clearer to the reader which points have been excluded.

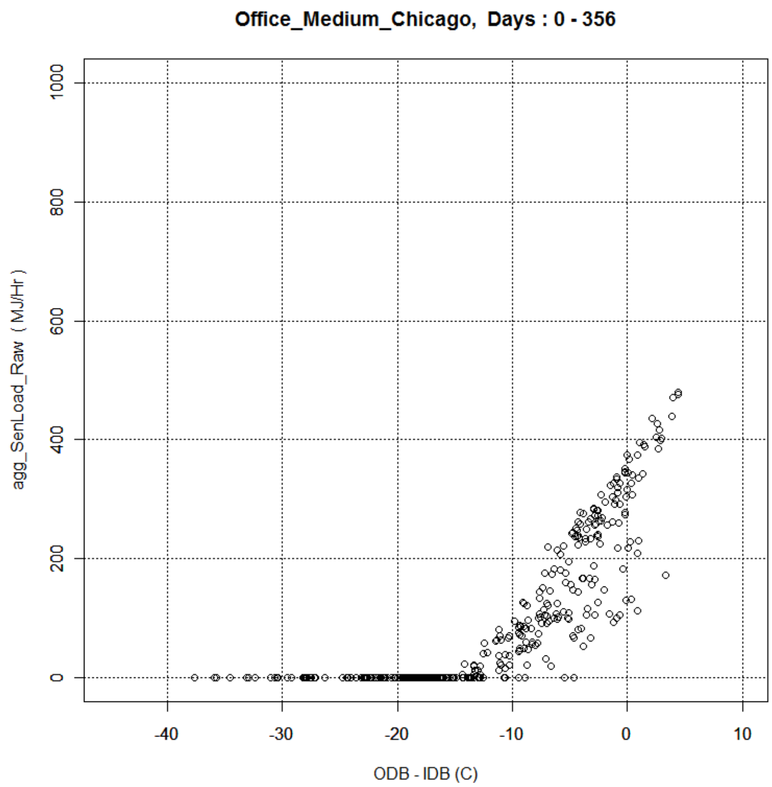


Figure 3-2 Daily average sensible cooling loads.

4 SENSITIVITY TESTING

The following sections have post-processing results from the EnergyPlus runs that are in support of the findings and sensitivity analysis. Section 4.1 has the most detailed explanations and serves as a key for interpreting the results for each building type as reported in Section 5.

4.1 RESTAURANT-FAST FOOD-CHICAGO

The post-processing analysis output for this first example run is explained here in detail. Most of the following runs will show a similar output. Differences are noted.

4.1.1 Sensible Load

In the two plots of Figure 4-1 the sum of the sensible-coil loads is shown left and the sum of the sensible-ventilation loads is shown right. Both plots are as a function of the outdoor-indoor temperature differential. Both plots show a linear-model line in red. The plot title identifies the building type and any special adaptations done to the IDF input file. The title also identifies the range of days included in the plot.

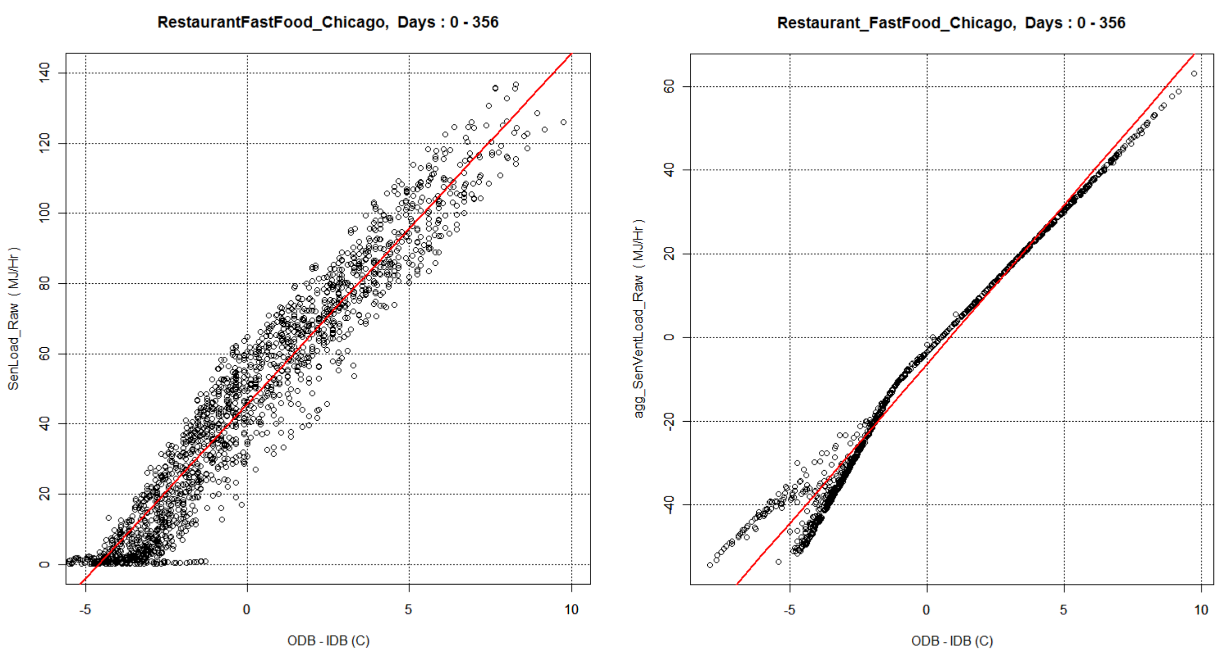


Figure 4-1 *Restaurant-Fast Food / Chicago*. Raw sensible load as affected by envelope temperature differential. *Left:* sensible load (Intercept = 45.8 +/- 0.2 MJ/Hr; Slope = 9.97 +/- 0.07 MJ/HrC). *Right:* sensible ventilation load (Slope = 7.61 +/- 0.03; Slope Fraction = 7.61/9.97 = 0.76).

Table 4-1 Calculation of S&I fraction in three cities using the Fast Food building model.

City	DT	S&I Fraction
SanFran	0.8	0.86
Chicago	7.5	0.38
Phoenix	18.0	0.20

Slope and intercept are reported in the figure caption for the coil-load model. Only slope is reported for the ventilation model (generally ventilation models have a zero or a nearly zero intercept). The slope and intercept form the main part of coil-load response model. This is then used to calculate the S&I fraction as defined in Equation 1 in the introduction. In some cases this result is shown for three example cities (see Table 4-1). For this case, the fraction of response due to ventilation is 7.61/9.97 = 0.763. This is shown in the figure caption after the ventilation slope. This slope fraction is the third parameter needed for the building response signature.

Here is an example call to the scripted R plotting functions that are used to plot the data and produce the regression model.:

```
Scan(blnReScan = TRUE, strMainDirectory="Restaurant_FastFood_Chicago", strSubDirectory="")
PlotVsTemp("DT", "CR", c(0,356), "agg_SenLoad_Raw", "GM", strUnits="MJ/Hr", ymin_fraction=0.00, strFitMode="T", myYlim=c(0,140), myXlim=c(-10,10))
PlotVsTemp("DT", "CR", c(0,356), "agg_SenVentLoad_Raw", "LF", strUnits="MJ/Hr", ymin_fraction=0.00, strFitMode="T", blnNoIntercept="T")
```

4.1.1.1 *Sensible Ventilation Load*

The left plot in Figure 4-2 shows the aggregate ventilation load for both kitchen and dining zones. The inside temperature is a simple average of the two zone temperatures. The raw plot on the right also includes loads less than or equal to zero. This is shown here for comparison with the following two individual-zone plots (see Figure 4-3 and Figure 4-4). This demonstrates the model's slope when based on aggregate zone data is equal to the sum of the two individual zone-model slopes (1.8 + 5.0 = 6.8). The right-side plot shows the raw, unfiltered, load data.

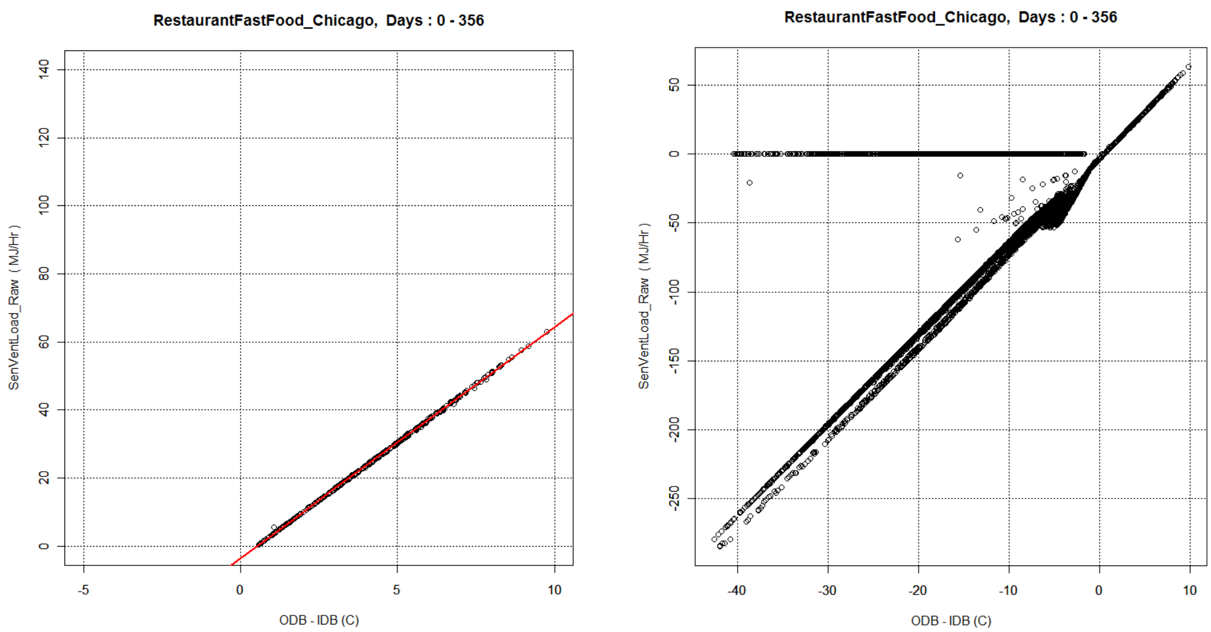


Figure 4-2 Sensible Ventilation Load for Kitchen and Dining Zones. *Left*: filtered to exclude negative loads; Slope = 6.8. *Right*: raw data.

Figure 4-3 and Figure 4-4 show single-zone ventilation loads. These plots demonstrate that the sum of the two zone slopes is equal to the slope in the aggregate plot (1.8 + 5.0 = 6.8).

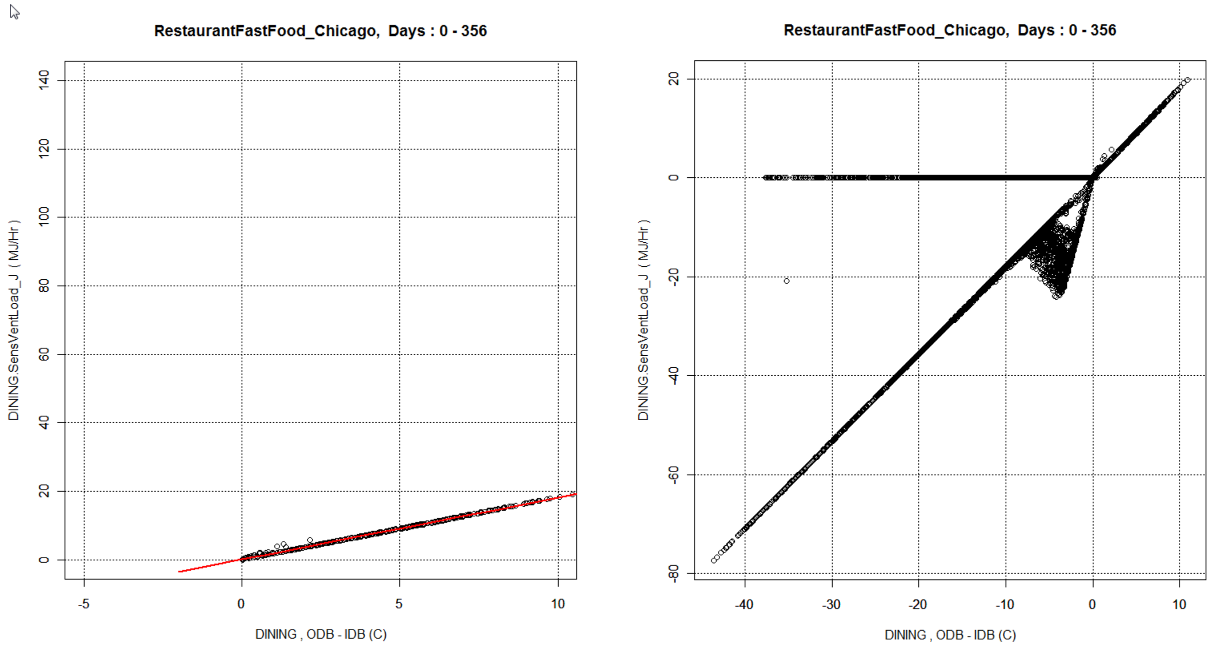


Figure 4-3 Sensible Ventilation Load for **Dining** Zone Only. *Left*: filtered to exclude negative loads; Slope = 1.8. *Right*: raw data.

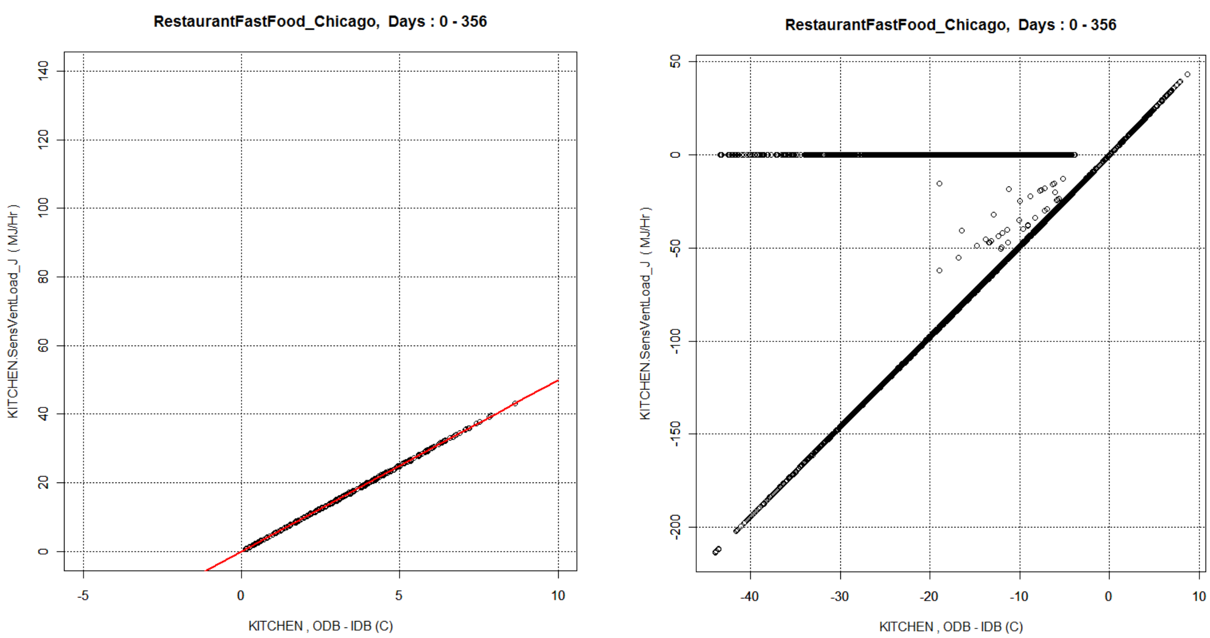


Figure 4-4 Sensible Ventilation Load for **Kitchen** Zone Only. *Left*: filtered to exclude negative loads; Slope = 5.0. *Right*: raw data.

4.1.2 Total (=sensible+latent) Loads

The total (sensible + latent) load data in Figure 4-5 illustrates how the response model from total loads produces S&I fraction calculations in Table 4-2 that are very similar to those in Table 4-1 which result from the sensible data shown in Figure 4-1. This result also demonstrates that the percentage of the ventilation line is similar to that in the sensible analysis. This comparison justifies using the total load data for those buildings that do not have DX cooling systems.

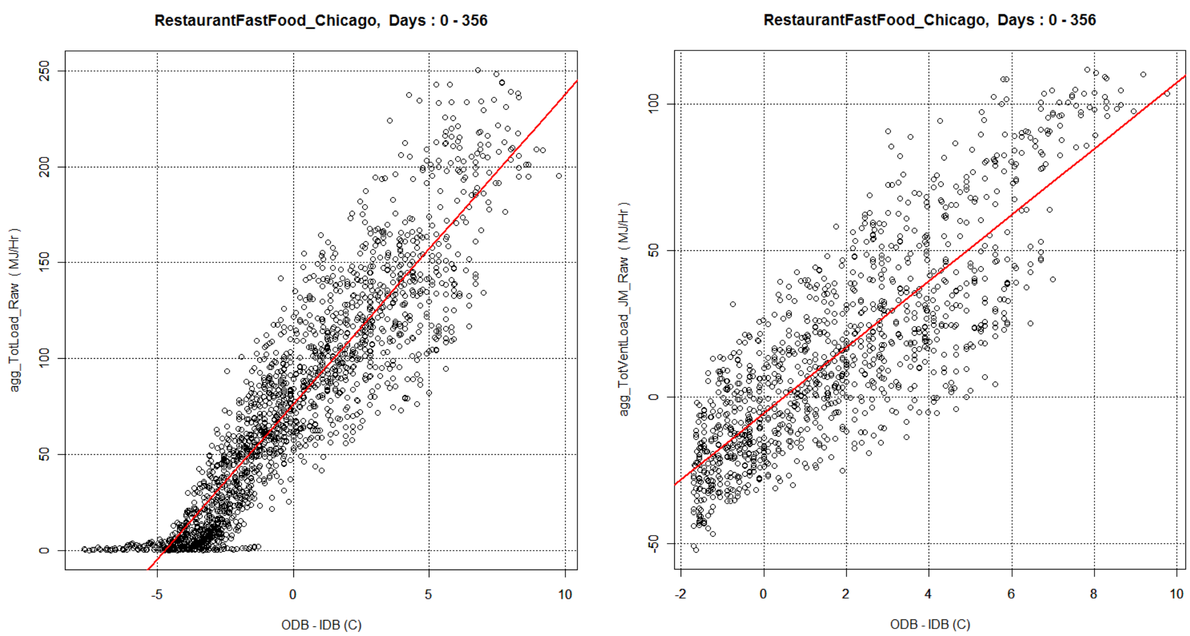


Figure 4-5 *Restaurant Fast Food / Chicago*. Raw **total (latent + sensible)** load as affected by envelope temperature differential. *Left:* total load (Intercept = 76.28 MJ/Hr; Slope = 16.16 MJ/HrC). *Right:* total ventilation load (Slope = 11.31; Slope Fraction = 11.31/16.16 = 0.70).

Table 4-2 Calculation of S&I fraction in three cities using the total-load version of the Fast Food building model.

City	DT	S&I Fraction
SanFran	0.8	0.86
Chicago	7.5	0.39
Phoenix	18.0	0.21

4.2 OFFICE-MEDIUM-CHICAGO

4.2.1 Sensible Loads Models and Weather Data

This section is a summary of the tests used to determine if the resulting linear-building models are affected by the weather data (city) used in the simulation runs. Table 4-3 shows that the ratio of the intercept to the slope is always within 5% of the baseline case (Chicago weather with the Office-Medium-Chicago building). The consistency in this ratio is a direct indicator as to the similarity of these models and how they will behave when scaled to match capacity in the RTUCC. This expected similarity in the calculator's output is a result of the scaling operation which is applied equally to both the slope and the intercept of the linear model. In the subsections that follow, detailed results and data plots are presented that yield each of the rows in Table 4-3.

Table 4-3 Summary of Office-Medium-Chicago building model as affected by four cities of weather data.

Weather City	Intercept (MJ/HrC)	Slope (MJ/HrC)	Intercept/slope (C)
Chicago	382	33.7	11.3
Phoenix	317	27.1	11.7
San Francisco	404	34.1	11.8
Miami	327	37.7	11.8

The following subsections also use their weather-specific version of the model to calculate the S&I fraction for several cities. Again, the S&I fraction is the ratio of internal load to the capacity of the unit at design conditions. It is to be expected that this calculated ratio for a particular city should be similar in each of these subsections, and that is the case. For example, the four different weather versions of the model yield S&I values of 0.39, 0.39, 0.40, and 0.33 when used in calculating the S&I ratio for Phoenix.

In summary, this test supports the idea that one linear model (for each building type) can be applied across the country. Refinements could be made by developing multiple versions of each building model to better represent secondary climate/building interactions. But the gain offered in this type of refinement appears to be small relative to general expectations for the uncertainty of the calculator.

4.2.1.1 *Chicago Weather*

This is the baseline case: the Chicago version of the Medium Office building run with Chicago weather. This case will be compared to others where the Medium-Office-Chicago building is run with different weather data. It will also be compared to a different city version of the Medium-Office building run with the corresponding weather data.

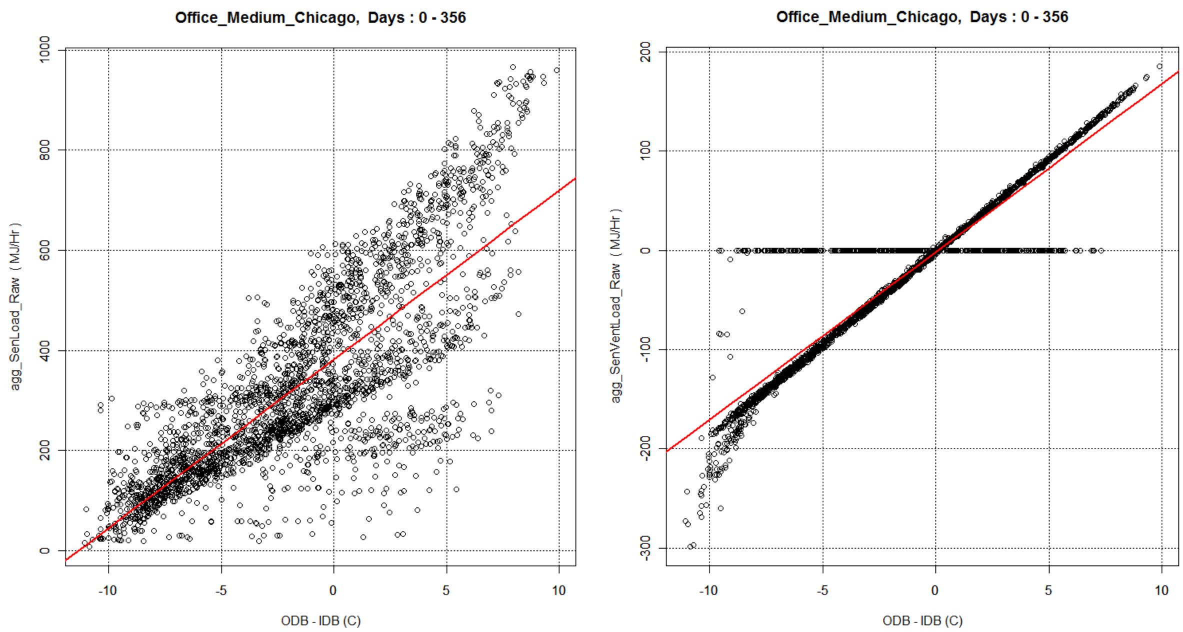


Figure 4-6 *Office-Medium-Chicago with Chicago Weather*. Raw **sensible** load as affected by envelope temperature differential. *Left:* sensible load (Intercept = 382 +/- 2 MJ/Hr; Slope = 33.7 +/- 0.5 MJ/HrC). *Right:* sensible ventilation load (Slope = 16.91 +/- 0.13; Slope Fraction = 0.50).

Table 4-4 Calculation of S&I fraction in three cities using an Office-Medium-Chicago building model with Chicago weather.

City	DT	S&I Fraction
SanFran	0.8	0.94
Chicago	7.5	0.60
Phoenix	18.0	0.39

4.2.1.1.1 Simple Outdoor Temperature Plot

This Medium-Office-Chicago plot uses the raw Outdoor Dry-Bulb (ODB) temperature, not the *ΔT* that is based on the aggregate zone temperature as is used in previous plots. Correlation levels are similar; some parts of the data appear more tightly correlated. The *ΔT* plot offers independence from thermostat setpoint and setback.

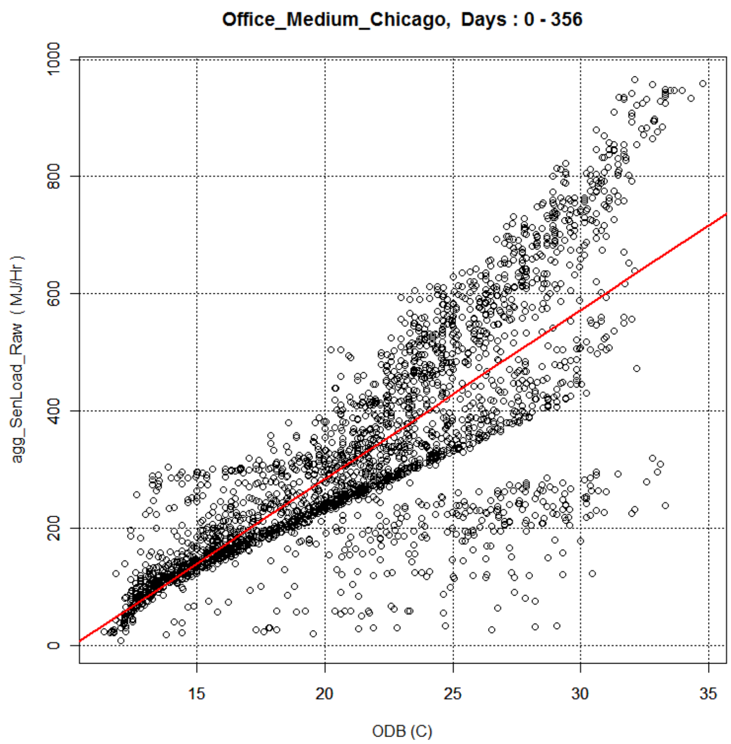


Figure 4-7 Raw sensible load for Office-Medium in Chicago. Load response shown as affected by outdoor temperature (not *ΔT*).

4.2.1.1.2 Setback Turned Off

The zone-aggregated temperature plots in Figure 4-8 illustrate the effect of turning off setback in the IDF file. The left plot has setback turned off and has a higher winter setpoint. The right one uses setpoints and setback and corresponds to the base case Chicago run. The plots in Figure 4-9 show the impact on the cooling-load response model as caused by removing setback.

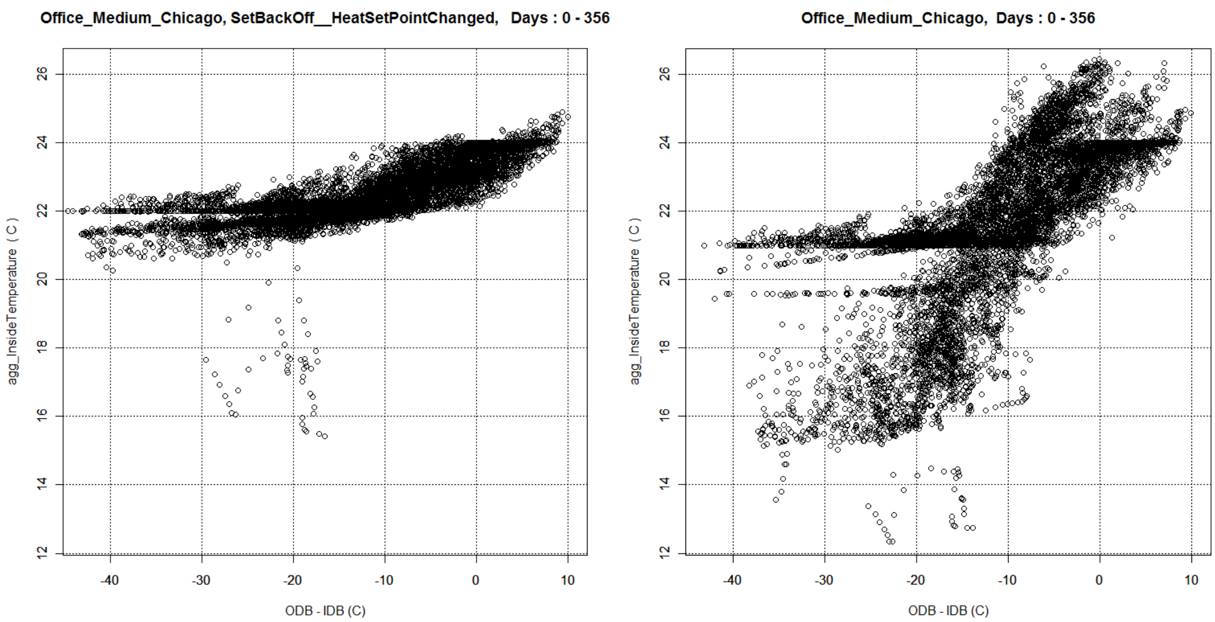


Figure 4-8 Indoor **temperature** as correlated with temperature differential. *Left*: no setback. *Right*: setback enabled.

Call parameters:

PlotVsTemp("DT", "CR", c(0,356), "agg_InsideTemperature", "raw", strUnits="C", ymin_fraction=0.0, strFitMode="F", myYlim=c(12.5,26.2),myXlim=c(-43,10))

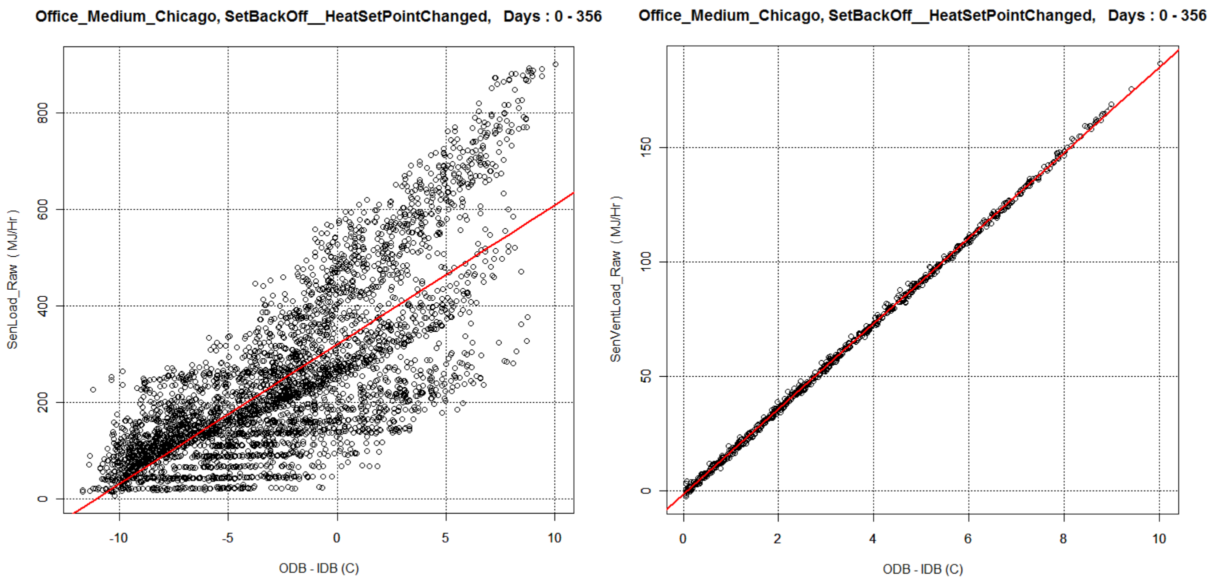


Figure 4-9 *Office Medium / Chicago with **no setback***. Raw sensible load as affected by envelope temperature differential. *Left:* sensible load (Intercept = 320.4 MJ/Hr; Slope = 28.87 MJ/HrC). *Right:* sensible ventilation load (Slope = 18.67; Slope Fraction = 18.67/28.87 = 0.65).

Table 4-5 Calculation of S&I fraction in three cities using the Office-Medium building model with no setback.

City	DT	S&I Fraction
SanFran	0.8	0.93
Chicago	7.5	0.60
Phoenix	18.0	0.38

For the data in Figure 4-9 and Table 4-5 the setback has been turned off. The effect of setback on the load model projections is small. Refer to Figure 4-8 for a corresponding illustration using a temperature plot.

4.2.1.1.3 No Ventilation

The plots in Figure 4-10 illustrate the effect of turning off mechanical ventilation in the IDF file. The two plots on the right show the base case with ventilation on (bottom right shows daily on/off pattern). For the two plots on the left, the mechanical cooling ventilation has been effectively turned off. However, there appears to be some ventilation in the heating season. The slope of the red load line (bottom left) is 19.2.

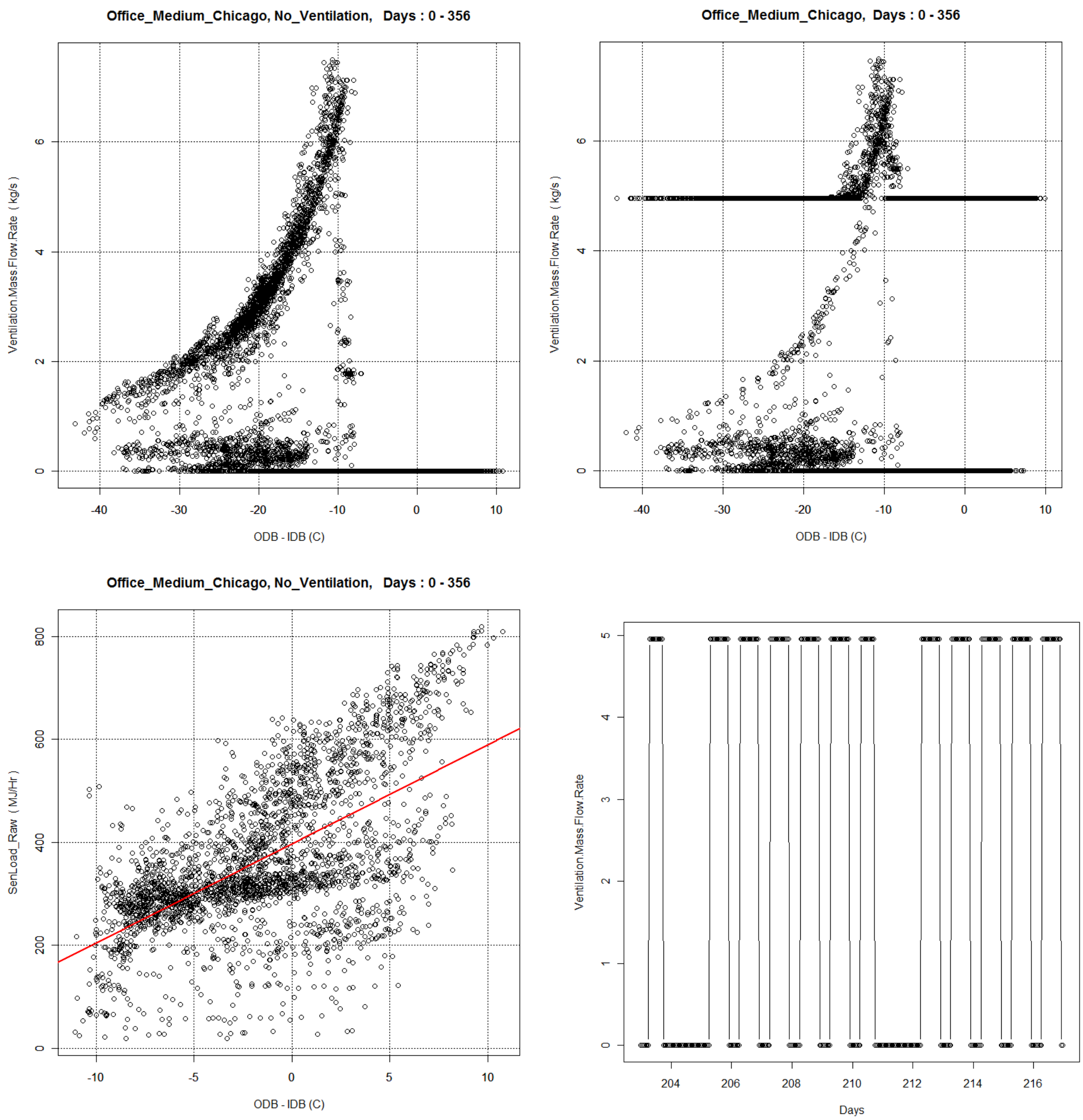


Figure 4-10 Data plots illustrating the patterns and impact of mechanical ventilation. *Left*: no mechanical ventilation. *Right*: mechanical ventilation enabled.

The end result of controlling ventilation levels this way (in the IDF files) is similar to that when done by calculating ventilation loads in post processing. The slope of 19.2 for the red load line in Figure 4-10 is reasonably close to that which would be predicted by subtracting the slope of the calculated ventilation load from the slope of the total sensible load line that includes ventilation (see Figure 4-6: 33.7 - 18.7 = 15.0).

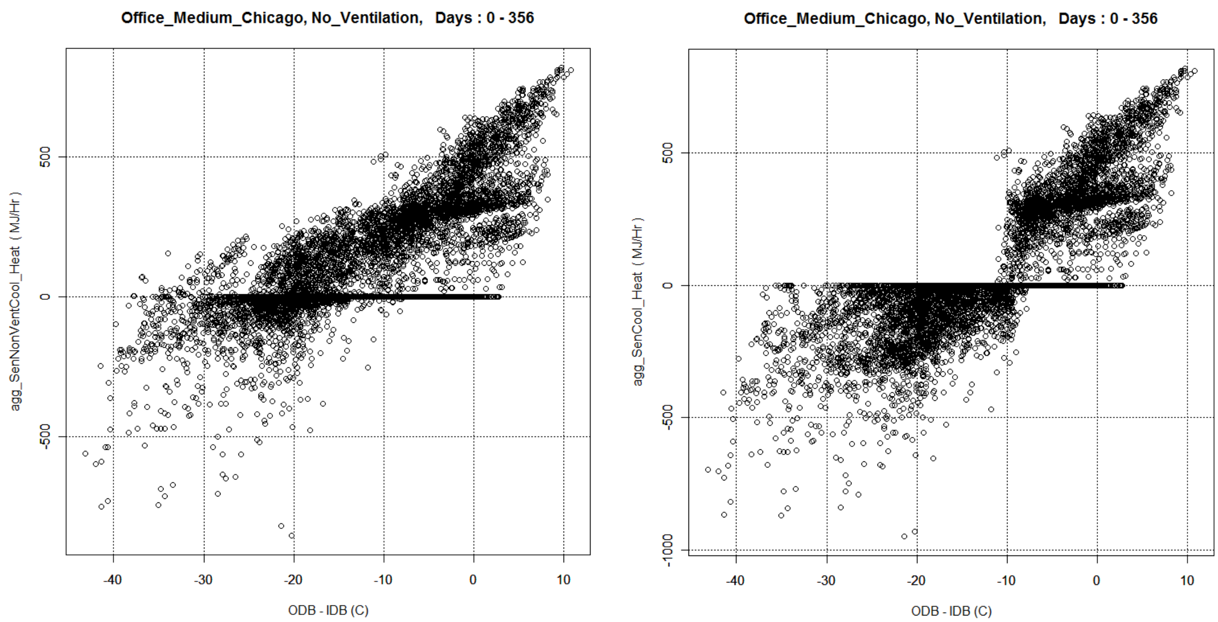


Figure 4-11 Heating and cooling loads in response to changing *ΔT*. *Left*: heating-ventilation load is removed. *Right*: raw data (includes heating-ventilation loads). Both plots have mechanical ventilation turned off.

The two plots in Figure 4-11 are given to show the building's heating and cooling loads on the same plot. The possibility shown here is that together the heating and cooling loads might give a cleaner overall picture of the building's response to outdoor temperature.

Heating loads are assigned negative values and then are added to the time series of cooling loads. Both plots have the mechanical ventilation turned off in their IDF file. (Note: this shutdown left some mechanical ventilation in the heating season.)

The right side plot is raw. The left side has the calculated heating ventilation subtracted out. This tends to shift up heating load and produce a true non-ventilation load line for both heating and cooling.

This was not conclusive as to whether cooling and heating load data would produce a better load model. The idea is presented here for possible future analysis.

4.2.1.2 Phoenix Weather

This run simulates the Office-Medium-Chicago building with Phoenix weather. A significant part of the data is at higher temperatures (the Chicago data is mostly below a 10 degree differential). However, the S&I calculations where the model is based on Phoenix weather are very similar to those based on Chicago weather.

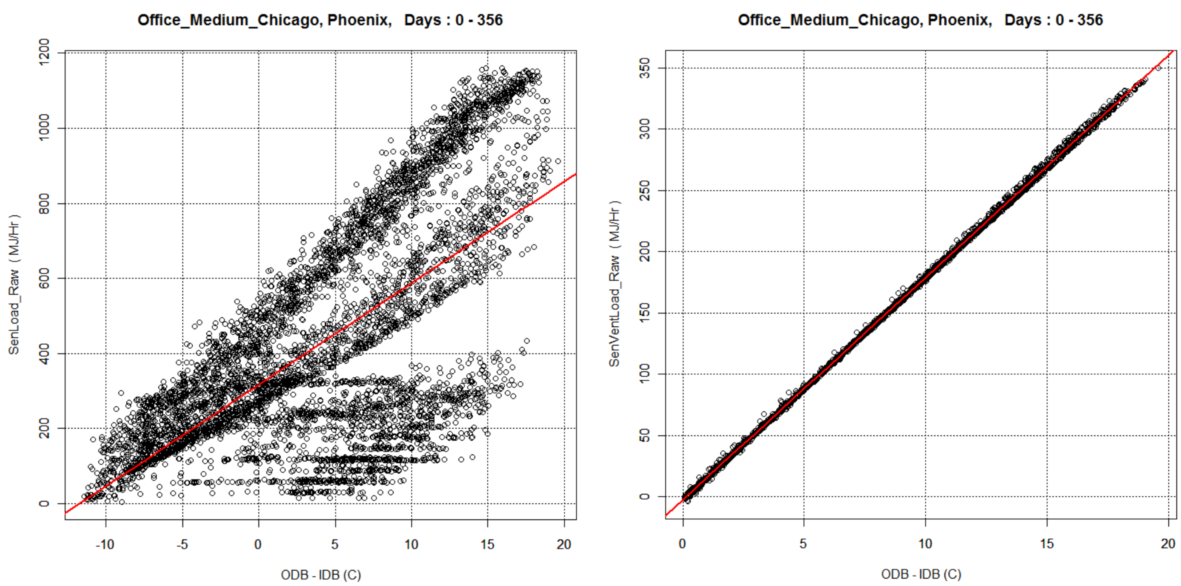


Figure 4-12 *Office-Medium-Chicago building simulated with **Phoenix** weather*. Raw sensible load as affected by envelope temperature differential. *Left*: sensible load (Intercept = 317.1 MJ/Hr; Slope = 27.06 MJ/HrC). *Right*: sensible ventilation load (Slope = 18.13; Slope Fraction = 18.13/27.06 = 0.67).

Table 4-6 Calculation of S&I fraction in three cities using the linear model resulting from the Office-Medium-Chicago building with **Phoenix** weather.

City	DT	S&I Fraction
SanFran	0.8	0.94
Chicago	7.5	0.61
Phoenix	18.0	0.39

4.2.1.3 San Francisco Weather

This run simulates the Office-Medium-Chicago building with San Francisco weather. Note that most of the data is at outdoor temperatures below the setpoint. However, the S&I results are very similar to the corresponding results when simulated with Chicago weather.

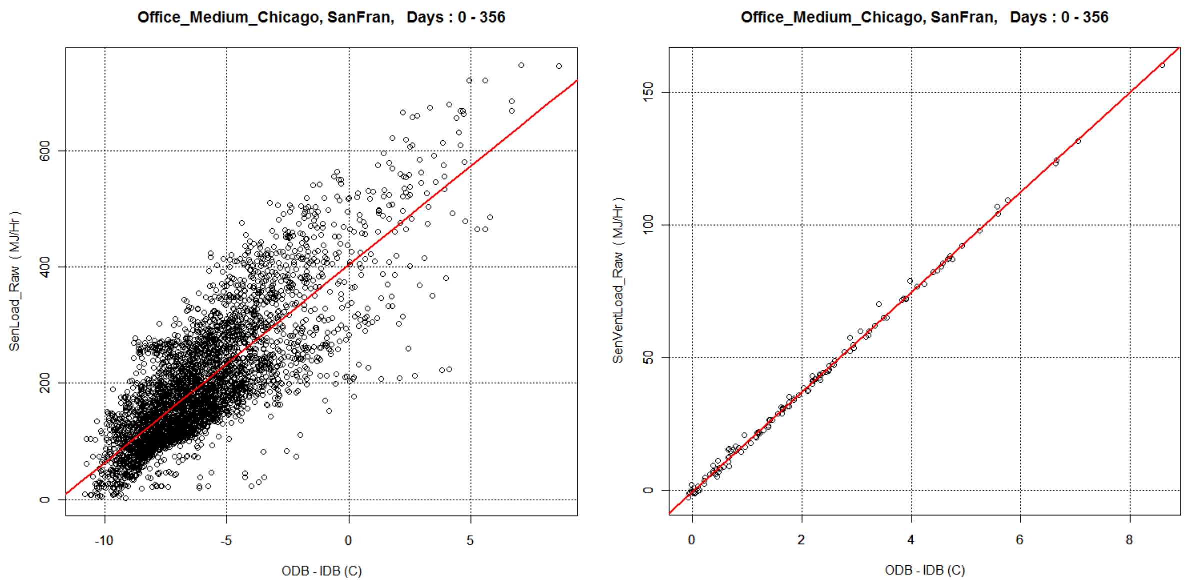


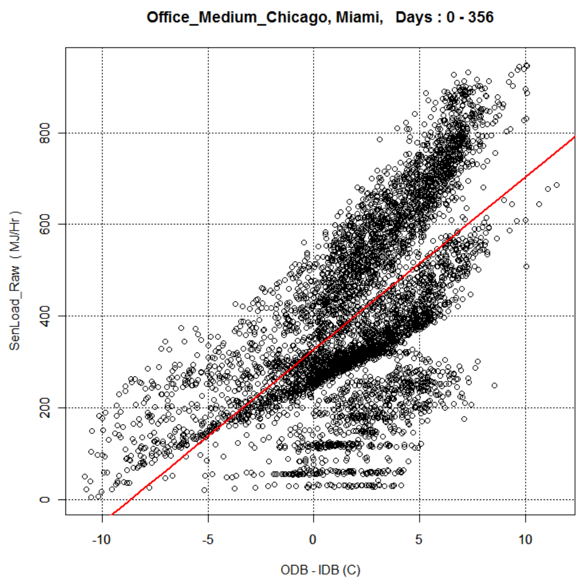
Figure 4-13 *Office-Medium-Chicago building simulated with* ***San Francisco*** *weather*. Raw sensible load as affected by envelope temperature differential. *Left*: sensible load (Intercept = 403.9 MJ/Hr; Slope = 34.05 MJ/HrC). *Right*: sensible ventilation load (Slope = 18.84; Slope Fraction = 18.84/34.05 = 0.55).

Table 4-7 Calculation of S&I fraction in three cities using the linear model resulting from the Office-Medium-Chicago building with ***San Francisco*** weather.

City	DT	S&I Fraction
SanFran	0.8	0.94
Chicago	7.5	0.61
Phoenix	18.0	0.40

4.2.1.4 Miami Weather

This run simulates the Office-Medium-Chicago building with Miami weather. Notice that most of the data is at outdoor temperatures cooler than Phoenix, a similar overall range to Chicago, but with much more of the data at deltas above setpoint ($\Delta T = 0$). However, the S&I results are lower but still reasonably similar to those calculated from a model based on Chicago weather.



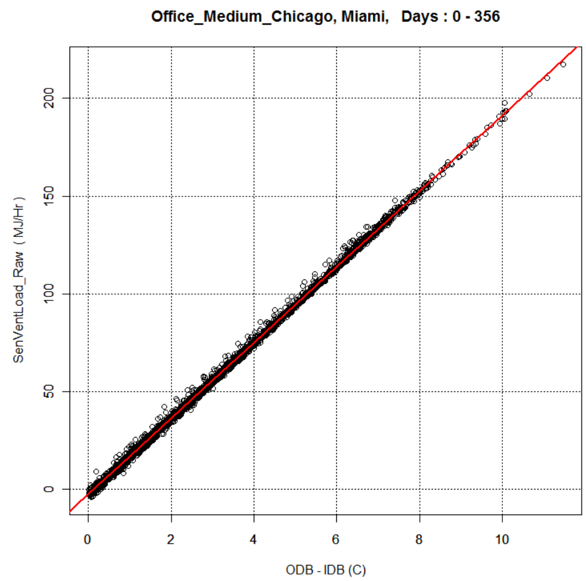


Figure 4-14 *Office-Medium-**Chicago** Building with **Miami** Weather*. Raw **sensible** load as affected by envelope temperature differential. *Left*: sensible load (Intercept = 326.55 MJ/Hr; Slope = 37.66 MJ/HrC). *Right*: sensible ventilation load (Slope = 19.38; Slope Fraction = 19.38/37.66 = 0.51).

Table 4-8 Calculation of S&I fraction in three cities using the Office-Medium-**Chicago** building model with **Miami** weather.

City	DT	S&I Fraction
SanFran	0.8	0.92
Chicago	7.5	0.54
Phoenix	18.0	0.33

4.3 Office-Medium-Phoenix

This result shows the Medium-Office-Phoenix (Phoenix version) of the Medium Office building simulated with Phoenix weather. The intercept to slope ratio of 327.65/29.45 = 11.1 for this run is within 2% of the Chicago-model-with-Chicago-weather run shown in Table 4-3. Also notice the S&I results here in Table 4-9 are very similar to the Chicago version simulated with Chicago weather shown in Table 4-3.

This result is supporting evidence for using only one version of the IDF files to represent a building.

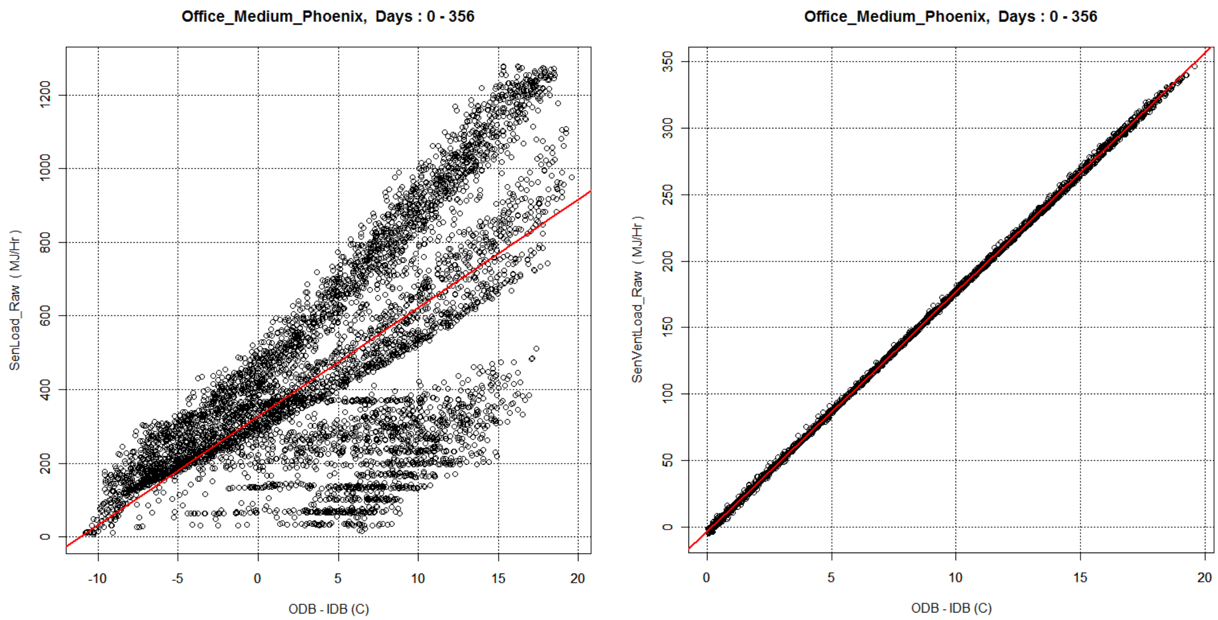


Figure 4-15 *Office-Medium-**Phoenix** Building with **Phoenix** Weather*. Raw **sensible** load as affected by envelope temperature differential. *Left*: sensible load (Intercept = 327.65 MJ/Hr; Slope = 29.45 MJ/HrC). *Right*: sensible ventilation load (Slope = 18.01; Slope Fraction = 18.01/29.45 = 0.61).

Table 4-9 Calculation of S&I fraction in three cities using the Office-Medium-**Phoenix** building model with **Phoenix** weather.

City	DT	S&I Fraction
SanFran	0.8	0.93
Chicago	7.5	0.60
Phoenix	18.0	0.38

4.4 Office-Large-Chicago

The Large-Office building uses chillers, no DX, so this model was based on total loads. The intercept-to-slope ratio is 4250/410 = 10.36 which is significantly smaller than values shown for Medium-Office in Table 4-3. This is evidence supporting the need to distinguish between these two versions of the office building type.

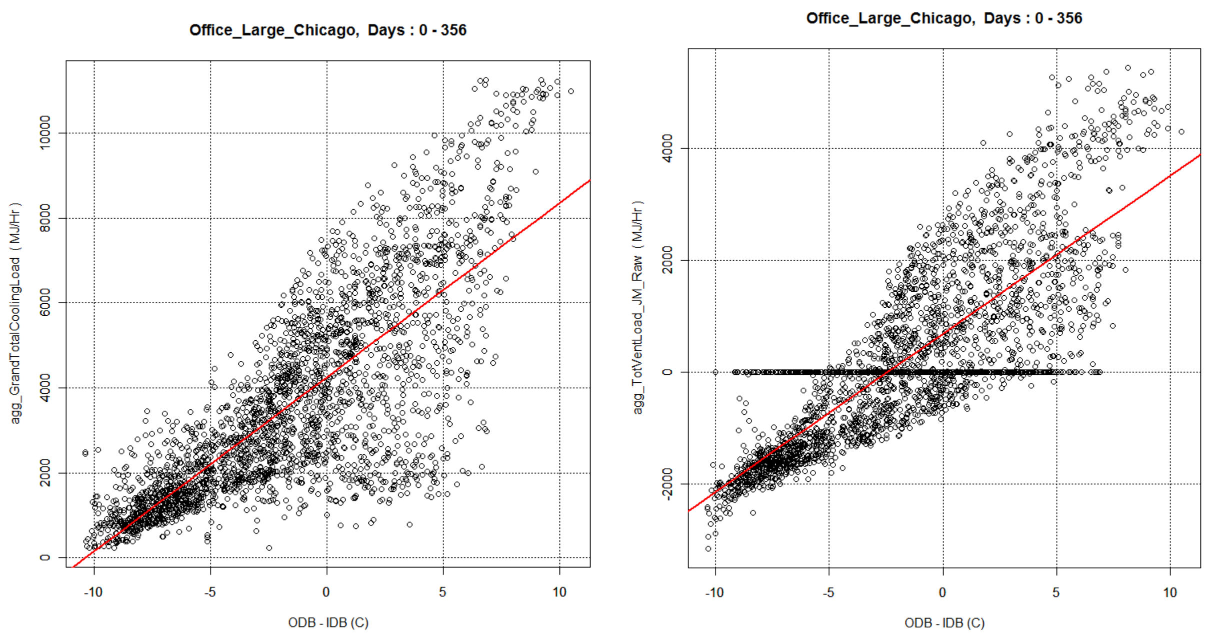


Figure 4-16 *Office-Large-**Chicago** Building with **Chicago** Weather*. Raw **total** load as affected by envelope temperature differential. *Left:* **total** load (Intercept = 4250 +/- 30 MJ/Hr; Slope = 410 +/- 6 MJ/HrC). *Right:* **total** ventilation load (Slope = 283 +/- 4; Slope Fraction = 0.69).

Table 4-10 Calculation of S&I fraction in three cities using the *Office-Large-**Chicago*** building model with ***Chicago*** weather.

City	DT	S&I Fraction
SanFran	0.8	0.93
Chicago	7.5	0.58
Phoenix	18.0	0.37

Post processing calls:

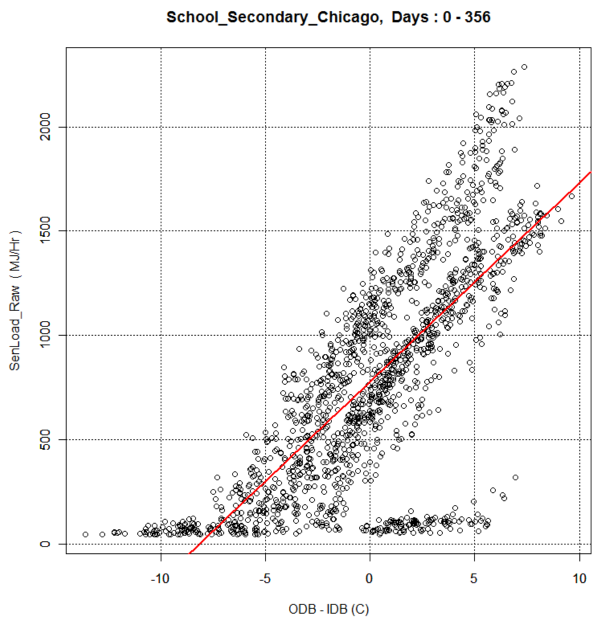
```
Scan(blnReScan = TRUE, strMainDirectory="Office_Large_Chicago", strSubDirectory="")
PlotVsTemp("DT", "CR", c(0,356), "agg_GrandTotalCoolingLoad", "GM", strUnits="MJ/Hr", ymin_fraction=0.02, strFitMode="T")
PlotVsTemp("DT", "CR", c(0,356), "agg_TotVentLoad_JM_Raw", "LF", strUnits="MJ/Hr", ymin_fraction=0.00, strFitMode="T", blnNoIntercept="F")
```

4.5 SCHOOL-SECONDARY-CHICAGO

This is a comparison of the sensible and total load models for the School-Secondary building. The sensible version is used in the RTUCC and reported in Table 2-1.

4.5.1 Sensible Loads

The School-Secondary building uses both DX and chiller. This sensible model is based on the DX systems in the building and is the one reported in Table 2-1.



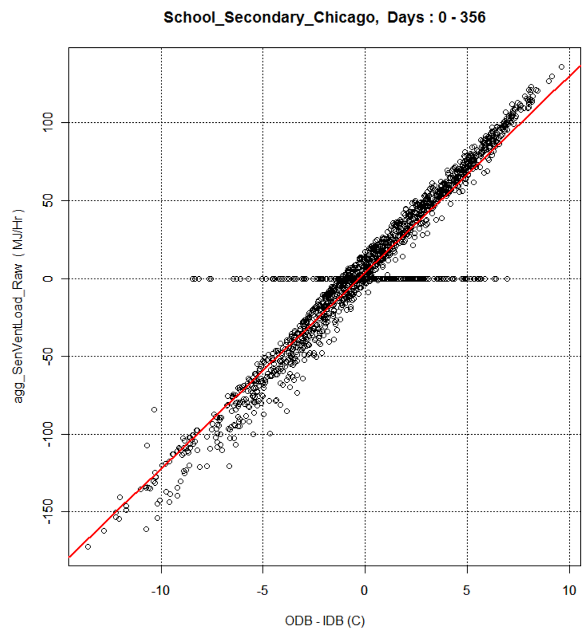


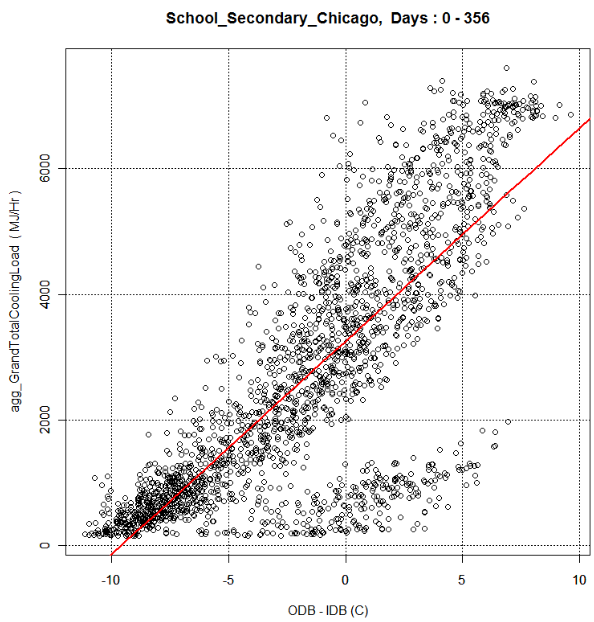
Figure 4-17 *School-Secondary*. *Left*: **sensible** load (Intercept = 779 +/- 9 MJ/Hr; Slope = 95 +/- 2 MJ/HrC; I/S=8.2C). *Right*: **sensible** ventilation load (Slope = 12.62 +/- 0.10; Slope Fraction = 0.13).

Post processing calls:

```
Scan(blnReScan = TRUE, strMainDirectory="School_Secondary_Chicago", strSubDirectory="")
PlotVsTemp("DT", "CR", c(0,356), "agg_SenLoad_Raw", "GM", strUnits="MJ/Hr", ymin_fraction=0.02, strFitMode="T")
PlotVsTemp("DT", "CR", c(0,356), "agg_SenVentLoad_Raw", "LF", strUnits="MJ/Hr", ymin_fraction=0.00, strFitMode="T", blnNoIntercept="F")
```

4.5.2 Total Loads

The School-Secondary building uses both DX and chiller. This total (= Sensible + Latent) model is based on both the DX and chiller systems in the building. The S&I predictions and I/S ratio are similar to those in section 4.5.1 that are based only on the DX systems.



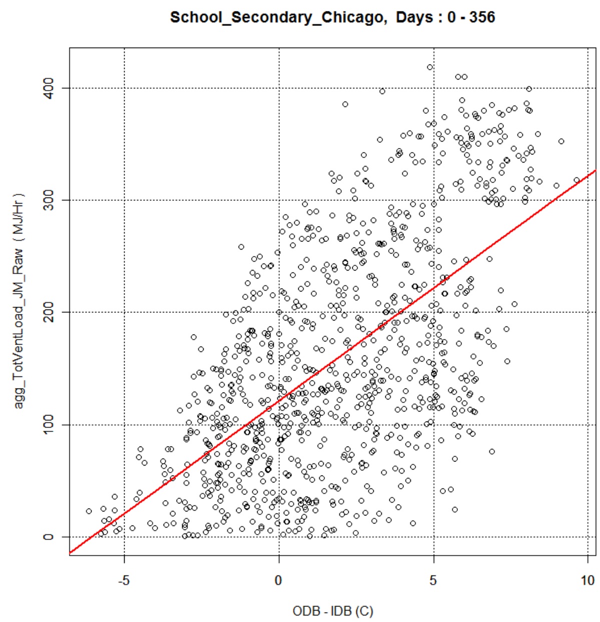


Figure 4-18 *School-Secondary*. *Left*: **total** load (Intercept = 3256 MJ/Hr; Slope = 339.1 MJ/HrC; I/S = 9.6C). *Right*: **total** ventilation load (Slope = 20.04; Slope Fraction = 0.06).

Post processing calls:

PlotVsTemp("DT", "CR", c(0,356), "agg_GrandTotalCoolingLoad", "GM", strUnits="MJ/Hr", ymin_fraction=0.02, strFitMode="T")

PlotVsTemp("DT", "CR", c(0,356), "agg_TotVentLoad_JM_Raw", "GM", strUnits="MJ/Hr", ymin_fraction=0.0, strFitMode="T", blnNoIntercept=F)

5 Model Runs / Chicago Weather

The subsections document the runs that serve as the basis for each linear building model. All of these have been simulated with Chicago weather. Models are based on sensible load data unless noted to be total load data. Later in this section, figures that are similar to Figure 5-1 will use a more abbreviated caption showing mainly numerical results; refer back to Figure 5-1 the full explanation.

5.1 Office-Small-Chicago

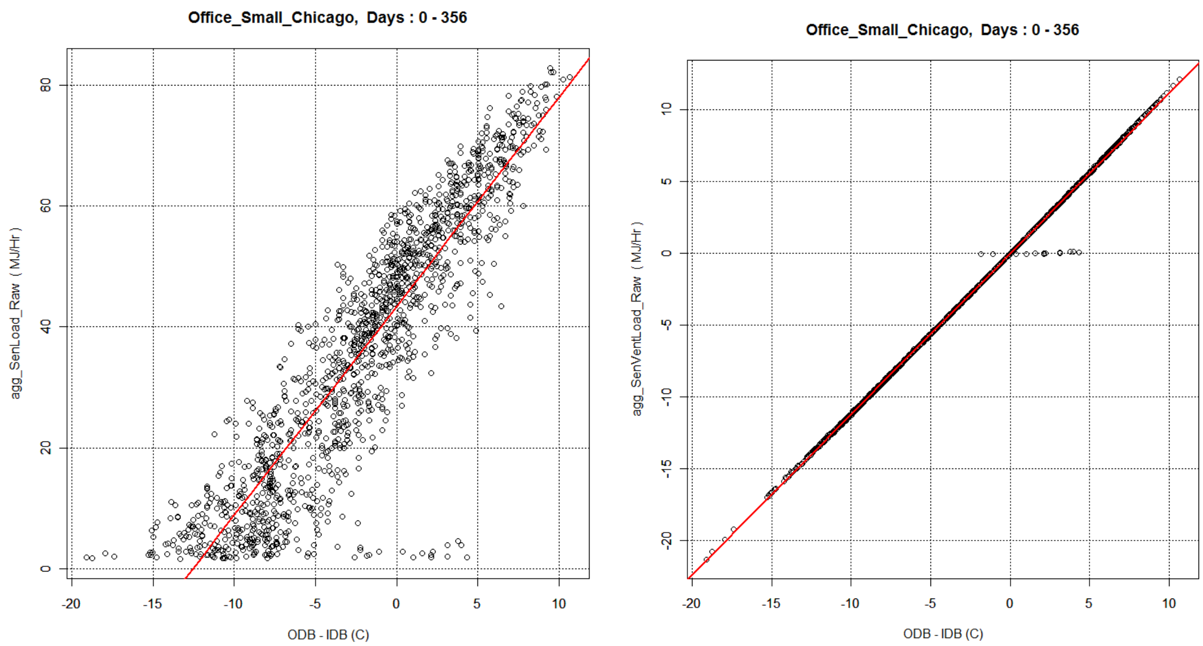


Figure 5-1 ***Office-Small****-Chicago Building with Chicago Weather*. Raw sensible load as affected by envelope temperature differential. *Left*: sensible load (Intercept = 43.4 +/- 0.3 MJ/Hr; Slope = 3.46 +/- 0.04 MJ/HrC). *Right*: sensible ventilation load (Slope = 1.120 +/- 0.001; Slope Fraction = 0.32).

5.2 Office-Medium-Chicago

See section 4.2.1.1 and Figure 4-6.

5.3 Office-Large-Chicago

See section 4.4 and Figure 4-16.

5.4 School-Primary-Chicago

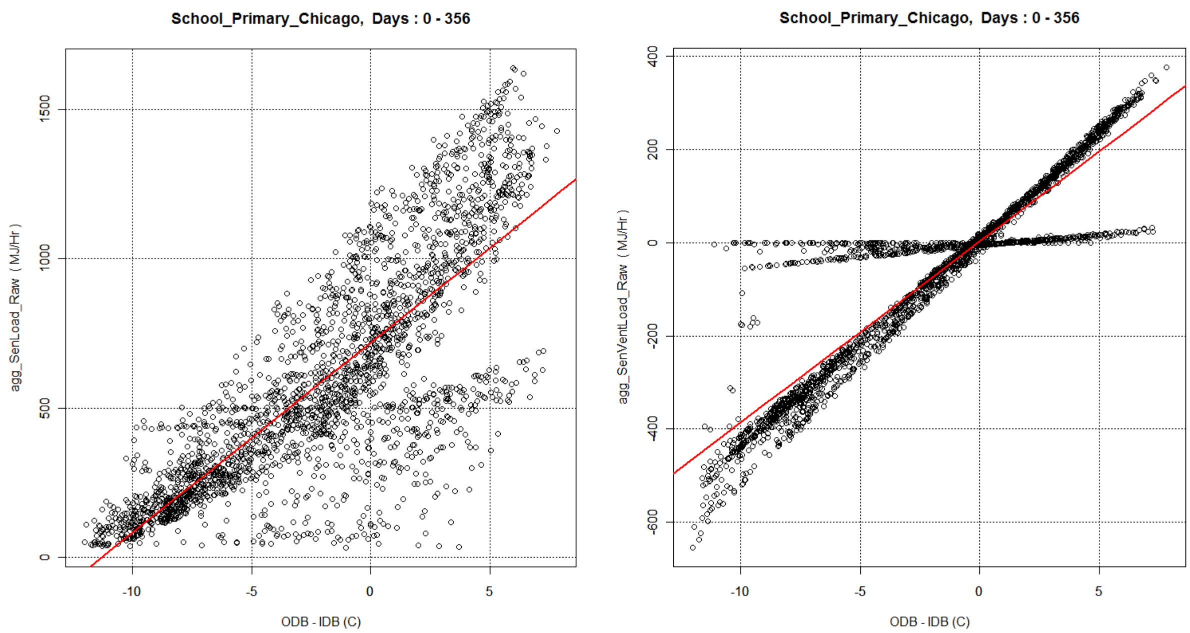


Figure 5-2 ***School-Primary***. *Left*: sensible load (Intercept = Intercept = 718 +/- 5 MJ/Hr; Slope = 63.5 +/- 1.0 MJ/HrC). *Right*: sensible ventilation load (Slope = 38.8 +/- 0.3; Slope Fraction = 0.61).

5.5 School-Secondary-Chicago

See section 4.5.1 and Figure 4-17.

5.6 Warehouse

This initial analysis shown in Figure 5-3 indicates strong economizer effects for the warehouse building type. It was re-analyzed in Figure 5-4 to use only hours where the ventilation loads are positive.

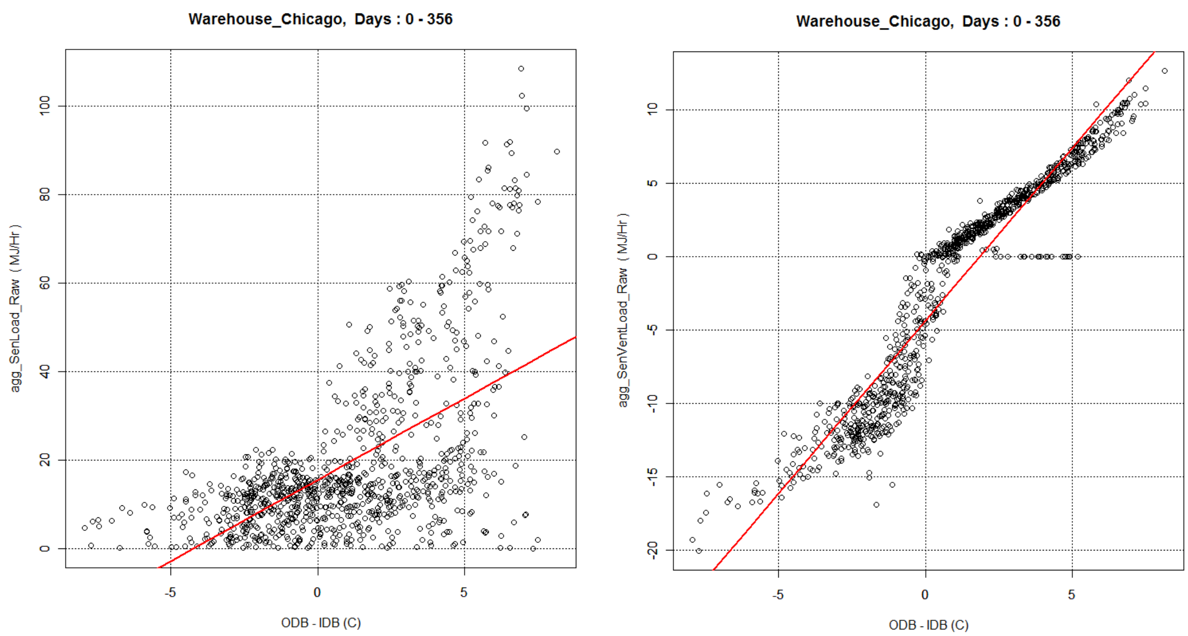


Figure 5-3 *Warehouse*. *Left:* sensible load (Intercept = 15.5 +/- 0.5 MJ/Hr; Slope = 3.68 +/- 0.16 MJ/HrC). *Right:* sensible ventilation load (Slope = 2.35 +/- 0.02; Slope Fraction = 0.64).

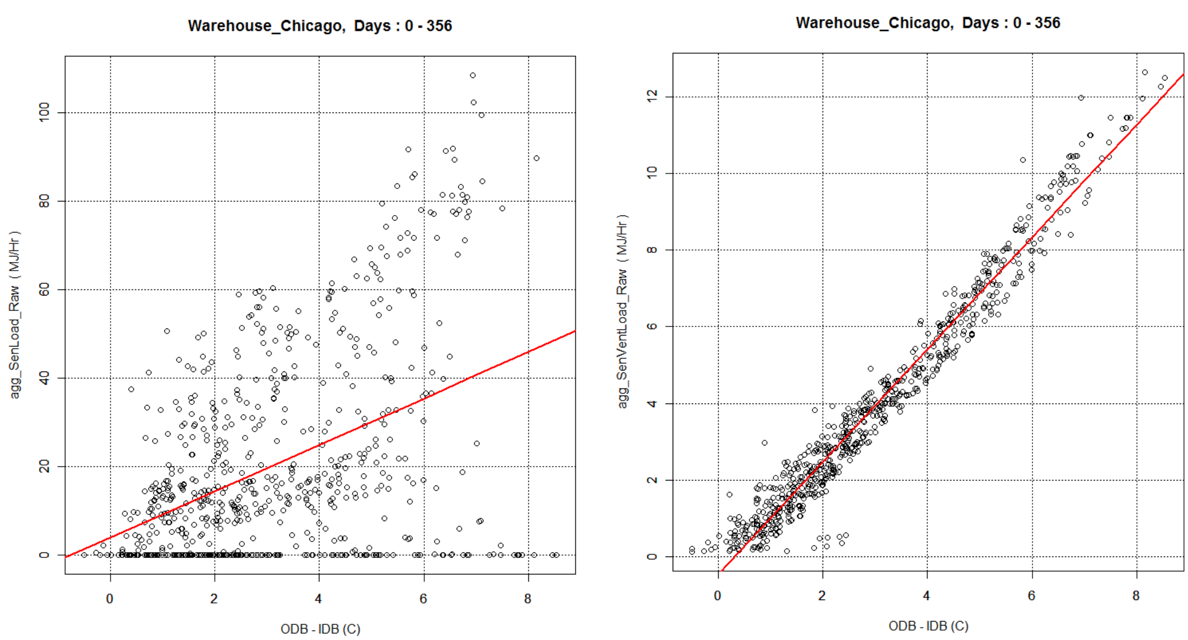


Figure 5-4 *Warehouse*. *Left:* sensible load (Intercept = 3.8 +/- 1.5 MJ/Hr; Slope = 5.3 +/- 0.4 MJ/HrC). *Right:* sensible ventilation load (Slope = 1.47 +/- 0.01; Slope Fraction = 0.28).

In Figure 5-4 negative ventilation loads are excluded. This is done by filtering on the ventilation load data and then using the resulting set of hours in the sensible load plot. This still left some zero-load points. These were excluded in one more level of filtering as shown in Figure 5-5. These final results are the ones used in the RTUCC.

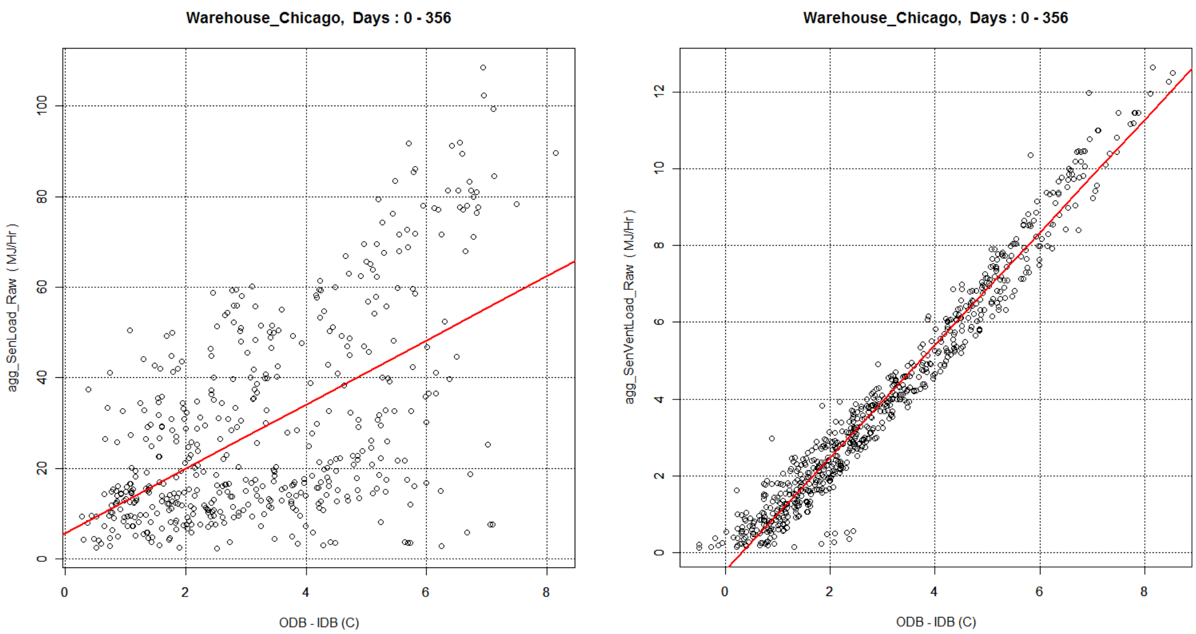


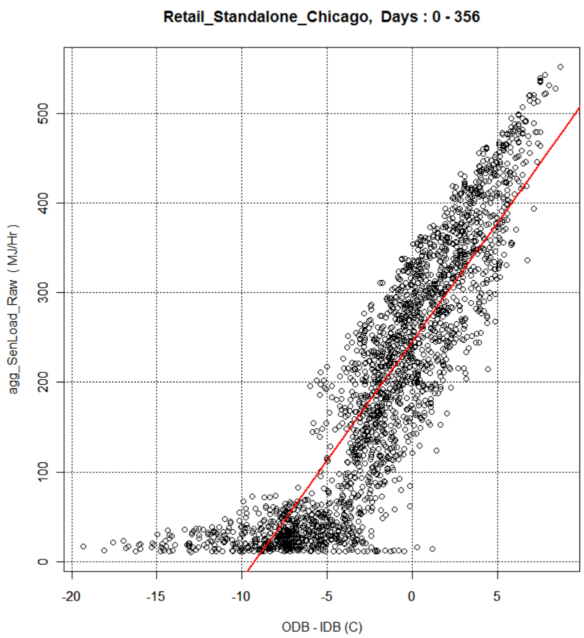
Figure 5-5 *Warehouse*. *Left:* sensible load (Intercept = 5.7 +/- 1.7 MJ/Hr; Slope = 7.1 +/- 0.5 MJ/HrC). *Right:* sensible ventilation load (Slope = 1.47 +/- 0.01; Slope Fraction = 0.21).

Note the order in the following summary of calls. The ventilation load data is processed first. That acts to produce the subsetting vector which is applied in the next two commands.

Post processing calls:

```
Scan(blnReScan = TRUE, strMainDirectory="Warehouse_Chicago", strSubDirectory="")
PlotVsTemp("DT", "CR", c(0,356), "agg_SenVentLoad_Raw", "GM", strUnits="MJ/Hr", ymin_fraction=0.01, strFitMode="T", blnNoIntercept="F")
PlotVsTemp("DT", "CR", c(0,356), "agg_SenLoad_Raw", "LF", strUnits="MJ/Hr", ymin_fraction=0.02, strFitMode="T")
PlotVsTemp("DT", "CR", c(0,356), "agg_SenLoad_Raw", "LFGM", strUnits="MJ/Hr", ymin_fraction=0.02, strFitMode="T")
```

5.7 Retail-Standalone



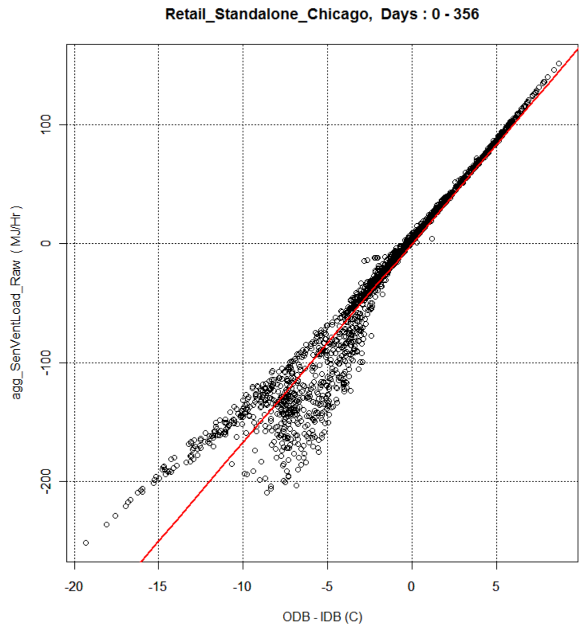
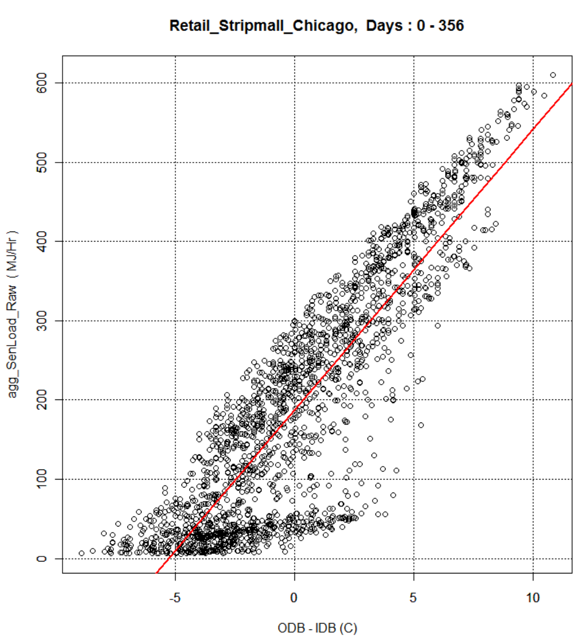


Figure 5-6 Retail-Standalone. *Left:* sensible load (Intercept = 245.4 +/- 1.5 MJ/Hr; Slope = 26.5 +/- 0.3 MJ/HrC). *Right:* sensible ventilation load (Slope = 16.69 +/- 0.09; Slope Fraction = 0.63).

5.8 Retail-Stripmall



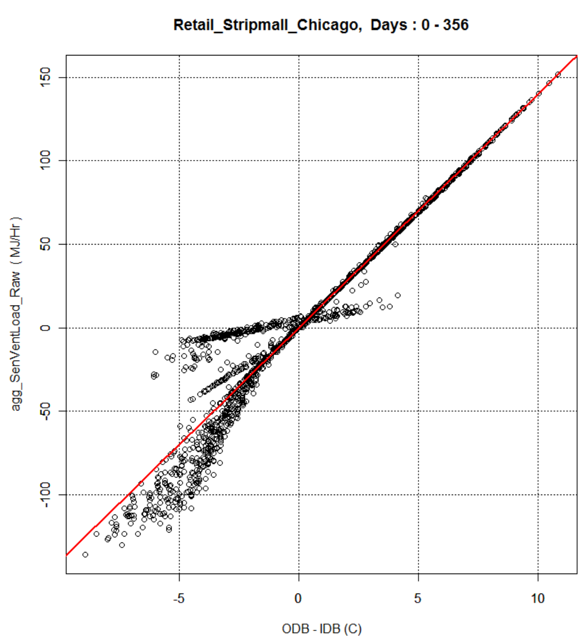
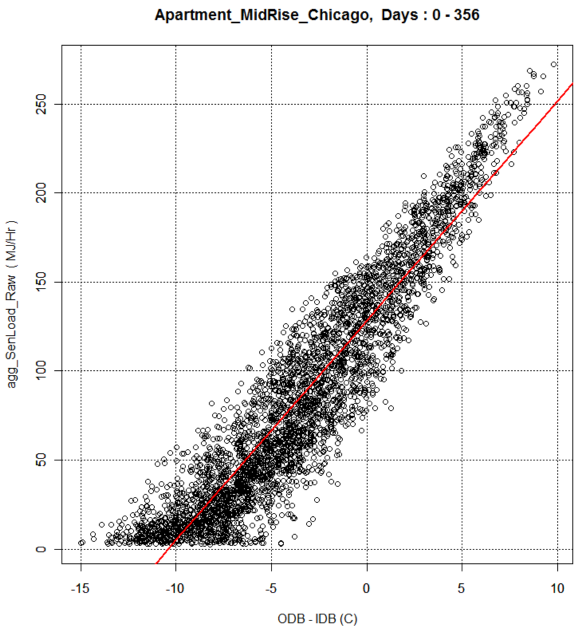


Figure 5-7 Retail-Stripmall. *Left:* sensible load (Intercept = 187.2 +/- 1.6 MJ/Hr; Slope = 35.4 +/- 0.4 MJ/HrC). *Right:* sensible ventilation load (Slope = 14.00 +/- 0.09; Slope Fraction = 0.40).

5.9 Apartment-Midrise



(Mechanical ventilation not reported.)

Figure 5-8 Apartment-Midrise. *Left:* sensible load (Intercept = 128.3 +/- 0.5 MJ/Hr; Slope = 12.32 +/- 0.08 MJ/HrC). *Right plot (none)*. Slope Fraction = NA (0.30 assumed).

5.10 Restaurant Sit-down

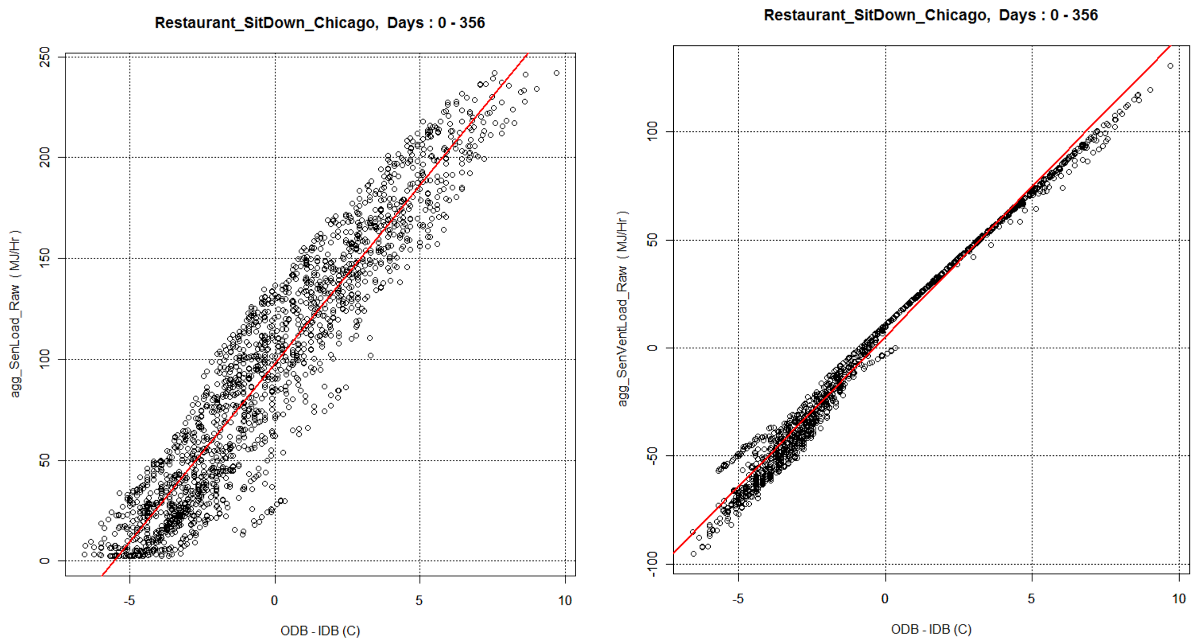


Figure 5-9 Restaurant Sit-Down. *Left:* sensible load (Intercept = 98.0 +/- 0.5 MJ/Hr; Slope = 17.65 +/- 0.14 MJ/HrC). *Right:* sensible ventilation load (Slope = 13.88 +/- 0.04; Slope Fraction = 0.79).

5.11 Restaurant Fast-Food

See section 4.1.1 and Figure 4-1.

5.12 Hotel-Large

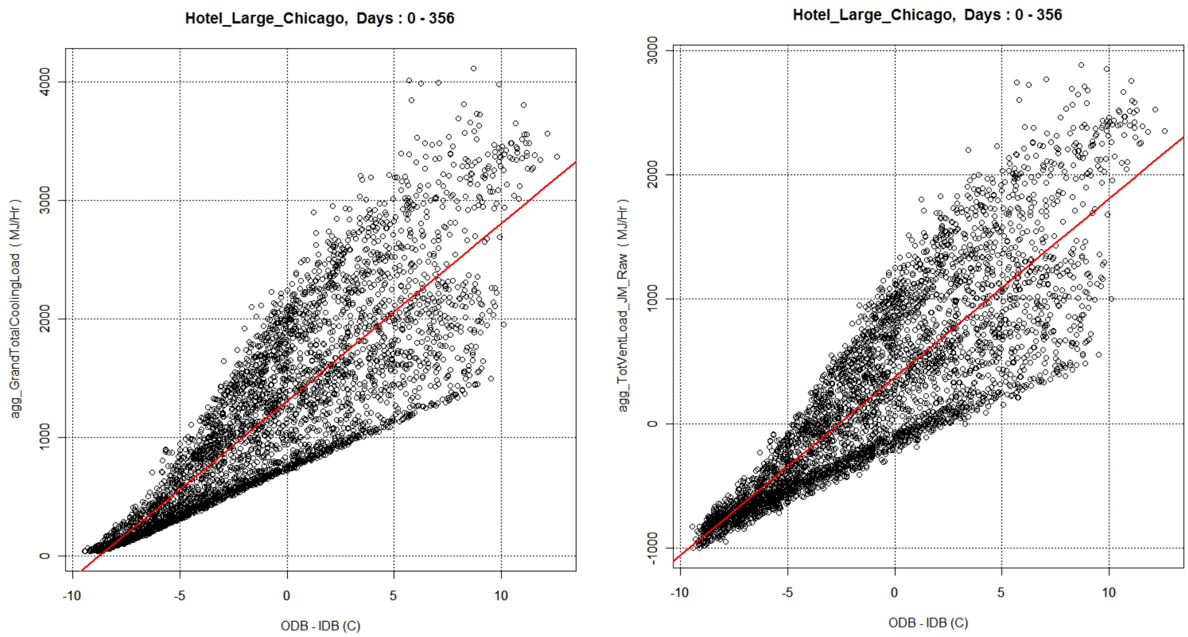
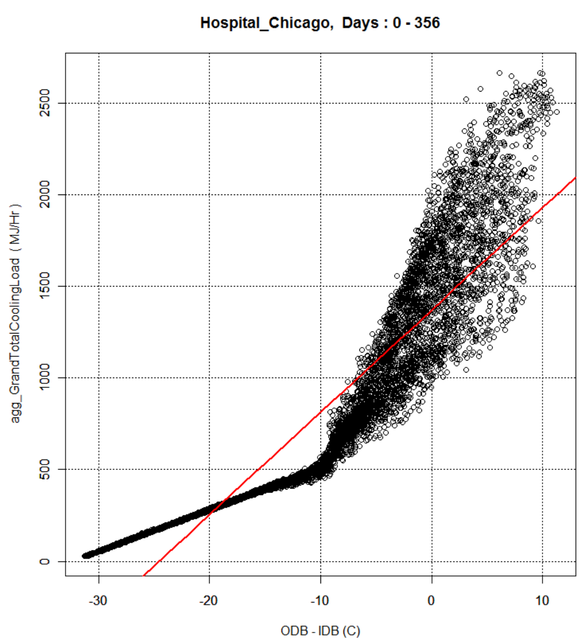


Figure 5-10 Hotel-Large. *Left:* sensible load (Intercept = 1313 +/- 7 MJ/Hr; Slope = 149.5 +/- 1.4 MJ/HrC). *Right:* sensible ventilation load (Slope = 143.3 +/- 1.3; Slope Fraction = 0.96).

5.13 Health Care-Hospital



(Ventilation loads not reported)

Figure 5-11 Health Care-Hospital. *Left:* sensible load (Intercept = 1370 +/- 4 MJ/Hr; Slope = 55.8 +/- 0.3 MJ/HrC). *Right plot (none)*. Slope Fraction = NA (0.8 assumed).

5.14 Health Care-Outpatient

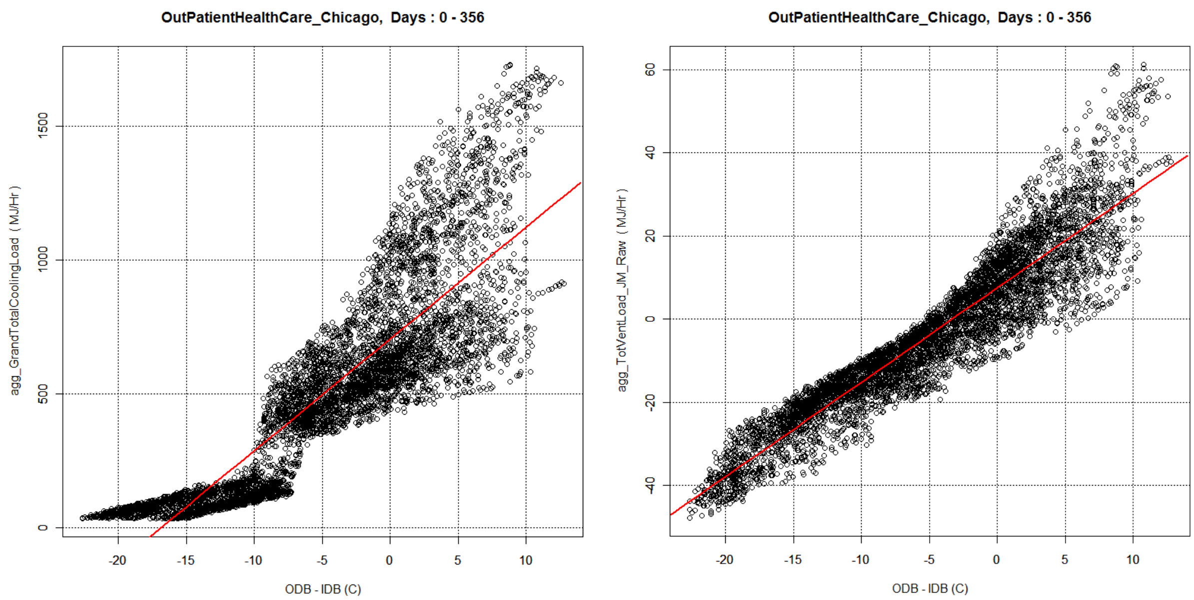


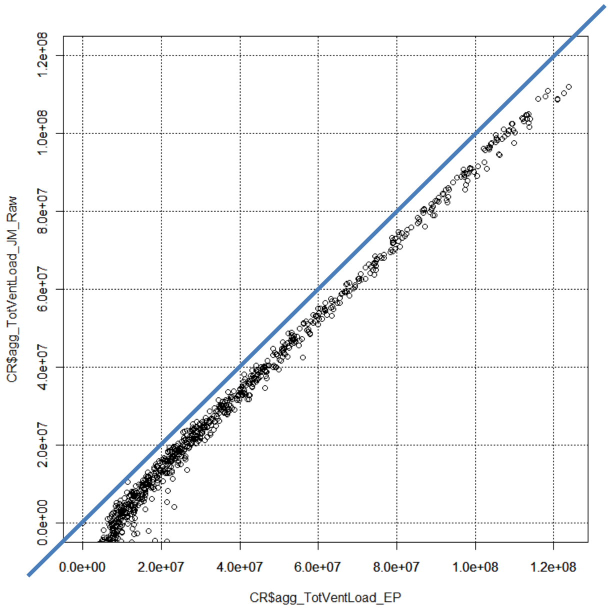
Figure 5-12 Health Care-Outpatient. *Left:* sensible load (Intercept = 704 +/- 3 MJ/Hr; Slope = 41.8 +/- 0.3 MJ/HrC). *Right:* sensible ventilation load (Slope = Slope = 2.270 +/- 0.011; Slope Fraction = 0.054).

Post processing calls:

```
Scan(blnReScan = TRUE, strMainDirectory=" OutPatientHealthCare_Chicago", strSubDirectory="")
PlotVsTemp("DT", "CR", c(0,356), "agg_GrandTotalCoolingLoad", "GM", strUnits="MJ/Hr", ymin_fraction=0.02, strFitMode="T")
PlotVsTemp("DT", "CR", c(0,356), "agg_TotVentLoad_JM_Raw", "LF", strUnits="MJ/Hr", ymin_fraction=0.00, strFitMode="T", blnNoIntercept="F")
```

6 CHECK OF TOTAL VENTILATION LOAD CALCULATION

Medium Office



Restaurant

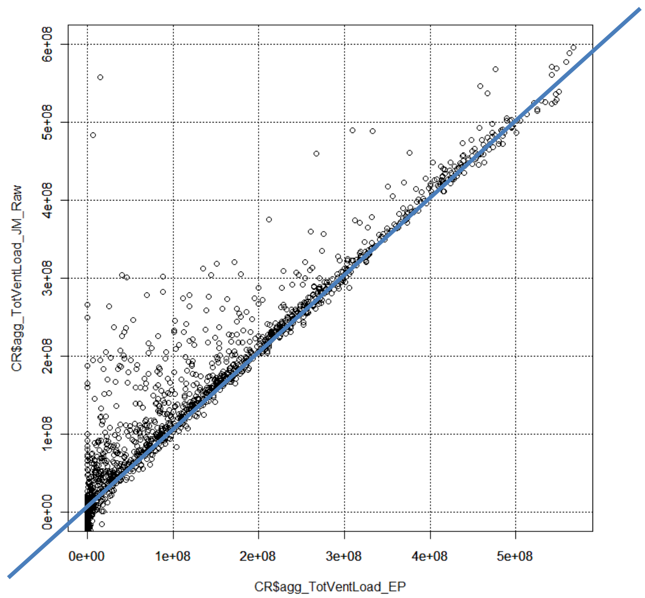


Figure 6-1 Comparison of the calculated total-ventilation load (calculated in post processing using ventilation mass flow) and reported ventilation load (load reported directly from EnergyPlus). The blue line indicates where data would be expected if there was one-to-one agreement. *Left*: Medium Office. *Right*: Restaurant.

The plots in Figure 6-1 are a comparison check between the total-ventilation loads calculated in the post processing and the ventilation loads reported by EnergyPlus in the Zone.Mechanical.Ventilation.Cooling.Load.Increase variable. There is primarily one-to-one agreement in the Restaurant data (right plot). EnergyPlus documentation does not specify if their ventilation variable is sensible or total; agreement here indicates it must be total. A similar sensible variable is not available in EnergyPlus. For this reason, ventilation loads were calculated wherever sensible loads were used to establish the building model.

7 HUMIDITY-RATIO DIFFERENCE

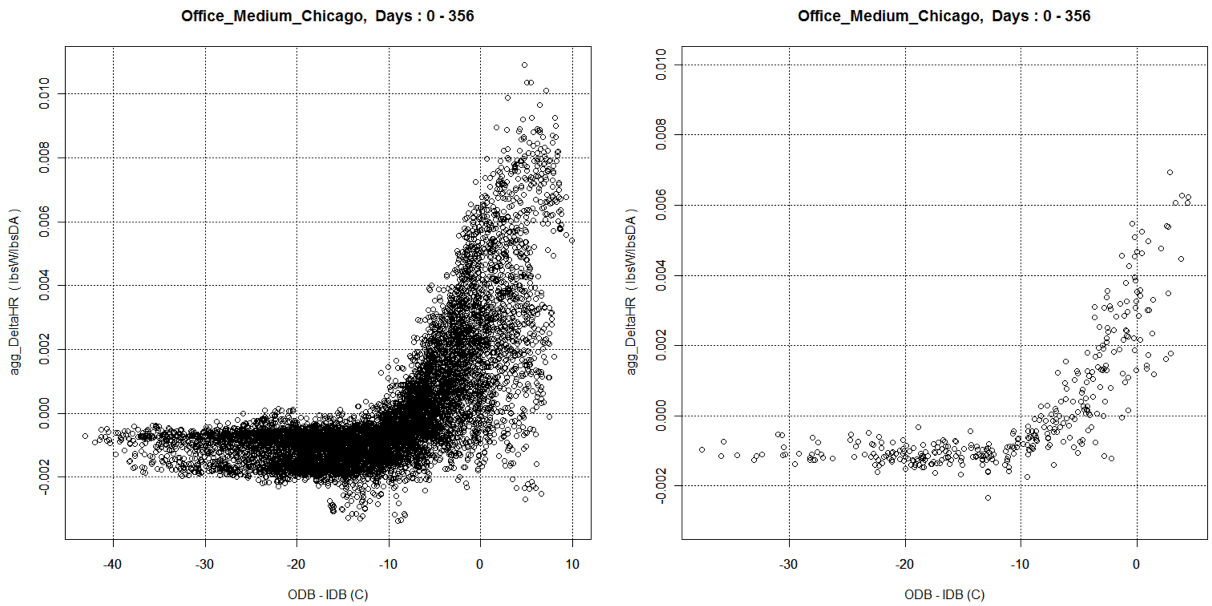


Figure 7-1 Humidity-ratio differential (outdoor minus indoor) as affected by temperature differential (outdoor minus indoor). *Left*: raw hourly data. *Right*: daily averages.

The plots in Figure 7-1 illustrate the difference between the outside and inside humidity ratio throughout the year as indexed by temperature differential. This shows a positive humidity-ratio difference during the summer cooling season and a negative difference in the winter. Summer cooling and the resulting dehumidification acts to suppress the indoor humidity ratio. This is shown here for future reference in support of developing an indoor humidity-ratio model based on EnergyPlus runs.