Title

IMPROVEMENT OF DEMAND RESPONSE QUICK ASSESSMENT TOOL (DRQAT) AND TOOL VALIDATION CASE STUDIES:

Authors

Yin, Rongxin
Black, Doug

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Rongxin Yin, Doug Black

Lawrence Berkeley National Laboratory
Berkeley, CA

August 2015

The work described in this study was coordinated by the Demand Response Research Center and funded by the California Energy Commission (Energy Commission), Public Interest Energy Research (PIER) Program, under work for others Contract No.500-03-026. The authors are grateful for the extensive support from numerous individuals who assisted in this project: David Hungerford (California Energy Commission), Nance Matson (Demand Response Research Center) for project management and review assistance effort, Dennis Roman (ASWB Engineering) for providing the feedback and technical review of the software tool – DRQAT.

Disclaimer

Energy Research and Development Division
FINAL PROJECT REPORT

IMPROVEMENT OF DEMAND RESPONSE QUICK ASSESSMENT TOOL (DRQAT) AND TOOL VALIDATION CASE STUDIES

Prepared for: California Energy Commission
Prepared by: Lawrence Berkeley National Laboratory

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PREPARED BY:

Primary Author(s):
Rongxin Yin
Doug Black

Lawrence Berkeley National Laboratory
Demand Response Center
1 Cyclotron Road
Berkeley, CA 94720

Contract Number: 500-03-026

Prepared for:

California Energy Commission

David Hungerford
Contract Manager

Virginia Lew
Office Manager
Energy Efficiency Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Improvement of Demand Response Quick Assessment Tool (DRQAT) and Tool Validation Case Studies is the final report for the PIER project (contract number 500-03-026, work authorization number 3) conducted by the Demand Response Research Center. The information from this project contributes to Energy Research and Development Division's Energy Systems Integration Program.

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ABSTRACT

In 2006, the Demand Response Research Center (DRRC) at Lawrence Berkeley National Laboratory (LBNL) initiated the development of a quick assessment tool for demand response in buildings and, in 2007 the DRRC released the first version of the Demand Response Quick Assessment Tool (DRQAT) for public use. Over the past few years, the DRRC has been improving the DRQAT tool based on users' feedback and upgrading the engine with the EnergyPlus energy simulation tool. Currently, DRQAT enables users to evaluate a single DR strategy configuration at a time. Users could greatly benefit from being able to run multiple strategy configurations at a time and directly compare their performance in a single output report. The latest update of DRQAT, described in this report, enables users to do just that to compare different pre-cooling and reset strategies. Also, to help customers better understand the demand response performance of their facilities; this report presents several case studies to compare demand response predictions with measured values. A previous study indicated that the predictive value of the DRQAT simulation model could be significantly improved after calibrating the model with measured data. Most users are not familiar with model calibration, a process that can be time consuming. This report shows a comparison of DRQAT results generated as a typical user would—without calibration. The results show that the DRQAT tool can generate credible predictions of peak demand savings and load shapes throughout demand response event hours.

Keywords: EnergyPlus; Demand Response; DR Strategy; Prediction Value; Calibration

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EXECUTIVE SUMMARY

Introduction

In 2006, LBNL's Demand Response Research Center (DRRC) initiated the development of a quick assessment tool for DR in buildings and, in 2007 the DRRC released the first version of the Demand Response Quick Assessment Tool (DRQAT) for public use.

To date, nearly a hundred universities, research institutions, and consulting firms have downloaded the DRQAT for various purposes, with a focus on the demand response in commercial buildings. At the same time, DRRC has been collecting feedback from users, and the tool has been updated. With the feedback, bugs have been corrected and upgrades have been made. The tool is also updated when new versions of the simulation engine, EnergyPlus, become available.

Project Purpose

In the summer of 2008, DRRC conducted a comprehensive pilot study of field tests in eleven buildings in San Bernardino, California. In this study, the DRQAT was used for optimizing various "pre-cooling and zone temperature reset" control strategies. Comparisons of the DRQAT predictions and the field measurements are summarized in the report (Yin et al., 2010a).

In this study, new features of the latest version (DRQATV5.0) are presented, including the input interface and output reports. This latest version enables users to run multiple DR simulations of various pre-cooling and reset strategies in a single run. Users can view the output of multiple simulations in a single report and select the best pre-cooling DR strategy. In addition, a comprehensive study validating the tool was conducted by using the field test data from the San Bernardino buildings. The validation report demonstrates the credibility of the DRQAT predictions with simple building model inputs, and guides users to improve the model's accuracy.

Project Results

Those features enable users to conduct more efficient DR simulation with DRQAT V5.0 and to perform DR analysis with more variety. With a focus on the tool validation using several case studies, the studies in the rest of the report show the results of comparisons between the measured DR impacts and the DRQAT predicted values. The following metrics are presented to quantify the DR impacts on whole-building power: peak demand (kW), load shape and absolute demand savings (kW), and relative demand savings (%).

- **Peak demand savings during the peak period**. The DRQAT predictions show consistent peak demand savings on the 12 hottest days in summer, because the embedded EnergyPlus models have no variability with the building and system operational behavior between the baseline model and DR model. On the other hand, the building HVAC system capacity is well sized in the simulation model. Overall, the DRQAT predictions assume the ideal operational conditions for the building and relevant mechanical systems. For the first case study building, the DRQAT predictions show a constant average demand savings of 10~11 percent for all DR event days, which are slightly higher than those of the measured values by nearly 2 percent. As for the absolute demand savings (kW), the predicted values are very close to the average value of the measured peak demand savings (kW), while the measured values fluctuated over the actual DR events.

- **Load shape throughout the DR event day**. Given the similar office building characteristics, for most of case study buildings, the predicted load shape in the peak period can match the measured whole-building demand power throughout the DR event day, even the case study models are not calibrated. However, there are still many uncertainties that are hard to capture in the DRQAT model. As a result, the predicted peak demand and load shape can be widely different from the measured value. However, by taking the demand changes as a metric, it can avoid uncertainties from the building operational behavior, space loads such as lighting and plug load. The results show that the pattern of demand changes over time is pretty close between the DRQAT predictions and the measured data.
- **Demand savings vs. outside air temperature**. The DRQAT predictions indicate that the absolute demand savings (kW) increase slightly with the peak outside air temperatures—a result that can also be found in a previous study (Yin., et al., 2010). In comparison to the measured value, note that the average outside air temperature of the 12 hottest days in TMY weather data is higher than that of the field test DR event days, and the predicted demand savings are slightly higher, but the average demand savings are very close.

Project Benefits

DRQAT has been recognized as as the Demand Response (DR) estimation tool in National Action Plan on Demand Response in U.S. and been widely used in the field of academia and industry. The upgrade of this tool will provide more capabitilies to users by allowing fast simulation of multiple models with the core of EnergyPlus V8.1. In addition, the validation results of case studies indicate the prediction value of the software for the estimation of DR potentials. In California, building owners and operators can use the enhanced DRQAT V5.0 to identify which DR strategies will provide the best energy and peak electrical demand savings, economic savings, and thermal comfort impacts.

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CHAPTER 1:
Introduction

In the past decade, Lawrence Berkeley National Laboratory (LBNL) has conducted a number of field tests of demand response (DR) control strategies in buildings in different climate zones across California. Many field tests, laboratory studies, and simulations have demonstrated that building thermal mass in buildings can be very effective for load shifting and demand shed while maintaining occupant comfort. Energy simulation can be used to develop physical building models to analyze various DR control strategies with less time and effort. In 2006, LBNL's Demand Response Research Center (DRRC) initiated the development of a quick assessment tool for DR in buildings and, in 2007 the DRRC released the first version of the Demand Response Quick Assessment Tool (DRQAT) for public use.

To date, nearly a hundred universities, research institutions, and consulting firms have downloaded the DRQAT for various purposes, with a focus on the demand response in commercial buildings. At the same time, DRRC has been collecting feedback from users, and the tool has been updated. With the feedback, bugs have been corrected and upgrades have been made. The tool is also updated when new versions of the simulation engine, EnergyPlus, become available. In 2009, in collaboration with Natural Resources Canada, the tool was updated to include five Canadian cities' prototype building models and the capability to simulate Thermal Energy Storage (TES) in commercial buildings.

In the summer of 2008, DRRC conducted a comprehensive pilot study of field tests in eleven buildings in San Bernardino, California. In this study, the DRQAT was used for optimizing various "pre-cooling and zone temperature reset" control strategies. Comparisons of the DRQAT predictions and the field measurements are summarized in the report (Yin et al., 2010a).

In this study, new features of the latest version (DRQATV5.0) are presented, including the input interface and output reports. This latest version enables users to run multiple DR simulations of various pre-cooling and reset strategies in a single run. Users can view the output of multiple simulations in a single report and select the best pre-cooling DR strategy. In addition, a comprehensive study validating the tool was conducted by using the field test data from the San Bernardino buildings. The validation report demonstrates the credibility of the DRQAT predictions with simple building model inputs, and guides users to improve the model's accuracy.

CHAPTER 2:
New Features of DRQAT V5.0

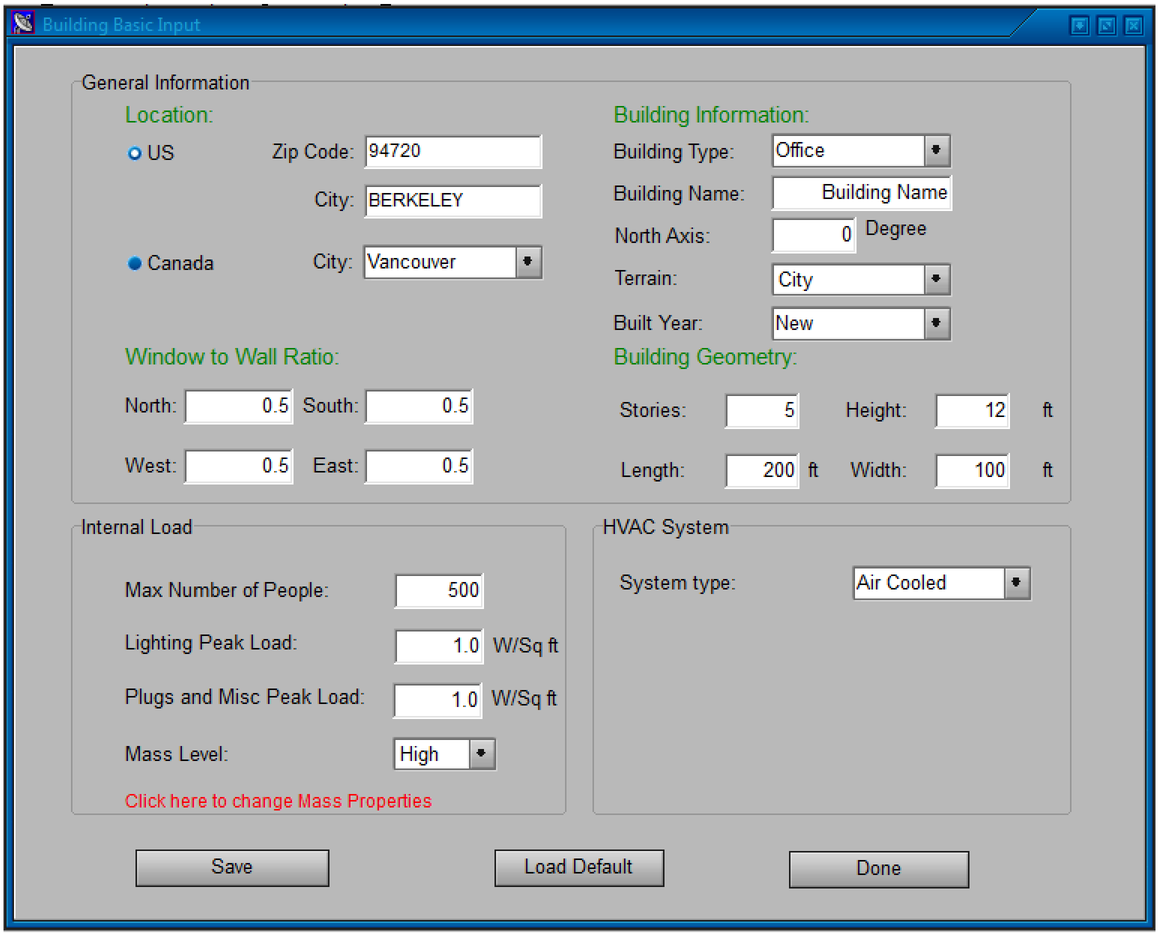
2.1 Inputs

2.1.1 Building Basic Input

For the new version of DRQAT, the main interface of the building basic input (Figure 1) has the following new features:

- **Auto fill of number of people:** Automatically calculate the number of people in a building using gross floor area and 200 square feet (ft^2)/ per person (ASHRAE 62.1-2004). Number of People = $(Length \times Width \times Stories)/200$.
- **Auto fill of lighting and plug load based on California Title 24 and year built:** Add input for the year built and the model will automatically fill in light and plug loads based on year and Title 24. For pre-Title-24, it uses U.S. Department of Energy (DOE) reference model values (see Table 1).

Figure 1: Building Basic Input of DRQAT V5.0



Building Basic Input

General Information

Location:

○ US

Zip Code: 94720

City: BERKELEY

● Canada

City: Vancouver

Window to Wall Ratio:

North: 0.5 South: 0.5

West: 0.5 East: 0.5

Building Information:

Building Type: Office

Building Name: Building Name

North Axis: 0 Degree

Terrain: City

Built Year: New

Building Geometry:

Stories: 5 Height: 12 ft

Length: 200 ft Width: 100 ft

Internal Load

Max Number of People: 500

Lighting Peak Load: 1.0 W/Sq ft

Plugs and Misc Peak Load: 1.0 W/Sq ft

Mass Level: High

Click here to change Mass Properties

HVAC System

System type: Air Cooled

Table 1: DOE Reference Office Building Models V5.0

Model	Floor Area (ft^2)	New		Post-1980		Pre-1980	
		Lights (W/ft^2)	Plug (W/ft^2)	Lights (W/ft^2)	Plug (W/ft^2)	Lights (W/ft^2)	Plug (W/ft^2)
Large	500K	1.0	1.0	1.5	1.0	1.5	1.0
Medium	54K	1.0	1.0	1.6	1.0	1.6	1.0
Small	5.5K	1.0	0.75	1.8	0.75	1.8	0.75

2.1.2 Utility Input

Utility inputs interface was updated with additional DR program information and additional navigation capabilities. More specifically:

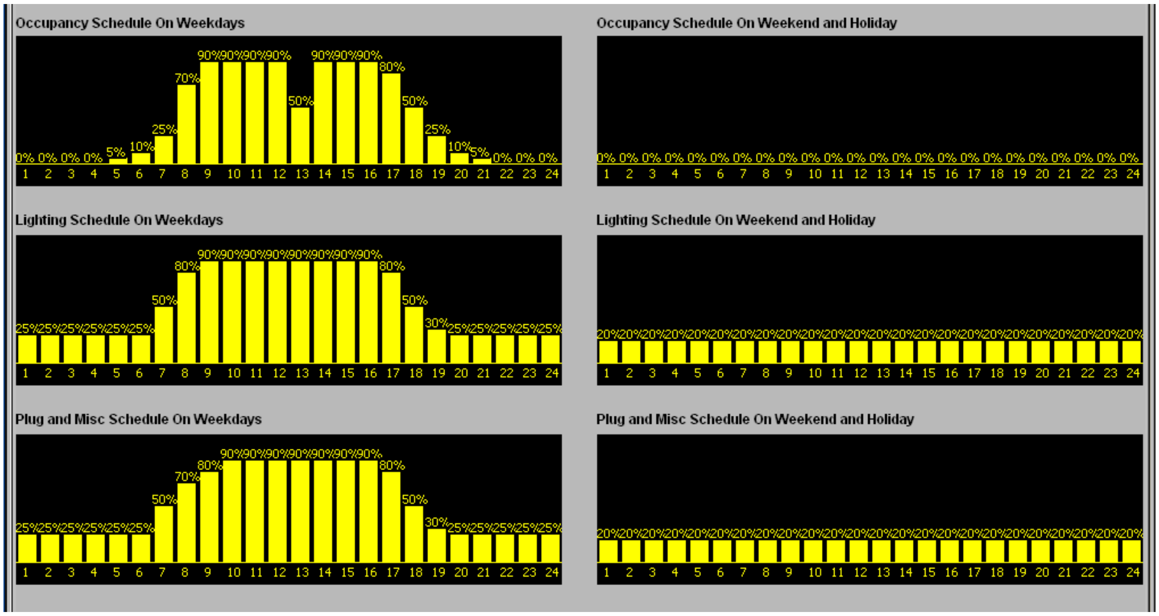
- Updated Pacific Gas and Electric (PG&E) automated demand response (AutoDR) days of all CPP (Critical Peak Pricing) to PDP (Peak Day Pricing) and added text explaining that 10–15 PDP could be called in a PDP "season" (5/1–10/31) and DRQAT selected the 12 hottest days in the TMY3 (Typical Meteorological Year) weather file of the climate zone that corresponded to the building ZIP code and models those as PDP event days.
- Added a "Done" button to the "Utility Inputs" window based on the user's feedback.

2.1.3 Input Baseline Schedule

The operational schedules of building occupant, lighting, and plug loads have significant impacts on the predictions of load shape and DR performance in buildings. The following updates were made in DRQAT V5.0.

- It will automatically set heating, ventilation, and air conditioning (HVAC) operation hours and first hours of chiller setpoint schedules according to building operation hours that the user entered in the basic building information.
- It will change default internal load schedules to those shown in Figure 1, to better represent what has been observed in field studies and other "real" data.

Figure 2: Input of operational schedules of building occupant, lighting and plug loads



2.1.3 DR Control Strategies

Specifying DR control strategies can be very challenging for those with little or no experience with demand response. Building owners and operators may not be clear about which type of zone temperature reset strategy is suitable for their buildings. In DRQAT V5.0, users select pre-programmed pre-cooling strategies based on the previous field tests and DR control strategies guidelines, as shown in Table 2.

Table 2: Pre-programmed DR Strategies for Users' Selection

DR Strategies	Pre-cooling in morning	Zone Temperature Reset during the Peak Hours
PC-0-Step	No	Step temp adjustment
PC-1-Step	Pre-cool by -1°F	Step temp adjustment
PC-2-Step	Pre-cool by -2°F	Step temp adjustment
PC-0-Exp	No	Exponential temp adjustment
PC-1-Exp	Pre-cool by -1°F	Exponential temp adjustment
PC-2-Exp	Pre-cool by -2°F	Exponential temp adjustment

The following equations are used to calculate the step and exponential hourly reset strategies during peak hours.

Exponential: $T_{HOUR} = T_{12} + (T_{19} - T_{12}) \times (1 - e^{(12-HOUR)})$

Where

T_{12} = Temperature setpoint at hour 12

T_{19} = Temperature setpoint at hour 19

$13 <= HOUR <= 18$: This assumes that the DR event period starts at hour 13 (in the DRQAT schedule notation, hour 13 is the period from 12pm to 1 pm), and the building is unoccupied and HVAC shut down at hour 19.

Step: $T_{13-15} = T_{12} + 0.8 \times (T_{19} - T_{12})$

Where

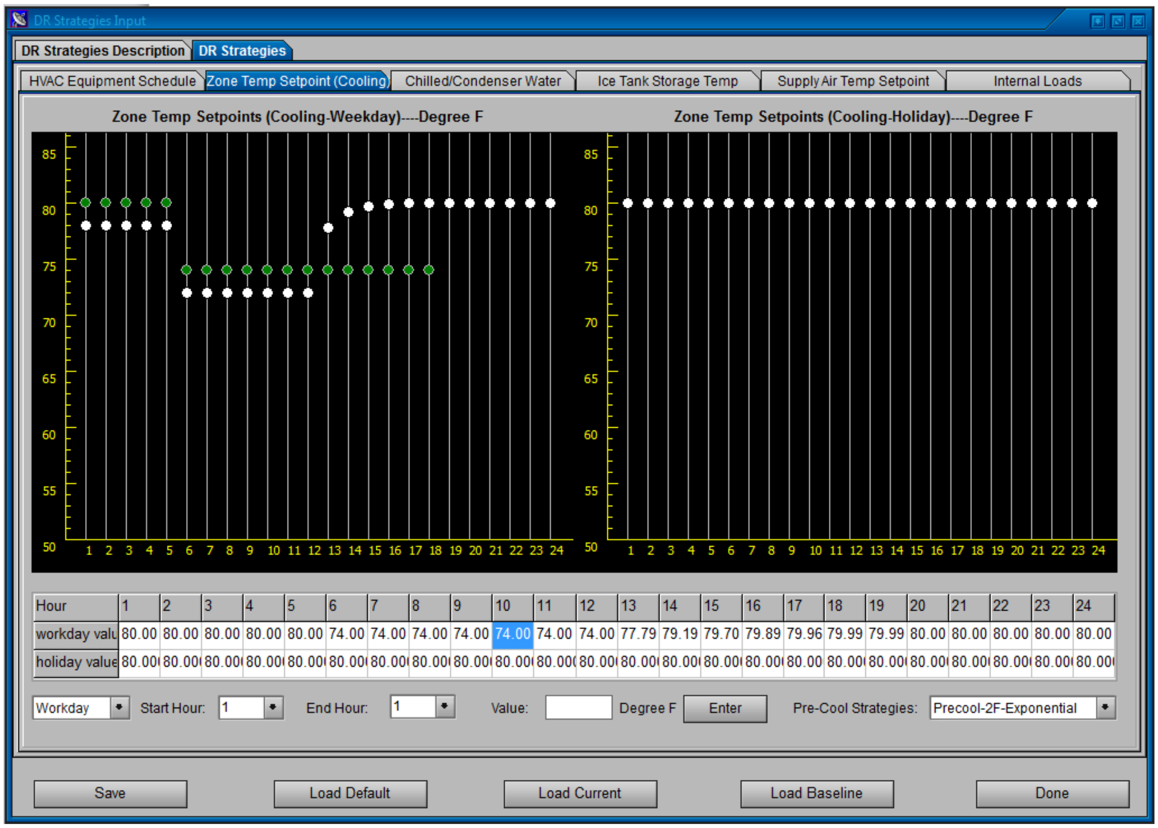
T_{13-15} = Temperature setpoint for hours 13, 14, and 15

T_{12} = Temperature setpoint at hour 12

T_{19} = Temperature setpoint at hour 19

- Added text or pop-up with text to DR strategies window that will explain what demand shifting with pre-cooling is, and that by selecting the "pre-cooling" checkbox DRQAT V5.0 will automatically recommend the combination of pre-cooling setpoint and event-period reset strategy after running several models of different combinations, which may take up to 10 minutes to complete.
- If pre-cooling is a strategy selected by the user (even if combined with other strategies) DRQAT V5.0 will automatically run one baseline model with zone sizing equal to 1.2, medium mass level, and "medium" loads level (1.6 watts per square foot [W/ft2] lighting, 1.0 W/ft2 equipment, and occupancy based on 200 ft2 per person). The medium levels of mass and lighting are referred to the model input of the DOE prototype benchmark model. For an instance, the mass level in a library can be defined as "heavy" mass level in the model.
- DRQAT V5.0 will also automatically run six DR strategy models with the pre-cooling setpoint applied from the hour that the HVAC normally starts according to the baseline schedule, up to and including hour 12. Event period temperature reset will start at hour 13 and end at hour 18 when the setpoint will equal the normal unoccupied setpoint.

Figure 3: DR Strategies Input



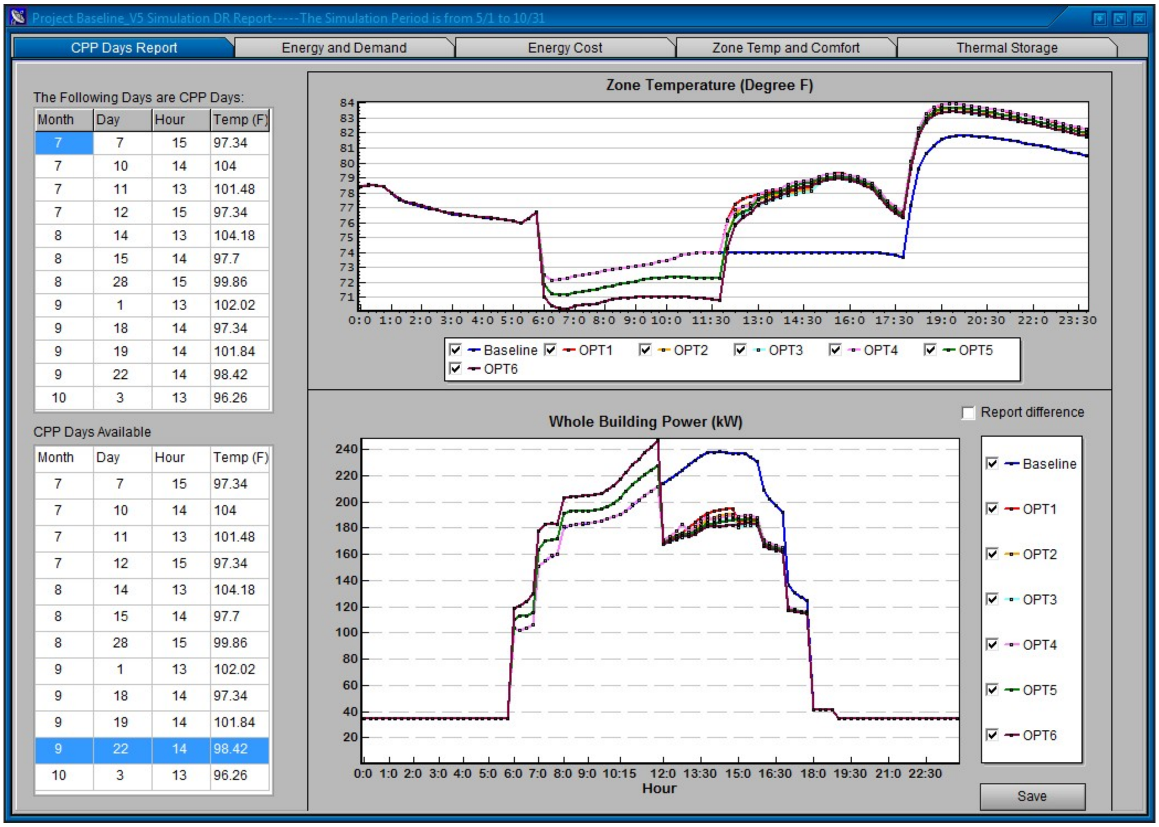
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
workday valu	80.00	80.00	80.00	80.00	80.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	77.79	79.19	79.70	79.89	79.96	79.99	79.99	80.00	80.00	80.00	80.00	80.00
holiday value	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00

Workday Start Hour: 1 End Hour: 1 Value: Degree F Pre-Cool Strategies: Precool-2F-Exponential

2.2 Output Reports

As mentioned above, six different "pre-cooling and zone temperature reset strategies" were added to the new version to enable users to select a control strategy. The new version offers two options: (1) a single run of DR control strategies, and (2) multiple runs of DR control strategies. For the second option, the tool will run all six DR simulations at a time and report all results in a graph, to show different effects of pre-cooling strategies on the demand power, as shown in Figure 4.

Figure 4: Report of Multiple Simulations of DR Control Strategies



The Following Days are CPP Days:

Month	Day	Hour	Temp (F)
7	7	15	97.34
7	10	14	104
7	11	13	101.48
7	12	15	97.34
8	14	13	104.18
8	15	14	97.7
8	28	15	99.86
9	1	13	102.02
9	18	14	97.34
9	19	14	101.84
9	22	14	98.42
10	3	13	96.26

CPP Days Available

Month	Day	Hour	Temp (F)
7	7	15	97.34
7	10	14	104
7	11	13	101.48
7	12	15	97.34
8	14	13	104.18
8	15	14	97.7
8	28	15	99.86
9	1	13	102.02
9	18	14	97.34
9	19	14	101.84
9	22	14	98.42
10	3	13	96.26

2.3 Multiple DR Simulations

In DRQAT V5.0, users can run multiple DR simulations with pre-programmed pre-cooling strategies at one time DRQAT simulation.

2.4 Debugging Test of DRQAT V5.0

As the tool became more complex, a comprehensive debugging test was conducted to validate new features of inputs and outputs. The process was implemented automatically through Python. By comparing all the input files in the folder of “~/DRQAT-V-5-0/Input” inputs from the interface were validated with the EnergyPlus input model (.idf). The debugging test also included a crosscheck of multiple simulation inputs. The input folder that includes all default files was used as the base case. The debugging process is automated by using the Python script. Table 3 presents the list of DRQAT profile entries.

Table 3: Validation of Data Exchange between the Interface and the Model

Inputs	Input files
User input	BuildingType.txt HVAC.txt DI.csv InputSchedule.csv InputSchedulesOriginal.csv InputSchedulesSimulation.csv
Defaults	Climate_Zones_Construction.csv Climate_Zones_Zipcode.csv DiOriginal.csv SI.csv SIOriginal.csv
Not required	Description.txt Pdes.txt Sdes.txt

After the debugging test, notice that three input files (highlighted in Table 3) are not required to be input of the software. Those input files were removed from the new version of the tool, and the validation results show that there are no data exchanged in those files.

For the utility tariff and the cost calculation algorithms, each utility tariff was verified with that of each utility company. However, those tariffs cannot be changed on the interface, so users have to modify the utility tariff data of the input files in "~/DRQAT-V-5-0-0/Utility/". The interface enables users to create custom utility tariff into one default input file.

It was also recommended to use the built-in function of EnergyPlus for calculating daily and monthly energy use, as well as demand and utility cost. Incentives will be calculated using the post-process function after the EnergyPlus simulation.

2.5 Potential Improvements to DRQAT

2.5.1 Web-based Application of DRQAT

Currently DRQAT users must download software and install it on their computers when they initially begin using it. Users must repeat this process each time an update to DRQAT becomes available. This is inconvenient for users and slows the rate of improving and updating DRQAT. An alternative approach is to create a web-based application of DRQAT that users could run via a website without having to download and install software directly to their own computers. Advantages and disadvantages of this approach are discussed below.

Advantages

- **Easy to access**: An advantage of any web-based application is ease of use. One can access the many time from any computer.
- **No installation and maintenance**: Since the web applications run on a web server, users do not have to install the application, eliminating the time and trouble required to install the software. At the same, since web servers are used, maintenance and troubleshooting are minimized.
- **Multiple platforms**: The beauty of a web application is that it works on multiple platforms, and applications can work on different internet browsers (e.g., Internet Explorer, Mozilla Firefox).
- **Version update**: Users do not have to download and install a new software package each time there is a software update. The server-based application is always up to date.

Disadvantages

There are certain disadvantages to web-based applications.

- **Web development**: Developing a web-based application often takes more time, as compared to the desktop software development. Ensuring that it is compatible with a variety of browsers can take considerable development time.
- **Web application connectivity**: Slow Internet connectivity can slow tool performance.
- **Simulation speed**: Multiple users can slow the tool's performance for each user.
- **Security**: Security measures must be implemented to protect the tool and user privacy.

2.5.1 Web-based Application of DRQAT

Currently DRQAT uses a prototype model and user inputs of general building characteristics to create a model that approximately represents the user's building. It is exactly this approach that puts the "Q" (quick) in DRQAT. Creating highly representative building energy models cannot be considered a quick process, but the additional time spent usually results in more accurate models. Maintaining the speed of DRQAT while improving its accuracy could be accomplished by automatically calibrating the modified prototype models with a user's actual building energy consumption or utility bill data. The least obtrusive way to incorporate this feature would be to automate an upload of a user's data directly from their utility interval meter data, but manual uploads could also be used.

2.5.2 Model Calibration with User's Utility Interval Meter Data

Currently DRQAT uses a prototype model and user inputs of general building characteristics to create a model that approximately represents the user's building. It is exactly this approach that puts the "Q" (quick) in DRQAT. Creating highly representative building energy models cannot be considered a quick process, but the additional time spent usually results in more accurate models. Maintaining the speed of DRQAT while improving its accuracy could be accomplished by automatically calibrating the modified prototype models with a user’s actual building energy consumption or utility bill data. The least obtrusive way to incorporate this feature would be to automate an upload of a user’s data directly from their utility interval meter data, but manual uploads could also be used.

2.5.2 Improved User Output Interface and Reports

DRQAT outputs present useful graphical interfaces that provide a quick assessment of the kilowatt shed and utility bill savings for a DR strategy configuration. Users could benefit from more comprehensive tabular and graphical outputs in the spreadsheet export formats. Users also could benefit from summaries of key metrics, such as maximum and average kilowatt shed over peak periods that are applicable to various utility DR programs, along with similar metrics that characterize any kilowatt increases during pre-cool periods, rebound during post-event periods, and occupant comfort.

CHAPTER 3:
Validation Report of DRQAT

3.1 Introduction

As described above, DRQAT is based on the EnergyPlus simulation engine, and the tool requires a relatively small number of parameters as inputs for a building energy simulation model with a focus on quick assessment of demand response strategies. The model creation process and DR analysis in DRQAT is very fast and cost effective. However, the challenge is how to build a valid and credible simulation model in DRQAT. If the model does not accurately represent the actual building, the DR analysis results derived from the tool could lead to incorrect DR strategy decisions.

Building simulation models are used in the design phase, to help achieve code compliance certification, evaluate different design alternatives, and help make decisions in terms of building energy and comfort performance. Empirical validation methods have traditionally been used to evaluate the accuracy of models for simulating the energy intensity of existing buildings, to identify model uncertainties, and to calibrate input variables by comparing them to measured values. Empirical validation has been demonstrated in many field studies (Pan et al., 2008; Yin et al., 2010b; Raftery et al., 2011; Yin et al., 2012; Wang et al., 2013; O'Neill and Eisenhower, 2013).

DRQAT is not necessary intended to predict actual building energy use, but rather to help users compare various DR strategies. However, when building energy simulation moves from the design phase to the operation phase, especially for DR analysis, uncertainties in simulation models can be significant. The predictive performance of DRQAT can be improved significantly by calibrating the model with the measured data (Yin et al., 2010a). The question is: For experienced users of model calibration, can DRQAT provide accurate simulation results with high predictive value of DR analysis?

We used seven buildings as case studies to evaluate the performance of DRQAT by comparing results between the model predictions and field measurements in buildings. We compared the model predictions with the measurements, using the following metrics: peak demand (kW), load shape and absolute demand savings (kW), and relative demand savings (%).

3.2 Building Examples

We present and discuss results from two office buildings to demonstrate the application of DRQAT V5.0 in the DR field test (Figure 5).

The first test site, designated as Building 685, is a two-story, 68,955-square-foot typical office building in San Bernardino, California. As shown in Figure 5A, the building is a medium-mass L-shaped building with most floors carpeted. The window-to-wall ratio on the each side is about 50 percent. There are two 50-ton air-handling rooftop units and another two 55-ton air-handling rooftop units that chill water to condition outside air and provide air circulation throughout the entire facility. All are single-duct variable air volume (VAV) air-handling units. The building operates as a typical office building, with occupant, lighting, and plug loads. The HVAC system starts at 5am and turns off at 6pm.

The second test site, designated as Building 560, is a four-story, 68,955-square-foot typical office building, also in San Bernardino (Figure 5B). It is a medium-mass rectangular building with most floors carpeted. The building has single-pane low-emissivity windows with a window-to-wall ratio of 60 percent at each side. There are four 55-ton air-handling rooftop units, with a single-duct VAV system in the building. The HVAC system has the same operational schedule as Building 685.

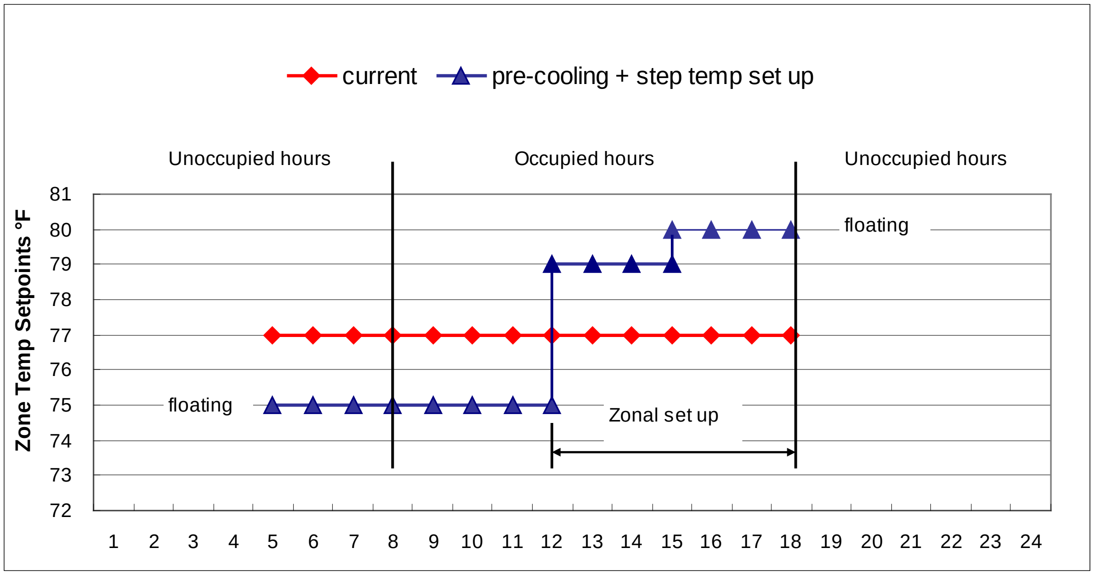
Figure 5: Building 685 (A) and Building 560 (B)

(A) (B)

3.2 Tested DR Control Strategies and Baselines

During summer 2008, Global Energy Partners (GEP) implemented "pre-cooling with step temperature set up" strategies at the field sites, and conducted Auto-DR tests on the 12 DR events from July through September. Figure 6 shows the pre-cooling strategy used on the Auto-DR event days for the buildings.

Figure 6: Pre-cooling strategy used on the Auto-DR event days



As discussed in the Auto-DR field test report (Yin et al., 2008), baseline days for each test day were selected based on the similarity in peak outside air temperatures and outside air temperatures profiles. DR simulations in DRQAT do not have the problem of the baseline since the DR simulation models have the exactly same input parameters as the baseline models, except the input parameters of DR control strategies. It is one of the biggest advantages for the building energy simulations compared to the field test in actual buildings.

3.4 Validation Results

The primary hours of interest for evaluating the model's performance were the DR event peak period hours (12 pm~6 pm). Second, pre-cooling may set a new daily peak in the morning period if the load profile is flat during the day, which can be observed both in the simulation and measurement. Last, as the model was not calibrated from tool users' perspective, we were much more concerned about the model's performance during the occupied period, rather than unoccupied period after 6pm.

3.4.1 Results of Building 685

For Building 685, DR test events were conducted on 11 hot days in the summer of 2008. The peak outside air temperature (OAT) were over 90°F.

3.4.1.1 DRQAT baseline and event day compared to the actual baseline and event day

Comparisons of measured and DRQAT predicted for two different temperatures are shown in Figure 7 and Figure 8. The simulation model was developed using DRQATV5.0 with the available building information inputs. The peak demand and load shape of the uncalibrated model agreed with the actual building power, except for the underestimated demand in unoccupied hours. The predicted peak demand from uncalibrated models agreed with the measured data within ±20 percent. However, the uncalibrated model cannot follow the measured load shape in the late afternoon hours due to the operational behavior of the building's occupants and each end use in the building.

Figure 7: Comparison of Whole Building Power between DRQAT Predictions and Measurements for Building 685 (Peak OAT: 98°F)

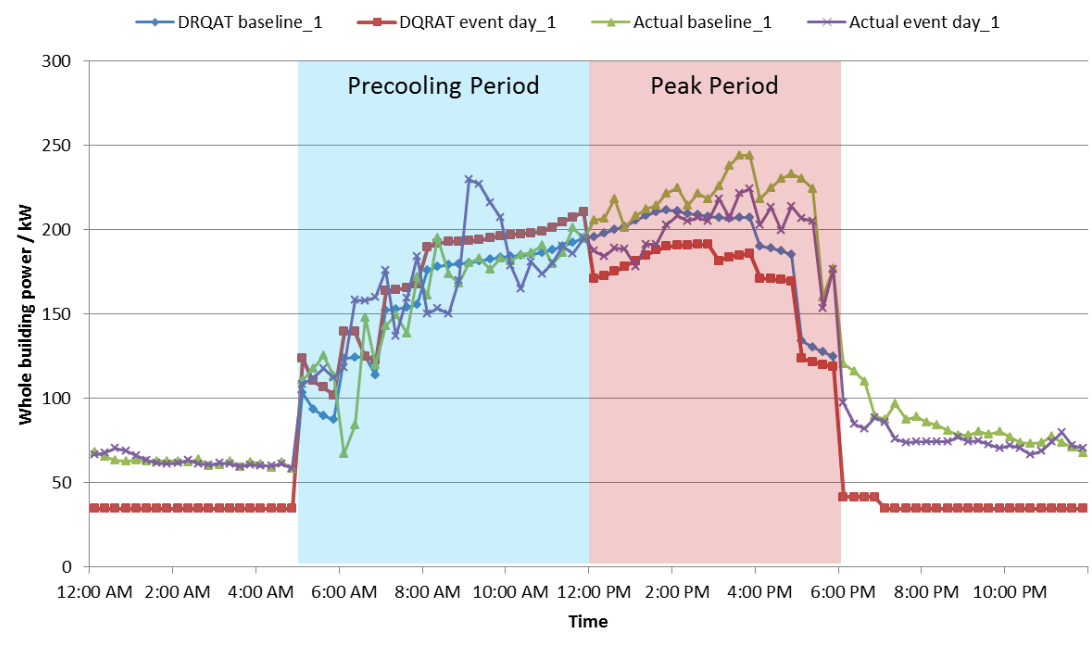
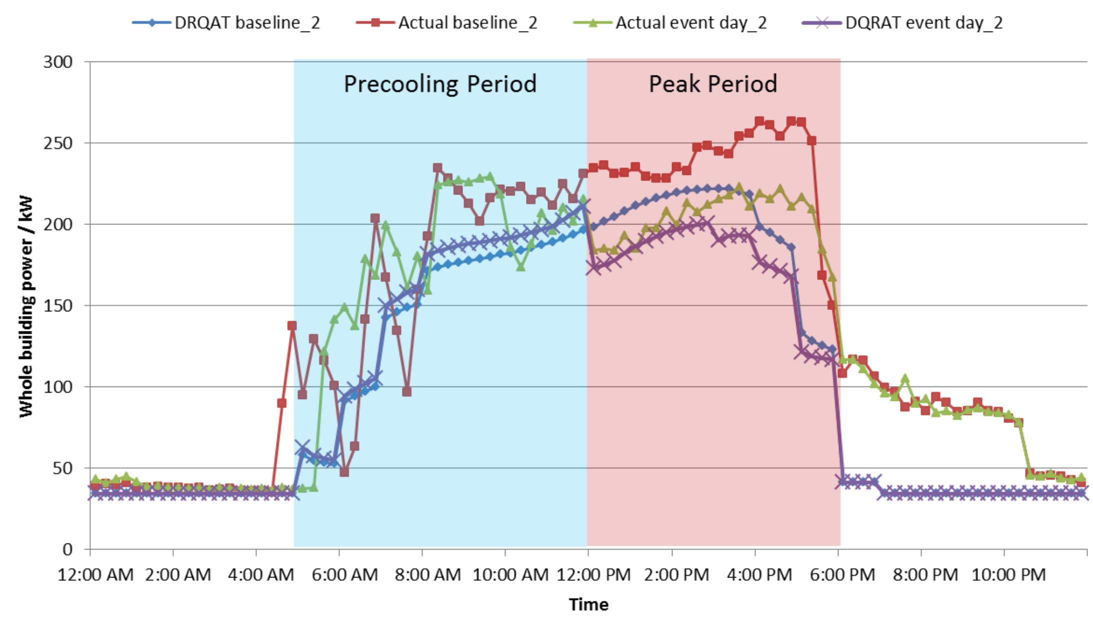


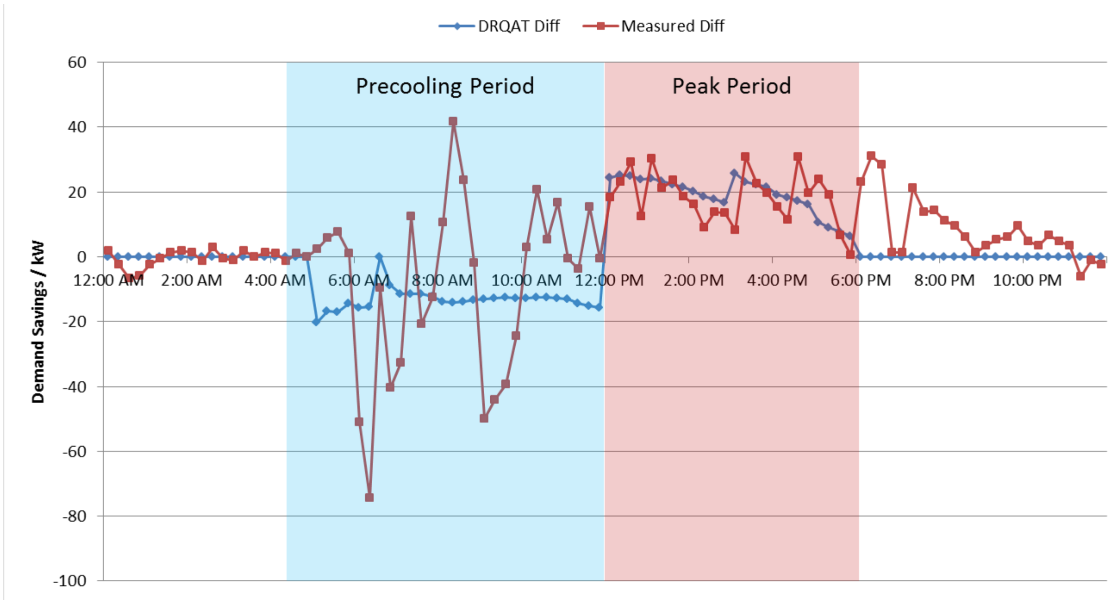
Figure 8: Comparison of Whole Building Power between DRQAT Predictions and Measurements for Building 685 (Peak OAT: 99°F)



3.4.1.2 Demand savings comparisons between DRQAT predictions and measured data

Figure 9 shows the comparison of demand savings between the DRQAT predictions and the actual measurements on a DR event day in Building 685. Note that morning pre-cooling in the actual building started from 6am, which was one hour later than the regular HVAC system start time. The change of demand power due to the pre-cooling fluctuates over the whole morning pre-cooling period, while the DRQAT predictions show a constant load increase.

Figure 9: Comparison of Demand Savings between DRQAT and Measured on DR Event Day 1



During the peak period from 12pm to 6pm, it can be seen that the DRQAT prediction of demand savings is close to the measured demand savings, especially in terms of average demand savings. All the metrics during the peak period agree well. Especially for the peak demand savings, the DRQAT tool shows a prediction value of 20.6 kW, which is close to that of the measured demand reduction. Both the DRQAT predictions and measurements show an average demand savings of 10 percent. In absolute terms, the DRQAT prediction gives a peak demand savings of 25.9 kW, which is 15% less than the measurement.

Table 4: Difference of Demand power between the baseline and DR Event for DRQAT Predictions and Measurements

Metrics	Morning Pre-cool Period				Peak Period			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-20.3	-20	-74.4	-89	25.9	13	30.7	15
Avg Diff (kW)	-13.2	-9	-8.6	-9	19.2	10	18.3	8
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**20.6**	**10%**	**19.7**	**8%**

Note:

1. *Max Diff = maximum of difference between DR and Baseline for each 15-minute time step.*
2. *Peak Demand = Maximum DR demand – Max Baseline demand over the period.*

Figure 10 shows another comparison of demand savings between the DRQAT predictions and the measurement on DR event Day 2 in Building 685. It shows the similar comparison results during the morning pre-cooling period and that the DQRAT gives a good prediction of average demand increase. Note that DRQAT predicts demand savings in the peak period better when comparing them with the predictions on DR event Day 1.

Figure 10: Comparison of Demand Savings between DRQAT and Measured on DR Event Day 2

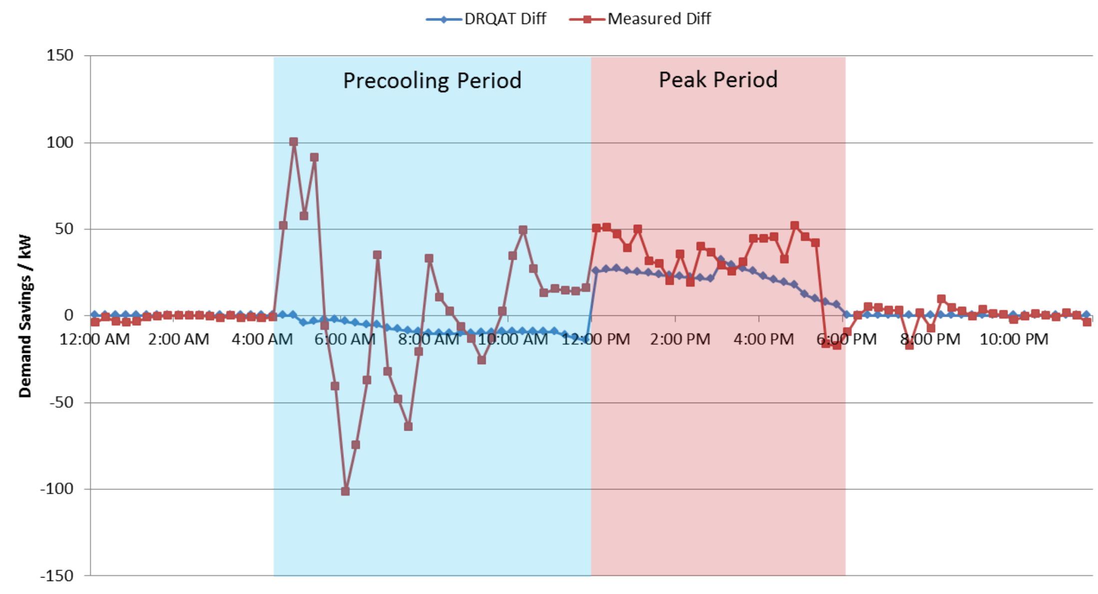


Table 5: Difference of Demand power between the baseline and DR Event for DRQAT Predictions and Measurements

Metrics	Morning Pre-cool Period				Peak Period			
	DRQAT DR vs. Baseline		Measured DR vs. Baseline		DRQAT DR vs. Baseline		Measured DR vs. Baseline	
	(kW)	(%)	(kW)	(%)	(kW)	(%)	(kW)	(%)
Max Diff (kW)	-14.4	-7	-101.3	-213	31.8	14	51.8	22
Ave Diff (kW)	-8.2	-6	-2.4	-11	21.5	11	33.7	13
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**20.9**	**9%**	**40.3**	**15%**

3.4.2 Results of Building 560

3.4.2.1 DRQAT baseline, DRQAT event day, actual baseline and actual event day

As shown in Figure 11 and Figure 12, it can be clearly seen that the DRQAT predictions agree well with those of the measured peak demand and load shape.

Figure 11: Comparison of Whole Building Power between DRQAT Predictions and Measurements for Building 560 (Peak OAT: 98°F)

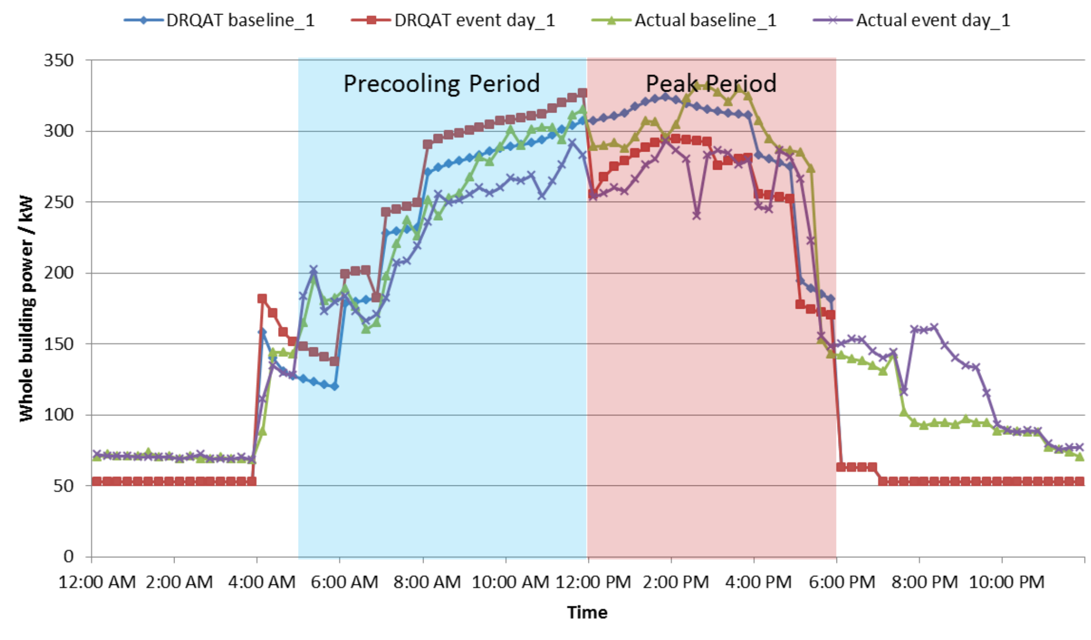
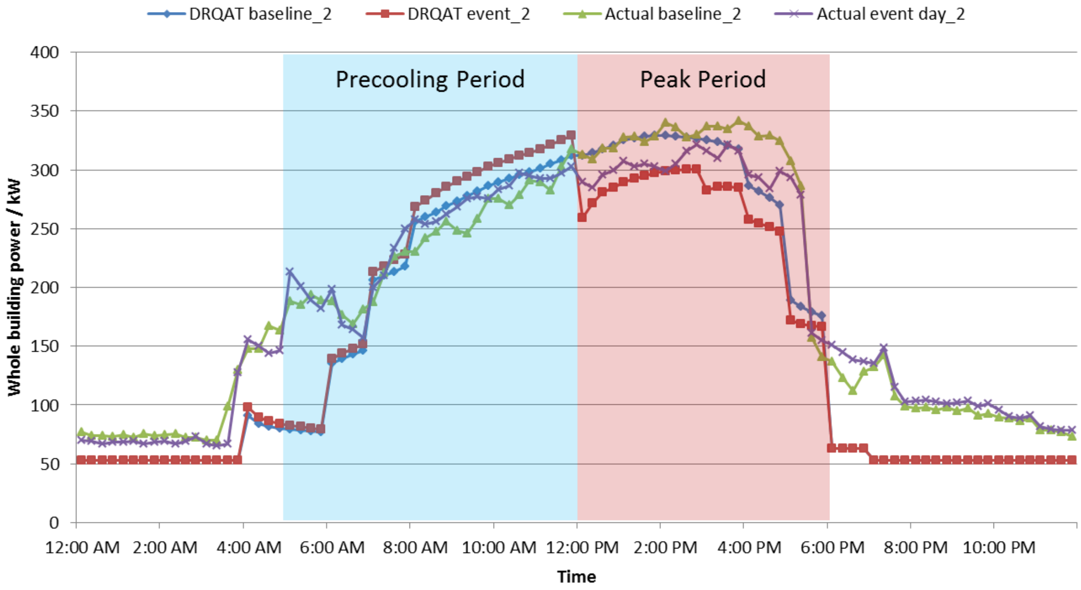


Figure 12: Comparison of Whole Building Power between DRQAT Predictions and Measurements for Building 560 (Peak OAT: 99°F)



3.4.2.2 Demand saving comparison between DRQAT and measurements

Figure 13 and Figure 14 shows the comparison of demand savings between the DRQAT predictions and the measurements on two DR event days. On the DR event Day1, the strategy of pre-cooling in the early morning did not increase the demand power of the HVAC system as expected. This could be due to an inaccurate baseline model for this DR event day. On DR event Day2, it can be clearly seen that the pattern and the amplitude of the predicted demand savings matches the measurements.

Figure 13: Comparison of Demand Savings between DRQAT and Measured on DR Event Day 1

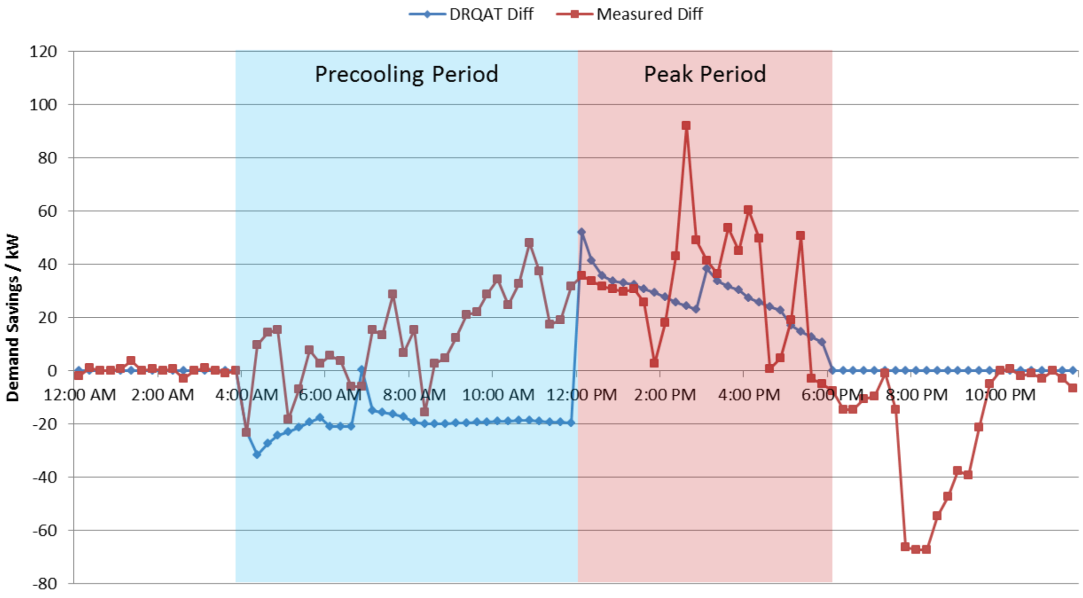


Table 6 and Table 7 present the results of different metrics for comparing the DRQAT predictions and the measurements. In absolute terms, the DRQAT prediction gives a peak demand savings of 29.4 kW, which is 10 kW less than the measurement. However, the DRQAT predictions and the measurements show 9 percent and 12 percent of relative peak demand savings, respectively.

Table 6: Difference of Demand power between the baseline and DR Event for DRQAT Predictions and Measurements

Metrics	Morning Pre-cool Period				Peak Period			
	DRQAT DR vs. Baseline		Measured DR vs. Baseline		DRQAT DR vs. Baseline		Measured DR vs. Baseline	
	(kW)	(%)	(kW)	(%)	(kW)	(%)	(kW)	(%)
Max Diff (kW)	-22.9	-18	-18.3	-11	52.0	17	92.2	28
Ave Diff (kW)	-18.4	-8	13.8	5	28.3	10	32.4	10
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**29.4**	**9%**	**39.4**	**12%**

Figure 14: Comparison of Demand Savings between DRQAT and Measurements on DR Event Day 2

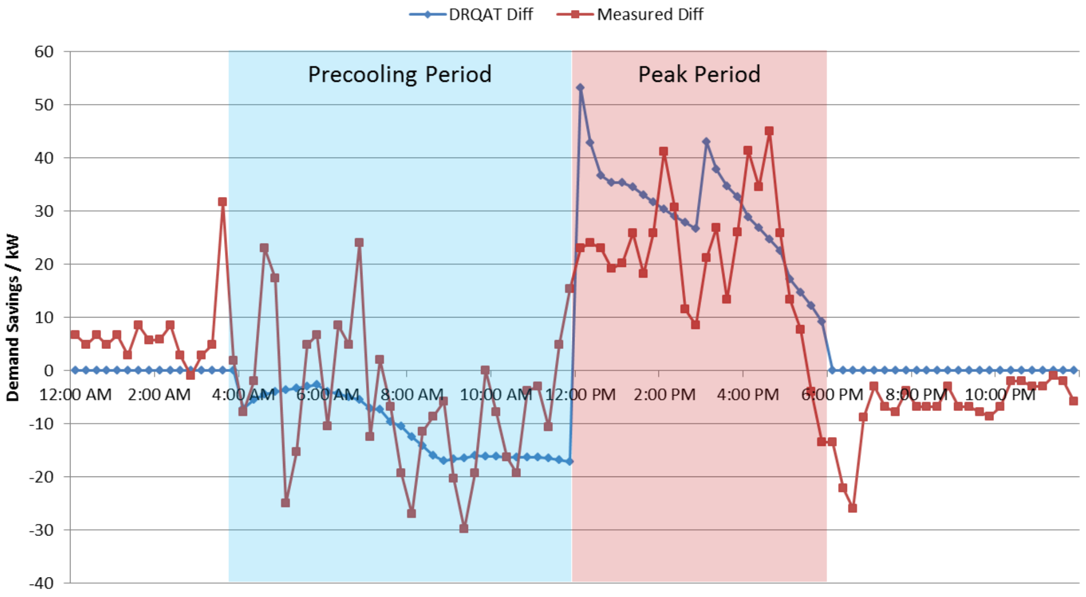


Table 7: Difference of Demand power between the baseline and DR Event for DRQAT Predictions and Measurements

Metrics	Morning Pre-cool Period				Peak Period			
	DRQAT DR vs. Baseline		Measured DR vs. Baseline		DRQAT DR vs. Baseline		Measured DR vs. Baseline	
	(kW)	(%)	(kW)	(%)	(kW)	(%)	(kW)	(%)
Max Diff (kW)	-17.2	-6	-29.7	-13	53.2	17	45.1	14
Ave Diff (kW)	-11.5	-5	-7.2	-3	30.1	10	21.2	6
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**29.2**	**9%**	**20.2**	**6%**

3.4.3 Summary of Results

Figure 15 and Figure 16 show the predictions of peak demand savings (kW) and average demand savings (%), respectively, throughout the peak hours in Building 685.Note that the average outside air temperature of the 12 hottest days in typical meteorological year (TMY) weather data is higher than that of the field test DR event days by 5°F. For DRQAT users, the actual weather data are not easy to achieve, and the process of the weather data conversion requires more advanced experience of building energy simulation. From this point of view, we compared the DRQAT predictions with the TMY weather and the measurements with the actual weather data to validate whether DRQAT can provide reasonable predictions under normal use.

For 4 of 11 DR event days, the field test results did not show much demand savings during the peak hours. There are several reasons for that, including (1) building operational behavior, (2) selection of baseline days, and (3) DR control strategies did not perform as proposed. For all other days, the peak demand savings ranged from 10kW to 30kW, with an average value of 20 kW. For the DRQAT predictions, the peak demand savings range from 20 kW to 28 kW, with an average value of 22 kW.

In terms of the average demand savings, the DRQAT predictions showed a constant value of 10~11 percent for all DR event days, which are slightly higher than those of the measured demand savings by nearly 2 percent.

Figure 15: Comparison of Peak Demand Savings between the DRQAT Predictions and the Measured in Building 685

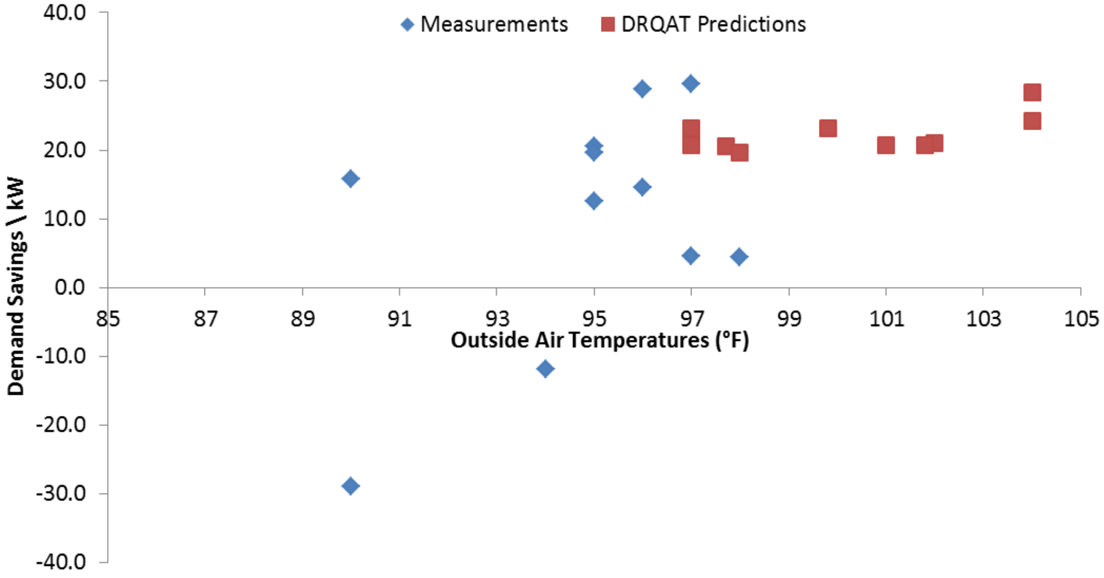


Figure 16: Comparison of Average Demand Savings between the DRQAT Predictions and the Measured in Building 685

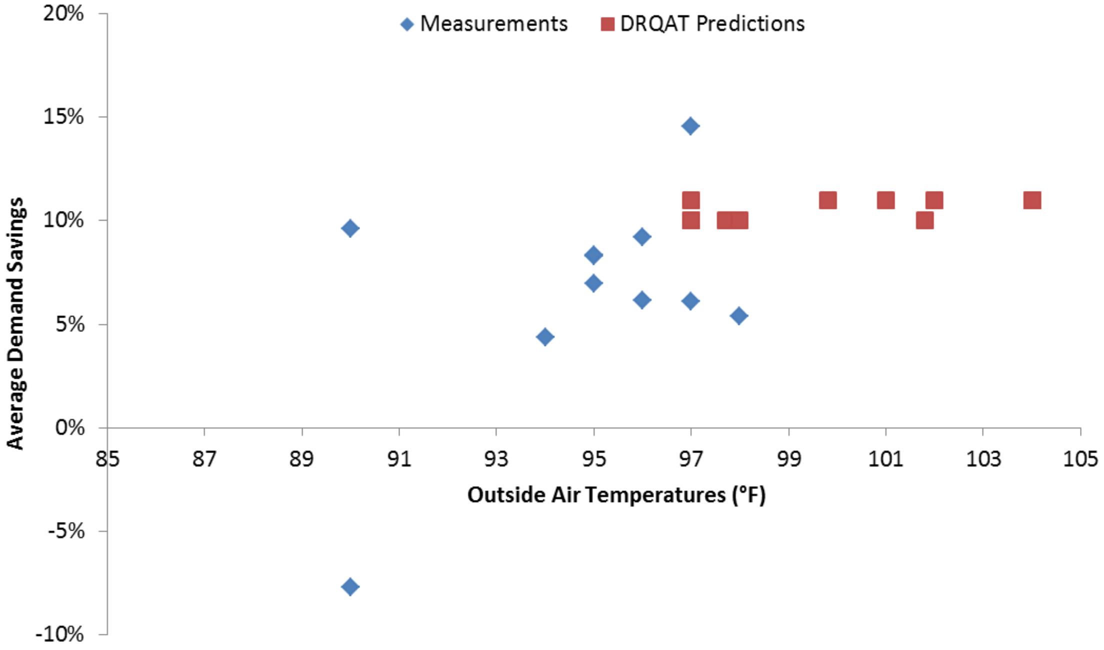


Figure 17 and Figure 18 show the peak demand savings (kW) and average demand savings (%), respectively, of Building 560. Note that this building has DRQAT predictions of demand savings (%) similar to those of Building 685 because the required building and system parameters are very close for those two building models in DRQAT. As shown in Figure 18, the measured demand savings are below the predicted values for most DR event days. The predicted demand savings are consistently around 10 percent, while the measured values range from 1 to 10 percent, except for the negative savings on one actual DR event day.

Figure 17: Comparison of Peak Demand Savings between the DRQAT Predictions and the Measured in Building 560

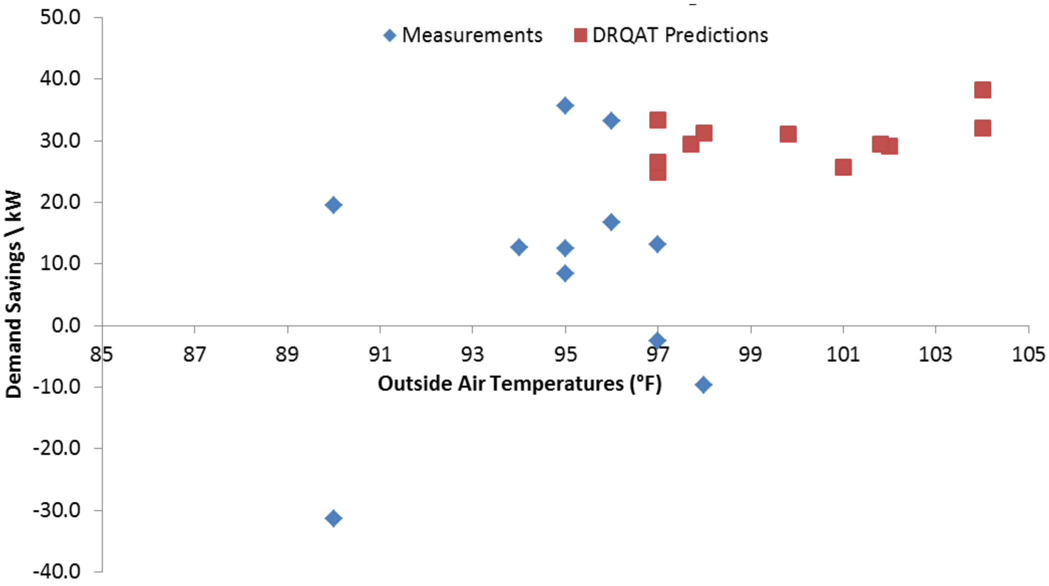
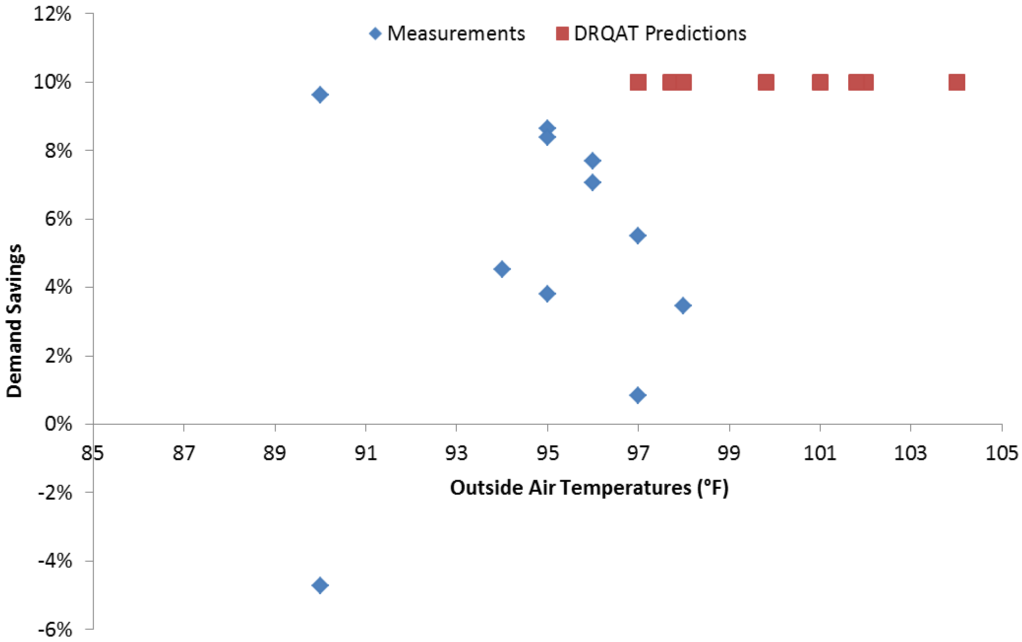


Figure 18: Comparison of Average Demand Savings between the DRQAT Predictions and the Measured in Building 560



CHAPTER 4:
Summary and Conclusions

This report describes the new features of DRQAT V5.0, including the key updates of building information inputs and multiple DR simulations. Those features enable users to conduct more efficient DR simulation with DRQAT V5.0 and to perform DR analysis with more variety. With a focus on the tool validation using several case studies, the studies in the rest of the report show the results of comparisons between the measured DR impacts and the DRQAT predicted values. The following metrics are presented to quantify the DR impacts on whole-building power: peak demand (kW), load shape and absolute demand savings (kW), and relative demand savings (%).

- Peak demand savings during the peak period. The DRQAT predictions show consistent peak demand savings on the 12 hottest days in summer, because the embedded EnergyPlus models have no variability with the building and system operational behavior between the baseline model and DR model. On the other hand, the building HVAC system capacity is well-sized in the simulation model. Overall, the DRQAT predictions assume the ideal operational conditions for the building and relevant mechanical systems. For the first case study building, the DRQAT predictions show a constant average demand savings of 10~11 percent for all DR event days, which are slightly higher than those of the measured values by nearly 2 percent. As for the absolute demand savings (kW), the predicted values are very close to the average value of the measured peak demand savings (kW), while the measured values fluctuated over the actual DR events.
- Load shape throughout the DR event day. Given the similar office building characteristics, for most of case study buildings, the predicted load shape in the peak period can match the measured whole-building demand power throughout the DR event day, even the case study models are not calibrated. However, there are still many uncertainties that are hard to capture in the DRQAT model. As a result, the predicted peak demand and load shape can be widely different from the measured value. However, by taking the demand changes as a metric, it can avoid uncertainties from the building operational behavior, space loads such as lighting and plug load. The results show that the pattern of demand changes over time is pretty close between the DRQAT predictions and the measured data.
- Demand savings vs. outside air temperature. The DRQAT predictions indicate that the absolute demand savings (kW) increase slightly with the peak outside air temperatures—a result that can also be found in a previous study (Yin., et al., 2010). In comparison to the measured value, note that the average outside air temperature of the 12 hottest days in TMY weather data is higher than that of the field test DR event days, and the predicted demand savings are slightly higher, but the average demand savings are very close.

GLOSSARY

Term	Definition
AutoDR	Automated Demand Response
DR	Demand Response
DRQAT	Demand Response Quick Assessment Tool
DRRC	Demand Response Research Center
GEP	Global Energy Partners
HVAC	Heating, Ventilation and Air-Conditioning
LBNL	Lawrence Berkeley National Laboratory
OAT	Outside Air Temperature
PG&E	Pacific Gas and Electric
TES	Thermal Energy Storage
TMY	Typical Meteorological Year

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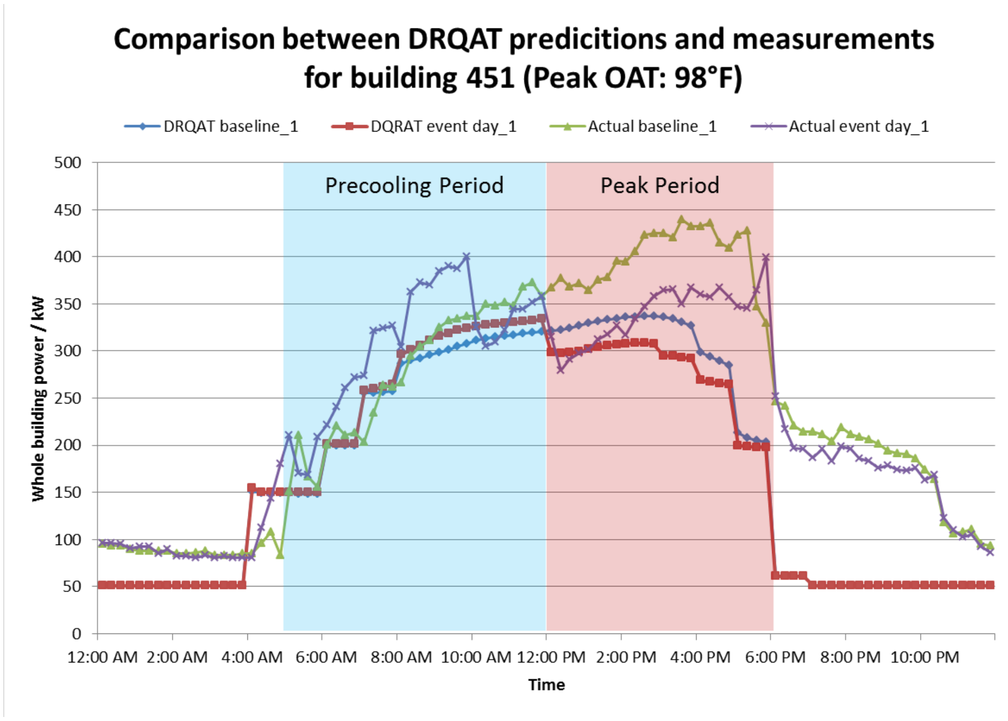
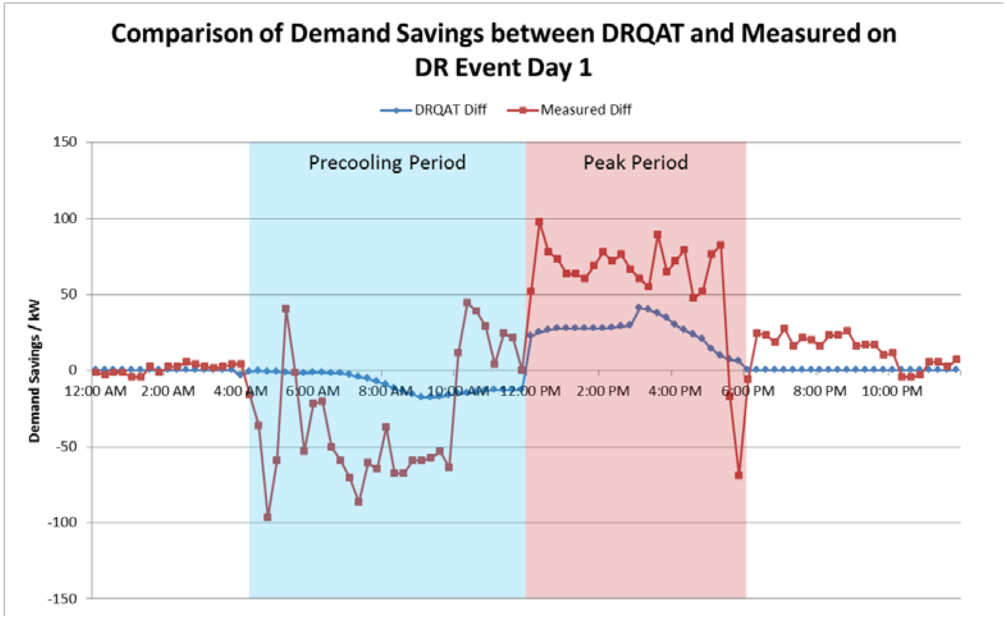
APPENDIX A:
Results of All Seven Buildings

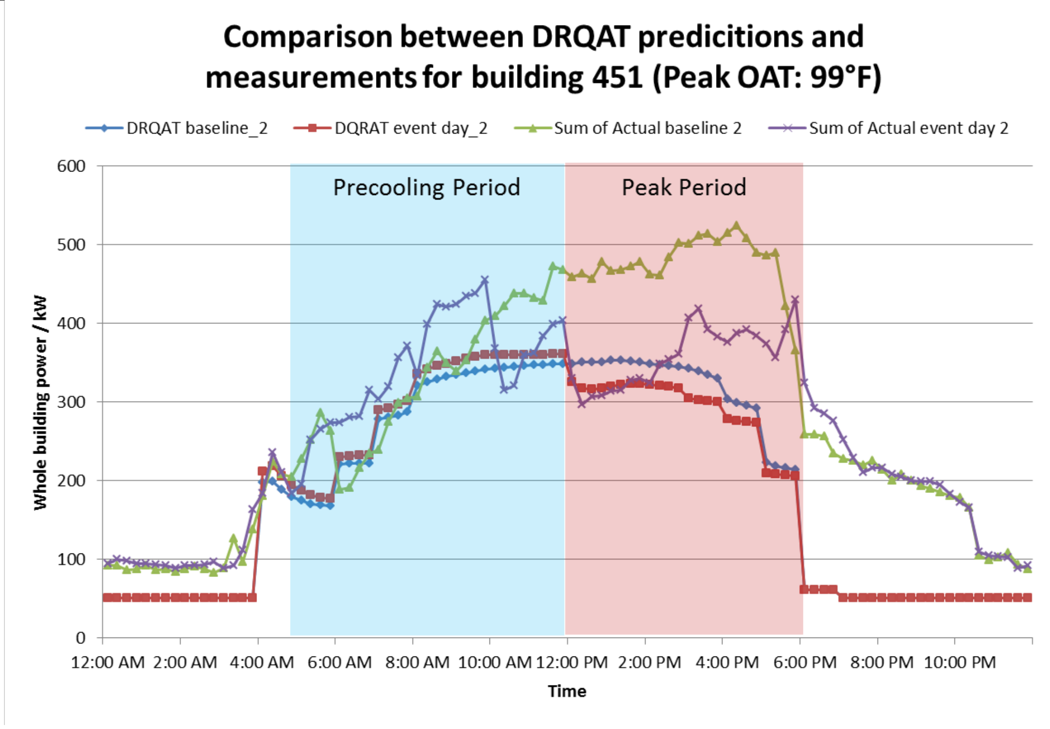
The figures in the appendix include data from all seven buildings in the case study.

Building 451

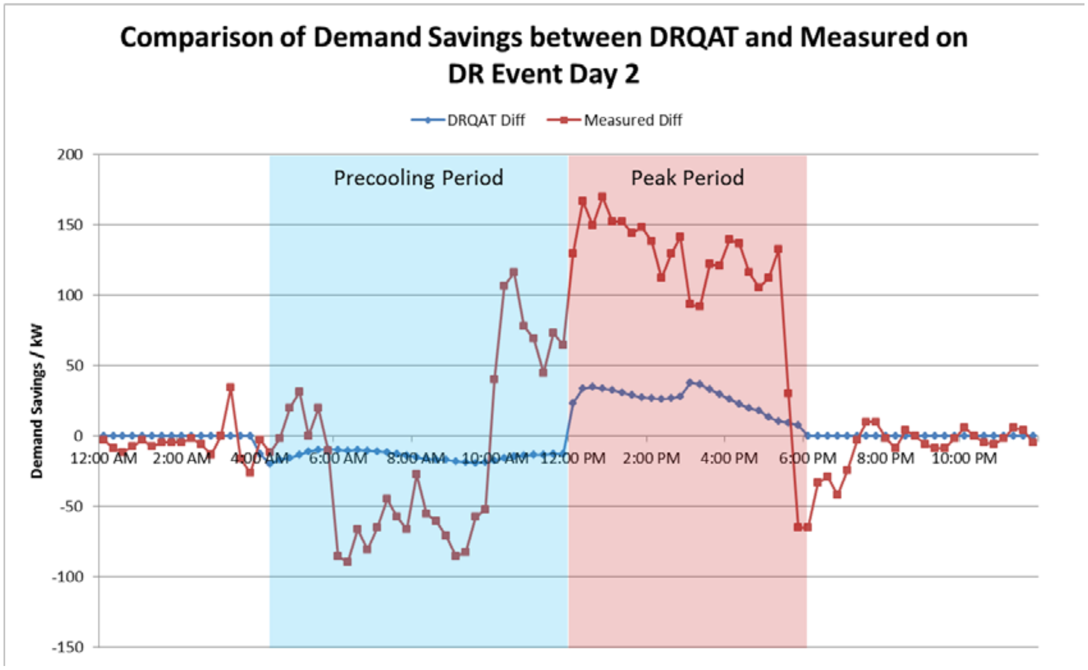




	Morning Pre-cool Period				Peak Period			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-17.7	-6	-86.4	-39	40.7	12	97.9	26
Ave Diff (kW)	-9.3	-3	-28.5	-12	25.7	8	60.1	15
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**28.6**	**8%**	**40.3**	**9%**

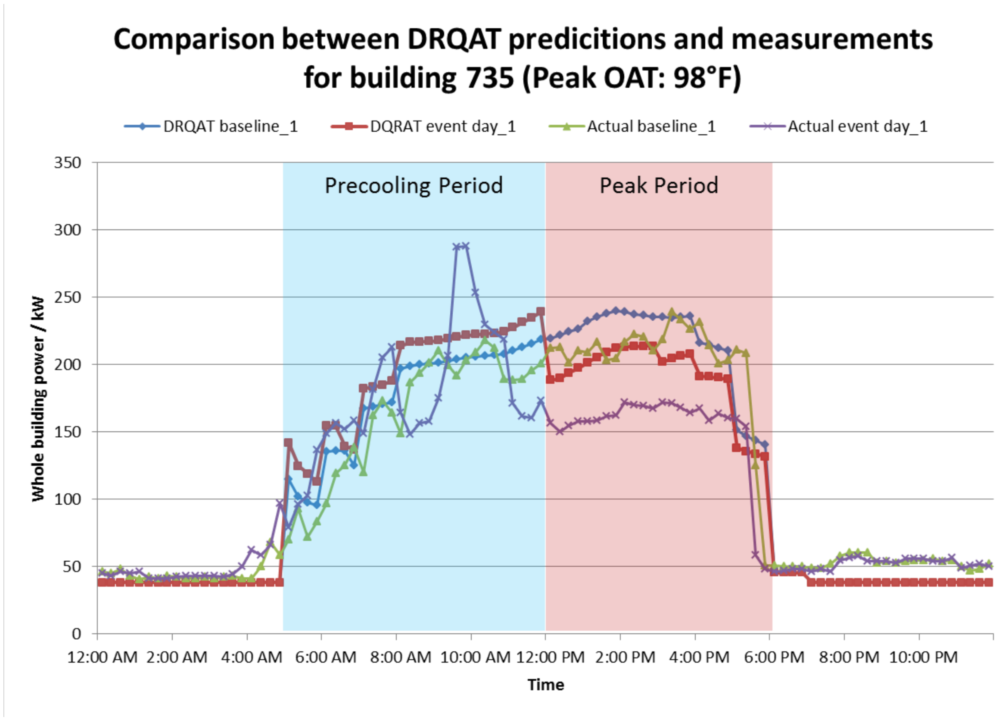


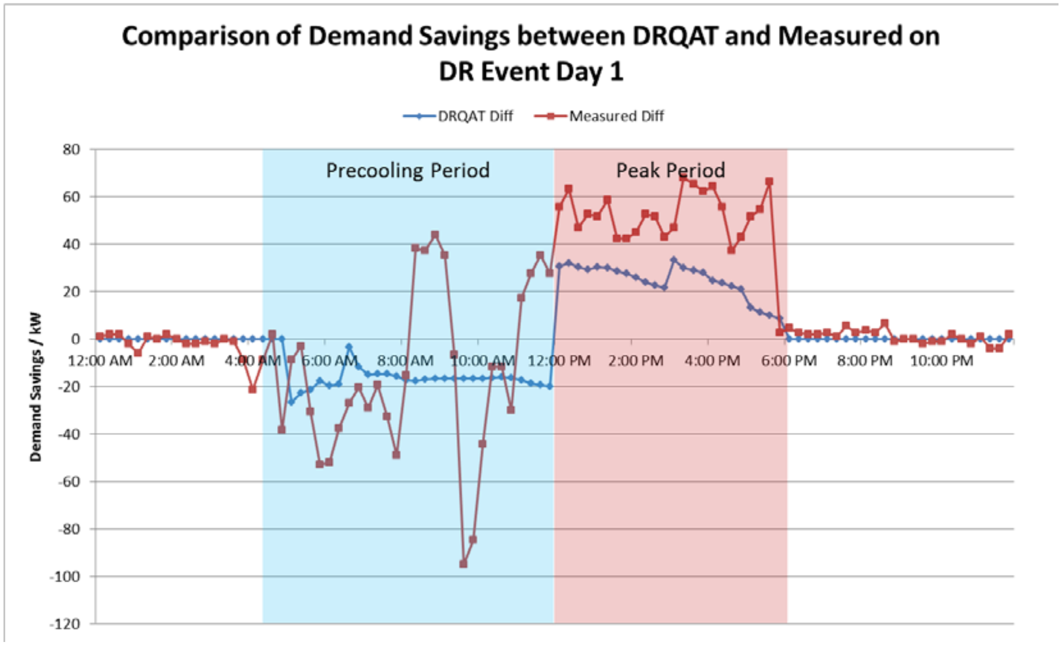
Comparison between DRQAT predicitions and measurements for building 451 (Peak OAT: 99°F)



	Morning Pre-cool Period				**Peak Period**			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-19.1	-8	-89.3	-47	37.8	11	169.9	36
Ave Diff (kW)	-13.7	-5	-14.6	-8	25.8	8	119.7	25
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**27.6**	**8%**	**93.6**	**18%**

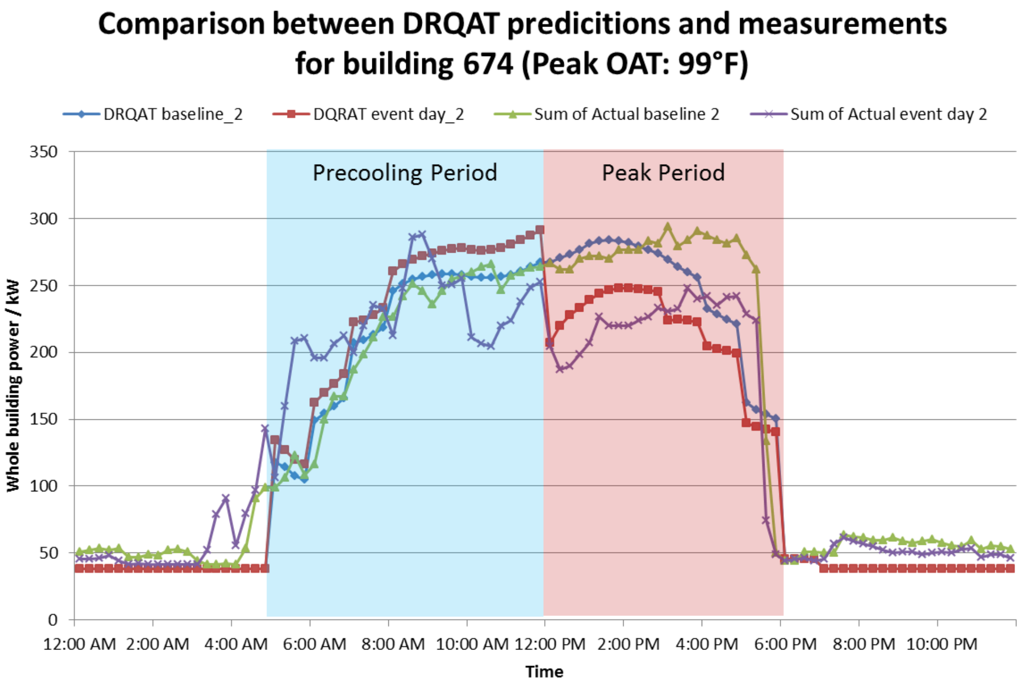
Building 735

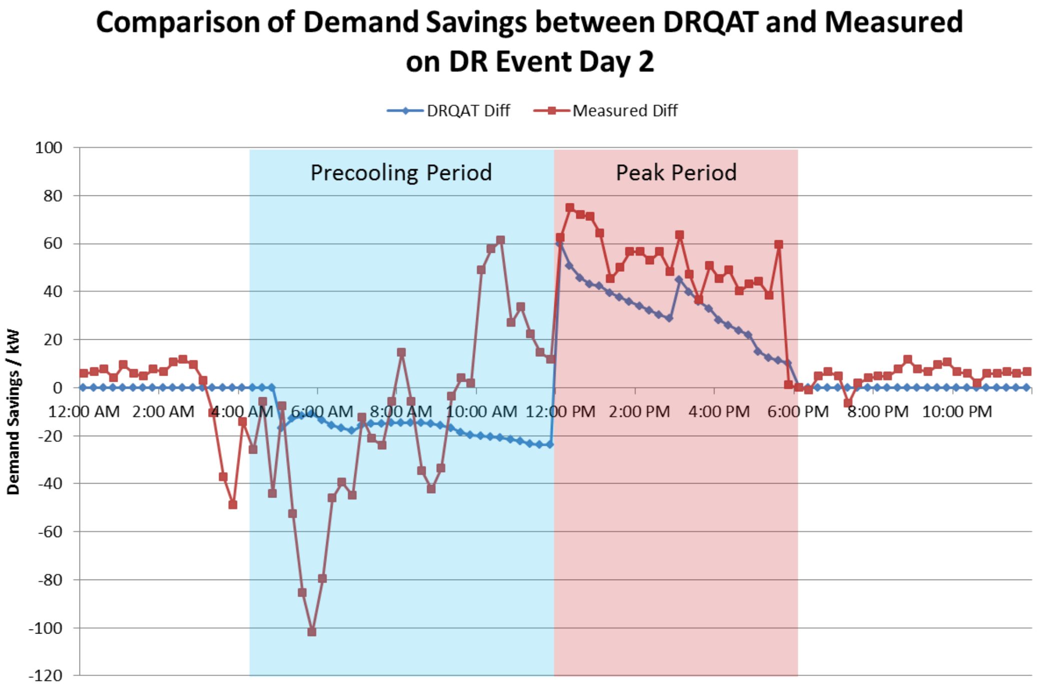




	Morning Pre-cool Period		Peak Period	
	DRQAT DR vs. Baseline	Measured DR vs. Baseline	DRQAT DR vs. Baseline	Measured DR vs. Baseline

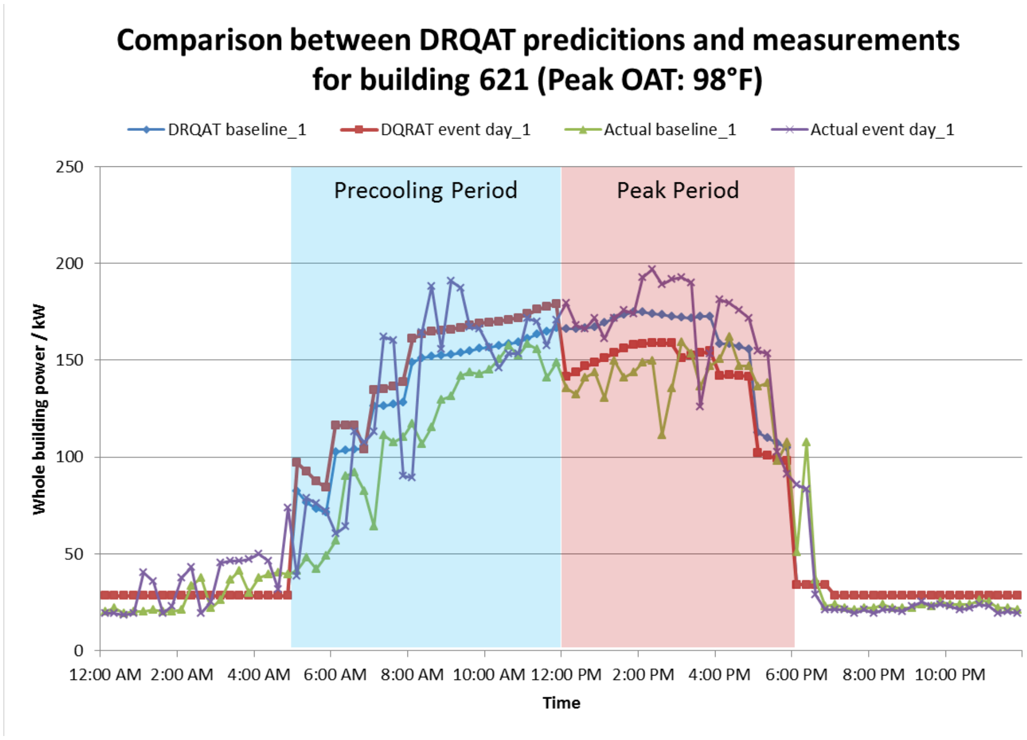
	(kW)	(%)	(kW)	(%)	(kW)	(%)	(kW)	(%)
Max Diff (kW)	-26.6	-23	-95.0	-63	33.3	14	68.2	53
Ave Diff (kW)	-17.0	-10	-14.1	-12	24.6	11	51.1	25
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**26.0**	**11%**	**67.2**	**28%**

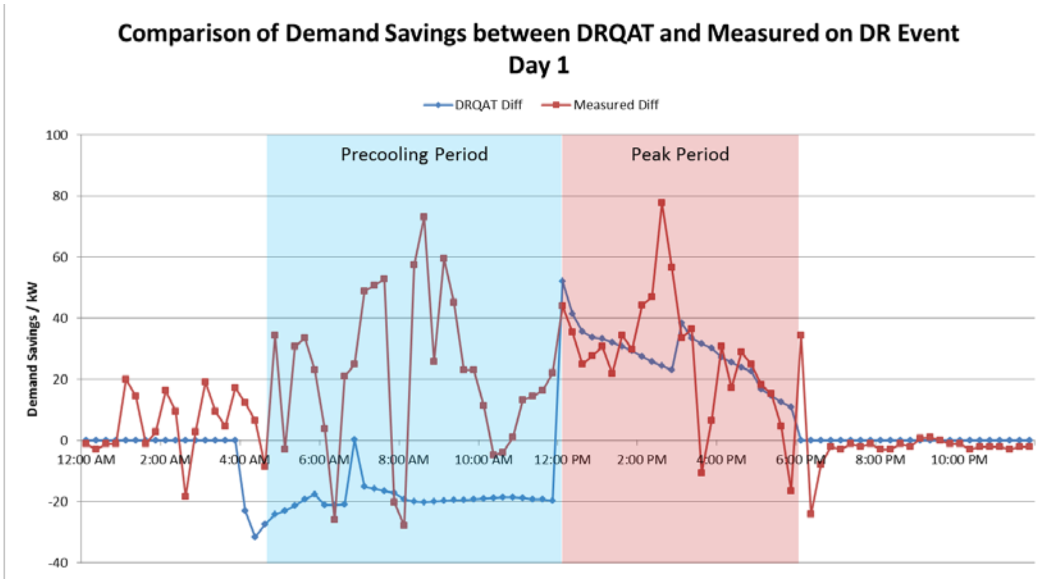




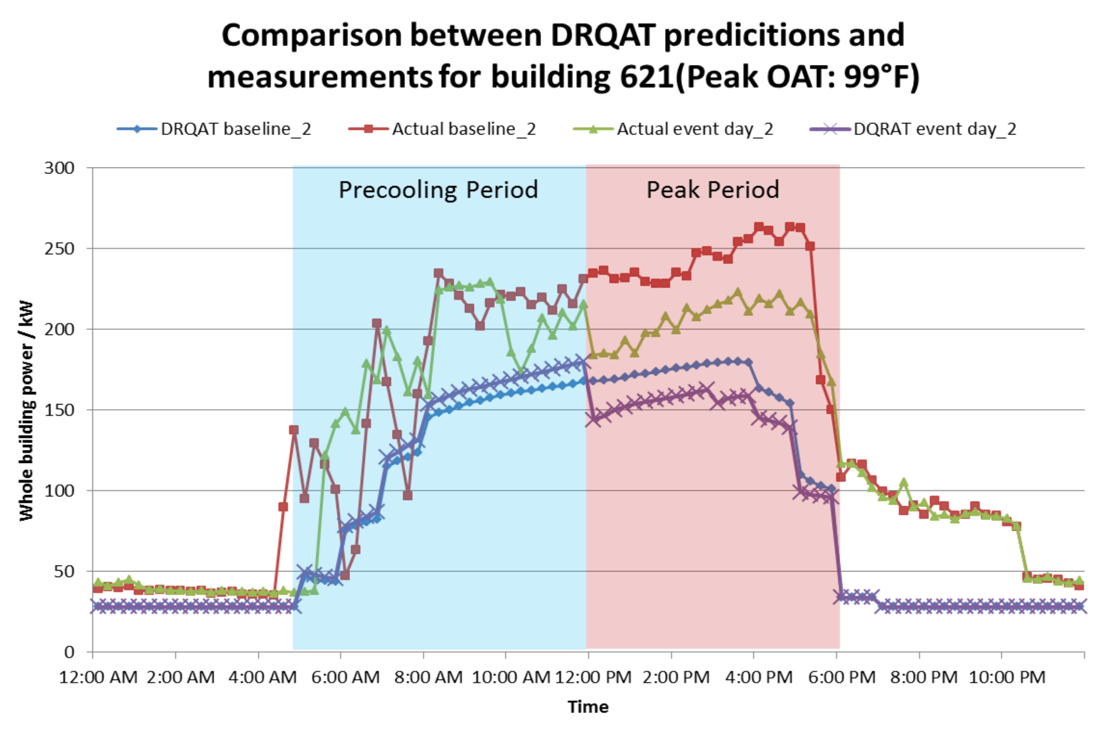
	Morning Pre-cool Period				Peak Period			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-23.8	-14	-101.8	-94	59.7	22	74.9	45
Ave Diff (kW)	-17.3	-8	-12.3	-12	32.5	13	51.2	20
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**36.1**	**13%**	**46.1**	**16%**

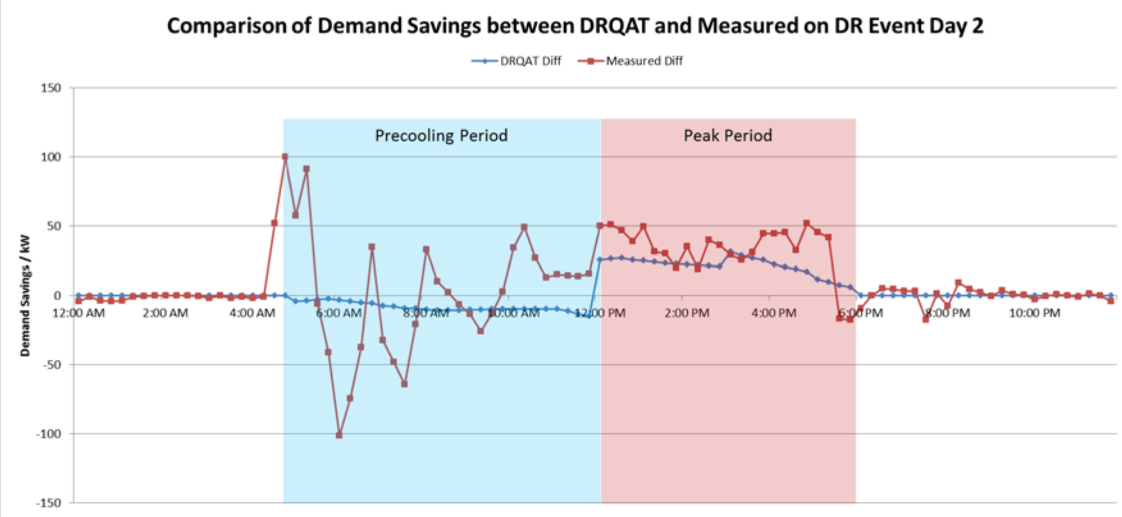
Building 621





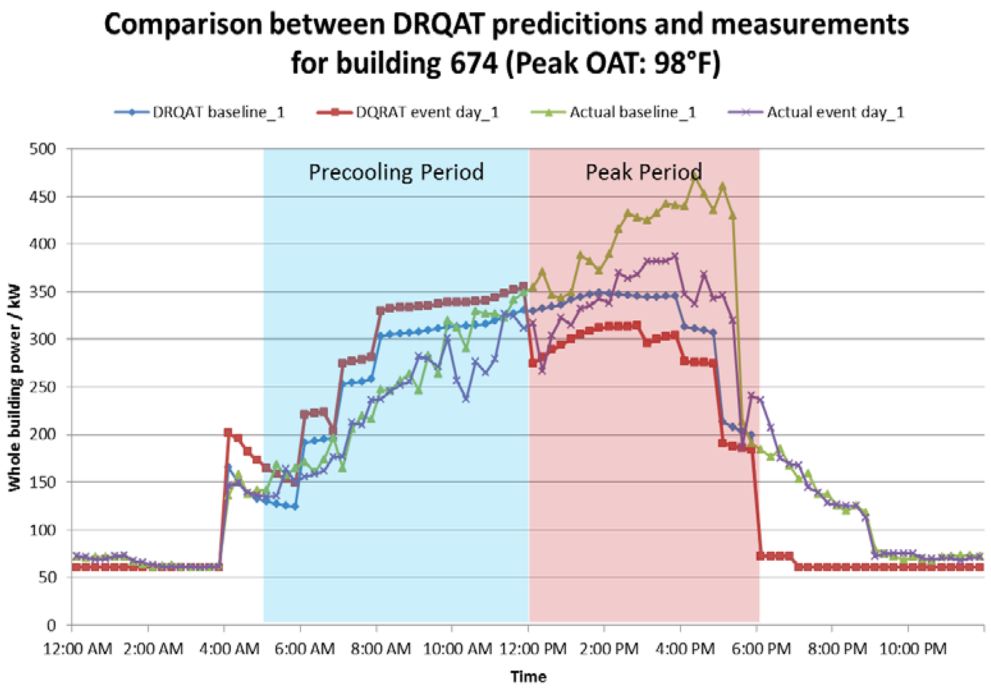
	Morning Pre-cool Period				**Peak Period**			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-15.9	-21	-27.8	-40	24.4	15	77.7	41
Ave Diff (kW)	-12.0	-10	21.1	14	16.3	10	27.7	15
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**16.3**	**9%**	**34.6**	**18%**

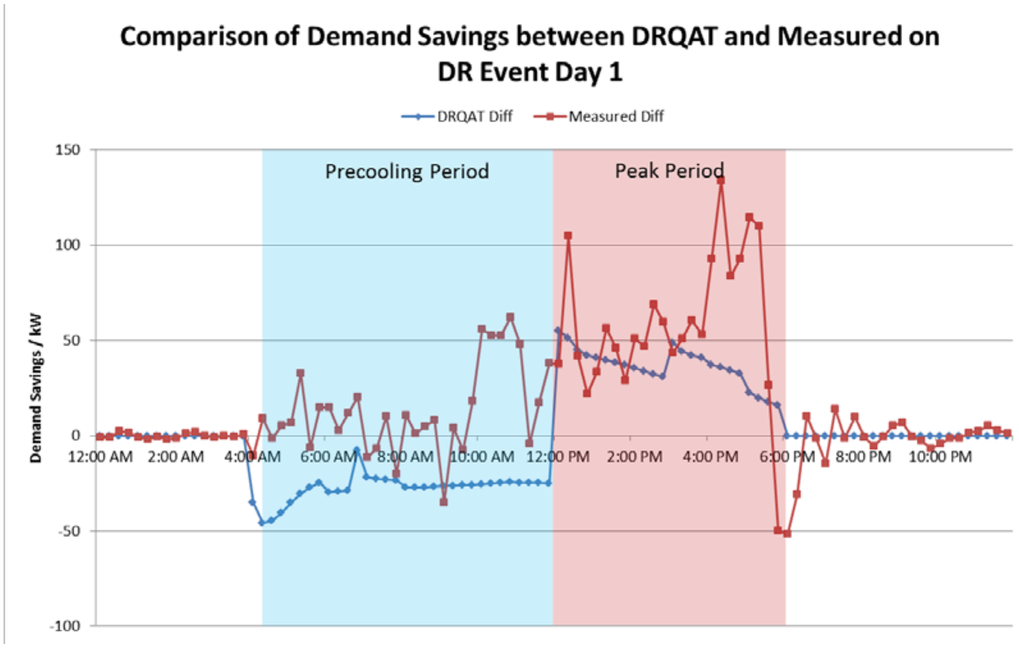




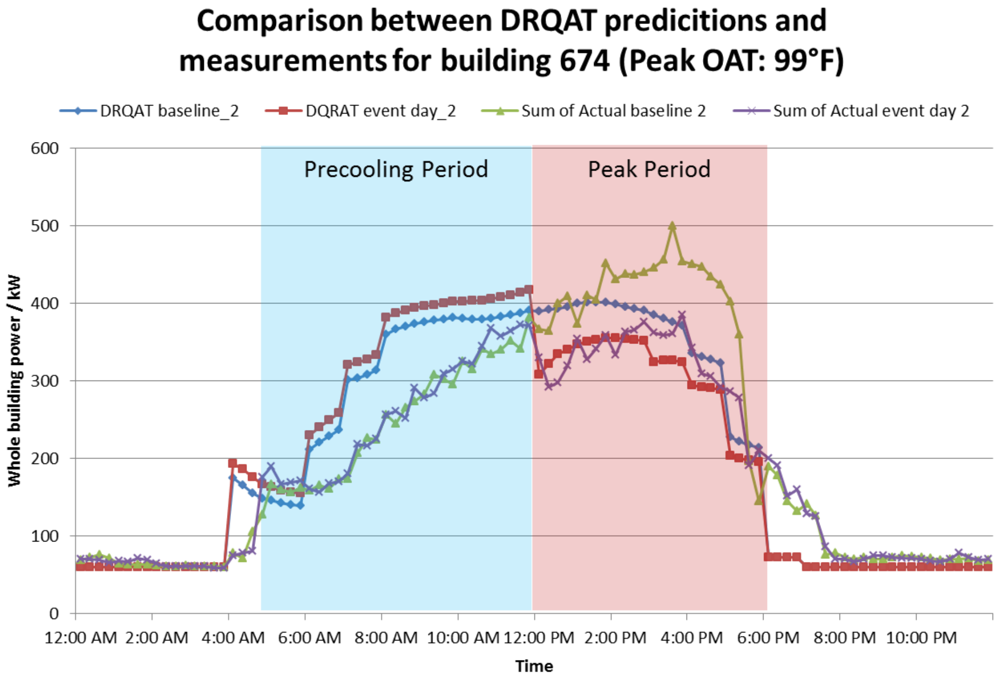
	Morning Pre-cool Period				**Peak Period**			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-14.4	-7	-101.3	-213	31.8	14	51.8	22
Ave Diff (kW)	-8.2	-6	-2.4	-11	21.5	11	33.7	13
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**20.9**	**9%**	**40.3**	**18%**

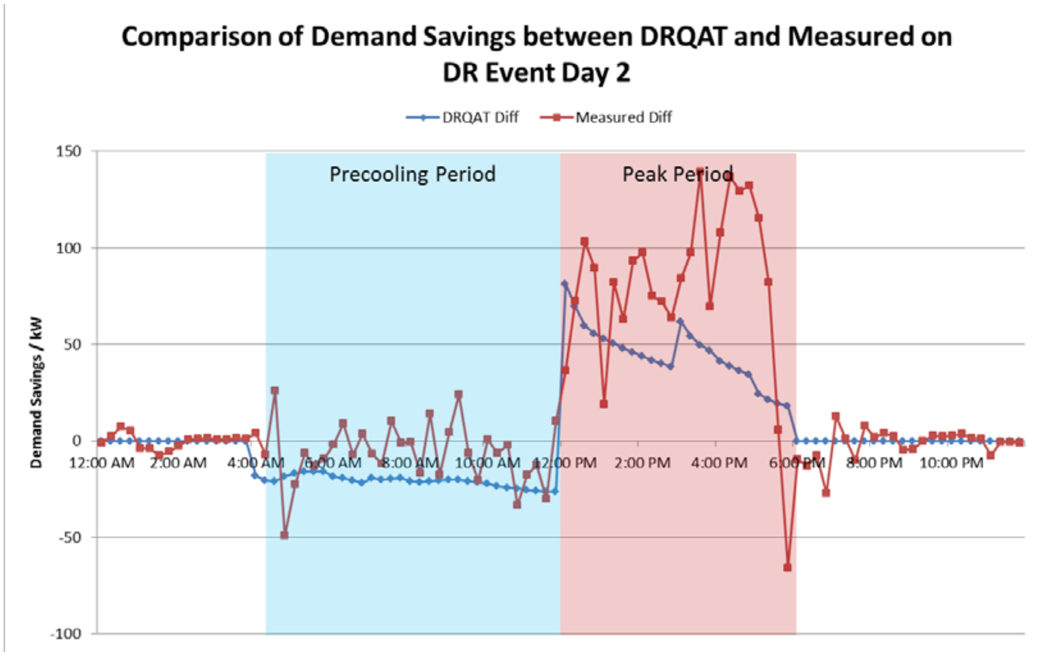
Building 674





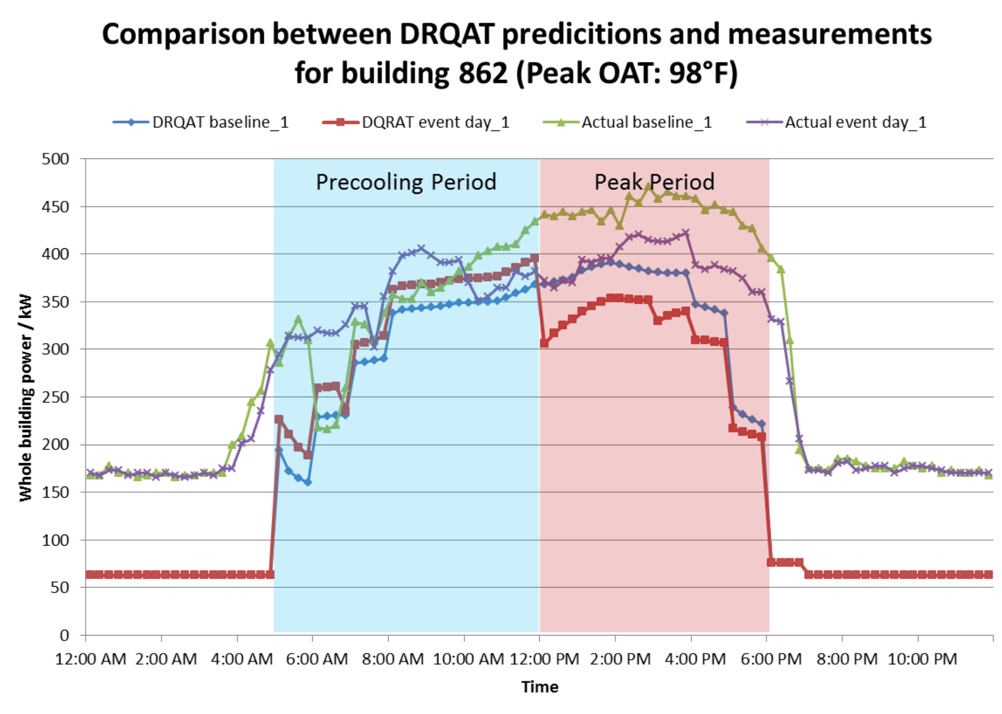
	Morning Pre-cool Period				**Peak Period**			
	DRQAT DR vs. Baseline		**Measured DR vs. Baseline**		**DRQAT DR vs. Baseline**		**Measured DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-35.0	-27	-35.0	-14	55.0	17	133.9	28
Ave Diff (kW)	-25.5	-11	14.1	5	36.4	11	58.6	14
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**35.2**	**10%**	**83.5**	**18%**

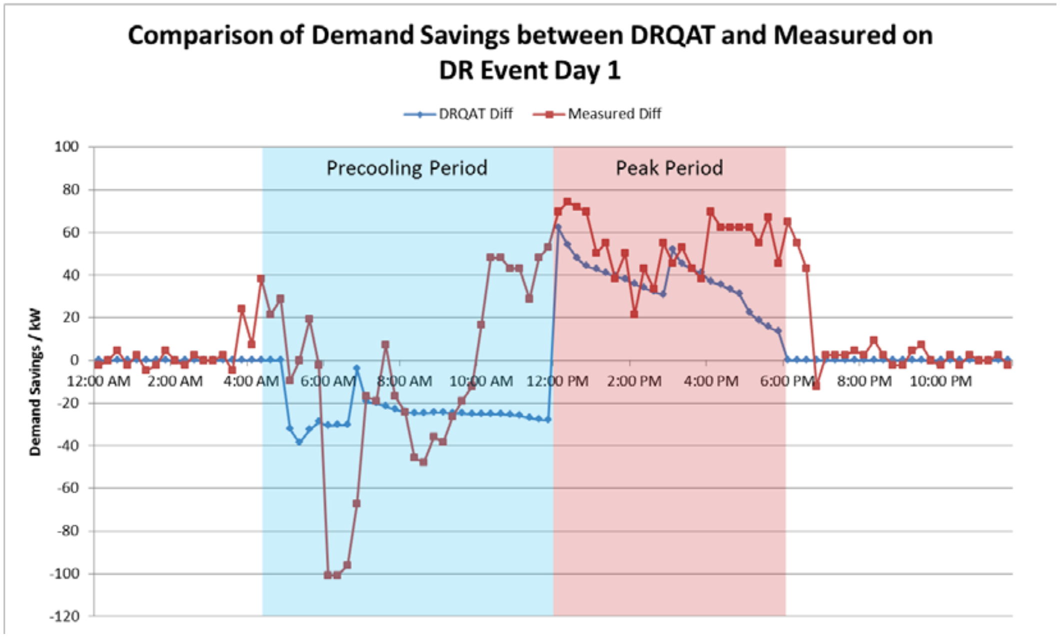




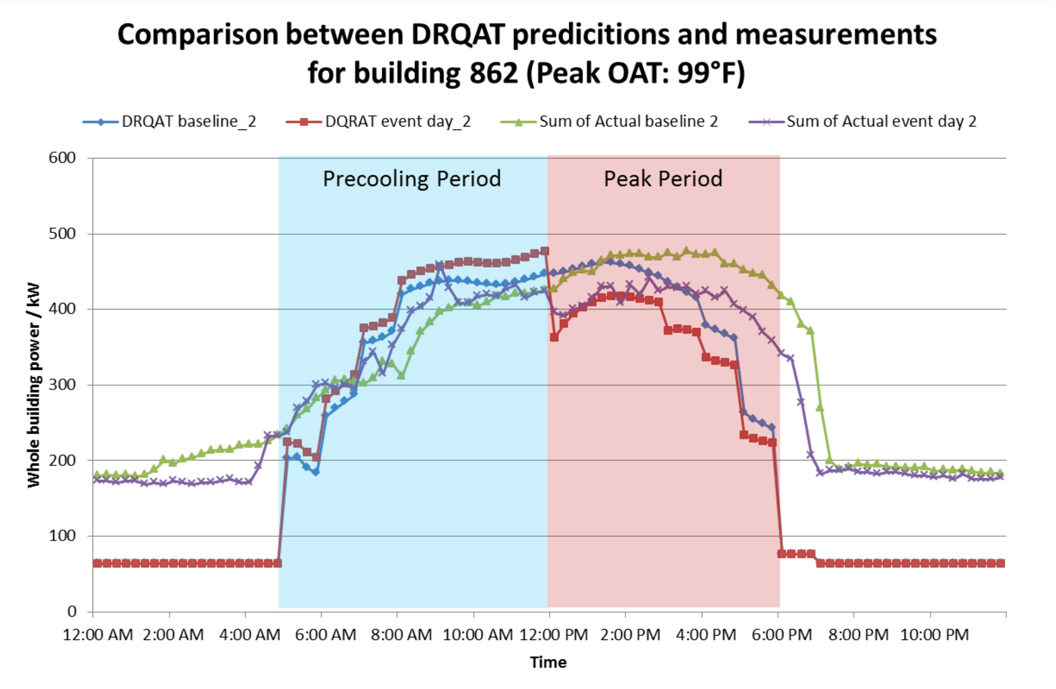
	Morning Pre-cool Period				Peak Period			
	DRQAT DR vs. Baseline		Measured DR vs. Baseline		DRQAT DR vs. Baseline		Measured DR vs. Baseline	
	(kW)	(%)	(kW)	(%)	(kW)	(%)	(kW)	(%)
Max Diff (kW)	-26.5	-11	-33.6	-13	81.2	21	139.2	31
Ave Diff (kW)	-21.0	-7	-6.0	-3	44.7	12	79.1	17
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**46.7**	**12%**	**115.7**	**23%**

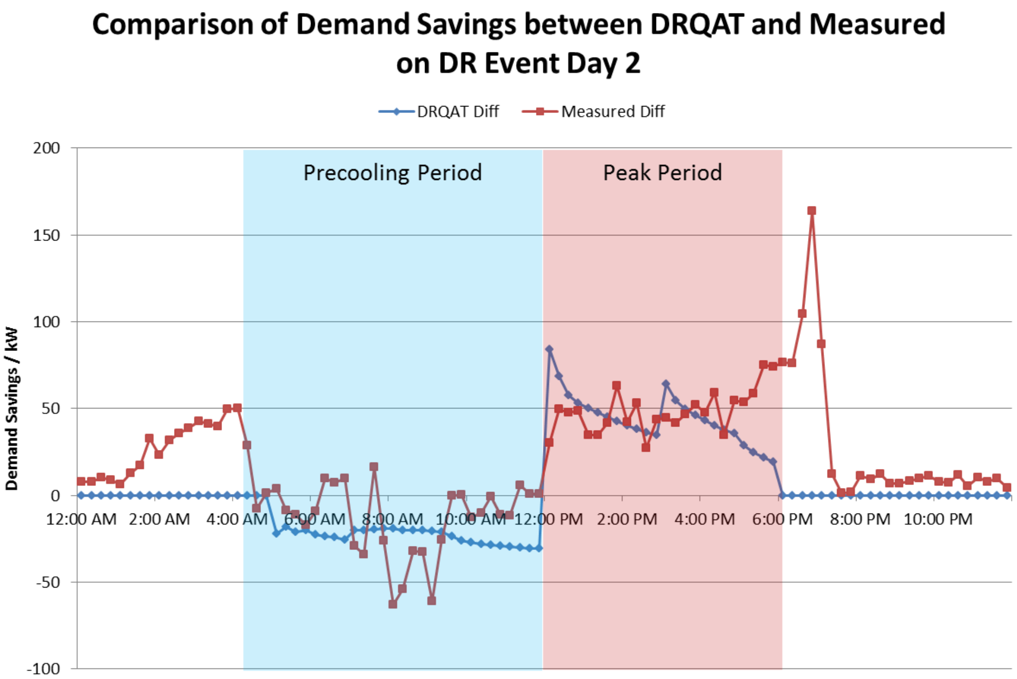
Building 862





	Morning Pre-cool Period				**Peak Period**			
	DRQAT **DR vs. Baseline**		**Measured** **DR vs. Baseline**		**DRQAT** **DR vs. Baseline**		**Measured** **DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-38.6	-22	-100.8	-47	62.2	17	74.4	17
Ave Diff (kW)	-25.7	-9	-11.6	-6	37.0	10	54.2	12
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**37.7**	**10%**	**48.0**	**10%**


Comparison between DRQAT predicitions and measurements for building 862 (Peak OAT: 99°F)


Comparison of Demand Savings between DRQAT and Measured on DR Event Day 2

	Morning Pre-cool Period				**Peak Period**			
	DRQAT DR vs. Baseline		**Measured DR vs. Baseline**		**DRQAT DR vs. Baseline**		**Measured DR vs. Baseline**	
	(kW)	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**	**(kW)**	**(%)**
Max Diff (kW)	-30.6	-11	-62.9	-20	84.0	19	74.8	17
Ave Diff (kW)	-23.5	-7	-14.1	-4	44.4	11	48.3	11
Peak Demand Savings (kW)	**-**	**-**	**-**	**-**	**44.8**	**10%**	**34.8**	**7%**