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Task Report for the

Energy Efficient and Affordable Small Commercial and Residential Buildings Research Program

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Project 2.5 – Pattern-Recognition Based Fault Detection and Diagnostics

Task 2.5.1 - Select Diagnostics for Automation

Version 2

M. R. Brambley, Battelle Northwest Division
R. S. Briggs, Battelle Northwest Division
S. C. Gaines, Battelle Northwest Division
R.G. Lucas, Battelle Northwest Division
S. S. Waterbury, Architectural Energy Corporation

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Prepared for
Architectural Energy Corporation

Battelle Northwest Division
Richland, Washington 99352

Contents

1 Executive Summary

This report is on Task 2.5.1 - Select Diagnostics for Automation of Project 2.5 - Pattern-Recognition Based Fault Detection and Diagnostics. The project focuses on automating the diagnostic methods developed by Architectural Energy Corporation (AEC) for use with the ENFORMA software. This report presents the methodology and results of the process of selecting building systems for development of automated diagnostics. These diagnostics will be based on the diagnostic methods made available in AEC's ENFORMA software and related documents.

The process used for selecting systems is based on the subjective judgment of the three lead investigators for the project. The process was based on examination of available data on system use in California and on the professional experience of the investigators. Factors explicitly recognized in this process include:

- Potential Usefulness/Impact, consisting of
    - ✓ Prevalence of system in California
    - ✓ Availability of measured data required
    - ✓ Frequency of fault occurrence
    - ✓ Ease of corrective action

- Technical Difficulty/Risk, consisting of
    - ✓ Effectiveness of the ENFORMA diagnostic method based on past experience
    - ✓ Technical difficulty and development cost

The assessment led to selection of two major systems for development of automated diagnostics:

- *boilers and*
- *chillers*.

Several additional systems were identified as desirable candidates for automation if time and resources permit including them in the project. They include: cooling towers, Dx cooling units, heat pumps, zones, and other air distribution equipment/systems. These additional promising candidates will be reassessed for automation of diagnostics as more information regarding the cost and difficulty of development emerges from Task 2.5.2 – Select Pattern Recognition Techniques and as additional information is collected on the prevalence of systems in California and frequency of failures in specific systems. This draft report will be revised when sufficient new information becomes available to warrant revisions to the systems selected or to firm these decisions by issuance of a final version of the report.

2 Purpose of This Task Report

Project 2.5 focuses on automating select diagnostic procedures previously developed and disseminated as part of Architectural Energy Corporation's ENFORMA software. ENFORMA assists with planning data collection, initializing loggers used for short-term data collection, processing and plotting collected data, and interpreting the data. ENFORMA provides a powerful set of features for filtering and plotting data in various ways to reveal operation characteristics and problems of building equipment, which a knowledgeable investigator can use to identify and diagnose operation and performance problems. To extend usability of these diagnostic tools, ENFORMA also provides a set of sample plots that represent particular sorts of equipment behavior that can be used by investigators to identify and diagnose building-equipment performance problems. It also includes a set of example applications to a variety of buildings, systems, and equipment. The diagnostic process used with ENFORMA is primarily one of visual identification of parameter values and patterns in the data plots. The purpose of this project is to automate that fault identification process to make it faster to implement and usable by a larger (possibly less engineering trained) set of users including building operators, field service technicians, as well as building engineers, commissioning providers, energy service providers, and researchers.

The purpose of this report is to document Task 2.5.1 Select Diagnostics for Automation. This task represents the first step in selecting equipment and systems for which to automate fault detection and diagnosis from the set of equipment and systems available in ENFORMA. The report provides a description of the selection process, results of applying it, and key data used in selecting building systems and equipment for which to automate diagnostics.

3 Selection Process

3.1 Overview of the Selection Process

The ENFORMA software contains approximately 150 diagnostic plots and procedures. A table summarizing all the ENFORMA diagnostics is included as an appendix to this report. The selection process involved six primary steps:

- Developing familiarity with the fault detection and diagnostics in ENFORMA
- Collecting and analyzing data on the prevalence of systems and equipment in California (in collaboration with Project 6.1)
- Developing evaluation criteria
- Categorizing ENFORMA methods and systems/equipment
- Assessing system/equipment categories with respect to evaluation criteria
- Presentation of results.

Because the evaluation presented in this draft report was based largely on the subjective judgment of the three primary investigators for this task plus data from the Commercial Buildings Energy Consumption Survey (CBECS) database, we propose to obtain further opinions regarding the prevalence of equipment/system types in California and frequency of failures from a small sample of building service practitioners working in the California market. After collecting this additional information, the conclusions of this draft report will be reviewed and revised, if necessary, and a revision to this report will be prepared and submitted.

As Task 2.5.2 Selection of Pattern Recognition Techniques progresses, the evaluation of technical difficulty and risk will also be reassessed and adjustments made, if necessary, to the selections presented in this report.

This report provides the research team's selections of systems and equipment upon which to focus. It also provides lists of diagnostics available for each type of system and equipment that are available from ENFORMA; however, which of the diagnostics to implement for the selected equipment and systems has not been decided yet. To do so would be premature until parts of Task 2.5.2 are performed. Therefore, selection of specific diagnostics for each equipment/system category will be presented in a future report.

3.2 Equipment/System Categories

Based on review of the diagnostics in ENFORMA (see the Appendix for a comprehensive list), we created the following major categories for evaluation:

- Economizers
- Boilers
- Chillers
- Cooling towers
- Direct expansion (Dx) cooling units
- Heat pumps
- Water-loop heat pumps
- Evaporative coolers
- Zones
- Other air distribution
- Thermal energy storage
- Humidifiers/dehumidifiers.

3.3 Evaluation Criteria

Two primary criteria were used in evaluating the existing diagnostics in ENFORMA for suitability for automation in this project: 1) the expected impact of successful automation and 2) the estimated technical risk and level of effort required to automate. These two primary decision criteria are described more completely in the subsections that follow.

3.3.1 Impact of Successful Automation

The benefits from successfully automating diagnostics are likely to be influenced by four factors that will affect deployment of the diagnostic systems and the benefits that accrue from their use. These factors are:

1. How prevalent each type of system or component to which the diagnostics apply is in California.
2. How suitable the types of systems or components are to deployment of automated diagnostic technologies.
3. How common the types of faults that the diagnostics detect are for each equipment type.
4. How severe the impacts are for the types of faults the diagnostics detect.

1. Prevalence of System/Component Types in California – Most of the diagnostics used in ENFORMA are applicable only to specific types of systems or equipment. The more common the

Table 1 - Prevalence of System Types in the California Commercial Building Stock based on data from the *1995 Commercial Buildings Energy Consumption Survey (CBECS).*

System Type	Buildings		Building Floor Area		Energy Use in Buildings with System Type		
	Number	% of Total	10^6 ft^2	% of Total	Use	10^{12} Btu	% of Total
Economizers	72,905	16.7	1,769	31.3	cooling	12.8	38.3
					heating	20.6	30.0
Boilers	34,989	8.0	1,268	22.5	cooling	NA	NA
					heating	16.6	24.2
Chillers	8,957	2.0	1,013	17.9	cooling	7.9	23.7
					heating	NA	NA
Packaged Air Conditioners	201,105	46.0	2,490	44.1	cooling	18.2	54.6
					heating	NA	NA
Heat Pumps (air-to-air and hydronic)	27,267	6.2	344	6.1	cooling	2.7	8.1
					heating	0.7	1.0
Evaporative Coolers	16,676	3.8	117	2.1	cooling	< 0.1	0.2
					heating	NA	NA
All Commercial Buildings	437,276	100.0	5,644	100	cooling	33.4	100.0
					heating	68.6	100.0

applicable equipment is in California buildings, the more opportunity there will be to realize significant impact from an automated diagnostic that monitors and diagnoses faults in that equipment. Table 1 *Prevalence of Selected Characteristics in the California Commercial Building Stock* provides estimates of the population of buildings having applicable systems and equipment. The types of systems and equipment in Table 1 are not identical to the categories identified in Section 3.2, but the data are useful to identify the predominance of certain types of equipment. These data, along with the impressions of the principle investigators are the basis for the scores for prevalence of systems in California (reported later in Table 5).

The data in Table 1 are from the 1995 CBECS, published by the U.S. Department of Energy, Energy Information Administration (EIA). Although more accurate data will be gathered as part of other projects now underway in the CEC PEIR programs, the 1995 CBECS represent the best and most up-to-date source of data on the characteristics of commercial building stock throughout the State of California that are readily available now.

Unfortunately, CBECS is not organized so that data can be reported for the State of California separately from data from other states. However, by using data for buildings whose locations have less than 4,000 heating degree days (base 65ºF) and are also located in the Pacific Census Region (which includes California, Oregon, and Washington), we are able to establish good estimates for the State of California as a whole. The intersection of the census and climatic regions includes all but the northeast corner of the state (the areas with light and medium-colored shading in Figure 1). We estimate that roughly 90% or more of California's building stock is represented by this region.

There are several other noteworthy limitations to the CBECS data. While the survey is designed to gather some detailed information about mechanical equipment used in the buildings, survey administrators and

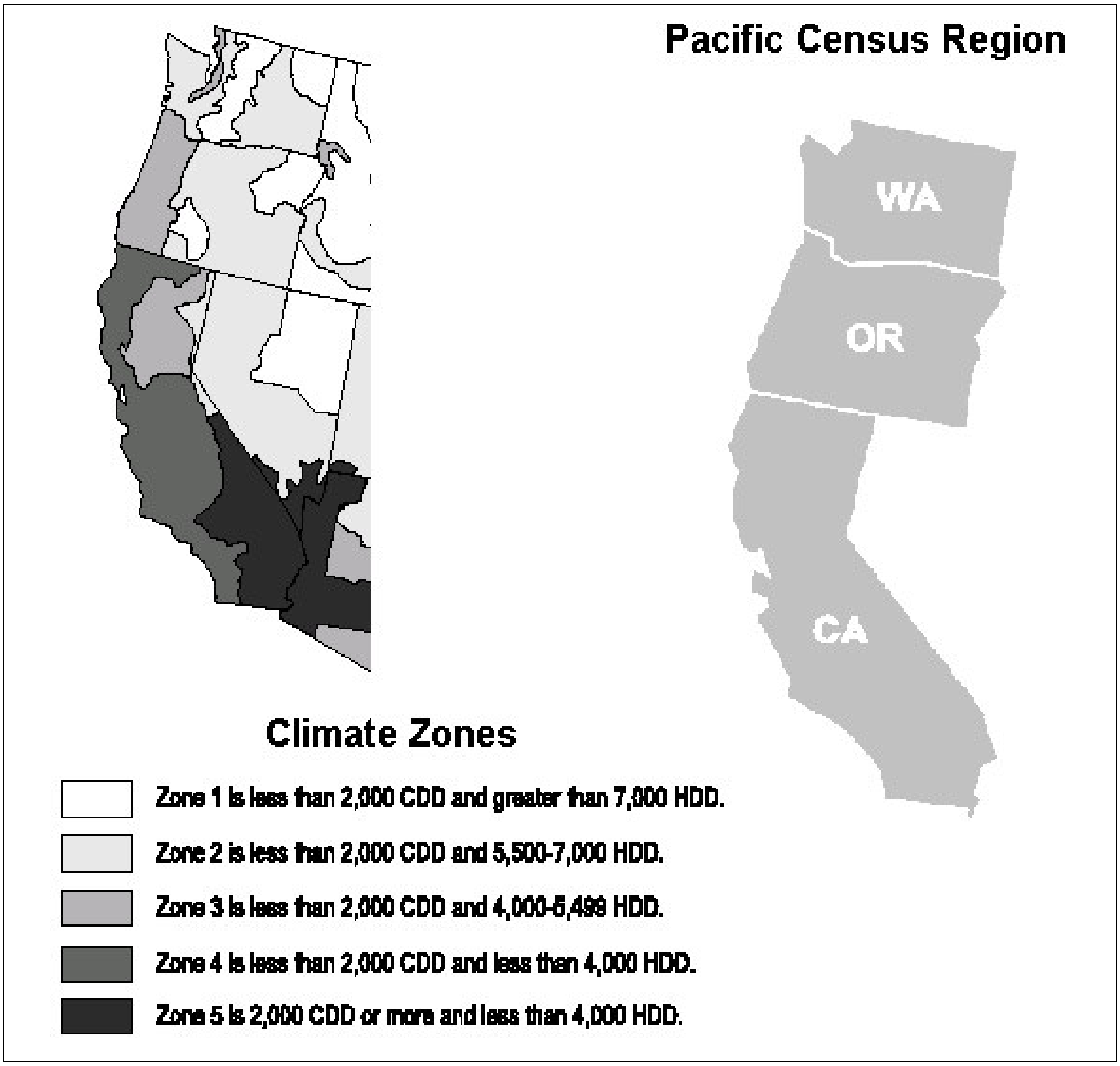

Figure 1 – The intersection of EIA Climate Zones 4 and 5 and the Pacific Census Region provides a reasonably satisfactory means to isolate California data in the CBECS sample.

(usually) survey respondents are not engineers and are not highly knowledgeable about the heating, ventilation, and air-conditioning (HVAC) systems in the buildings on which they report. As a result, data on the type of equipment present in the sample buildings may not be highly reliable, and frequently the distinctions we are most interested in were not addressed in the original survey. In addition, the statistical significance and predictive value of the CBECS data are reduced whenever the sample size is small, such as is the case with some of the less-common HVAC equipment types listed in Table 1. End-use component data (e.g., for cooling energy consumption) from CBECS are imputed rather than measured. The process of imputing end-use components has the potential for introducing additional errors not present in the whole-building consumption values, which are measured. While the 1995 CBECS contains the most recent data available, five years have passed since they were collected. Data from the past five years would be relevant and valuable for characterizing new buildings and possible trends in equipment use; however, the automated diagnostics developed in this project will be useful on equipment of all vintages in the building stock. For these and other reasons, we view the data shown in Table 1 as useful and suggestive of the prevalence and importance of the selected building characteristic, but it should not be viewed as absolute or highly precise.

Table 1 contains estimates of the numbers of buildings, their floor space, and their associated energy use for heating and cooling for buildings that use the types of equipment listed in the left-most column. The listed equipment types conform roughly with ENFORMA diagnostics that are under consideration for use in automated diagnostics. The numbers in the table serve as measures of the potential impact of the various types of diagnostics.

For example, a major question that emerges in evaluating diagnostics for chillers, cooling towers, and boilers is how important these central-plant equipment types are to overall commercial energy-use in California as compared with package HVAC equipment types. Table 1 shows that there may be only 4% (8957 buildings with chillers/201,105 buildings with packaged air conditioners) as many buildings in California that use central-plant chillers as use package cooling equipment. Most buildings that use chillers though are much larger, and the ratio of the two basic types of system is greatly increased (to about 41% = 1,013 million square feet for buildings with chillers/2,490 million square feet for buildings with packaged air conditioners) when floor area is considered. This ratio is increased even further (to about 43% = 7.9 trillion Btu for buildings with chillers/18.2 trillion Btu for buildings with packaged air conditioners) when energy consumption is considered. Buildings with package air conditioners still use more than double the energy that buildings with chillers in California use for cooling, but the energy consumed by buildings with chillers is much larger than might be realized from a casual inspection of number of buildings only. All three of these metrics—numbers of buildings, their floor area, and their energy consumption may be useful indicators of equipment importance in assessing potential impact and difficulty of achieving that impact, but their differences must be recognized.

Similar questions arise in considering the significance of heat pumps in the commercial building stock in California. Table 1 suggests that approximately 6% of commercial buildings use heat pumps for heating. From an energy consumption perspective, these buildings represent a relatively small part of the heating energy consumption picture (≈ 1%), and as a result, they have a modest contribution to energy use in California. Therefore, the potential energy impact of diagnostics for heat pumps in commercial buildings in California is much less than for systems (like roof-top packaged air-conditioning units) that represent a much larger fraction of the California building stock and space-conditioning energy use. These differences are exhibited in our assessment presented in the Results section and Table 5.

Evaporative coolers (or swamp coolers, as they are commonly called) are another equipment type that was confirmed to have low potential impact based on the CBECS data. Table 14 indicates that roughly 4% of California commercial buildings have evaporative coolers, however, these buildings tend to be quite small and to use very little energy for cooling (≈ 0.2% of the cooling energy for the commercial sector). Therefore, we would not select evaporative coolers as a target for diagnostics.

As noted earlier, the data do not show possible current trends toward more use of certain, hopefully more efficient, types of equipment. However, our judgment as the investigators is that the greatest impacts will result from focusing on the types of equipment currently predominate in the building stock. If we succeed in bringing automated diagnostics to existing equipment, new equipment will likely readily adopt automated diagnostics in the future.

Furthermore, because residential air-conditions and heat pumps are based on the same fundamental technology as commercial air-to-air heat pumps and packaged air-conditioners, diagnostics developed for commercial units might be directly (or with slight modification) applied to residential units. Therefore,

Table 2 - Prevalence of System Types in the California Residential Building Stock based on data from the *1997 Residential Energy Consumption Survey* (RECS).

System Type	Buildings		Building Floor Area		Energy Use in Buildings with System Type		
	Number	% of Total	10^6 ft^2	% of Total	Use	10^{12} Btu	% of Total
Packaged Air Conditioners	3,081,619	26.8	5042	32.5	cooling	13.2	79.0
					heating	NA	NA
Heat Pumps (air-to-air and hydronic)	295,641	2.6	380	2.4	cooling	0.9	5.3
					heating	1.3	0.6
All Residential Buildings	11,484,357	100	15,508	100	cooling	16.7	100
					heating	219.7	100

impacts for these types of units might extend into the residential sector, increasing the impact of diagnostics developed for the equivalent commercial systems. Table 2 contains estimates of the numbers of residential buildings, their floor space, and their associated energy use for packaged air conditioners and heat pumps for residences based on the *1997 Residential Energy Consumption Survey (RECS)*. The numbers in the table serve as indicators of the potential impact of the various types of diagnostics. The data in Table 2 show that:

- ✓ Package air conditioners are used in 27% of the total residential building stock
- ✓ Packaged air conditioners represent 79% of the residential energy-use for cooling
- ✓ Heat pumps represent only about 2.5% of cooling systems used in California residences.

From this, we can conclude that if diagnostic technology for commercial package units could be transferred to residential units, the potential impacts for this diagnostic technology could roughly double compared to the impacts from application to commercial units only (based on nearly equal use of energy by package commercial and residential air conditioners). On the other hand, even considering heat pumps in both the commercial and residential sectors, too few heat pumps are prevalent in California for diagnostics for heat pumps to have a significant impact compared to diagnostics for other system types.

To corroborate the results based on Table 1, we examined data reported by Pacific Gas & Electric (PG&E 1997 and 1999) and Southern California Edison (ADM Associates 1997). The results based on installed capacity are presented in Table 3. Although the service territory of the third largest electric utility in the state, SDG&E, is not included and the metrics are not identical to those in Table 1 (energy use in Table 1 and installed capacity in Table 3), most of the results tend to corroborate one another. Key conclusions from comparison of the results in Tables 1 and 3 include:

- ✓ Boilers represent about 38% (Table 3) of the heating capacity and 24% of the heating energy use (Table 1) in California commercial buildings.
- ✓ Package DX cooling units represent 42% of the cooling capacity and 55% of the cooling energy use.
- ✓ Chillers (centrifugal) represent 20% of cooling capacity and 24% of the cooling energy use.
- ✓ Heat pumps represent a small fraction (<10%) of the heating and cooling capacity and energy use.
- ✓ Evaporative coolers represent a very small fraction of the commercial cooling capacity and energy use.
- ✓ Economizer data are inconsistent between CBECS and the utility surveys.

2. Availability of Data – In order for an automated diagnostic capability to be deployed, some mechanism must be available for acquiring the requisite data from the monitored component or system. Potential mechanisms for deploying automated diagnostics vary from stand-alone software packages that analyze data collected by other systems to adding diagnostic logic to building automation systems to

Table 3 - Space conditioning equipment types prevalent in the PG&E and SCE service territories.

System Type	**PG&E and SCE Service Territories**	
Cooling	**tons**	**% of Total**
Packaged Cooling		
Packaged DX units (non-heat pumps)	2,494,736	42%
Heat Pumps	1,160,634	19%
Packaged evaporative coolers	56,090	1%
Packaged Cooling Capacity	**3,711,460**	**62%**
Built-up Cooling		
Centrifugal Chiller	1,199,500	20%
Reciprocating chiller/screw compressor	874,800	15%
Heat Pumps	18,730	0%
Other	159,900	3%
Built-up Cooling Capacity	**2,252,930**	**38%**
Total Cooling	***5,964,390***	***100%***
Heating	**10^6 Btu/h**	**% of Total**
Packaged Heating		
Gas furnace	54,971	49%
Heat pumps	3,854	3%
Unit heater	5,591	5%
Other electric heat	1,562	1%
Packaged Heating Capacity	**65,978**	**58%**
Built-up Heating		
Boilers	43,044	38%
Other	3,782	3%
Built-up Heating Capacity	**46,826**	**42%**
Total heating	***112,804***	***100%***
Economizing (SCE service territory only)	**10^3 ft^2 floor area**	**% of Total**
A/C Economizer w/2 stage cooling (fully or partially implemented)	163,737	9%
All Buildings in SCE service territory	**1,838,180**	**100%**

incorporating diagnostic processes into the logic on a computer chip in an autonomous control circuit for a package roof-top air-conditioner. Data acquisition is usually expensive and can pose a severe limitation on the feasibility of successful deployment. Building owners are often very resistant to adding any sensors that are not absolutely required for control of building equipment. Consequently, those systems whose diagnostics use mostly data for which sensors are already commonly installed are given higher ratings in our evaluation. In addition, for some systems data from sensors may be used locally for control but not generally be available for other uses. The investigators' impressions of this situation are used as the basis for our evaluation of suitability for automation in this project, with systems having greater data availability given higher ratings.

3. Frequency of Fault Occurrence – The benefits from automated diagnostics will be influenced strongly by how frequently the systems fail during routine operation. If a system fails frequently, targeting it with automated diagnostics is likely to provide greater impacts than a system that fails infrequently. In addition to failure during operation, many components are improperly installed and commissioned. In previous work, Battelle staff have found many equipment faults already present by using automated diagnostic tools. Certain HVAC components, such as economizers, are notorious for having operational and commissioning problems. As a result, we expect that the automated diagnostic tools developed in this project will prove valuable as aids in routine operation as well as in commissioning of new buildings and retro-commissioning of existing buildings. Account for both of these perspectives is taken in evaluation of this criterion, frequency of fault occurrence.

4. Significance of Malfunctions – The value of fault detection information depends on how serious the consequences are of the types of malfunction addressed by the diagnostic. Some malfunctions can damage equipment, others may seriously degrade overall building energy efficiency, while others serve only to diminish the efficiency improvements the system was designed to provide, and still others may have only small impacts on energy use and the cost of operation. This factor is used to indicate the significance of the faults that the candidate diagnostics would detect and diagnose, which would also be indicators of the savings that would result from correcting the detected problems.

5. Ease of Corrective Action – The value of fault detection information also depends on the ease and cost-effectiveness of correcting the faults. Some operational problems can be remedied through simple control system adjustments. Others may require large capital investments to correct. In every case, the decision to correct a problem is affected by the ease of correction and the cost of correction. This criterion is intended to capture these issues. The other major factor affecting the likelihood of a problem being corrected is the magnitude of the impact, which is captured in criterion 4.

3.3.2 Technical Risk/Level of Effort

The second major aspect of the diagnostic evaluation focuses on risk, as opposed to returns or impact. Given inherent uncertainties in the development process, this part of the evaluation focuses on identifying the diagnostics with the highest likelihood of successful development, accurate performance of the resulting diagnostics, and reasonable cost of development. Technical complexity, the novelty of the methods used, and the number of diagnostic problems addressed all add to technical risk. New methods potentially pose unexpected implementation problems. Until tested new methods pose risk. Automated pattern recognition has not been applied previously to building systems diagnostics, so risk is inherent in taking this new approach. Finally, the number of diagnostic problems addressed in the project increases the amount of effort required and, therefore, the cost of the project. Selecting diagnostics that are riskier and more technically challenging to automate would necessarily require greater effort and diminish the number of diagnostics that can be addressed within project scope. We are seeking to balance these factors in this selection process.

These risk factors are addressed in greater detail by the following two criteria used in this assessment:

1. How reliable and effective the diagnostics have been in identifying the fault when used manual within ENFORMA.
2. How technically complex we anticipate automation of the diagnostics for a system/equipment category to be. This criterion includes the need to handle expected uncertainty in the data for

each specific diagnostic, as well as the complexity of automating the ENFORM diagnostic method even in the absence of uncertainty in the data used.

1. Effectiveness of ENFORMA methods – If a diagnostic has not proven reliable when applied by expert users of ENFORMA at AEC, it is less likely that the diagnostic would perform well when automated. The assessment of effectiveness included in Table 3 was provided by the lead AEC investigator for this project based on AEC's experiences in using each of the ENFORMA diagnostics on a number of buildings. In addition to the success of the methods when used, the number of uses by AEC and its customers is also factored into evaluation of this criterion. Methods for which AEC has less experience are given less weight than those applied successfully in many cases.

2. Technical difficulty and development cost – Several factors (as discussed above) contribute to the technical difficulty of automating a diagnostics procedure. Among these factors is 1) the complexity of the method itself, 2) whether the automation method has been used previously on diagnostic problems and diagnostic problems in the buildings domain, 3) the intermittence or continuity of a problem when it occurs, and 4) uncertainty inherent in the data used for diagnosis. This criterion is intended to capture these factors in a rating.

3.4 Evaluation Matrix

Table 4 presents an empty copy of the matrix used to record the evaluation of the criteria presented in Section 3.3. On the left-most axis of the matrix are the major system/equipment categories from ENFORMA, which were identified in Section 3.3.1. In the second column, candidate diagnostics for automation from ENFORMA are shown for each system/equipment category. Which of these diagnostics to automate for each of the system/equipment categories selected in this task will be decided later in the project, while performing Task 2.5.2. In many cases, ENFORMA contains several plots and diagnostic assessments that are part of a single diagnostic entry in Table 4.

Evaluation criteria have been divided into two major categories—Potential Usefulness/Impact and Technical Difficulty/Risk, as discussed in Section 3.3. Under each of these major categories are the detailed criteria described in Section 3.3. In addition to the detailed criteria, an overall assessment is provided in the last (right-most) column of the matrix.

3.5 Assignment of Scores

Scores were assigned to each criterion for each system/equipment category (i.e., cell in the matrix). Scores were assigned subjectively by the three primary investigators, with each investigator first assigning scores independently of the other investigators for all cells for which the investigator felt qualified. These scores were based on individual knowledge and the data on system/equipment prevalence presented in Section 3.3.1. This scoring process was used for the investigators to develop some familiarity with the criteria and with the process of scoring. The investigators then met and developed a consensus set of scores through discussion of each cell and its related criterion as applied to each system/equipment category. These are the scores presented in Table 5. The "Overall Rating" in the right-most column was also assigned subjectively. It was not developed mathematically from the other scores but rather assigned independently except for consideration of the thinking behind assignment of the detailed scores. The detailed scoring is provided in Table 5 as information for reviewers and to document the team's thinking with respect to separate criteria.

Table 4 - Evaluation matrix showing system categories and evaluation criteria.

System Category	Diagnostics	Potential Usefulness/Impact				Technical Difficulty/Risk		Overall Rating
		1. Prevalence of System in CA	2. Availability of Measured Data	3. Frequency of Fault Occurrence	4. Ease of Corrective Action	5. Effectiveness of ENFORMA method (based on past experience)	6. Technical Difficulty and Development Cost	
Economizers	Scheduling Proper modulation Performance							
Boilers	Scheduling Hot-water-temperature control							
Chillers	Scheduling Chilled-water-temperature control Efficiency/ performance							
Cooling Towers	Interlock Temperature control							
Dx Cooling Units	Heat rejection Interlock Efficiency/ performance							
Heat Pumps	Scheduling Back-up heat Interlock Efficiency/ performance							
Water-loop heat pump	Scheduling Interlock Temperature control							
Evaporative Coolers	Humidity and temperature control Performance							
Zones	Temperature control Terminal-system operation							
Other Air Distribution	Scheduling Static pressure & fan control System performance							
Thermal energy storage	Schedule Operating modes Interactions Interlock Temperature control							
Humidifier dehumidifier	Performance							

System Category	Diagnostics	Potential Usefulness/Impact				Technical Difficulty/Risk		Overall Rating
		1. Prevalence of System in CA	2. Availability of Measured Data	3. Frequency of Fault Occurrence	4. Ease of Corrective Action	5. Effectiveness of ENFORMA method (based on past experience)	6. Technical Difficulty and Development Cost	
Economizers	Scheduling Proper modulation Performance	3	3	3	3	3	3	**1***
Boilers	Scheduling Hot-water-temperature control	3	3	2	3	3	3	**3**
Chillers	Scheduling Chilled-water-temperature control Efficiency/performance	3	3	2	2	3	3	**3**
Cooling Towers	Interlock Temperature control	3	3	1	3	3	2	**2**
Dx Cooling Units	Heat rejection Interlock Efficiency/performance	3	2	2	2	2	1	**2**
Heat Pumps	Scheduling Back-up heat Interlock Efficiency/performance	2	2	3	2	2	2	**2**
Water-loop heat pump	Scheduling Interlock Temperature control	1	2	2	2	3	3	**1**
Evaporative Coolers	Humidity and temperature control Performance	1	2	3	3	2	2	**1**
Zones	Temperature control Terminal-system operation	3	1	2	2	1	1	**2**
Other Air Distribution	Scheduling Static pressure & fan control System performance	3	2	2	2	2	2	**2**
Thermal energy storage	Schedule Operating modes Interactions Interlock Temperature control	1	2	3	1	1	1	**1**
Humidifier dehumidifier	Performance	1	1	3	3	2	2	**1**

* Economizers were given a score of 1 because of an additional criterion not applicable to the other categories. The Outdoor Air Economizer Diagnostician (OAE), developed by a team led by Battelle staff, exists, performs well, and is undergoing testing and demonstration in Project 2.4 of this program. The investigators judged the incremental value and impact of developing another economizer diagnostician would, therefore, probably be small.

Each criterion applied to each system category was scored on a scale of 1 to 3. These numerical scores corresponded to barely satisfying (1), moderately satisfying (2), and highly satisfying (3) the criterion (or

Table 6 - Results of system selection.

Automation Selection Category	Overall Rating in Evaluation	Systems in Selection Category
Will automate diagnostics	3	Boilers Chillers
Uncertain – would like to automate diagnostics if resources permit	2	Cooling Towers Dx Cooling Units Heat Pumps Zones Other Air Distribution
Will not automate diagnostics	1	Economizers (see footnote to Table 5) Water-loop Heat Pumps Evaporative Coolers Thermal Energy Storage Humidifier/dehumidifiers

simply low, medium, high). For example, system categories that receive ratings of 3 for the "Potential Usefulness/Impact" criteria have in the judgment of the investigators the potential for a large impact through widespread deployment and significant energy savings by successfully identifying a large numbers of faults that have significant energy impacts. Technical difficulty/risk ratings of 3 mean that in the judgment of the investigators automated diagnostics for this system category are relatively easy to develop and the ENFORMA methods on which they are based are highly reliable.

4 Results

The results of the evaluation are shown in Table 6. The system categories were divided into three final decision categories based on their overall rating. Systems with scores of 3 were selected for definite automation of diagnostics; systems with scores of 1 were eliminated from further consideration for automation of diagnostics; and systems with scores of 2 were placed in a category that we assign an uncertain decision. As the team develops more information in revising this report for Task 2.5.1 and in performing Task 2.5.2, one or two of the systems in this middle category may be moved to the top category for automation, if resources appear sufficient to develop automated diagnostics for additional systems, and a small number of systems may be moved to the lowest, won't automate, category. The current selections for automation are summarized in Table 6 – *Results of System Selection*.

5 References

ADM Associates. May 1997. *Commercial Saturation Survey, Final Report.* Prepared for Southern California Edison Company Energy Efficiency and Market Services Division by ADM Associates, Inc., Sacramento, CA.

Architectural Energy Corporation (AEC). 2000. *ENFORMA, Demonstration and Installation CD-ROM*, *HVAC Analyzer v3.116, Lighting Evaluation System v.2.2, MicroDataLogger-DataManager Software v3.0.2.1.* Boulder, Colorado.

Architectural Energy Corporation (AEC). *ENFORMA Portable Diagnostic Solutions HVAC Analyzer User's Guide.* Boulder, Colorado.

Pacific Gas and Electric Company (PG&E). 1999. Commercial Building Survey Report, San Francisco, California.

Pacific Gas and Electric Company (PG&E). September 1997. Commercial Building Survey Report, San Francisco, California.

U.S. Department of Energy, Energy Information Administration (EIA). 1995. *1995 Commercial Buildings Energy Consumption Survey (CBECS), Public Use Data*, Micro-data files on EIA website: http://www.eia.doe.gov/emeu/cbecs/microdat.html.

U.S. Department of Energy, Energy Information Administration (EIA). 1997. *1997 Residential Energy Consumption Survey* (RECS). Data available on the EIA website: http://www.eia.doe.gov/emeu/recs/recs97/publicusefiles.html.

6 Appendix – Table of ENFORMA Diagnostics

This appendix consists of a table (Table 7) containing information on each of the diagnostics contained in the ENFORMA software. The following explains each column in the table:

Plot No. – The diagnostic plot number used in ENFORMA.

Plot Label – The diagnostic plot label used in ENFORMA

System Category – The major system categories used to characterize diagnostic capabilities in the ENFORMA literature

Diagnostic Category – The system attribute (or diagnostic descriptor) used to characterize diagnostic capabilities in the ENFORMA literature

Limitation on Applicability – Limitations on the applicability of a diagnostic to systems or equipment having the listed characteristics. The diagnostic is limited to use with systems conforming with the listed limitation.

Plot Description/Diagnostic Value – A description of the plot or its diagnostic value taken from the descriptions of diagnostic plots in the ENFORMA Help system.

Table 7 - ENFORMA Diagnostics

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
40	Supply Air Delta T vs. Hour	Air distribution	Distribution system heat gain	Air distribution system	Determine if there are heat gains or losses along the supply ductwork.
30	Mixed Air Temperature vs. Ambient Air Temp.	Air distribution	Economizer	Economizer	Determine proper economizer operation.
81	Tmixed - Treturn vs. Tambient - Treturn	Air distribution	Economizer	Dry bulb temperature economizer	Determine if the economizer is modulating properly.
82	Tmixed - Treturn vs. Hambient - Hreturn	Air distribution	Economizer	Enthalpy economizer	Determine if the economizer is modulating properly.
97	Mixed Air Temp vs. Hour	Air distribution	Economizer	Economizer	Economizer diagnostic.
68	Direct Evap Cooler Effectiveness vs. Ambient Temperature	Air distribution	Evaporative cooler	Direct Evaporative Cooler	Observe variations in the direct evaporative cooler performance as the inlet dry bulb temperature varies.
69	Direct ECE vs. Inlet Wet Bulb Temp	Air distribution	Evaporative cooler	Direct Evaporative Cooler	Observe variations in the direct evaporative cooler performance as the inlet wet bulb temperature varies.
70	Indirect ECE vs. Dry Bulb Source Temp	Air distribution	Evaporative cooler	Indirect Evaporative Cooler	Observe variations in the indirect evaporative cooler performance as the source dry bulb temperature varies.
71	Indirect ECE vs. Wet Bulb Source Temp	Air distribution	Evaporative cooler	Indirect Evaporative Cooler	Observe variations in the indirect evaporative cooler performance as the source wet bulb temperature varies.
99	Direct Evaporative Cooler Temp out vs. Temp in	Air distribution	Evaporative cooler	Direct evaporative cooler	Observe the relationship between the outlet and inlet dry bulb temperatures across a direct evaporative cooler.
100	Direct Evap Cooler Enthalpy out vs. Enthalpy in	Air distribution	Evaporative cooler	Direct evaporative cooler	Observe the relationship between the outlet and inlet enthalpy across a direct evaporative cooler.
101	Direct Evaporative Cooler rh out vs. rh in	Air distribution	Evaporative cooler	Direct evaporative cooler	Observe the relationship between the outlet and inlet relative humidity across a direct

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
					evaporative cooler.
144	Evaporative Indirect T Inlet-T Outlet vs. Hour	Air distribution	Evaporative cooler	Indirect evaporative cooler	Daily variations in the delta T across an indirect evaporative cooler.
145	Evaporative Indirect T Inlet-T Outlet vs. T Inlet	Air distribution	Evaporative cooler	Evaporative cooler	Relationship between the delta T across an indirect evaporative cooler and the inlet temperature.
146	Evap. Indirect/Direct TInlet-TOutlet vs. Hour	Air distribution	Evaporative cooler	Evaporative cooler	Daily variations in the delta T across an indirect-direct evaporative cooler.
147	Evap. Indirect/Direct TInlet-TOutlet vs. TInlet	Air distribution	Evaporative cooler	Evaporative cooler	Relationship between the delta T across an indirect-direct evaporative cooler and the inlet temperature.
148	Evap. Indirect/Direct TInlet-TOutlet v TInletWB	Air distribution	Evaporative cooler	Evaporative cooler	Relationship between the delta T across an indirect-direct evaporative cooler and the inlet wet bulb temperature.
149	Evaporative Direct T Inlet-T Outlet vs. Hour	Air distribution	Evaporative cooler	Evaporative cooler	Daily variations in the delta T across a direct evaporative cooler.
150	Evaporative Direct T Inlet-T Outlet vs. T Inlet	Air distribution	Evaporative cooler	Evaporative cooler	Relationship between the delta T across a direct evaporative cooler and the inlet dry bulb temperature.
151	Evap. Indirect T Inlet-T Outlet vs. T Inlet WB	Air distribution	Evaporative cooler	Evaporative cooler	Relationship between the delta T across a direct evaporative cooler and the inlet wet bulb temperature.
152	Evap. Indirect/Direct ECE v TInlet	Air distribution	Evaporative cooler	Evaporative cooler	Variations in the indirect-direct evaporative cooler performance as the inlet dry bulb temperature varies.
153	Evap. Indirect/Direct ECE v TWB ambient	Air distribution	Evaporative cooler	Evaporative cooler	Variations in the indirect-direct evaporative cooler performance as the inlet wet bulb temperature varies.
154	Evap. Indirect/Direct TOutlet v TInlet	Air distribution	Evaporative cooler	Evaporative cooler	Outlet and inlet dry bulb temperatures across a direct-indirect evaporative cooler.
31	Relative Humidity vs. Hour	Air distribution	Humidifier (or dehumidifier)	Humidifier or dehumidifier	Determine proper operation of the humidifier
32	Humidity Ratio Humidified Air vs. Humidity Ratio Supply Air	Air distribution	Humidifier (or dehumidifier)	Humidifier or dehumidifier	Determine proper operation of the humidifier
17	Heating Air Flow vs. Hour	Air distribution	Scheduling, static pressure & fan control	Air distribution system	Determine proper heating supply fan operation.
18	Supply Air Flow vs. Hour	Air distribution	Scheduling, static pressure & fan control	Air distribution system	Determine proper fan operation.
79	Total Heating Supply Fan Power vs. Hour	Air distribution	Scheduling, static pressure & fan control	Dual duct	Determine the schedule of the hot deck air distribution system fan and variations in the hot deck supply fan power.
80	Total Cooling Supply Fan Power vs. Hour	Air distribution	Scheduling, static pressure & fan control	Dual duct	Determine the schedule of the cold deck air distribution system fan and variations in the cold deck supply fan power.
48	Static Pressure vs. Hour (Variable Air Volume Systems	Air distribution	Static pressure & fan control	VAV systems with static pressure control	Determine the proper operation of the VAV fan controls.
52	Supply Fan Power vs. Hour	Air distribution	Static pressure & fan control	Air distribution system	Determine the schedule of the air distribution system supply fan and magnitude of the variations in the air distribution

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
					system supply fan power.
53	Return Fan Power vs. Hour	Air distribution	Static pressure & fan control	Return fan	Determine the schedule of the air distribution system return fan and magnitude of the variations in the air distribution system return fan power.
54	Exhaust Fan Power vs. Hour	Air distribution	Static pressure & fan control	Exhaust fan	Determine the schedule of the air distribution system exhaust fan and magnitude of the variations in the air distribution system exhaust fan power.
96	Supply Fan Power vs. Flow	Air distribution	Static pressure & fan control	VAV or DDVAV	Checking the validity of power and / or flow measurements.
98	Return Fan Power vs. Supply Fan Power	Air distribution	Static pressure & fan control	Return fan	Determine if the return fan properly tracks the supply fan.
41	Static Pressure vs. Cooling Air Flow	Air distribution	Static pressure and fan control	VAV systems with static pressure control	Determine the proper operation of the VAV fan controls.
42	Static Pressure vs. Heating Air Flow	Air distribution	Static pressure and fan control	VAV systems with static pressure control	Determine the proper operation of the VAV fan controls.
156	Supply Air Temp. - Mixed Air Temp. vs. Hour	Air distribution	System performance	Air distribution system	Temperature difference across the cooling (and heating, if present) coils throughout the day.
157	Supply Air T - Mixed Air T vs. Supply Air Flow	Air distribution	System performance	VAV	Temperature difference across the cooling (and heating, if present) coils as the supply air flow varies.
2	Heating vs. hour	Air distribution	Temperature control	Dual duct system	Shows the daily heating profile for the hot deck of a dual duct air distribution system.
23	Cooling Air Temperature vs. Ambient Air Temperature	Air distribution	Temperature control	Cooling supply air reset on ambient	Determine proper operation of cooling supply air temperature reset controls.
24	Heating Air Temperature vs. Ambient Air Temperature	Air distribution	Temperature control	Central heating coil; no terminal heating	Determine proper operation of the control of heating air supply temperature reset on outside air.
25	Supply Air Temperature vs. Zone Air Temp.	Air distribution	Temperature control	Cooling supply air reset on zone air	Determine proper operation of the control of supply air temperature reset on zone air.
26	Supply Air Temperature vs. Return Air Temp.	Air distribution	Temperature control	Cooling supply air reset on return air	Determine proper operation of the control of supply air temperature reset on return air.
28	Supply Air Temperature vs. Hour	Air distribution	Temperature control	Multiple-zone system	Determine how the cold deck supply air temperature varies throughout the day.
29	Heating Supply Air Temperature vs. Hour	Air distribution	Temperature control	Multiple-zone system	Determine how the hot deck supply air temperature varies throughout the day.
34	Zone Supply Air Temp vs. Hour	Air distribution	Terminal system operation	1) Dual duct and multizone systems2) VAV with zone mixing dampers and reheat	Determine proper operation of zone mixing dampers.
35	Zone Air Velocity vs. Hour	Air distribution	Terminal system operation	1) Constant volume2) VAV mixing boxes3) Fan-powered boxes with reheat	Determine if the zone is receiving sufficient air flow.
4	Hot Water Supply Temp vs. Ambient Temp.	Boiler	Hot water temperature control	Boiler	Determine proper operation of the control of hot water supply temperature reset on outside air.
5	Hot Water Delta T vs. Ambient Air Temp.	Boiler	Hot water temperature control	Boiler	Determine proper operation of the boiler.
92	Total Boiler Stage Power vs. Ambient Temp	Boiler	Hot water temperature control	Boiler	Determine how the boiler electrical demand modulates in response to ambient

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
					temperature.
49	HW Pump Power vs. Hour	Boiler	Scheduling	Boiler	Determine the schedule of the hot water supply pump.
91	Total Boiler Stage Power vs. Hour	Boiler	Scheduling	Boiler	Determine how the boiler electrical demand varies throughout the day.
102	Hot Water Circulation Pump Pwr vs. Ambient Temp	Boiler	Scheduling	Boiler	Determine if the hot water circulation pump is operating according to the ambient temperature schedule.
103	Hot Water Circulation Pump Pwr vs. Hour	Boiler	Scheduling	Boiler	Determine the schedule of the hot water circulation pump and magnitude of the variations in the hot water circulation pump power.
7	Total Cooling vs. Hour	Chiller	CHW temperature control	Chiller	Determine proper operation of the control of ~~hot chilled~~ water supply temperature reset on outside air.
22	Chilled Water Supply Temperature vs. Ambient Air Temperature	Chiller	CHW temperature control	Chiller	Determine proper chilled water temperature control.
62	Chilled Water Delta T vs. Hour	Chiller	CHW temperature control	Chiller	Observe variations in the chiller delta temperature throughout the day.
133	Chilled Water Supply vs. Hour	Chiller	CHW temperature control	Chiller	Hourly variation in the temperature of the chilled water supplied to the load throughout the day.
51	Total Condenser Pump Power vs. Ambient Temp	Chiller	Heat rejection	Water cooled condensers	Determine if the condenser pump power is related to ambient temperature.
50	CHW Pump Power vs. Hour	Chiller	Scheduling	Chiller	Determine the schedule of the chilled water supply pump.
45	Compressor Power vs. Ambient Air Temp.	Chiller, DX cooling plant	Performance	Mechanical cooling	Determine if cooling plant compressor is able to 1) modulate in response to outdoor temperature fluctuations and 2) meet the existing cooling loads
10	Mechanical Cooling vs. Hour	Chiller, DX cooling plant	Scheduling, Performance	Mechanical cooling	Determine if the cooling equipment 1) is turning off during unoccupied times and 2) is able to meet the existing cooling loads.
165	Cooling Tower Fan Power vs. Chiller Condenser Pump Power	Cooling tower	Interlock	Cooling Tower	Determine if the cooling tower fans are properly interlocked with the chiller condenser pump
164	Cooling Tower Fan Power vs. Hour	Cooling tower	Scheduling, Temperature control	Cooling Tower	Schedule of the cooling tower fan, Magnitude of the variations in the cooling tower fan power.
38	Clg. Tower Range vs. Hour	Cooling tower	Temperature control	Cooling tower	Observe variations in the cooling tower range throughout the day.
39	Clg. Tower Range vs. Ambient Temp	Cooling tower	Temperature control	Cooling tower	Observe how the cooling tower range varies with the ambient temperature.
57	Cooling Tower Approach vs. Ambient Wet Bulb Temperature	Cooling tower	Temperature control	Cooling Tower	Observe variations in approach as wet bulb temperature varies.
58	Clg Tower Approach vs. Ambient Temp	Cooling tower	Temperature control	Cooling Tower	Observe variations in approach as the ambient dry bulb temperature varies.
59	Clg. Tower Fan Power vs. Ambient Temp	Cooling tower	Temperature control	Cooling tower	Observe variations in the cooling tower fan usage as the

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
					ambient dry bulb temperature varies.
60	Clg. Tower Pump Power vs. Ambient Temp	Cooling tower	Temperature control	Closed loop cooling tower with dedicated circulation pump	Observe variations in the cooling tower pump usage as the ambient dry bulb temperature varies.
61	Cooling Tower Sump Temperature vs. Ambient Wet Bulb Temperature	Cooling tower	Temperature control	Cooling Tower	Observe variations in the cooling tower sump temperature as the ambient wet bulb temperature varies.
111	Range vs. Ambient Wet Bulb Temp	Cooling tower	Temperature control	Cooling tower	Observe how the cooling tower range varies with the ambient temperature.
112	Cooling Tower Fan Power vs. Sump Temp	Cooling tower	Temperature control	Cooling tower	Determine if the cooling tower fan is cycling to properly maintain sump temperature.
64	Condenser Approach vs. Ambient Wet Bulb Temp	DX cooling plant	Heat rejection	Evaporative condenser	Observe the approach temperature of evaporative condensers as the wet bulb temperature varies.
65	Condenser Approach vs. Ambient Temperature	DX cooling plant	Heat rejection	Evaporative condenser	Observe variations in approach as the ambient dry bulb temperature varies.
66	Condenser Fan Power vs. Ambient Temp	DX cooling plant	Heat rejection	DX Cooling	Observe variations in the condenser fan usage as the ambient dry bulb temperature varies.
67	Condenser Sump Temp vs. Ambient Wet Bulb Temp	DX cooling plant	Heat rejection	Evaporative condenser	Observe variations in the evaporative condenser sump temperature as the ambient wet bulb temperature varies.
105	Compressor Power vs. Supply Fan Power	DX cooling plant	Interlock	DX Cooling	Determine if the compressor is properly interlocked with the supply fan.
106	Condenser Pump Power vs. Compressor Power	DX cooling plant	Interlock	DX Cooling	Determine if the condenser pump is properly interlocked with the compressor.
107	Condenser Fan Power vs. Compressor Power	DX cooling plant	Interlock	DX Cooling	Determine if the condenser fan is properly interlocked with the compressor.
104	Compressor Power vs. Hour	DX cooling plant	Scheduling	DX Cooling	Determine the schedule of the compressor and magnitude of the variations in compressor power.
63	Condenser Fan Power vs. Hour	DX cooling plant	Scheduling, Interlock	DX cooling	Determine the schedule of the condenser fan and magnitude of the variations in the cooling system condenser fan power.
109	Condenser Fan Power vs. Sump Temp	DX cooling plant	Scheduling, Operating modes	Evaporative Condenser	Determine if the evaporative condenser fan is cycling to properly maintain sump temperature.
110	Condenser Fan Power vs. Hour	DX cooling plant	Scheduling, Operating modes	DX cooling	Determine the schedule of the condenser fan and magnitude of variations in the condenser fan power.
56	Ambient Temperature vs. Hour	General	Ambient temperature	None	Shows the daily ambient temperature profiles for the monitoring period.
83	Heat Pump Backup Power vs. Source Temp	Heat pump	Backup heat	Air-air heat pump	Determine how the heat pump backup heat modulates in response to source temperature.
84	Heat Pump Backup Power vs. Hour	Heat pump	Backup heat	Air-air heat pump	Determine when the heat pump backup heat is being used.
155	Source Fan Power vs.	Heat pump	Cycling, Performance	Air-air heat pump	Observe the source fan

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
	Ambient Temp				staging.
85	Heat Pump Source Fan Power vs. Compressor Pwr	Heat pump	Interlock	Air-air heat pump	Determine if the source fan is properly interlocked with the heat pump compressor.
87	Heat Pump Source Pump Power vs. Compressor Pwr	Heat pump	Interlock	Air-air heat pump	Determine if the source pump is properly interlocked with the heat pump compressor.
72	Single Zone Heat Pump Power vs. Source Temp	Heat pump	Performance	Heat Pump	Determine how the heat pump modulates in response to source temperature.
73	Single Zone Heat Pump Power vs. Zone Temp	Heat pump	Performance	Air-air heat pump	Determine how the heat pump modulates in response to zone temperature
89	Heat pump Power vs. Ambient Temp	Heat pump	Performance	Air-air heat pump	Determine how the heat pump modulates in response to ambient temperature.
86	Heat Pump Source Fan Power vs. Hour	Heat pump	Scheduling	Air-air heat pump	Determine the schedule of the heat pump source pump and magnitude of the variations in the heat pump source pump power.
88	Heat Pump Source Pump Power vs. Hour	Heat pump	Scheduling	Water source heat pump	Determine the schedule of the heat pump source pump and magnitude of the variations in the heat pump source pump power.
90	Heat pump Power vs. Hour	Heat pump	Scheduling	Heat pump	Determine when the heat pump is being used.
95	SZHP Compressor Power vs. Hour	Heat pump	Scheduling	Heat pump	Determine when the heat pump is being used.
136	Cir Pmp Pwr vs. Compressor Power	Thermal energy storage	Interactions	Ice harvester systems	Determines if the circulation pump and compressor interlocks are operating properly.
134	Brine Pump Power vs. Compressor Power	Thermal energy storage	Interlock	Ice harvester systems	Determine if the brine pump and compressor are properly interlocked.
135	Cir Pmp Pwr vs. Hour	Thermal energy storage	Interlock	Ice harvester systems	For determining the ice harvester cooling delivery schedule.
132	Delta T Storage vs. Hour	Thermal energy storage	Operational modes	Thermal Energy Storage	Temperature difference between the storage inlet and outlet.
137	Chiller Temperature Inlet vs. Hour	Thermal energy storage	Operational modes	Thermal energy storage	Inlet temperature variation throughout the day, especially during the charge mode.
138	Chiller Temperature Outlet vs. Hour	Thermal energy storage	Operational modes	Thermal energy storage	Chiller outlet temperature variations throughout the day.
139	Chiller Delta T vs. Hour	Thermal energy storage	Operational modes	Thermal energy storage	Variation in the chiller temperature drop throughout the day.
141	Temperature Tank Outlet vs. Hour	Thermal energy storage	Operational modes	Thermal energy storage	Variation of the storage tank outlet temperature throughout the day.
142	Temperature Storage Outlet vs. Hour	Thermal energy storage	Operational modes	Thermal Energy Storage	Hourly variation in the storage outlet temperature.
140	Temperature Storage Outlet vs. Ambient Temp	Thermal energy storage	Scheduling	Thermal energy storage	Correlation between ambient temperature and the storage outlet temperature.
77	Boiler delta T vs. Water Loop Inlet Temperature	Water loop heat pump	Backup heat	Water loop heat pump	Determine if the boiler is properly responding to variations in the water loop inlet temperature.
78	Cooling Tower Range vs. Water Loop Inlet Temp	Water loop heat pump	Heat rejection	Water loop heat pump	Cooling tower response to variations in the water loop inlet temperature.

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
93	SZHP Tot Unit Pwr vs. Water Loop Circ Pump Pwr	Water loop heat pump	Interlock	Water loop heat pump	Determine if the water loop circulation pump is properly interlocked with the heat pump.
94	SZHP Compressor Pwr vs. Water Loop Circ Pump Pwr	Water loop heat pump	Interlock	Water loop heat pump	Determine if the water loop circulation pump is properly interlocked with the heat pump.
75	Water Loop Cooling Tower Range vs. Boiler deltaT	Water loop heat pump	Water temperature control	Water loop heat pump	Observe the interactions between the cooling tower and boiler control.
76	Water Loop Outlet Temperature vs. Hour	Water loop heat pump	Water temperature control	Water loop heat pump	Observe the variations in the water loop outlet temperature throughout the day.
116	Total Power vs. Hour	Zone	Schedule , Terminal system operation	Fan coils	Determine fan coil schedule and magnitude of the variations in the fan coil power.
159	Baseboard Temperature vs. Zone Temp	Zone	Scheduling, Simultaneous heating/cooling	Electric baseboard heating	Response of an electric baseboard heater to variations in zone temperature
160	Baseboard Current vs. Hour	Zone	Scheduling, Simultaneous heating/cooling	Electric baseboard heating	Performance of the an electric baseboard heater throughout the day.
158	Baseboard Temperature vs. Hour	Zone	Scheduling, Temperature control	Electric baseboard heating	Performance of an electric baseboard heater throughout the day.
121	Fan Power vs. Hour	Zone	Scheduling, zone temperature control	Fan coils	Determine the schedule of the fan coil unit
33	Zone Supply Air Temp vs. Hour	Zone	Temperature control	Air distribution system	Displays how the supply temperature to the zone varies through the day.
27	Fan Coil Air Temp vs. Zone Air Temp.	Zone	Terminal system operation	Fan coils	Determine proper operation of heating fan coil unit.
47	Baseboard Delta T vs. Ambient Air Temperature	Zone	Terminal system operation	Hydronic baseboards	Determine proper operation of hydronic baseboard heating systems.
55	Radiant Panel Temperature vs. Hour	Zone	Terminal system operation	Radiant panel heating	Determine the schedule of the radiant panel heating
114	Zone Supply Air Temp vs. Zone Velocity	Zone	Terminal system operation	VAV	Determine if the VAV box and reheat system are modulating properly.
115	Zone Velocity vs. Zone Temp	Zone	Terminal system operation	VAV	Determine if the VAV box and reheat system are modulating in response to the zone temperature.
117	Total Power vs. Zone Temperature	Zone	Terminal system operation	Fan coils with backup heat	Determine how the fan coil unit and backup heat modulate in response to zone temperature.
118	Total Power vs. Ambient Temperature	Zone	Terminal system operation	Fan coils with backup heat	Determine how the fan coil unit and backup heat modulate in response to ambient temperature.
119	Backup Power vs. Hour	Zone	Terminal system operation	Fan coils with backup heat	Determine when the fan coil unit backup heat is being used.
120	Backup Power vs. Zone Temperature	Zone	Terminal system operation	Fan coils with backup heat	Determine how the fan coil unit backup heat modulates in response to zone temperature.
123	Temperature Pipe Inlet vs. Hour	Zone	Terminal system operation	Two pipe fan coils	Determine how the pipe inlet temperature varies during day.
124	Pipe Delta Temperature vs. Hour	Zone	Terminal system operation	Two pipe fan coils	Determine how the pipe delta temperature varies during day.
125	Pipe Delta Temperature vs. Tzone	Zone	Terminal system operation	Two pipe fan coils	Determine if the delta temperature varies with zone temperature.
126	Temperature HW Pipe Inlet vs. Hour	Zone	Terminal system operation	Four-pipe fan coils	Determine how the pipe inlet temperature varies during day.
127	HW Pipe Delta Temperature vs. Hour	Zone	Terminal system operation	Hydronic heating	Determine if the pipe delta temperature varies during day.

Plot No.	Plot Label	System Category	Diagnostic Category	Limitation on Applicability	Plot Description/ Diagnostic Value
128	HW Pipe Delta Temperature vs. Zone Temperature	Zone	Terminal system operation	Four-pipe fan coils	Determine if the delta temperature varies with zone temperature.
129	Temperature CHW Pipe Inlet vs. Hour	Zone	Terminal system operation	Four-pipe fan coils	Determine how the pipe inlet temperature varies during day.
130	CHW Pipe Delta Temperature vs. Hour	Zone	Terminal system operation	Four-pipe fan coils	Determine if the pipe delta temperature varies during day.
131	CHW Pipe Delta Temperature vs. Zone Temperature	Zone	Terminal system operation	Four-pipe fan coils	Determine if the delta temperature varies with zone temperature.
36	Zone Temperature vs. Hour	Zone	Zone temperature control	None	Determine if proper room temperature is being maintained..
37	Zone Temp. vs. Inlet Temp	Zone	Zone temperature control	Air system	Determine the stratification of the zone air.
122	Fan Power vs. Zone Temperature	Zone	Zone temperature control	Fan coils	Determine how the fan coil unit modulates in response to zone temperature fluctuations.