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# Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools

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**A Report of Task 22, Subtask D  
Building Energy Analysis Tools  
Project D Empirical Validation**

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# Table of Contents

List of Tables .....	iii
List of Figures .....	iv
List of Figures .....	iv
PREFACE: INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY .....	v
BACKGROUND .....	v
SOLAR HEATING AND COOLING PROGRAM .....	v
Task 22: Building Energy Analysis Tools .....	vii
Goal and objectives of the task .....	vii
Scope of the task .....	vii
Means .....	viii
Participants .....	viii
Executive Summary .....	ix
Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools .....	1
1. Introduction .....	1
1.1. Background and Motivation for the work .....	1
1.2. Overview of the Energy Resource Station .....	1
1.3. Overview of the Testing Conducted .....	2
1.4. Overview of the Simulation Tools Used in the Study and Participating Organizations .....	3
1.5. Analysis procedure .....	3
1.5.1. Standard numerical summary .....	3
1.5.2. Comparative statistics .....	4
2. Economizer Test 1 .....	6
2.1. Description of the exercise .....	6
2.1.1. Run period and general weather conditions .....	6
2.1.2. Test rooms operation and control parameters .....	7
2.1.2.1. Internal loads and general room conditions .....	7
2.1.2.2. Room-level HVAC controls specifications .....	8
2.1.3. System-level HVAC operation and control .....	8
2.1.3.1. Air handling unit control and specifications .....	8
2.1.3.2. Economizer controls specifications .....	10
2.2. Comparison between experimental results and simulation results .....	11
2.2.1. Weather data .....	12
2.2.2. Economizer controlled system results .....	14
2.2.2.1. System level results for the “A” system .....	14
2.2.2.2. System level results for the “B” system .....	20
3. Economizer Test 2 .....	25
3.1. Description of the exercise .....	25
3.1.1. Run period and general weather conditions .....	25
3.1.2. Test rooms operation and control parameters .....	25
3.1.2.1. Internal loads and general room conditions .....	25
3.1.2.2. Room-level HVAC controls specifications .....	26
3.1.3. System-level HVAC operation and control .....	27
3.1.3.1. Air handling unit control and specifications .....	27
3.1.3.2. Economizer control specifications .....	28
3.2. Comparison between experimental results and simulation results .....	29

3.2.1. Weather data .....	29
3.2.2. Economizer controlled system results .....	32
3.2.2.1. System level results for the “A” system .....	32
3.2.2.2. System level results for the “B” system.....	37
4. Economizer Test 3 .....	41
4.1. Description of the exercise.....	41
4.1.1. Run period and general weather conditions.....	41
4.1.2. Test rooms operation and control parameters.....	41
4.1.2.1. Internal loads and general room conditions .....	42
4.1.2.2. Room-level HVAC controls specifications .....	42
4.1.3. System-level HVAC operation and control .....	43
4.1.3.1. Air handling unit controls and specifications .....	43
4.2.3.2. Economizer control specifications.....	45
4.2. Comparison between experimental results and simulation results .....	45
4.2.1. Weather data .....	45
4.2.2. Economizer controlled system results .....	48
4.2.2.1. System level results for the “A” system .....	48
4.2.2.2. System level results for the “B” system.....	53
5. Conclusions.....	58
Appendix A Energy Resource Station Specification .....	59
A.1. Input for the load calculations.....	59
A.1.1. Run Period.....	59
A.1.2. Weather data .....	59
A.1.3. Building Location .....	60
A.1.4. Building Shade.....	60
A.1.5. Floor Plan.....	60
A.1.6. Construction layer description .....	62
A.1.6.1. Layer type identification .....	62
A.1.6.2. Layer description.....	62
A.1.7. Window type and description .....	65
A.1.8. Space Description .....	65
A.1.8.1. Space identification.....	65
A.1.8.2. Space description .....	67
A.1.9. Test rooms operations .....	70
A.2. Input for system model .....	71
Appendix B Uncertainty Analysis .....	73
B.1 Calibration Information.....	73
B.2 Corrected Data.....	75
B.3 Propagation of Error.....	78
Appendix C Hourly Averaged Experimental Data .....	80
C.1. Weather Data.....	80
C.2. Hourly averaged data .....	80
C.3. Air Handling Unit Data.....	81
C.4. Test Room Data.....	82
Appendix D Modelers’ Reports .....	84
References.....	88

## List of Tables

Table 1.1 Test Cases .....	2
Table 1.2 Participants.....	3
Table 1.3 Output Data.....	3
Table 2.1 Lighting and baseboard power for each test room, in Watts. ....	7
Table 2.2 Lighting and first stage baseboard heating schedules for all test rooms. ....	7
Table 2.3 Test room set-point temperatures and airflow rates.....	8
Table 2.4 Minimum outside airflow rate. ....	11
Table 2.5 Statistical comparison of weather parameters. ....	12
Table 2.6 Statistical comparison of AHU-A parameters. ....	16
Table 2.7 Statistical comparison of additional AHU-A parameters. ....	18
Table 2.8 Statistical comparison of AHU-B parameters. ....	21
Table 2.9 Statistical comparison of additional AHU-B parameters. ....	23
Table 3.1 Lighting and baseboard power for each test room, in Watts. ....	26
Table 3.2 Lighting and first stage baseboard heating schedules for all test rooms. ....	26
Table 3.3 Test room set-point temperatures and airflow rates.....	27
Table 3.4 Statistical comparison of weather parameters .....	30
Table 3.5 Statistical comparison of AHU-A parameters .....	33
Table 3.6 Statistical comparison of additional AHU-A parameters. ....	35
Table 3.7 Statistical comparison of AHU-B parameters. ....	37
Table 3.8 Statistical comparison of additional AHU-B parameters. ....	39
Table 4.1 Lighting and baseboard power for each test room, in Watts. ....	42
Table 4.2 Lighting and first stage baseboard heating schedules for all test rooms .....	42
Table 4.3 Test room set-point temperatures and airflow rates.....	43
Table 4.4 Statistical comparison of weather parameters. ....	46
Table 4.5 Statistical comparison of AHU-A parameters. ....	49
Table 4.6 Statistical comparison of additional AHU-A parameters. ....	51
Table 4.7 Statistical comparison of AHU-B parameters. ....	54
Table 4.8 Statistical comparison of additional AHU-B parameters. ....	56
Table A.1 Identification of construction layers used in the ERS building .....	62
Table A.2 Thickness and thermal properties used for construction layers .....	63
Table A.3 Window identification and its characteristics with size.....	66
Table A.4 Identification of plenum and conditioned space .....	66
Table A.5 Description of the space and details of its six surfaces.....	68
Table B.1 Summary of the fit for the temperature calibration.....	74
Table B.2 Analysis of variance for the temperature calibration. ....	74
Table B.3 Parameter estimates for the temperature calibrations. ....	74
Table B.4 Summary of the fit for the airflow rate correction. ....	76
Table B.5 Analysis of variance for the airflow correction.....	77
Table B.6 Parameter estimates for the airflow correction. ....	77
Table B.7 Statistical parameters for uncertainty bound calculations for zone airflow rates. ....	78
Table B.8 Accuracy of ERS instrumentation.....	79
Table C.1 Fields modified in the TMY weather files .....	80
Table C.2 AHU System A and System B Nomenclature.....	82
Table C.3 Test rooms (East, South, West, Interior) nomenclature .....	83

## List of Figures

Figure 2.1 Supply fan power as function of airflow rate. ....	9
Figure 2.2 Economizer control sequence.....	10
Figure 2.3 Weather parameters.....	13
Figure 2.4 AHU-A parameters.....	17
Figure 2.5 Additional AHU-A parameters.....	19
Figure 2.6 AHU-B parameters.....	22
Figure 2.7 Additional AHU-B parameters.....	24
Figure 3.1 Supply fan power as function of airflow rate. ....	28
Figure 3.2 Economizer control sequence.....	29
Figure 3.3 Weather parameters.....	31
Figure 3.4 AHU-A parameters.....	34
Figure 3.5 Additional AHU-A parameters.....	36
Figure 3.6 AHU-B parameters.....	38
Figure 3.7 Additional AHU-B parameters.....	40
Figure 4.1 Supply fan power as function of airflow rate. ....	44
Figure 4.2 Economizer control sequence.....	45
Figure 4.3 Weather parameters.....	47
Figure 4.4 AHU-A parameters.....	50
Figure 4.5 Additional AHU-A parameters.....	52
Figure 4.6 AHU-B parameters.....	55
Figure 4.7 Additional AHU-B parameters.....	57
Figure A.1 A floor plan of the Energy Resource station .....	61
Figure A.2(a) Geometry presentation for plenum spaces .....	67
Figure A.2(b) Geometry presentation for conditioned spaces .....	67
Figure A.3 Air handling unit.....	71
Figure A.4 Zone level HVAC system.....	72
Figure B.1 Hart temperature versus RTD temperature with 95% uncertainty bounds.....	73
Figure B.2 East “A” test room airflow rate correction curve. ....	76
Figure C.1 Air handling unit schematic.....	81
Figure C.2 Test Room HVAC Schematic.....	83

# **PREFACE: INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY**

## **BACKGROUND**

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 24 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development, and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security, and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation, and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centers.

## **SOLAR HEATING AND COOLING PROGRAM**

The Solar Heating and Cooling Program was one of the first IEA Implementing Agreements to be established. Since 1977, its 21 members have been collaborating to advance active solar, passive solar, and photovoltaic technologies and their application in buildings.

The members are:

Australia	France	Norway
Austria	Germany	Portugal
Belgium	Italy	Spain
Canada	Japan	Sweden
Denmark	Mexico	Switzerland
European Commission	Netherlands	United Kingdom
Finland	New Zealand	United States

A total of 30 Tasks have been initiated, 21 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities – working groups, conferences, and workshops – have been organized.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

**Completed Tasks:**

Task 1	Investigation of the Performance of Solar Heating and Cooling Systems
Task 2	Coordination of Solar Heating and Cooling R&D
Task 3	Performance Testing of Solar Collectors
Task 4	Development of an Insolation Handbook and Instrument Package
Task 5	Use of Existing Meteorological Information for Solar Energy Application
Task 6	Performance of Solar Systems Using Evacuated Collectors
Task 7	Central Solar Heating Plants with Seasonal Storage
Task 8	Passive and Hybrid Solar Low Energy Buildings
Task 9	Solar Radiation and Pyranometry Studies
Task 10	Solar Materials R&D
Task 11	Passive and Hybrid Solar Commercial Buildings
Task 12	Building Energy Analysis and Design Tools for Solar Applications
Task 13	Advanced Solar Low Energy Buildings
Task 14	Advanced Active Solar Energy Systems
Task 16	Photovoltaics in Buildings
Task 17	Measuring and Modeling Spectral Radiation
Task 18	Advanced Glazing and Associated Materials for Solar and Building Applications
Task 19	Solar Air Systems
Task 20	Solar Energy in Building Renovation
Task 21	Daylight in Buildings
Task 30	Solar Cities

**Current Tasks and Working Groups:**

Task 22	Building Energy Analysis Tools
Task 23	Optimization of Solar Energy Use in Large Buildings
Task 24	Solar Procurement
Task 25	Solar Assisted Cooling Systems for Air Conditioning of Buildings
Task 26	Solar Combisystems Working Group Materials in Solar Thermal Collectors
Task 27	Performance Assessment of Solar Building Envelope Components
Task 28	Solar Sustainable Housing
Task 29	Solar Crop Drying
Task 31	Daylight Buildings in the 21st Century

**Task 22: Building Energy Analysis Tools****Goal and objectives of the task**

The overall goal of Task 22 is to establish a sound technical basis or analyzing solar, low-energy buildings with available and emerging building energy analysis tools. This goal will be pursued by accomplishing the following objectives:

Assess the accuracy of available building energy analysis tools in predicting the performance of widely used solar and low-energy concepts;

Collect and document engineering models of widely used solar and low-energy concepts for use in the next generation building energy analysis tools; and

Assess and document the impact (value) of improved building analysis tools in analyzing solar, low-energy buildings, and widely disseminate research results tools, industry associations, and government agencies.

**Scope of the task**

This Task will investigate the availability and accuracy of building energy analysis tools and engineering models to evaluate the performance of solar and low-energy buildings. The scope of the Task is limited to whole building energy analysis tools, including emerging modular type tools, and to widely used solar and low-energy design concepts. Tool evaluation activities will include analytical, comparative, and empirical methods, with emphasis given to blind empirical validation using measured data from test rooms of full scale buildings. Documentation of engineering models will use existing standard reporting formats and procedures. The impact of improved building energy analysis will be assessed from a building owner perspective.

The audience for the results of the Task is building energy analysis tool developers and national building energy standards development organizations. However, tool users, such as architects, engineers, energy consultants, product manufacturers, and building owners and managers, are the ultimate beneficiaries of the research, and will be informed through targeted reports and articles.



## **Means**

In order to accomplish the stated goal and objectives, the Participants will carry out research in the framework of four Subtasks:

- Subtask A: Tool Evaluation
- Subtask B: Model Documentation
- Subtask C: Comparative Evaluation
- Subtask D: Empirical Evaluation

## **Participants**

The participants in the Task are: Australia, Canada, Finland, France, Germany, Spain, Sweden, Switzerland, United Kingdom, and United States. The United States serves as Operating Agent for this Task, with Michael J. Holtz of Architectural Energy Corporation providing Operating Agent services on behalf of the U.S. Department of Energy.

This report documents work carried out under Subtask D Empirical Validation.

## Executive Summary

Under the auspices of Task 22 of the International Energy Agency's Solar Heating and Cooling Program, three economizer tests were developed to evaluate the ability of whole-building energy analysis simulation programs to accurately model air-side economizer operation in a commercial building. A CD is also available with this report that contains all the data from the experiment, weather files in TMY format, and simulation inputs.

Three tests were conducted at the Energy Resource Station to obtain data sets for use in model validation of three methods of economizer control typically used in commercial buildings in a variable air volume system. Each test contains four days of data collection. The data sets include measured values of system-level and room-level parameters as well as local weather data necessary to construct weather files for use in the simulations.

This report documents the experimental facility used for the empirical validation exercises, the specifications for each test, and the comparisons between simulation results and experimental results. The two simulation programs that were used for this validation exercise were DOE2.1E and TRNSYS.

A significant finding of this work showed that building simulation programs do predict the proper amount of air flow entering the building when the economizer cycle is enabled; however, the simulation programs do not accurately predict the outdoor air flow rate for variable air volume systems that use a fixed outdoor air damper position when the economizer cycle is disabled. Based on user input, the models maintain a constant outside air flow rate into the building when the economizer cycle is disabled; however, in most commercial buildings, the outdoor air flow rate varied as much as 85% as the supply air flow rate changed to meet the building load. This variation is a result of changing pressures within the air handling unit as the supply air flow changes. Because the outdoor air dampers are in a fixed position, as the pressure in the air handling unit changes, the air flow rate across the dampers will change. If the outdoor air flow rate were monitored and controlled, the system could maintain a constant outdoor air flow rate.

# **Economizer Control Tests for the Empirical Validation of Building Energy Analysis Tools**

## **1. Introduction**

### **1.1. Background and Motivation for the work**

This project is an extension of the work completed in IEA Task 22, Subtask A. The main goal of this project is to assess the accuracy of building energy analysis tools in predicting the performance of a realistic commercial building with real operating conditions and HVAC equipment. Specifically, this project addresses the accuracy of building energy software to model air-side economizer cycles in a variable air volume system utilizing terminal reheat.

An air-side economizer (hereafter referred to as economizer) cycle is a control strategy where outdoor air is used in lieu of mechanical cooling to meet the building's cooling load. The cycle is active when outdoor air conditions are favorable for use as supply air without the need for further cooling or dehumidification.

Tests were conducted at the Energy Resource Station facility to obtain building HVAC system data for a variety of economizer control schemes. Concurrent with the system data, local weather data were recorded. The data sets provide modelers with empirical results with which to compare the output from building energy simulation software.

The rationale for the Iowa ERS validation exercise work is as follows:

- Completion of the Iowa ERS empirical validation study would address designer needs for greater confidence in software tools used to design and analyze passive solar buildings, because realistic commercial construction material and practices are considered.
- To properly evaluate the amount of “conventional” energy displaced by passive solar design and active solar mechanical equipment, it must be shown that simulations are properly and accurately modeling “conventional” mechanical equipment.
- The ERS exercises intends to create a suite of test cases for evaluating the capability of building energy analysis tools to model HVAC system and realistic commercial construction buildings.
- This exercise could complement the HVAC BESTEST and the IEA BESTEST because these cases are more realistic and more program assumptions and default values are tested.

### **1.2. Overview of the Energy Resource Station**

The Energy Resource Station (ERS) building is an excellent test facility for conducting empirical validation because it is representative of commercial construction practices and operating conditions.

The ERS is part of the Iowa Energy Center, a non-profit research and education organization funded through and by utilities operating in Iowa. The research portion of the facility has two identical HVAC systems referred to as “A” and “B.” Each system serves four test rooms, three of which have exterior exposures (East, South, and West) and one which is interior. The eight test rooms are often referred to as “paired” in that they are positioned side by side with a particular orientation. The test rooms on the East side of the building are referred to as “East A” and “East B”. Similar pairings exist for the South and West exposures as well as the interior space. Each “A” test room is served by the “A” air handling unit system and each “B” test room is served by the “B” air handling unit system. Each pair of rooms is identical in construction, but differ in that their floor plans are mirror images of each other.

The rooms can be configured to test a variety of HVAC, control and architectural strategies. It is the only public facility in the United States with the ability to simultaneously test full-scale commercial building systems. Detailed data can be collected on any aspect of mechanical and electrical system behavior. With the ability to simultaneously collect detailed weather information, the ERS offers a unique opportunity to have a highly controlled experimental setting for data collection required for simulation tool validation.

A description of the ERS is provided in Appendix A. This description should be sufficient for a modeler to create an input file for energy simulation.

### 1.3. Overview of the Testing Conducted

Three tests have been conducted in this facility to obtain data sets for use in model validation of air-side economizer operation and the control strategies are shown in Table 1.1. Each test contains four days of data collection. The data sets include measured values of system-level and room-level parameters as well as local weather data necessary to construct weather files for use in the simulations.

Table 1.1 Test Cases

Case	Economizer control	Minimum outside air damper position, %
1	Return air temperature	20
2	Return air temperature	0
3	Return air enthalpy	0

Each test contains a different control method for economizer operation. In the first test, the minimum outdoor air damper position was set to 20% open, and the economizer was enabled when the outdoor air temperature was less than the return air temperature. For the second and third tests the minimum outdoor air damper position was set to 0% open. Thus, when the economizer mode was disabled there was no outside airflow into the system. For the second test, the economizer was enabled when the outdoor air temperature was less than the supply air temperature. For the third test, the economizer was enabled when the outdoor air enthalpy was less than the return air enthalpy.

## 1.4. Overview of the Simulation Tools Used in the Study and Participating Organizations

Two organizations participated in the validation exercises. Each organization used a different computer program. Table 1.2 identifies the organization and the simulation program used.

Table 1.2 Participants

Notation	Program	Implemented by.
DRESDEN	TRNSYS-TUD	Technical University of Dresden Dresden, Germany
IOWA	DOE2.1E	Iowa State University Ames, Iowa

## 1.5. Analysis procedure

An output format was defined, so each participant supplied the same hourly output data. The data considered are given in Table 1.3.

Table 1.3 Output Data

GLOBAL REPORT	
Description	Units
Outside Air Dry Bulb	°C
Outside Air Wet Bulb	°C
Direct Normal Solar Radiation	W/m <sup>2</sup>
Total Horizontal Solar Radiation	W/m <sup>2</sup>
SYSTEM REPORT	
Description	Units
Supply Air flow	m <sup>3</sup> /hr
Outside Air flow	m <sup>3</sup> /hr
Temp. of air entering cooling coil	°C
Temp. of air leaving cooling coil	°C
Temperature of return air	°C
Cooling coil energy input	W

Statistical parameters were used as the means for comparing simulation results to experimental results. In addition uncertainty analysis and propagation of error analysis of the experimental results was conducted in order to determine confidence limits for the experimental results. The statistical parameters calculated were divided into two general groups: standard numerical summary and comparative statistics.

### 1.5.1. Standard numerical summary

The standard numerical summaries are the parameters that describe results from an individual measurement or simulation program output. These parameters include: arithmetic mean,

standard deviation, and maximum and minimum values. These parameters were calculated for the experimental results as well as the building simulation results.

The arithmetic mean was calculated using the relationship defined by Equation 1.1.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (1.1)$$

where

$n$  is the number of samples.

$x_i$  is the individual value.

The sample standard deviation was calculated using the relationship defined by Equation 1.2.

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (1.2)$$

The maximum value was calculated using the following relationship defined by Equation 1.3

$$x_{max} = \max(x_i) \quad (1.3)$$

while the minimum value was calculated using the relationship defined by Equation 1.4.

$$x_{min} = \min(x_i). \quad (1.4)$$

## 1.5.2. Comparative statistics

Comparative statistics are used as a measure of the agreement between the outputs from the simulation programs to results obtained from ERS data. These quantities included: average difference, maximum and minimum differences, average absolute difference, and root mean squared difference.

The average difference is defined by Equation 1.5. This quantity provides relevant summary information about how well the results from the simulation programs compare with the empirical results.

$$\bar{D} = \frac{1}{n} \sum_{i=1}^n (E_i - P_i) \quad (1.5)$$

where:

$E_i$  is the measured experimental value at an instant in time.

$P_i$  is the predicted value for the building simulations, which corresponds to the measured value.

The maximum difference is defined by Equation 1.6. This quantity indicates the magnitude of the greatest error that was found between the experimental value and the simulation result.

$$D_{max} = \max |E_i - P_i| \quad (1.6)$$

The minimum difference is defined by Equation 1.7. This quantity indicates the magnitude of the smallest error that was found between the experimental value and the simulations results.

$$D_{\min} = \min|E_i - P_i| \quad (1.7)$$

The absolute average difference is the absolute value of the difference between the measured parameter at a given instance in time and value predicted by the building for that same instant in time normalized over the entire test. This quantity reflects how well the building simulation predicts hour-by-hour results compared to the empirical results. This quantity was calculated using the relationship defined by Equation 1.8.

$$|\overline{D}| = \frac{1}{n} \sum_{i=1}^n |E_i - P_i| \quad (1.8)$$

A root mean squared comparison is another valuable quantity when comparing the predicted results with the empirical results. This is a more conventional comparison that also accounts for differences without regard to positive or negative signs. This method also reflects how well the building simulation predicted hour-by-hour results compared with the experiment. The quantity was calculated using the relationship defined by Equation 1.9.

$$D_{rms} = \sqrt{\frac{1}{n} \sum_{i=1}^n (E_i - P_i)^2} \quad (1.9)$$

The error for the simulations was quantified in two different ways to quantify how the building simulations performed on an hour-by-hour analysis and over the duration of the experiments. Both parameters are important for the validation process. In the building design phase, where a simulation might be used to quantify energy savings by implementing or removing a hypothetical control scheme, it would be advantageous knowing that the building simulation does a good job predicting the annual energy usage. Whereas, in other instances, when looking at other quantities, it may be advantageous to know that the building simulation not only gives viable quantities for an annual, monthly, or weekly analyses, but also accurately predicts parameters on an hour-by-hour basis. The summary error, defined by Equation 1.10, is useful for comparing summary quantities.

$$SE = \frac{\sum_{i=1}^n (E_i - P_i)}{\sum_{i=1}^n E_i} \times 100\% \quad (1.10)$$

The instantaneous error, defined by Equation 1.11, is useful in comparing the experiment data with the predicted values at a given instant in time.

$$IE = \frac{\sum_{i=1}^n |E_i - P_i|}{\sum_{i=1}^n E_i} \times 100\% \quad (1.11)$$

## 2. Economizer Test 1

### 2.1. Description of the exercise

This section contains information regarding the operating parameters and conditions used for Economizer Test 1 conducted at the Energy Resource Station. The test was conducted over a four day period from May 2 through 5, 2002.

Internal heat loads for the test rooms were produced from lights and electric baseboard heaters. These were scheduled on during a portion of the day and off the remainder of the time. The windows of the test rooms did not have any blinds or drapes covering them thus allowing maximum solar heat gain.

Thermostats in the test rooms were programmed for a constant heating set-point temperature and a constant cooling set-point temperature. For non-test room spaces in the ERS that are adjacent to the test rooms, the zone thermostats were programmed with the same set-point temperatures as the test rooms. This reduces the possibility thermal interaction between the test rooms and the remainder of the building.

For this test, the “B” system was operated with the outdoor air dampers maintained at a fixed 20% open position, and the economizer cycle was disabled. The “A” system was operated with the minimum outdoor air damper position set to 20% open, and incorporated an economizer cycle based on return air temperature. Both systems were operated as variable air volume with hydronic terminal reheat at the zone level. The systems were run 24 hours per day and chilled water was available for mechanical cooling throughout the test period.

#### 2.1.1. Run period and general weather conditions

This item is used to specify the initial and final dates of the desired simulation period and also the general conditions and location of the ERS facility. The TMY weather file that accompanies this report has ERS weather station information only for the dates of the tests.

- Test dates: May 2 through May 5, 2002
- Weather data for the ERS is organized into TMY format. The weather file is called “IEA2002.tmy”.
- Building location
  - Latitude: 41.71 °N
  - Longitude: 93.61 °W
  - Altitude: 285.9 m (938 ft)
  - Time-zone: 6, Central time zone in U.S.
  - Daylight-saving: YES



## 2.1.2. Test rooms operation and control parameters

This item describes the operation and control of the test rooms that apply to this test.

### 2.1.2.1. Internal loads and general room conditions

The only internal heating loads used during this test are from ceiling mounted fluorescent lights and baseboard electric heaters. These internal loads were scheduled “ON” for only certain hours during the day. The baseboard heaters have two stages of heat; however, for this test, only the first stage of baseboard heat was used. Due to variations in the installed equipment, the baseboard power is not identical for each unit. Furthermore, slight variations also exist for the lighting power. Table 2.1 provides power values for the lights and baseboard heaters for each test room.

Table 2.1 Lighting and baseboard power for each test room, in Watts.

Room	Stage 1	Stage 2	Lights
East A	890	890	536.0
East B	890	880	536.0
South A	890	880	531.0
South B	880	890	536.5
West A	860	860	530.5
West B	890	890	526.5
Interior A	870	900	530.0
Interior B	900	900	535.0

Table 2.2 provides the schedule for the operation of the lights and the first stage of baseboard heat used in this test. The time represents the beginning of each hour where 1 represents 1 AM and 24 represents midnight.

Table 2.2 Lighting and first stage baseboard heating schedules for all test rooms.

Hour	Lights	Stage 1 Baseboard	Hour	Lights	Stage 1 Baseboard
1	OFF	ON	13	ON	ON
2	OFF	ON	14	ON	ON
3	OFF	ON	15	ON	ON
4	OFF	ON	16	ON	ON
5	OFF	ON	17	ON	ON
6	OFF	ON	18	ON	ON
7	ON	ON	19	OFF	ON
8	ON	ON	20	OFF	ON
9	ON	ON	21	OFF	ON
10	ON	ON	22	OFF	ON
11	ON	ON	23	OFF	ON
12	ON	ON	24	OFF	ON

### 2.1.2.2. Room-level HVAC controls specifications

Space temperature conditions were maintained by utilizing variable airflow rates (VAV) for space cooling and hydronic reheat for space heating. The cooling and heating set-point temperatures were the same for all test rooms and their values remained fixed throughout the test.

In heating mode the terminal unit operates at a prescribed minimum airflow rate, and the two-way hot water control valve modulates in response to the zone heating needs. In cooling mode, the two-way hot water control valve is closed, and the terminal unit modulates the primary supply airflow rate in response to the zone cooling needs. In addition to a minimum airflow rate, each unit has a maximum airflow rate. The values of these airflow rates depend on whether the room is an exterior room or an interior room. Table 2.3 provides values for the temperature set points and airflow rates for the test rooms.

Table 2.3 Test room set-point temperatures and airflow rates.

Test room location	Heating Set-point temperature, °C	Cooling set-point temperature, °C	Minimum airflow rate, m <sup>3</sup> /hr	Maximum airflow rate, m <sup>3</sup> /hr
Interior	22.2	22.8	340	680
Exterior	22.2	22.8	340	1,699

### 2.1.3. System-level HVAC operation and control

The items in this section describe how the air handling units were configured for the tests. The economizer control was enabled on the “A” system while the “B” system maintained the fixed minimum damper position. Besides the economizer control on the “A” system, the systems were configured identically.

#### 2.1.3.1. Air handling unit control and specifications

The system controls were configured as follows:

- Heating schedule: always available.
- Cooling schedule: always available.
- Cooling control supply air temperature set point after the fan: 15 °C.
- Preheat: NOT available.
- Humidity control: NOT available.
- Economizer: enabled when the return air temperature exceeded the outdoor air temperature for the “A” system.

The system air for both the “A” and the “B” systems was specified as follows:

- Supply airflow rate: maximum 5,777 m<sup>3</sup>/hr.
- Return air path: plenum
- Minimum outside airflow: 20% damper position.
- Duct heat gain: 1.1 °C.

The fans were identically configured for the “A” and the “B” air-handling units. The following configurations were used for the economizer test:

- Supply air static pressure: 348.4 Pa.
- Fan schedule: always on.
- Supply fan control: 348.4 Pa.
- Return fan control differential: 90% of supply air.
- Motor placement: In-air flow.
- Fan placement: Draw-through.

Figure 2.1 shows the relationship between the supply fan power and supply airflow rate. A quadratic regression of the data and coefficient of determination for the regression are shown on the plot.

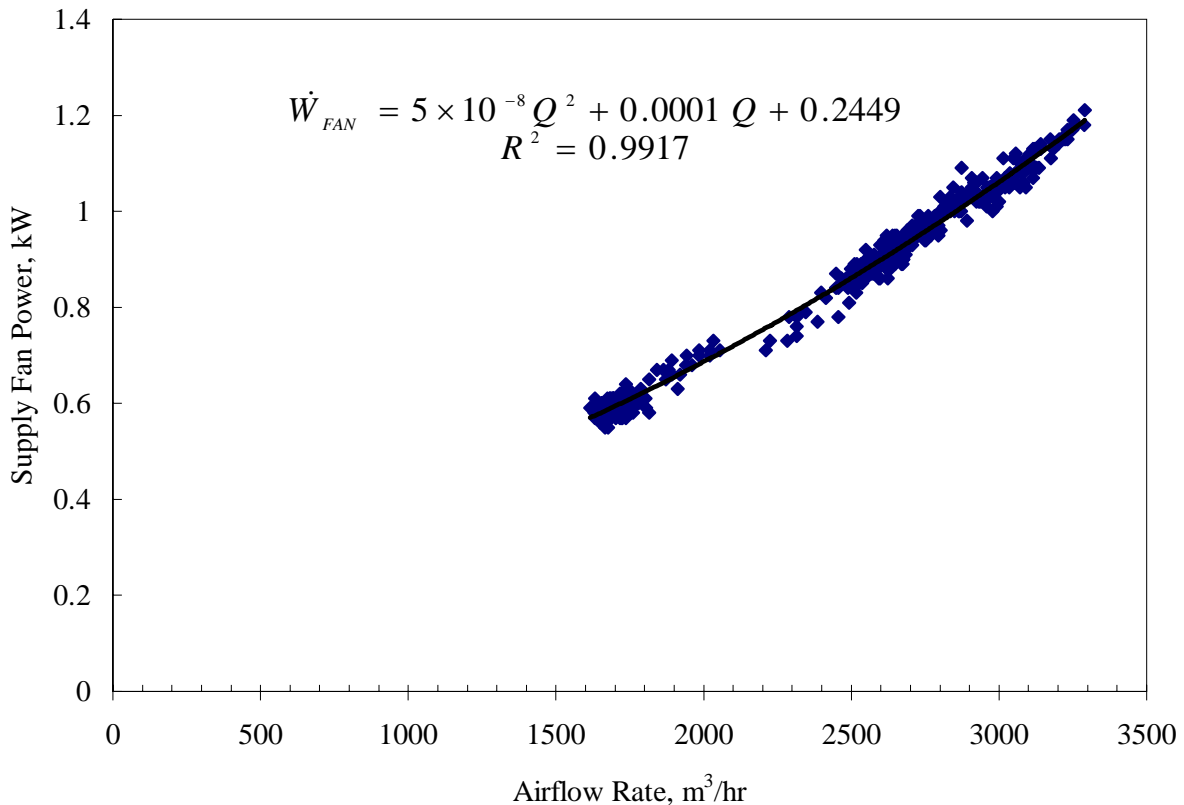


Figure 2.1 Supply fan power as function of airflow rate.

### 2.1.3.2. Economizer controls specifications

System A was used for the economizer study. Figure 2.2 illustrates the economizer sequence. The economizer control was based on comparison of return air temperature to outdoor air temperature. Switch over to economizer control was enabled when the outdoor dry-bulb temperature was less than the return air temperature.

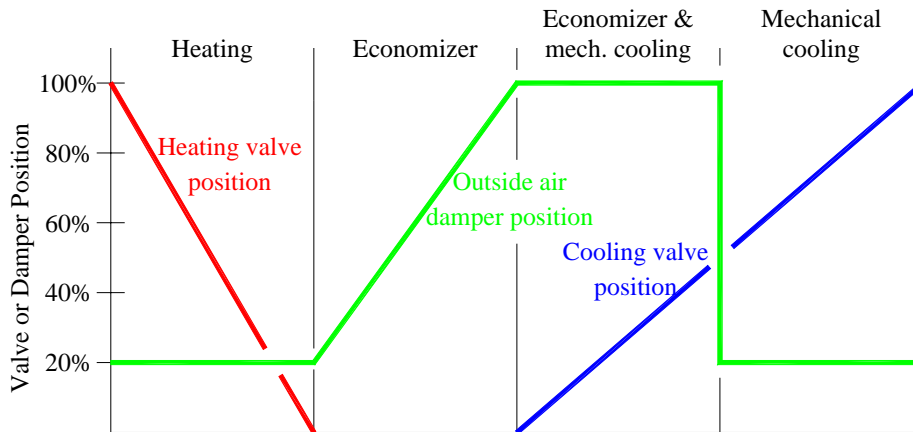


Figure 2.2 Economizer control sequence

At the onset of economizer control the outdoor air damper opens to 100%. As the outdoor air temperature continues to decrease, the system cooling coil control valve continues to close until the outdoor air temperature is cool enough that the entire system cooling load is satisfied by the outdoor air. Further reduction in outdoor air temperature causes the outdoor air damper to close until the minimum position is reached. At this point, further reduction of outdoor air temperature causes the systems preheat coil control valve to open. The primary system supply air is maintained at a constant set-point temperature throughout the test.

For this test the “B” system outdoor air damper was fixed at the same position as the minimum position for the “A” system. The “B” system was operated without economizer control throughout the test. An important distinction must be made regarding the outdoor airflow rate and outdoor air damper position. For a fixed outdoor air damper position, the outdoor airflow rate entering the system depends on the airflow rate drawn through the air handling unit by the supply fan. Thus, as the supply airflow rate to the building varies in response to the building cooling load, the volume flow rate of outdoor air will vary even though the outdoor damper position remains fixed.

During the test, the “A” and “B” test rooms were configured identically so that both air-handling units would be required to meet the same loads. The outside air damper for the “B” system remained in a fixed position while the outside air damper for the “A” system modulated to take advantage of “free cooling”. When there was no longer potential for “free cooling”, the outside air damper for the “A” system returned to the same damper position as the “B” system. It was assumed that the outside airflow rate for the “B” system would be identical to the outside airflow rate of the “A” system when the economizer control was disabled. Table 2.4 contains an hour-

by-hour schedule of the outside airflow rate for the “B” system. This schedule was used in the simulations to specify the outside airflow rate when the economizer was not enabled.

Table 2.4 Minimum outside airflow rate.

Hour	Minimum outside airflow rate, m <sup>3</sup> /hr			
	May 2, 2002	May 3, 2002	May 4, 2002	May 5, 2002
1	98	74	51	124
2	93	59	53	134
3	80	73	74	129
4	65	71	70	123
5	73	65	54	127
6	82	92	89	135
7	78	126	114	164
8	113	98	94	263
9	115	98	93	301
10	117	95	102	336
11	96	117	135	395
12	78	91	108	413
13	85	106	104	345
14	89	114	108	399
15	77	131	110	432
16	74	146	103	447
17	92	126	55	418
18	81	103	53	391
19	83	99	50	200
20	75	63	53	142
21	59	48	47	138
22	108	49	52	139
23	97	54	55	145
24	64	56	129	124

## 2.2. Comparison between experimental results and simulation results

In this section the results from the computer simulations are compared with the values obtained from the experiments run at the ERS. The comparisons are made both graphically and statistically using the statistical parameters defined in Section 1.5.

Before comparing the results for any system or zone level parameters, the weather information used by each model must be validated. Weather data collected at the ERS were converted to TMY format and provided to each modeler. Comparison of the key weather parameters is made to assure each program’s weather processor is correctly interpreting the provided weather information from the TMY weather file.

### 2.2.1. Weather data

The key weather parameters are dry-bulb and wet-bulb temperatures, direct normal solar irradiation, and total horizontal solar irradiation. Table 2.5 gives the statistical comparison of the temperatures and solar fluxes. Figure 2.3 illustrates the weather parameters during the four day test period. The agreement between the ERS data and the models is acceptable.

Table 2.5 Statistical comparison of weather parameters.

Statistical Parameter	Dry-bulb temperature, °C			Wet-bulb temperature, °C			Direct normal irradiation, W/m <sup>2</sup>			Total horizontal irradiation, W/m <sup>2</sup>		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.7	13.6	13.7	8.7	8.6	8.6	367.7	362.6	362.6	286.4	311.2	311.3
s	6.3	6.4	6.3	4.2	4.3	4.2	411.9	417.3	419.0	340.1	367.9	369.7
$x_{\max}$	27.4	27.2	27.3	16.8	17.2	16.6	1026.0	1024.6	1029.2	954.0	1027.7	1026.1
$x_{\min}$	3.4	3.3	3.7	1.4	1.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0
$\bar{D}$		0.1	0.0		0.0	0.0		5.2	5.2		-24.9	-25.0
$D_{\max}$		1.3	1.0		1.1	0.7		168.0	168.0		109.7	90.7
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.4	0.2		0.3	0.1		14.8	18.7		29.1	29.6
$D_{\text{rms}}$		0.4	0.3		0.3	0.2		35.3	39.7		43.1	44.1
SE		0.7	-0.1		0.0	0.3		1.4	1.4		-8.0	-8.0
IE		2.6	1.8		3.2	1.7		4.1	5.2		9.3	9.5

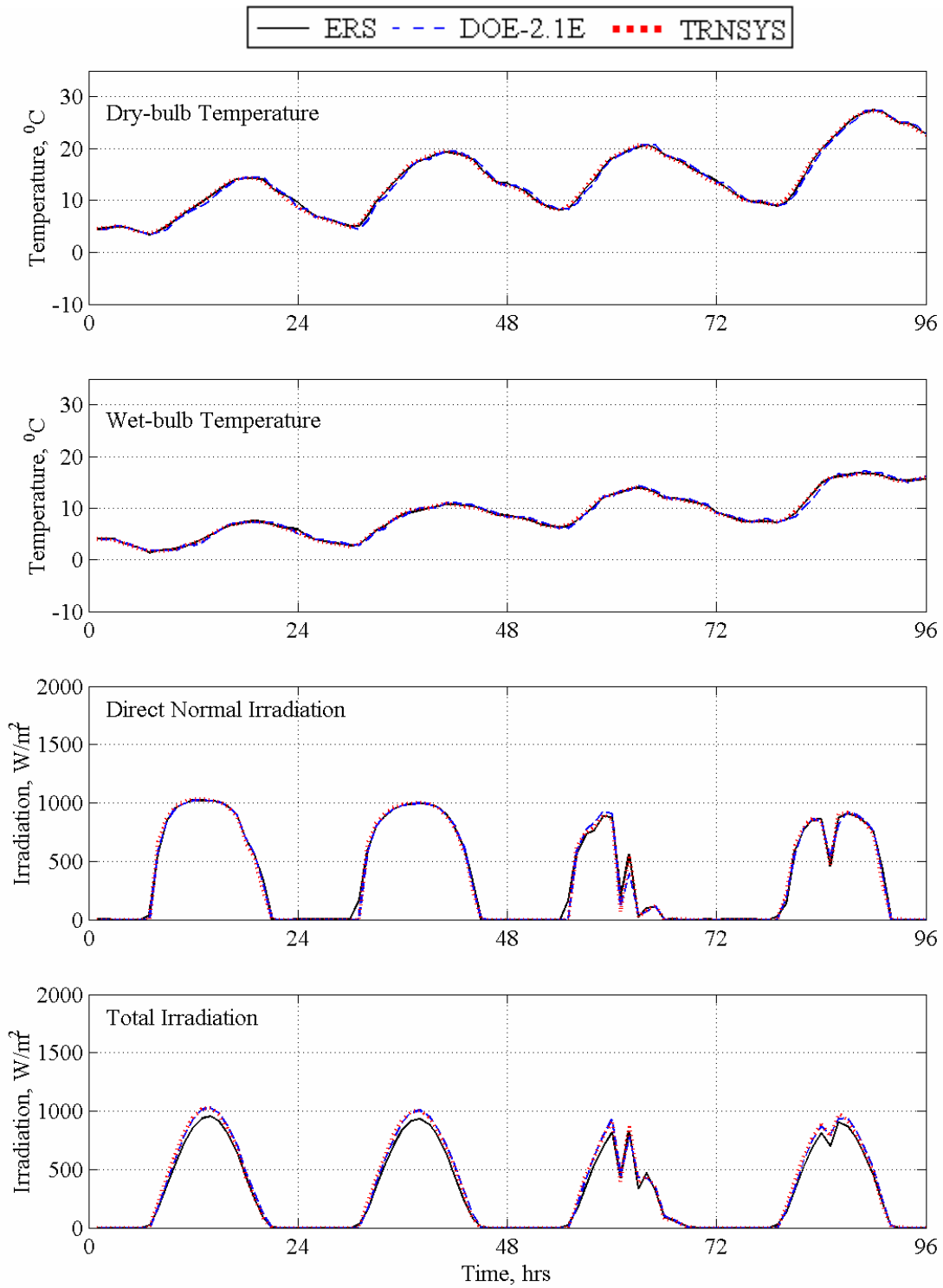


Figure 2.3 Weather parameters.

## 2.2.2. Economizer controlled system results

### 2.2.2.1. System level results for the “A” system

Air handling unit “A” supplies air to the “A” test rooms. As was shown Table 1.2, the parameters generally used for system-level comparison are the supply airflow rate, the outside airflow rate, the air temperature entering the cooling coil, the air temperature leaving the cooling coil, the temperature of return air, and the cooling coil heat transfer rate.

Air handling unit “A” supplies air to the “A” test rooms. Table 2.6 provides a statistical summary of supply airflow rate, outside airflow rate, the difference between the return and outside dry-bulb temperature, and the cooling heat transfer rate for air handling unit “A”. The graphical results for the four-day test are shown in Figure 2.5. The significance of the temperature difference between the return air and the outside air is in the economizer control. Recall that when the outside air temperature is less than the return air temperature, the economizer is enabled; therefore, during the time when the temperature difference is negative, the economizer is enabled.

The cooling coil heat transfer rate was not directly measured during the experiment instead it was calculated from parameters that were measured. The cooling coil heat transfer rate was calculated as shown is Equation 2.1.

$$HTR = (\dot{m}_{SA} - \dot{m}_{OA})h_{RA} + \dot{m}_{OA}h_{OA} - \dot{m}_{SA}h_{SA} \quad (2.1)$$

where

$\dot{m}_{SA}$  is the supply mass flow rate.

$\dot{m}_{OA}$  is the outside mass flow rate.

$h_{RA}$  is the return air enthalpy.

$h_{OA}$  is the outside air enthalpy.

$h_{SA}$  is the supply air enthalpy.

The mass flow rates were calculated assuming the air behaved as an ideal gas and using data measured at the facility. The mass flow rate was calculated as shown in Equation 2.2.

$$\dot{m} = \frac{Q(p - p_v)}{RT} \quad (2.2)$$

where

$Q$  is airflow rate.

$p$  is the ambient pressure.

$p_v$  is the pressure of the water vapor.

$R$  is the gas constant for air.

$T$  is the temperature where the airflow rate was measured.

The enthalpies were calculated using temperature and relative humidity parameters measured at the ERS. The enthalpy calculation is shown in Equation 2.3.



$$h = c_{p,air}T + \omega(h_{fg} + c_{p,H2O}T) \quad (2.3)$$

where

$c_{p,air}$  is the constant specific of air at standard temperature.

T is the temperature of the air stream.

$\omega$  is the humidity ratio.

$h_{fg}$  is the latent heat of vaporization of H<sub>2</sub>O.

$c_{p,H2O}$  is the constant specific heat of water vapor at standard temperature.

The humidity ratio was calculated using the ambient pressure, relative humidity, and the temperature of the air. The humidity ratio calculation is shown in Equation 2.4.

$$\omega = 0.6219 \frac{p_v}{p - p_v} \quad (2.4)$$

The water vapor pressure was calculated using Equation 2.5. The saturation pressure was calculated using the Hyland-Wexler equation.

$$p_v = \phi p_{sat} \quad (2.5)$$

where

$\phi$  is the relative humidity.

$p_{sat}$  is the saturation pressure of water.

Table 2.6 provides a statistical summary of the air handling unit parameters, while Figure 2.4 shows the graphical results for the four days of the test. From the statistical summary and the graphical results some general trends are apparent between the simulations and the experiment for air handling unit “A” parameters. TRNSYS slightly over-predicts the supply airflow rate while it is under-predicted by DOE2.1E and both building simulations under-predict the outside airflow rate.

The return air/outdoor air temperature difference parameter was the control parameter enabling or disabling the economizer control. A positive value for this parameter indicates the economizer control is enabled and the system is reducing the cooling coil load by bringing in cooler outside air. A negative value indicates the economizer control is disabled, which is indicated in Figure 2.4. Both models do a good job of predicting the cooling heat transfer rate during the test.

Table 2.6 Statistical comparison of AHU-A parameters.

Statistical Parameter	Supply airflow rate, m <sup>3</sup> /hr			Outside airflow rate, m <sup>3</sup> /hr			Return air/outdoor air temperature difference, °C			Cooling coil heat transfer rate, kW		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{X}$	1991.9	1780.0	2078.4	1788.4	1394.4	1502.1	9.3	9.5	9.1	1.8	1.8	1.7
$\sigma$	34.9			25.5			0.2			0.6		
S	628.3	452.2	698.1	862.8	649.2	870.3	6.3	6.2	6.1	2.7	2.5	2.7
X <sub>max</sub>	3131.0	2889.0	3107.0	3321.0	2576.0	2986.0	19.7	19.2	18.8	9.9	9.0	9.7
X <sub>min</sub>	1354.0	1359.0	1360.0	165.0	138.0	139.0	-4.4	-3.9	-4.3	0.0	0.0	-0.2
$\bar{D}$		211.9	-86.5		394.0	286.4		-0.2	0.2		0.0	0.1
D <sub>max</sub>		814.0	798.0		1223.0	1573.0		1.4	1.2		2.3	2.9
D <sub>min</sub>		0.0	0.0		9.0	1.0		0.0	0.0		0.0	0.0
D		225.4	154.4		444.6	361.0		0.4	0.4		0.4	0.3
D <sub>rms</sub>		323.1	233.5		518.3	435.4		0.5	0.5		0.6	0.6
SE		11.9	-4.2		28.3	19.1		-1.8	1.8		-1.9	5.2
IE		12.7	7.4		31.9	24.0		3.9	4.9		20.0	18.8

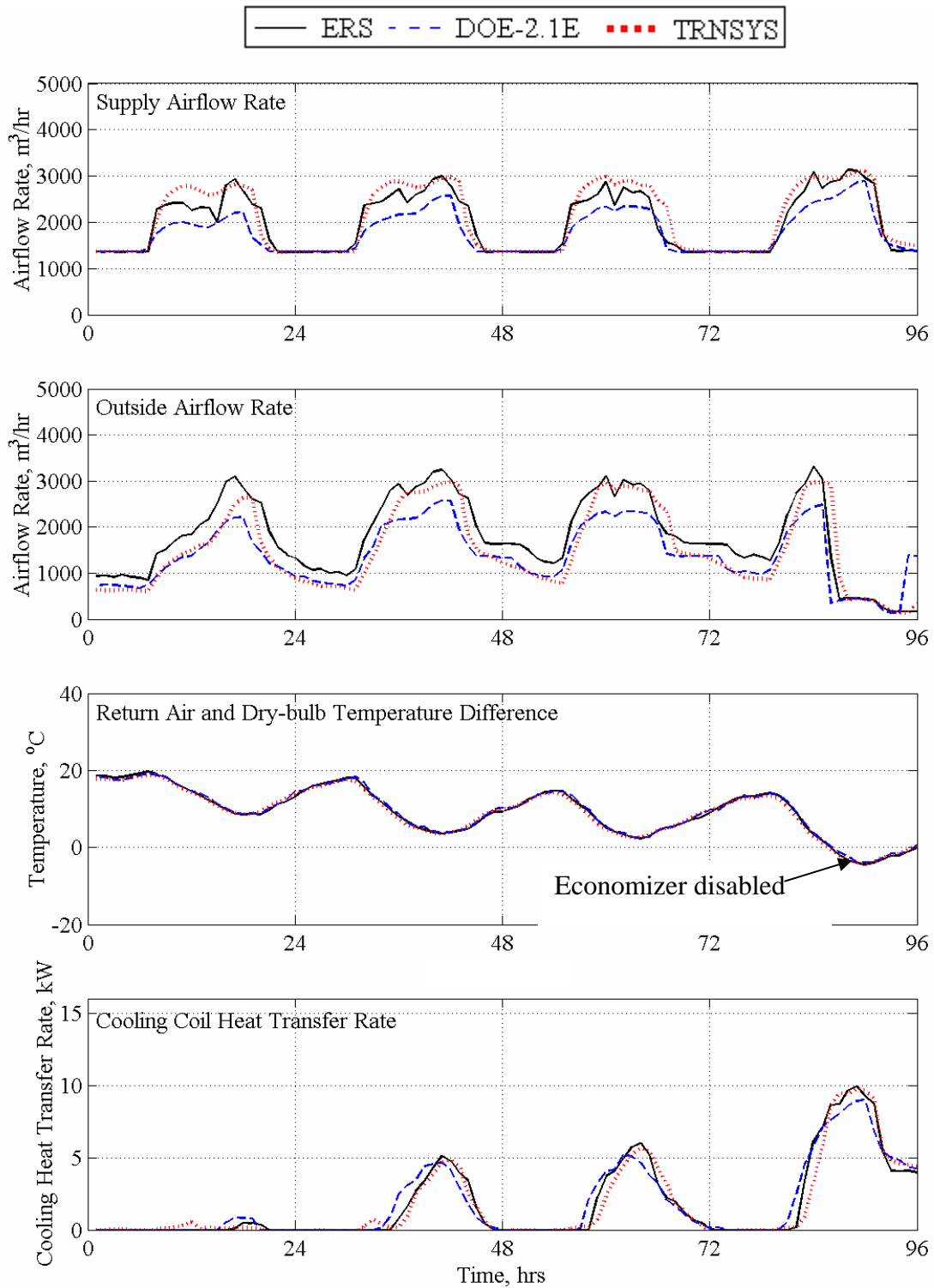


Figure 2.4 AHU-A parameters.

Table 2.7 provides a statistical summary of additional system parameters, which include the leaving coil air temperature, mixed air temperature, and return air temperature for air handling unit “A”. The graphical results for these parameters are shown in Figure 2.5 for the four-day test.

The statistical summary and the graphical results provide a valuable tool for comparing the additional system parameters. Because the leaving cooling coil temperature is very closely related to the supply air temperature (the temperature rise across the supply fan was supplied in the test specifications), good predictions for this parameter were seen by both TRNSYS and DOE2.1E. Both TRNSYS and DOE2.1E under-predict the mixed air temperature the first three days of the test and then over-predict it on the fourth day of the test. Both TRNSYS and DOE2.1E predict a value for return air temperature within the range seen in the experiment.

Table 2.7 Statistical comparison of additional AHU-A parameters.

Statistical Parameter	Leaving coil air temperature, °C			Mixed air temperature, °C			Return air temperature, °C		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.5	13.3	13.5	16.4	15.8	15.7	23.0	23.0	22.8
$\sigma$	0.2			0.2			0.2		
S	0.2	0.5	0.0	3.3	3.8	3.4	0.3	0.2	0.2
$x_{\max}$	14.2	14.6	13.5	23.2	23.9	24.0	23.5	23.5	23.0
$x_{\min}$	12.8	12.9	13.5	13.1	12.9	12.9	22.1	22.5	22.4
$\bar{D}$		0.2	0.0		0.6	0.7		-0.1	0.1
$D_{\max}$		1.2	0.7		2.2	4.0		1.0	0.8
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.5	0.2		0.8	0.9		0.3	0.3
$D_{\text{rms}}$		0.5	0.2		0.9	1.3		0.4	0.4
SE		1.7	0.4		3.7	4.3		-0.3	0.6
IE		3.4	1.4		5.1	5.6		1.4	1.2

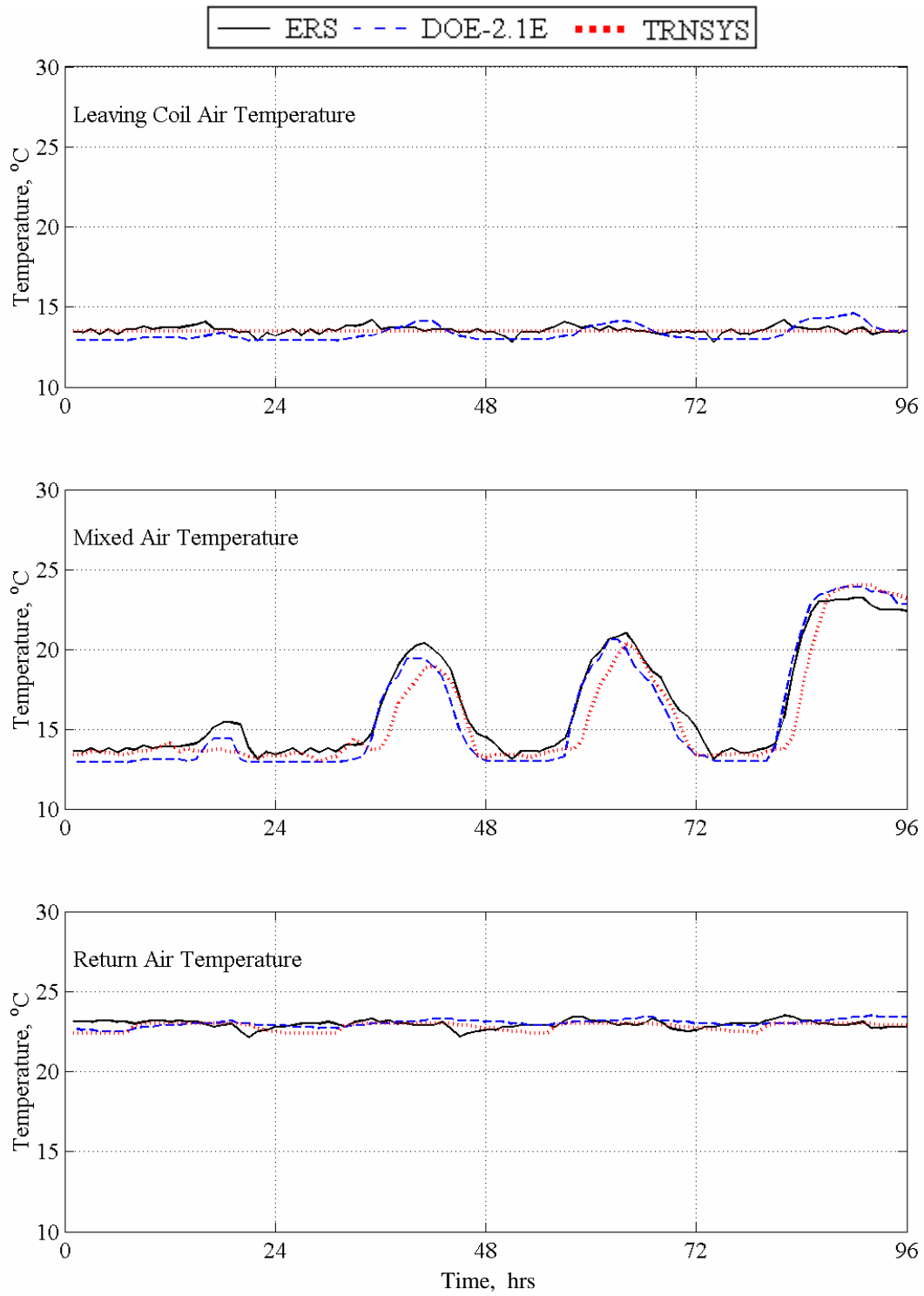


Figure 2.5 Additional AHU-A parameters.

#### **2.2.2.2. System level results for the “B” system**

Air handling unit “B” supplies air to the “B” test rooms. As was shown Table 1.2, the parameters generally used for system-level comparison are the supply airflow rate, the outside airflow rate, the temperature of the air entering cooling coil, the temperature of the air leaving cooling coil, the temperature of the return air, and the cooling coil energy heat transfer rate.

Table 2.8 provides a statistical summary of supply airflow rate, outside airflow rate, return and outside dry-bulb temperature difference, and cooling heat transfer rate for air handling unit “B”. The graphical results for the four-day test are shown in Figure 2.6.

Recall that economizer control was not used with the “B” system and the outdoor damper remained in a fixed position. As discussed in Section 2.1.3.2, a fixed minimum damper position does not mean the outdoor air flow rate remains constant. Variations in supply air flow rate inherent to a VAV system will cause variations in the outdoor air drawn into the air handling unit. Neither TRNSYS nor DOE2.1E models this phenomenon. Measured outdoor air flow rates were used to construct an outdoor air flow rate schedule that was an input to each model. This assured the models used the same outdoor air flow rate as was measured in the experiment and is evident in Figure 2.6 which shows the outdoor air flow rates.

The results between the return and outside air temperature differences are similar to those seen for air handling unit “A. For the cooling coil heat transfer rate, both TRNSYS and DOE2.1E do a good job of predicting the cooling coil heat transfer rate.

When comparing the cooling coil heat transfer rates between the “A” and “B” systems, the advantage of the economizer control is clearly seen. When the outdoor air conditions are favorable, a significant reduction in mechanical cooling is possible by utilizing more outdoor air.

Table 2.8 Statistical comparison of AHU-B parameters.

Statistical Parameter	Supply airflow rate, m <sup>3</sup> /hr			Outside airflow rate, m <sup>3</sup> /hr			Return air/outdoor air temperature difference, °C			Cooling coil heat transfer rate, kW		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{X}$	1981.8	1863.0	2104.6	126.1	125.8	125.6	9.1	9.5	9.3	5.7	5.6	5.8
$\sigma$	35.3			8.24			0.2			0.5		
S	619.7	504.7	717.3	97.0	97.0	95.7	6.3	6.2	6.1	2.0	1.5	2.3
X <sub>max</sub>	3262.0	2839.0	3184.0	447.0	446.9	440.0	19.6	19.3	18.9	10.1	9.1	10.0
X <sub>min</sub>	1358.0	1362.0	1360.0	47.0	46.5	48.0	-4.6	-3.9	-4.0	3.5	3.7	3.2
$\bar{D}$		118.9	-122.8		0.2	0.4		-0.3	-0.2		0.1	-0.1
D <sub>max</sub>		803.0	839.0		73.1	96.0		1.5	1.4		2.0	2.3
D <sub>min</sub>		2.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0
D		152.4	184.5		1.7	9.7		0.5	0.4		0.5	0.6
D <sub>rms</sub>		245.5	270.5		8.1	15.9		0.6	0.5		0.7	0.8
SE		6.4	-5.8		0.2	0.3		-3.6	-2.0		1.9	-2.4
IE		8.2	8.8		1.4	7.7		4.8	4.4		9.7	10.2

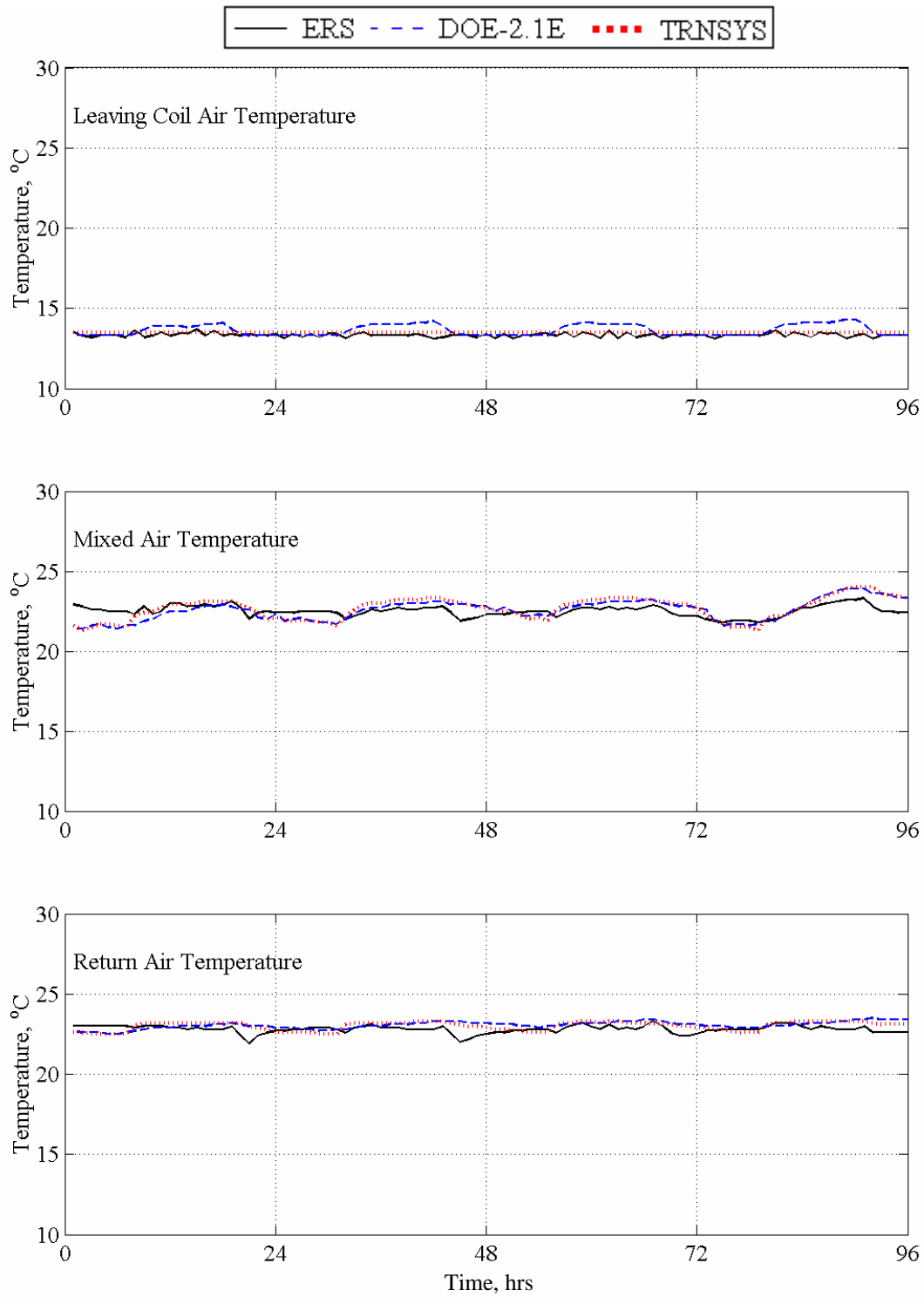


Figure 2.6 AHU-B parameters.



Table 2.9 provides a statistical summary of additional parameters, which include the leaving coil air temperature, mixed air temperature, and return air temperature for air handling unit “B”. The graphical results for these parameters are shown in Figure 2.7. The mixed air temperature and the return air temperature are almost identical. This is due to the fact that very little of return air was exhausted from the system and replaced by outside air.

Table 2.9 Statistical comparison of additional AHU-B parameters.

Statistical Parameter	Leaving coil air temperature, °C			Mixed air temperature, °C			Return air temperature, °C		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.3	13.6	13.5	22.5	22.6	22.7	22.8	23.1	23.0
$\sigma$	0.2			0.2			0.2		
S	0.1	0.3	0.0	0.3	0.6	0.7	0.2	0.2	0.3
$x_{\max}$	13.7	14.3	13.5	23.3	23.9	24.0	23.3	23.5	23.3
$x_{\min}$	13.1	13.3	13.5	21.8	21.4	21.3	21.9	22.5	22.5
$\bar{D}$		-0.3	-0.2		-0.1	-0.2		-0.2	-0.2
$D_{\max}$		1.2	0.4		1.5	1.5		1.3	1.1
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.3	0.2		0.4	0.5		0.3	0.3
$D_{\text{rms}}$		0.5	0.2		0.6	0.6		0.4	0.4
SE		-2.2	-1.3		-0.3	-0.7		-1.1	-0.9
IE		2.5	1.4		2.0	2.2		1.5	1.5

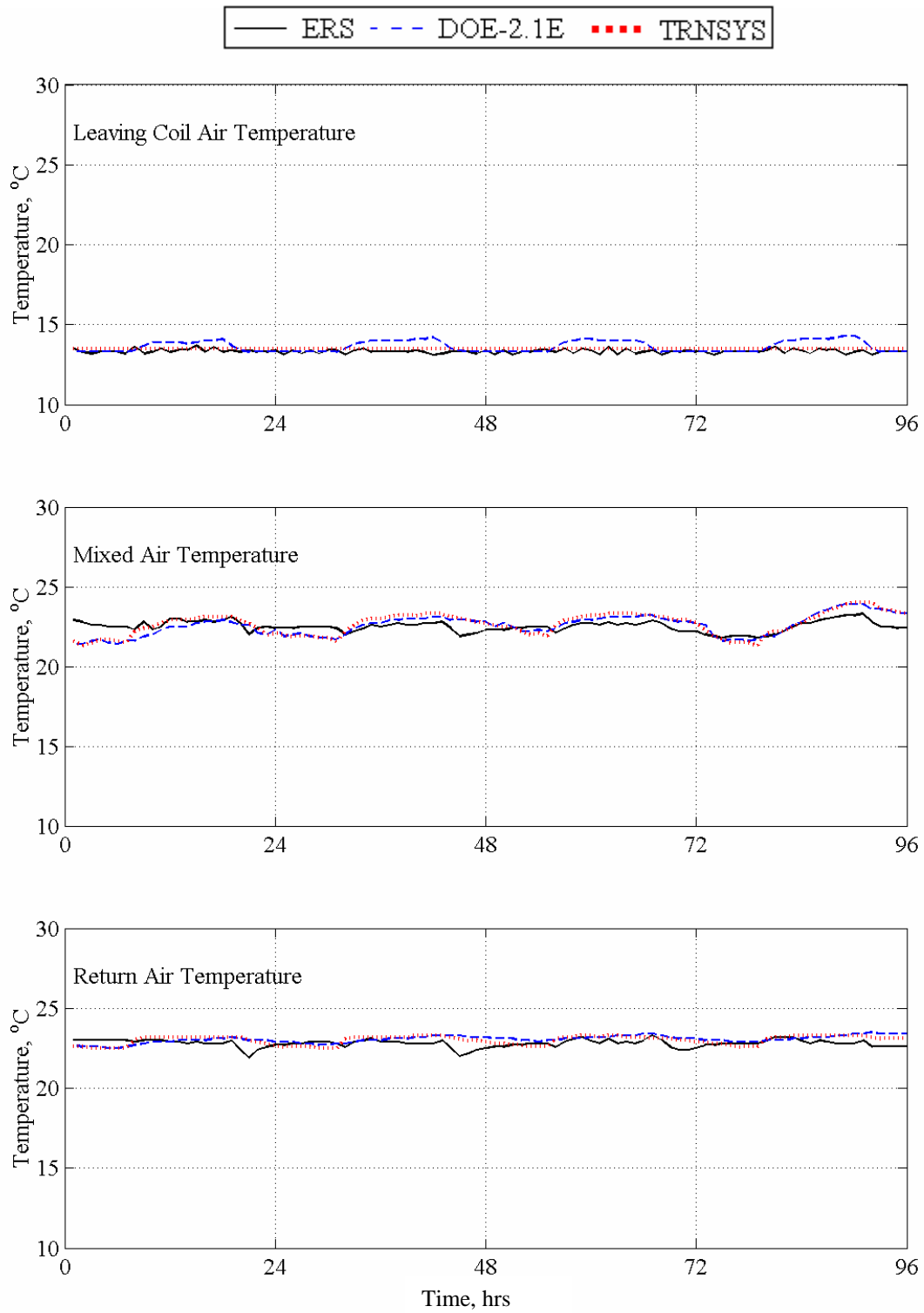


Figure 2.7 Additional AHU-B parameters.

## 3. Economizer Test 2

### 3.1. Description of the exercise

This section contains information regarding the operating parameters and conditions used for Economizer Test 2 conducted at the Energy Resource Station. The test was conducted over a four day period from March 25 through 28, 2003.

Internal heat loads for the test rooms were produced from lights and electric baseboard heaters. These were scheduled on during a portion of the day and off the remainder of the time. The windows of the test rooms did not have any blinds or drapes covering them thus allowing maximum solar heat gain.

Thermostats in the test rooms were programmed for a constant heating set-point temperature and a constant cooling set-point temperature. For non-test room spaces in the ERS that are adjacent to the test rooms, the zone thermostats were programmed with the same set-point temperatures as the test rooms. This reduces the possibility thermal interaction between the test rooms and the remainder of the building.

For this test, the “B” system was operated with the outdoor air dampers in the closed position, and the economizer cycle was disabled. The “A” system was operated with the minimum outdoor air dampers in the closed position when the economizer was disabled and incorporated an economizer cycle based on return air temperature. Both systems were operated as variable air volume with hydronic terminal reheat at the zone level. The systems were run 24 hours per day and chilled water was available for mechanical cooling throughout the test period.

#### 3.1.1. Run period and general weather conditions

This item is used to specify the initial and final dates of the desired simulation period and also the general conditions and location of the ERS facility. The TMY weather file that accompanies this report has ERS weather station information only for the dates of the tests.

- Test dates: March 25 through March 28, 2003.
- Weather data for the ERS is organized into TMY format. The weather file is called “IEA2003.tmy”.
- Building location
  - Latitude: 41.71 °N
  - Longitude: 93.61 °W
  - Altitude: 285.9 m (938 ft)
  - Time-zone: 6, Central time zone in U.S.
  - Daylight-saving: NO

#### 3.1.2. Test rooms operation and control parameters

This item describes the operation and control of the test rooms that apply to this test.

##### 3.1.2.1. Internal loads and general room conditions

The only internal heating loads used during this test are from ceiling mounted fluorescent lights and baseboard electric heaters. These internal loads were scheduled “ON” for only certain hours

during the day. The baseboard heaters have two stages of heat; however, for this test, only the first stage of baseboard heat was used. Due to variations in the installed equipment, the baseboard power is not identical for each unit. Furthermore, slight variations also exist for the lighting power. Table 3.1 provides power values for the lights and baseboard heaters for each test room.

Table 3.1 Lighting and baseboard power for each test room, in Watts.

Room	Stage 1	Stage 2	Lights
East A	890	890	538.0
East B	890	880	538.5
South A	890	880	540.0
South B	880	890	540.0
West A	860	860	536.5
West B	890	890	532.5
Interior A	870	900	533.5
Interior B	900	900	534.5

Table 3.2 provides the schedule for the operation of the lights and the first stage of baseboard heat used in this test. The time represents the beginning of each hour where 1 represents 1 AM and 24 represents midnight.

Table 3.2 Lighting and first stage baseboard heating schedules for all test rooms.

Hour	Lights	Stage 1 Baseboard	Hour	Lights	Stage 1 Baseboard
1	OFF	ON	13	ON	ON
2	OFF	ON	14	ON	ON
3	OFF	ON	15	ON	ON
4	OFF	ON	16	ON	ON
5	OFF	ON	17	ON	ON
6	OFF	ON	18	ON	ON
7	ON	ON	19	OFF	ON
8	ON	ON	20	OFF	ON
9	ON	ON	21	OFF	ON
10	ON	ON	22	OFF	ON
11	ON	ON	23	OFF	ON
12	ON	ON	24	OFF	ON

### 3.1.2.2. Room-level HVAC controls specifications

Space temperature conditions were maintained by utilizing variable airflow rates (VAV) for space cooling and hydronic reheat for space heating. The cooling and heating set-point temperatures were the same for all test rooms and their values remained fixed throughout the test.

In heating mode the terminal unit operates at a prescribed minimum airflow rate, and the two-way hot water control valve modulates in response to the zone heating needs. In cooling mode,

the two-way hot water control valve is closed, and the terminal unit modulates the primary supply airflow rate in response to the zone cooling needs. In addition to a minimum airflow rate, each unit has a maximum airflow rate. The values of these airflow rates depend on whether the room is an exterior room or an interior room.

Table 3.3 provides values for the temperature set points and airflow rates for the test rooms.

Table 3.3 Test room set-point temperatures and airflow rates

Test room Location	Heating set-point temperature, °C	Cooling set-point temperature, °C	Minimum airflow rate, m <sup>3</sup> /hr	Maximum airflow rate, m <sup>3</sup> /hr
East “A”	22.2	22.8	298	1,103
East “B”	22.2	22.8	323	1,064
South “A”	22.2	22.8	306	1,048
South “B”	22.2	22.8	283	1,025
West “A”	22.2	22.8	291	1,025
West “B”	22.2	22.8	307	1,023
Interior “A”	22.2	22.8	310	618
Interior “B”	22.2	22.8	298	591

### 3.1.3. System-level HVAC operation and control

The items in this section describe how the air handling units were configured for the tests. The economizer control was enabled on the “A” system while the “B” system remained the fixed minimum damper position. Besides the economizer control on the “A” system, the systems were configured identically.

#### 3.1.3.1. Air handling unit control and specifications

The system controls were configured as follows:

- Heating schedule: always available.
- Cooling schedule: always available.
- Cooling control supply air temperature set point after the fan: 15 °C.
- Preheat: NOT available.
- Humidity control: NOT available.
- Economizer: enabled when the return air temperature exceeded the outdoor air temperature for the “A” system.

The system air for both the “A” and the “B” systems was specified as follows:

- Supply airflow rate: maximum 4,248 m<sup>3</sup>/hr.
- Return air path: plenum
- Minimum outside airflow: 0% damper open position.
- Duct heat gain: 1.0 °C.

The fans were identically configured for the “A” and the “B” air-handling units. The following configurations were used for the economizer test:

- Supply air static pressure: 547.4 Pa.
- Fan schedule: always on.
- Supply fan control: 547.4 Pa.
- Return fan control differential: 90% of supply air.
- Motor placement: In-air flow.
- Fan placement: Draw-through.

Figure 3.1 shows the relationship between the supply fan power and supply airflow rate. A quadratic regression of the data and coefficient of determination for the regression are shown on the plot.

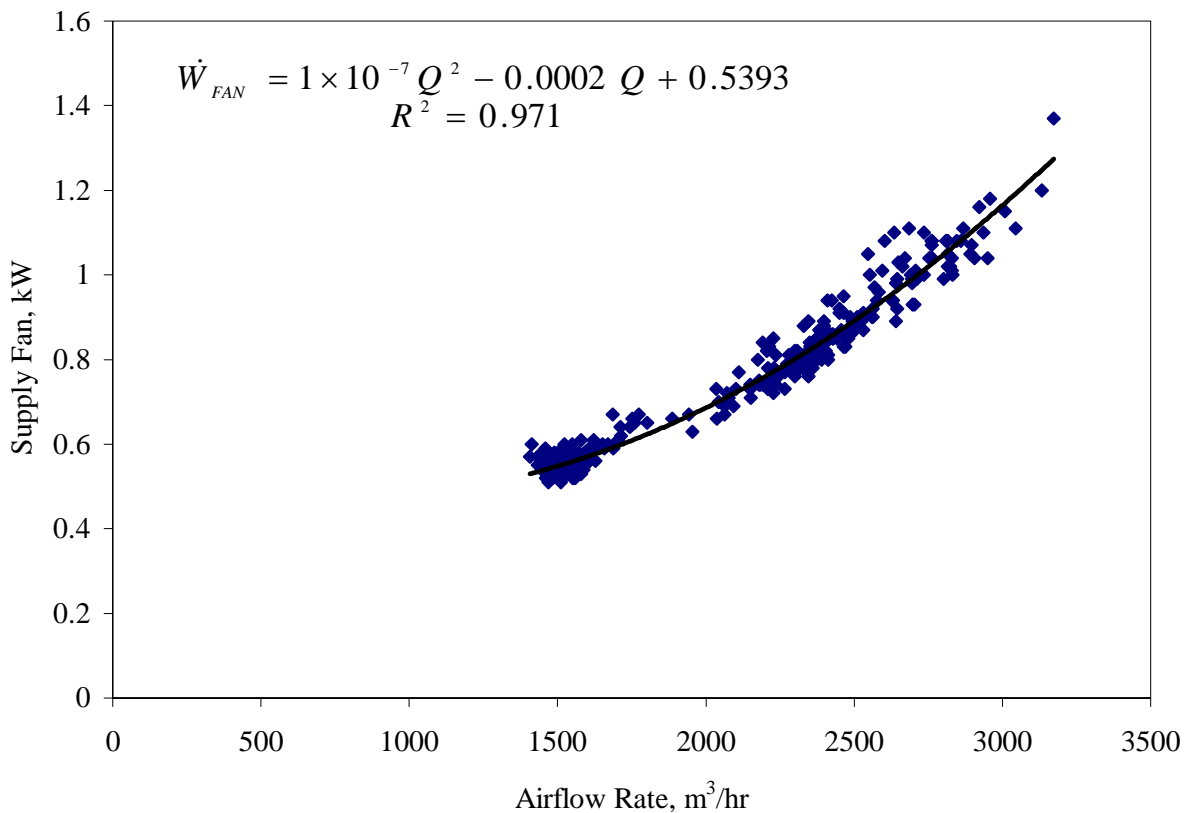


Figure 3.1 Supply fan power as function of airflow rate.

### 3.1.3.2. Economizer control specifications

At the onset of economizer control the outdoor air damper opens to 100%. As the outdoor air temperature continues to decrease, the system cooling coil control valve continues to close until the outdoor air temperature is cool enough that the entire system cooling load is satisfied by the outdoor air. Further reduction in outdoor air temperature causes the outdoor air damper to close until the damper is completely closed. At this point, further reduction of outdoor air temperature

causes the systems preheat coil control valve to open. The primary system supply air is maintained at a constant set-point temperature throughout the test. For this test the “B” system outdoor air damper positions were closed and the economizer control was disabled. Figure 3.2 shows the control strategy used for Economizer Test 2.

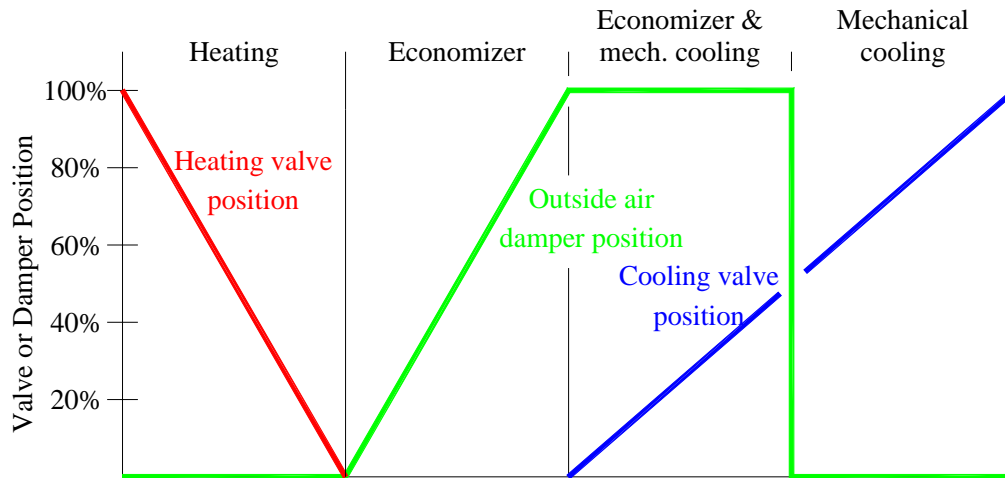


Figure 3.2 Economizer control sequence

### 3.2. Comparison between experimental results and simulation results

In this section the results from the computer simulations are compared with the values obtained from the experiments run at the ERS. The comparisons are made both graphically and statistically. The statistical parameters used were defined in Section 1.5.

Before comparing the results for any system or zone level parameters, the weather information used by each model must be validated. Weather data collected at the ERS were converted to TMY format and provided to each modeler. Comparison of the key weather parameters is made to make sure each program’s weather processor is correctly interpreting the provided weather information.

#### 3.2.1. Weather data

The key weather parameters are dry-bulb and wet-bulb temperatures, direct normal solar irradiation, and total horizontal solar irradiation. Table 3.4 gives the statistical comparison of the temperatures and solar fluxes, respectively. Figure 3.3 illustrates the weather parameters during the four-day test period. The agreement between the ERS data and the models is acceptable.

Table 3.4 Statistical comparison of weather parameters

Statistical Parameter	Dry-bulb temperature, °C			Wet-bulb temperature, °C			Direct normal irradiation, W/m <sup>2</sup>			Total horizontal irradiation, W/m <sup>2</sup>		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	7.8	7.8	7.8	4.3	4.3	4.2	121.9	131.6	131.7	118.2	118.4	118.5
S	4.5	4.5	4.4	2.8	2.8	2.8	273.1	293.7	295.4	199.3	198.4	199.5
$x_{\max}$	15.9	15.6	15.6	9.1	8.9	8.9	946.0	1005.6	1022.2	793.0	791.3	786.4
$x_{\min}$	0.0	-0.6	0.3	-0.8	-1.1	-0.8	0.0	0.0	0.0	0.0	0.0	0.0
$\bar{D}$		-0.1	0.0		0.0	0.0		-9.7	-9.8		-0.3	-0.3
$D_{\max}$		1.6	3.0		0.6	1.5		132.9	211.1		32.9	86.5
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.2	0.6		0.2	0.3		13.9	21.8		5.1	13.8
$D_{\text{rms}}$		0.3	0.8		0.3	0.4		32.6	51.9		9.5	25.2
SE		-0.6	-0.6		-0.9	0.5		-7.3	-7.4		-0.2	-0.2
IE		3.1	7.2		4.6	6.9		10.6	16.5		4.3	11.6



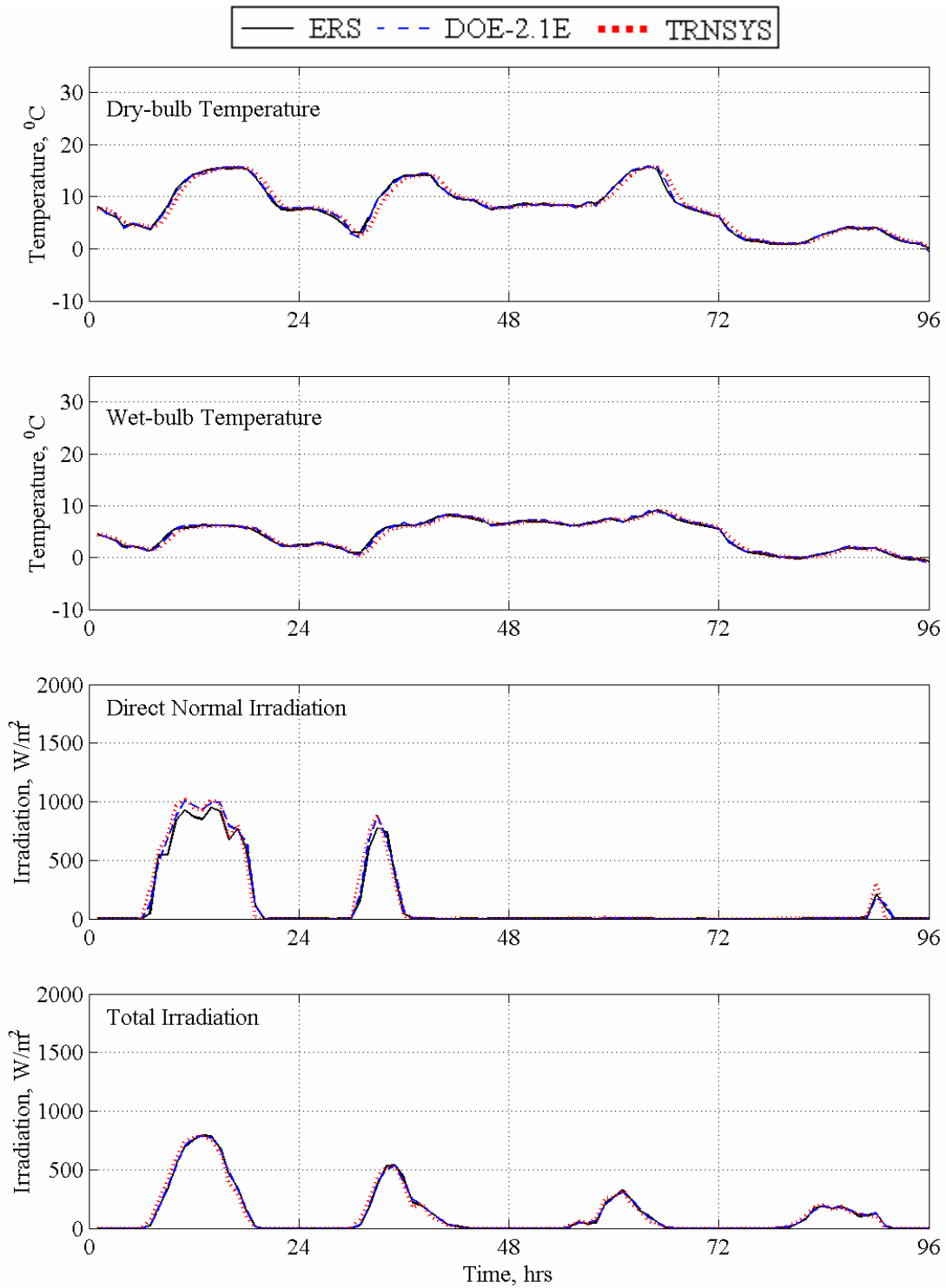


Figure 3.3 Weather parameters

## 3.2.2. Economizer controlled system results

### 3.2.2.1. System level results for the “A” system

Air handling unit “A” supplies air to the “A” test rooms. As was shown Table 1.2, the parameters generally used for system-level comparison are the supply airflow rate, the outside airflow rate, the air temperature entering the cooling coil, the air temperature leaving the cooling coil, the temperature of return air, and the cooling coil heat transfer rate.

Air handling unit “A” supplies air to the “A” test rooms. Table 3.5 provides a statistical summary of supply airflow rate, outside airflow rate, the difference between the return and outside dry-bulb temperature, and the cooling heat transfer rate for air handling unit “A”. The graphical results for the four day test are shown in Figure 3.4. The significance of the temperature difference between the return air and the outside air is in the economizer control. Recall that when the outside air temperature is less than the return air temperature, the economizer is enabled; therefore, during the time when the temperature difference is negative, the economizer is enabled.

Table 3.6 provides a statistical summary of the air handling unit parameters, while Figure 3.4 shows the graphical results for the four-day test. From the statistical summary and the graphical results some general trends are apparent between the simulations and the experiment for air handling unit “A” parameters. Both TRNSYS over-predicts the supply airflow rate while DOE2.1E under-predicts it for the first two days of the test, but during the last two days of the test when the solar load was almost non-existent both simulations over-predict the supply airflow rate. The outside air flow rates for both TRNSYS and DOE2.1E followed the experimental trend closely through out the test.

The return air/outdoor air temperature difference parameter was the control parameter enabling or disabling the economizer control. A positive value for this parameter indicates the economizer control is enabled and the system is reducing the cooling coil load by bringing in cooler outside air. As seen from Figure 3.4, the economizer control was enabled for the entire four-day test.

Although mechanical cooling was not required for most of the four day test, both TRNSYS and DOE2.1E predicted when the cooling coil came on during peak cooling loads. Due to the large uncertainty associated with the heat transfer rate calculations, the 95% error bounds were far larger than the measured and predicted values making the inconsistencies in the differences unreliable. Despite this discrepancy, both TRNSYS and DOE2.1E accurately predict the average cooling coil heat transfer rate for the test.

Table 3.5 Statistical comparison of AHU-A parameters

Statistical Parameter	Supply airflow rate, m <sup>3</sup> /hr			Outside airflow rate, m <sup>3</sup> /hr			Return air/outdoor air temperature difference, °C			Cooling coil heat transfer rate, kW		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{X}$	1504.8	1479.5	1785.9	1161.9	1018.5	1178.1	15.4	14.7	15.0	0.1	0.1	0.1
$\sigma$	76.2			28.9			0.2			0.9		
s	452.8	344.0	634.4	642.8	541.4	750.5	4.5	4.1	4.3	0.4	0.4	0.2
X <sub>max</sub>	2753.0	2262.0	3102.0	2870.0	2262.0	3050.0	23.1	21.9	22.2	1.6	1.4	1.0
X <sub>min</sub>	1201.0	1199.0	1214.0	519.0	432.0	461.0	7.7	7.5	7.4	0.0	0.0	0.0
$\bar{D}$		25.3	-281.1		143.4	-16.3		0.7	0.4		0.0	0.0
D <sub>max</sub>		809.0	837.0		900.0	726.0		2.1	3.8		0.7	0.9
D <sub>min</sub>		0.0	1.0		2.0	2.0		0.0	0.1		0.0	0.0
D		130.1	289.5		171.6	189.7		0.7	0.8		0.0	0.1
D <sub>rms</sub>		203.1	413.8		242.4	240.1		0.9	1.0		0.1	0.2
SE		1.7	-15.7		14.1	-1.4		4.9	2.9		-17.9	-1.8
IE		8.8	16.2		16.8	16.1		5.1	5.1		33.8	78.3

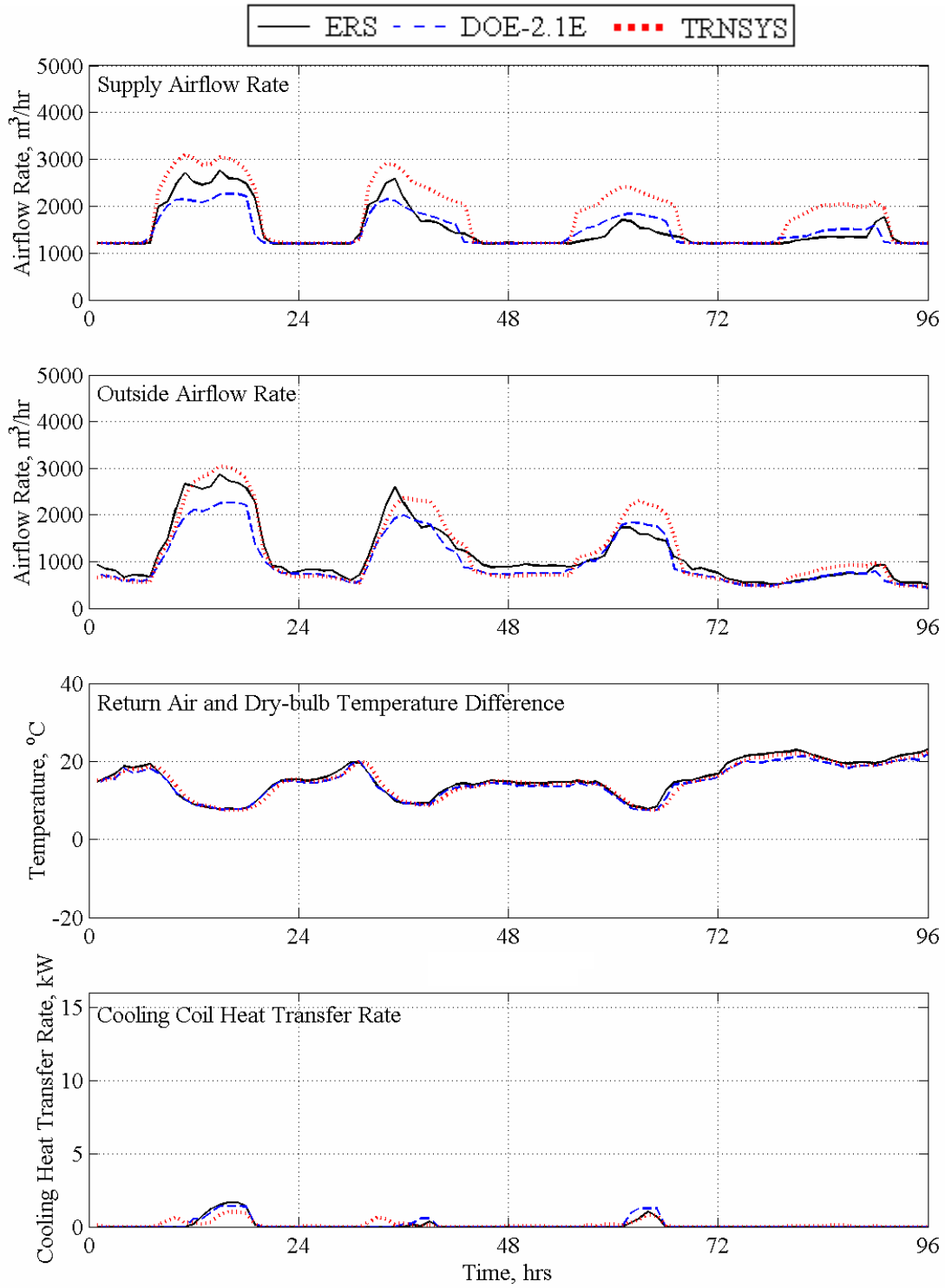


Figure 3.4 AHU-A parameters

Table 3.6 provides a statistical summary of additional system parameters, which include the leaving coil air temperature, mixed air temperature, and return air temperature for air handling unit “A”. The graphical results for these parameters are shown in Figure 3.5.

The statistical summary and the graphical results provide valuable tools for comparing the additional parameters for air handling unit “A”. Because the leaving cooling coil temperature is very closely related to the supply air temperature (the temperature rise across the supply fan was provided in the test specifications), good predictions for this parameter were seen by both TRNSYS and DOE2.1E. Both TRNSYS and DOE2.1E under-predict the mixed air temperature during the entire test. TRNSYS predicts a value for return air temperature within the range seen in the experiment, while DOE2.1E under-predicts the return air temperature for the entire test.

Table 3.6 Statistical comparison of additional AHU-A parameters.

Statistical Parameter	Leaving coil air temperature, °C			Mixed air temperature, °C			Return air temperature, °C		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.4	13.5	13.5	14.0	13.7	13.6	23.2	22.5	22.8
$\sigma$	0.2			0.2			0.2		
S	0.2	0.1	0.0	0.9	0.6	0.4	0.3	0.6	0.2
$x_{\max}$	14.1	13.8	13.5	16.6	15.6	14.7	23.8	23.4	23.2
$x_{\min}$	12.6	13.4	13.5	12.9	13.4	13.0	22.6	21.3	22.5
$\bar{D}$		0.0	-0.1		0.3	0.4		0.7	0.4
$D_{\max}$		0.8	0.9		1.5	2.3		1.8	0.9
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.2	0.2		0.3	0.5		0.7	0.4
$D_{\text{rms}}$		0.2	0.2		0.5	0.8		0.8	0.5
SE		-0.3	-0.4		2.1	3.1		2.9	1.7
IE		1.1	1.2		2.3	3.5		3.1	1.8

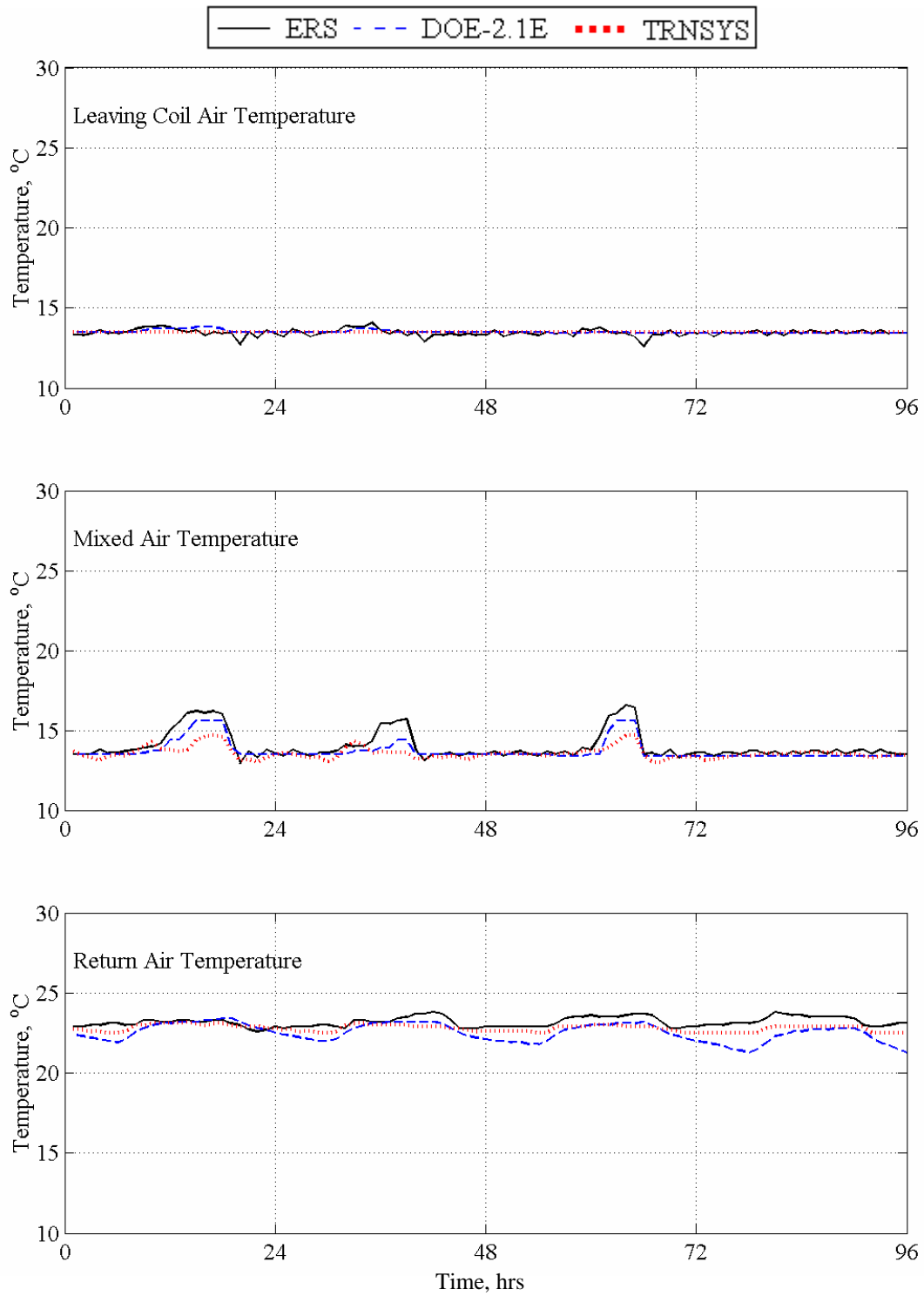


Figure 3.5 Additional AHU-A parameters.

### 3.2.2.2. System level results for the “B” system

Air handling unit “B” supplies air to the “B” test rooms. As was shown Table 1.2, the parameters generally used for system-level comparison are the supply airflow rate, the outside airflow rate, the temperature of air entering cooling coil, the temperature of air leaving cooling coil, the temperature of return air, and the cooling coil energy heat transfer rate.

Table 3.7 provides a statistical summary of supply airflow rate, outside airflow rate, return and outside dry-bulb temperature difference, and cooling heat transfer rate for air handling unit “B”. The graphical results for the four-day test are shown in Figure 3.6.

From the statistical summary and the graphical results some general trends are apparent between the simulations and the experiment for air handling unit “B” parameters, which are similar to the results seen for the air handling unit “A”. When cooling is required, both TRNSYS and DOE2.1E over-predict the supply airflow rate.

For the cooling coil heat transfer rate, TRNSYS over-predicts the value during the day. DOE2.1E under-predicts the cooling heat transfer rate during the first day and then over-predicts it for the rest of the test.

Table 3.7 Statistical comparison of AHU-B parameters.

Statistical Parameter	Supply airflow rate, m <sup>3</sup> /hr			Temperature difference, °C			Cooling coil heat transfer rate, kW		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	1457.7	1532.7	1811.5	15.3	14.7	15.1	4.3	4.7	5.2
$\sigma$	112.0			0.2			1.2		
s	417.3	371.4	629.1	4.4	4.1	4.3	1.4	1.3	1.9
$x_{\max}$	2605.0	2349.0	3093.0	23.0	22.0	22.3	8.3	7.5	9.2
$x_{\min}$	1207.0	1226.0	1239.0	7.6	7.5	7.6	2.9	3.3	3.4
$\bar{D}$		-75.0	-353.9		0.5	0.2		-0.4	-0.9
$D_{\max}$		597.0	963.0		1.9	3.5		1.7	2.6
$D_{\min}$		2.0	5.0		0.0	0.0		0.0	0.0
$ D $		146.8	355.9		0.6	0.7		0.6	1.0
$D_{\text{rms}}$		218.4	498.0		0.8	0.9		0.8	1.3
SE		-4.9	-19.5		3.7	1.2		-8.6	-18.1
IE		9.6	19.6		4.1	4.4		11.8	18.6

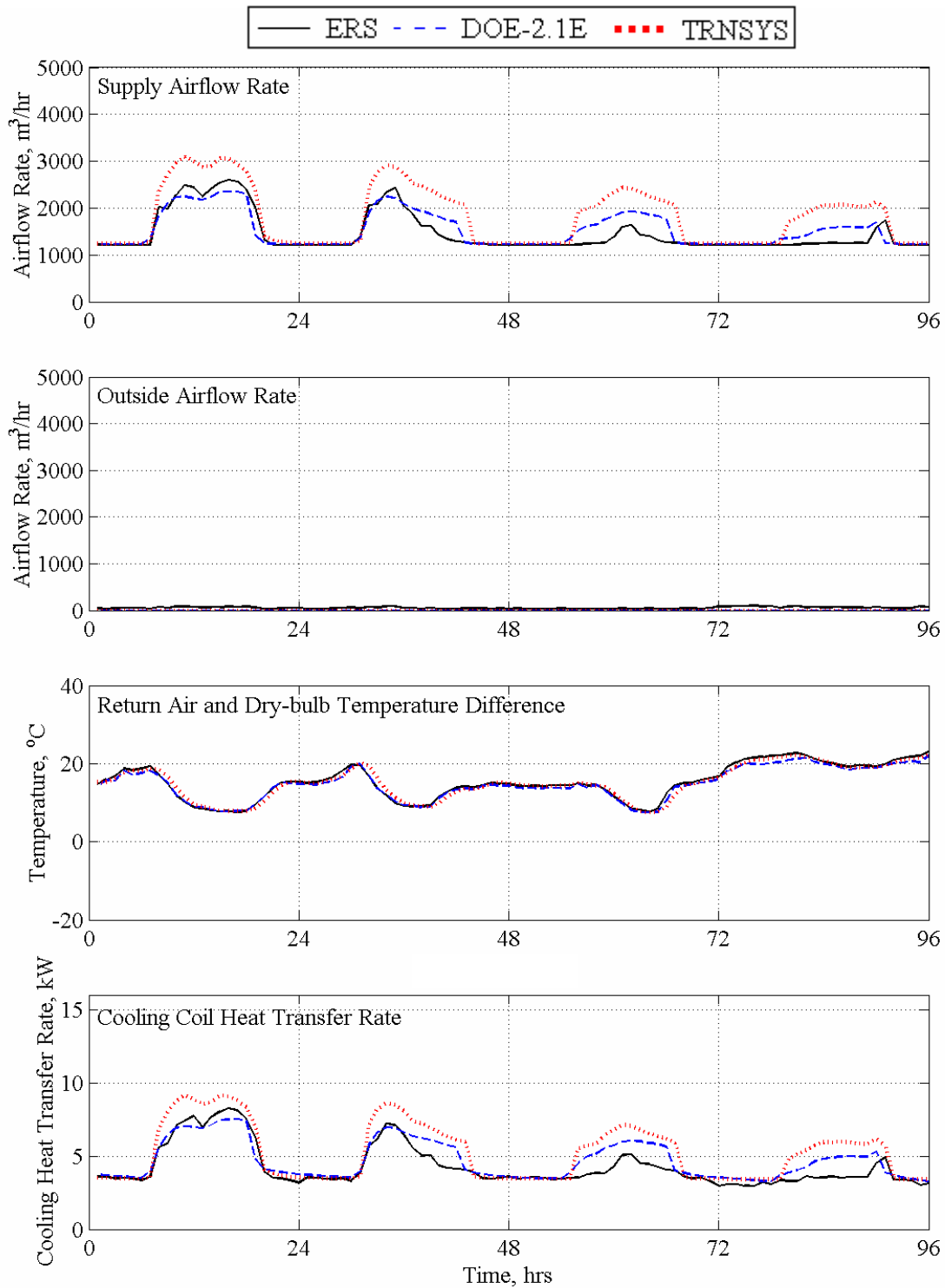


Figure 3.6 AHU-B parameters.



Table 3.8 provides a statistical summary of additional parameters, which include the leaving coil air temperature, mixed air temperature, and return air temperature for air handling unit “B”. The graphical results for these parameters are shown in Figure 3.7. The cooling coil heat transfer rate remains relatively constant during the entire test.

Both TRNSYS and DOE2.1E over-predict the mixed air temperature during most of the test. The predicted mixed air temperature for DOE2.1E fluctuates up and down within a range of about 1°C from day to night. The mixed air temperature predicted from TRNSYS and measured at the ERS remains relatively constant during the four-day test. The same trend seen for the DOE2.1E mixed air temperature is also seen for the return air temperature, which is expected when using 100% re-circulated air.

Table 3.8 Statistical comparison of additional AHU-B parameters.

Statistical Parameter	Leaving coil air temperature, °C			Mixed air temperature, °C			Return air temperature, °C		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.2	13.5	13.5	22.8	22.6	23.1	23.1	22.6	22.9
$\sigma$	0.2			0.2			0.2		
S	0.1	0.1	0.0	0.2	0.5	0.2	0.3	0.5	0.2
$x_{\max}$	13.8	13.8	13.5	23.3	23.5	23.6	23.6	23.5	23.4
$x_{\min}$	12.9	13.4	13.5	22.3	21.4	22.8	22.6	21.4	22.6
$\bar{D}$		-0.3	-0.3		0.2	-0.4		0.5	0.1
$D_{\max}$		0.8	0.6		1.3	1.0		1.6	0.7
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.3	0.3		0.4	0.4		0.5	0.2
$D_{\text{rms}}$		0.3	0.3		0.5	0.4		0.7	0.3
SE		-1.9	-2.2		0.9	-1.6		2.2	0.6
IE		2.0	2.3		1.6	1.6		2.4	1.0

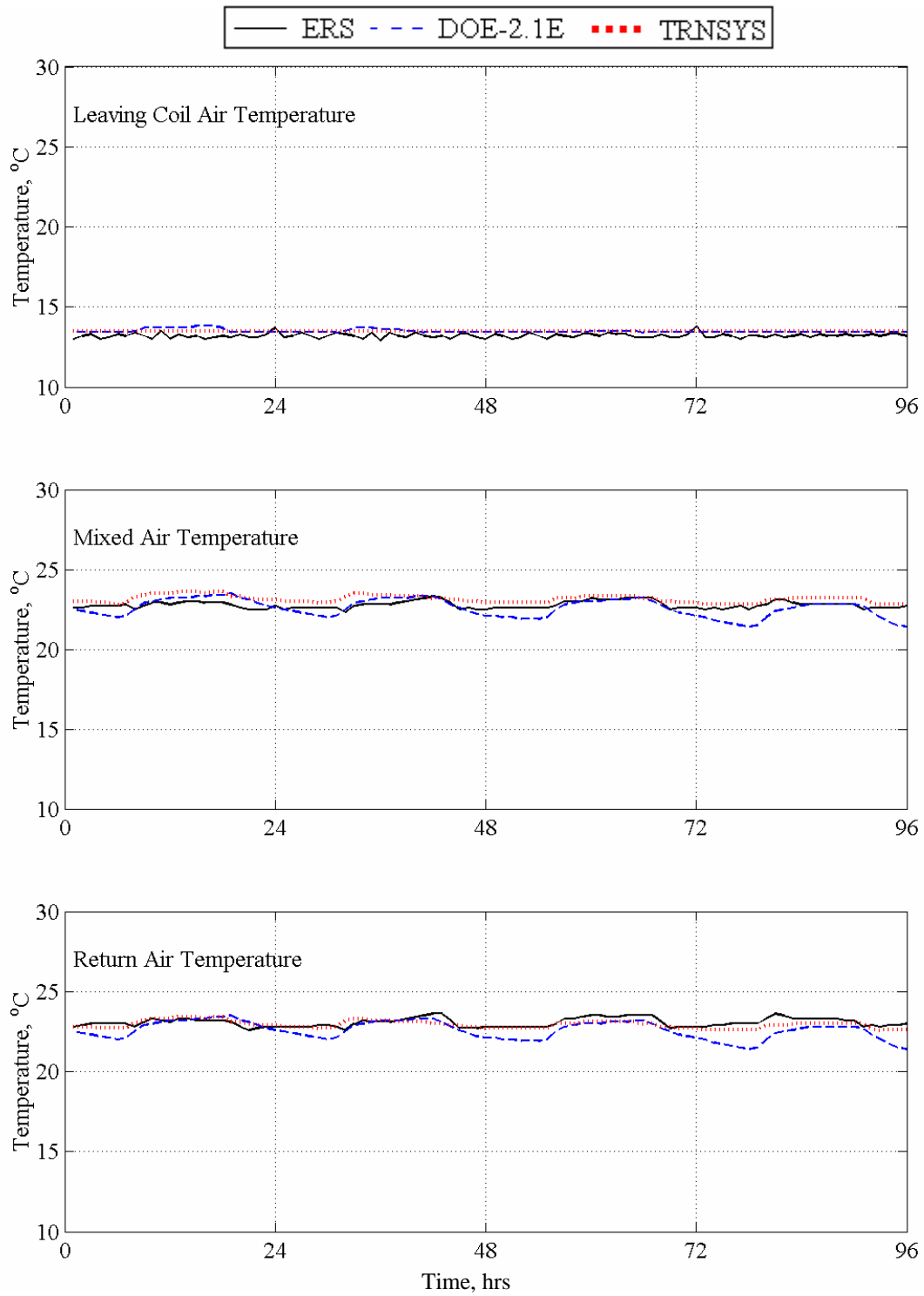


Figure 3.7 Additional AHU-B parameters.

## 4. Economizer Test 3

### 4.1. Description of the exercise

This section contains information regarding the operating parameters and conditions used for Economizer Test 3 conducted at the Energy Resource Station. The test was conducted over a four-day period from March 29 through April 1, 2003.

Internal heat loads for the test rooms was produced from lights and electric baseboard heaters. These were scheduled on during a portion of the day and off the remainder of the time. The windows of the test rooms did not have any blinds or drapes covering them thus allowing maximum solar heat gain.

Thermostats in the test rooms were programmed for a constant heating set-point temperature and a constant cooling set-point temperature. For non-test room spaces in the ERS that are adjacent to the test rooms, the zone thermostats were programmed with the same set-point temperatures as the test rooms. This reduces the possibility thermal interaction between the test rooms and the remainder of the building.

For this test, the “B” system was operated with the outdoor air dampers in the closed position, and the economizer cycle was disabled. The “A” system was operated with the minimum outdoor air dampers in the closed position when the economizer was disabled and incorporated an economizer cycle based on return air enthalpy. Both systems were operated as variable air volume with hydronic terminal reheat at the zone level. The systems were run 24 hours per day and chilled water was available for mechanical cooling throughout the test period.

#### 4.1.1. Run period and general weather conditions

This item is used to specify the initial and final dates of the desired simulation period and also the general conditions and location of the ERS facility. The TMY weather file that accompanies this report has ERS weather station information only for the dates of the tests.

- Test dates: March 29 through April 1, 2003.
- Weather data for the ERS is organized into TMY format. The weather file is called “IEA2003.tmy”.
- Building location
  - Latitude: 41.71 °N
  - Longitude: 93.61 °W
  - Altitude: 285.9 m (938 ft)
  - Time-zone: 6, Central time zone in U.S.
  - Daylight-saving: NO

#### 4.1.2. Test rooms operation and control parameters

This item describes the operation and control of the test rooms that apply to this test.

#### 4.1.2.1. Internal loads and general room conditions

The only internal heating loads used during this test are from ceiling mounted fluorescent lights and baseboard electric heaters. These internal loads were scheduled “ON” for only certain hours during the day. The baseboard heaters have two stages of heat; however, for this test, only the first stage of baseboard heat was used. Due to variations in the installed equipment, the baseboard power is not identical for each unit. Furthermore, slight variations also exist for the lighting power. Table 3.1 provides power values for the lights and baseboard heaters for each test room.

Table 4.1 Lighting and baseboard power for each test room, in Watts.

Room	Stage 1	Stage 2	Lights
East A	890	890	536.0
East B	890	880	536.0
South A	890	880	531.0
South B	880	890	536.5
West A	860	860	530.5
West B	890	890	526.5
Interior A	870	900	530.0
Interior B	900	900	535.0

Table 4.2 provides the schedule for the operation of the lights and the first stage of baseboard heat used in this test. The time represents the beginning of each hour where 1 represents 1 AM and 24 represents midnight.

Table 4.2 Lighting and first stage baseboard heating schedules for all test rooms

Hour	Lights	Stage 1 Baseboard	Hour	Lights	Stage 1 Baseboard
1	OFF	ON	13	ON	ON
2	OFF	ON	14	ON	ON
3	OFF	ON	15	ON	ON
4	OFF	ON	16	ON	ON
5	OFF	ON	17	ON	ON
6	OFF	ON	18	ON	ON
7	ON	ON	19	OFF	ON
8	ON	ON	20	OFF	ON
9	ON	ON	21	OFF	ON
10	ON	ON	22	OFF	ON
11	ON	ON	23	OFF	ON
12	ON	ON	24	OFF	ON

#### 4.1.2.2. Room-level HVAC controls specifications

Space temperature conditions were maintained by utilizing variable airflow rates (VAV) for space cooling and hydronic reheat for space heating. The cooling and heating set-point

temperatures were the same for all test rooms and their values remained fixed throughout the test.

In heating mode the terminal unit operates at a prescribed minimum airflow rate, and the two-way hot water control valve modulates in response to the zone heating needs. In cooling mode, the two-way hot water control valve is closed, and the terminal unit modulates the primary supply airflow rate in response to the zone cooling needs. In addition to a minimum airflow rate, each unit has a maximum airflow rate. The values of these airflow rates depend on whether the room is an exterior room or an interior room.

Table 4.3 provides values for the temperature set points and airflow rates for the test rooms.

Table 4.3 Test room set-point temperatures and airflow rates

Test room location	Heating set-point temperature, °C	Cooling set-point temperature, °C	Minimum airflow rate, m <sup>3</sup> /hr	Maximum airflow rate, m <sup>3</sup> /hr
East "A"	22.2	22.8	298	1,103
East "B"	22.2	22.8	323	1,064
South "A"	22.2	22.8	306	1,048
South "B"	22.2	22.8	283	1,025
West "A"	22.2	22.8	291	1,025
West "B"	22.2	22.8	307	1,023
Interior "A"	22.2	22.8	310	618
Interior "B"	22.2	22.8	298	591

### 4.1.3. System-level HVAC operation and control

The items in this section describe how the air handling units were configured for the tests. The economizer control was enabled on the "A" system while the "B" system remained the fixed minimum damper position. Besides the economizer control on the "A" system, the systems were configured identically.

#### 4.1.3.1. Air handling unit controls and specifications

The system controls were configured as follows:

- Heating schedule: always available.
- Cooling schedule: always available.
- Cooling control supply air temperature set point after the fan: 15 °C.
- Preheat: NOT available.
- Humidity control: NOT available.
- Economizer: enabled when the return air enthalpy exceeded the outdoor enthalpy for the "A" system.

The system air for both the “A” and the “B” systems was specified as follows:

- Supply airflow rate: maximum 4,248 m<sup>3</sup>/hr.
- Return air path: plenum
- Minimum outside airflow: 0% damper open position.
- Duct heat gain: 1.0 °C.

The fans were identically configured for the “A” and the “B” air-handling units. The following configurations were used for the economizer test:

- Supply air static pressure: 547.4 Pa.
- Fan schedule: always on.
- Supply fan control: 547.4 Pa.
- Return fan control differential: 90% of supply air.
- Motor placement: In-air flow.
- Fan placement: Draw-through.

Figure 3.4 shows the relationship between the supply fan power and supply airflow rate. A quadratic regression of the data and coefficient of determination for the regression are shown on the plot.

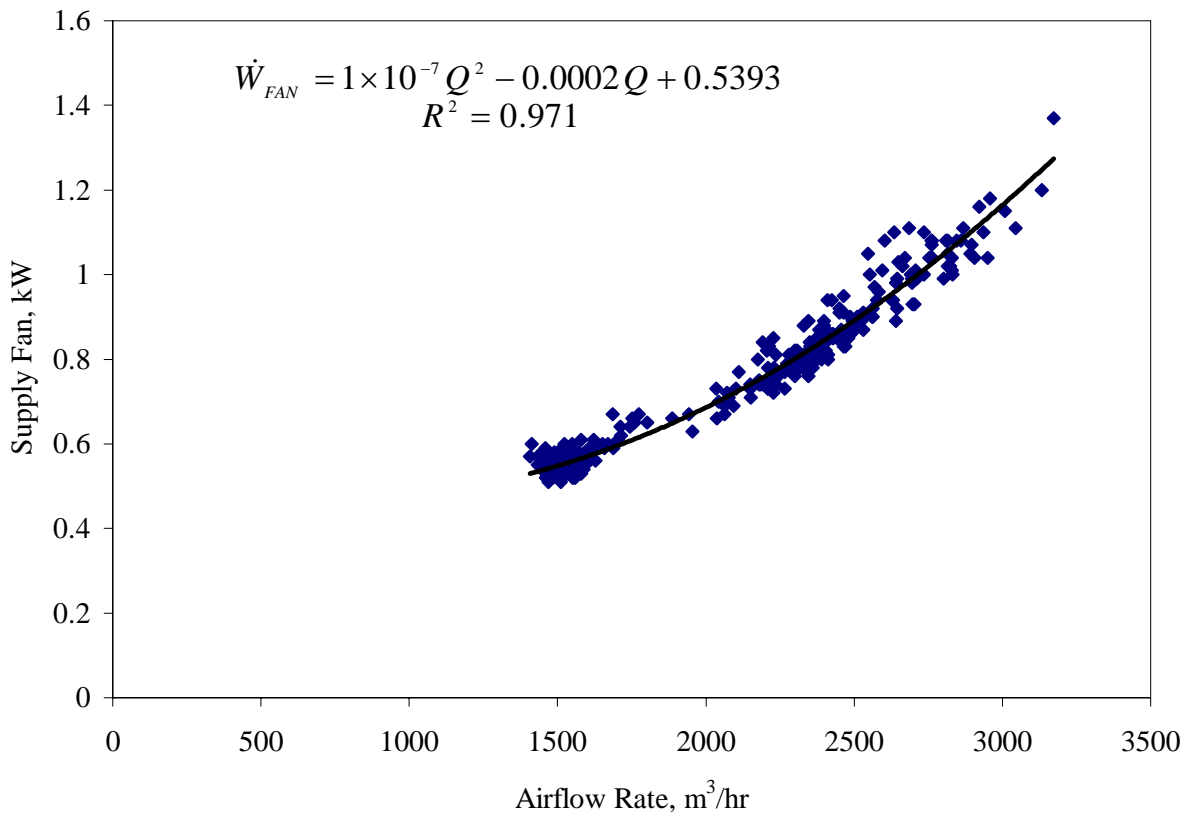


Figure 4.1 Supply fan power as function of airflow rate.

### 4.2.3.2. Economizer control specifications

At the onset of economizer control the outdoor air damper opens to 100%. As the outdoor air enthalpy continues to decrease, the system cooling coil control valve continues to close until the outdoor air enthalpy is low enough that the entire system cooling load is satisfied by the outdoor air. Further reduction in outdoor air enthalpy causes the outdoor air damper to close until the damper is completely closed. At this point, further reduction of outdoor air enthalpy causes the systems preheat coil control valve to open. The primary system supply air is maintained at a constant set-point temperature throughout the test. For this test the “B” system outdoor air damper positions were closed and the economizer control was disabled. Figure 4.2 illustrates the control strategy used for Economizer Test 3.

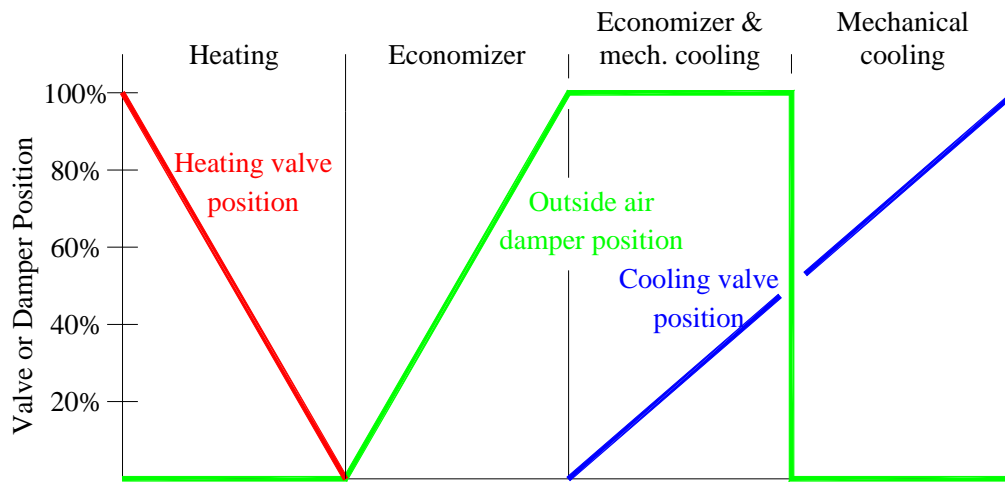


Figure 4.2 Economizer control sequence.

## 4.2. Comparison between experimental results and simulation results

In this section the results from the computer simulations are compared with the values obtained from the experiments run at the ERS. The comparisons are made both graphically and statistically. The statistical parameters used were defined in Section 1.5.

Before comparing the results for any system or zone level parameters, the weather information used by each model must be validated. Weather data collected at the ERS were converted to TMY format and provided to each modeler. Comparison of the key weather parameters is a test to assure each program’s weather processor is correctly interpreting the provided weather information.

### 4.2.1. Weather data

The key weather parameters are dry-bulb and wet-bulb temperatures, direct normal solar irradiation, and total horizontal solar irradiation. Table 4.4 gives the statistical comparison of the temperatures and solar fluxes, respectively. Figure 4.3 illustrates the weather parameters during the four-day test period. The agreement between the ERS data and the models is acceptable.

Table 4.4 Statistical comparison of weather parameters.

Statistical Parameter	Dry-bulb temperature, °C			Wet-bulb temperature, °C			Direct normal irradiation, W/m <sup>2</sup>			Total horizontal irradiation, W/m <sup>2</sup>		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	9.6	9.6	9.5	3.8	3.9	3.7	201.5	217.2	217.4	205.3	205.4	205.5
S	9.8	9.8	9.8	6.0	6.0	6.0	281.5	302.2	305.4	259.3	259.0	259.6
x <sub>max</sub>	30.0	30.0	29.9	14.3	14.4	14.3	904.0	964.7	977.5	822.0	816.5	816.9
x <sub>min</sub>	-3.3	-3.9	-3.4	-4.3	-4.4	-4.3	0.0	0.0	0.0	0.0	0.0	0.0
$\bar{D}$		0.0	0.1		-0.1	0.1		-15.7	-15.9		-0.1	-0.2
D <sub>max</sub>		1.2	2.1		0.9	1.3		164.2	199.3		96.3	110.8
D <sub>min</sub>		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0
D		0.3	0.7		0.2	0.4		30.4	36.6		9.8	21.7
D <sub>rms</sub>		0.3	0.9		0.3	0.5		49.6	59.0		21.9	36.1
SE		0.4	1.5		-1.4	2.9		-7.2	-7.3		0.0	-0.1
IE		2.7	7.3		5.4	10.0		14.0	16.8		4.8	10.6



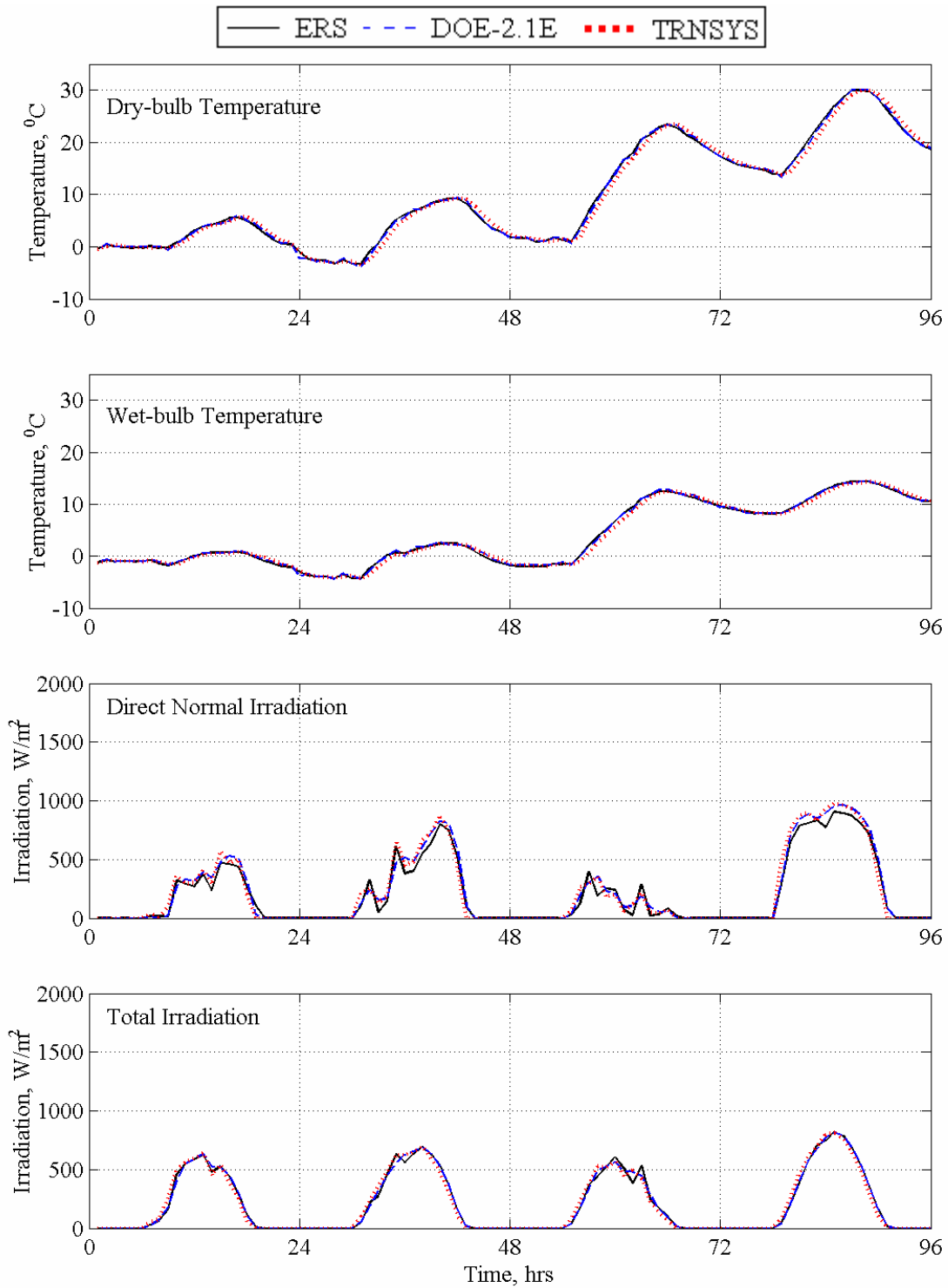


Figure 4.3 Weather parameters.

## 4.2.2. Economizer controlled system results

### 4.2.2.1. System level results for the “A” system

Air handling unit “A” supplies air to the “A” test rooms. As was shown Table 1.2, the parameters generally used for system-level comparison are the supply airflow rate, the outside airflow rate, the air temperature entering the cooling coil, the air temperature leaving the cooling coil, the temperature of return air, and the cooling coil heat transfer rate.

Air handling unit “A” supplies air to the “A” test rooms. Table 4.5 provides a statistical summary of supply airflow rate, outside airflow rate, the difference between the return and outside enthalpy, and the cooling heat transfer rate for air handling unit “A”. The graphical results for the four-day test are shown in Figure 4.5. The significance of the enthalpy difference between the return air and the outside air is in the economizer control. Recall that when the outside air enthalpy is less than the return air temperature, the economizer is enabled; therefore, during the time when the enthalpy difference is negative, the economizer is disabled.

Table 4.5 provides a statistical summary of the air handling unit parameters, while Figure 4.4 shows the graphical results for the four-day test. From the statistical summary and the graphical results some general trends are apparent between the simulations and the experiment for air handling unit “A” parameters. Both TRNSYS and DOE2.1E over-predict the supply airflow rate when zone cooling is required for the system.

The outside air flow rate predictions for both TRNSYS and DOE2.1E followed the experimental results closely during the test except on the last day when both TRNSYS over-predicted the outside airflow rate. On the third day, TRNSYS remained in economizer mode the entire day and DOE2.1E only disabled the economizer for one hour despite the fact the economizer controls at the ERS were disabled for four hours. The return and outdoor enthalpy difference plotted in Figure 4.4 shows the control strategy employed for economizer control. For a few hours on the third day, the enthalpy difference fluctuated near zero. To prevent an economizer controlled system from rapid cycling between economizer and non-economizer mode when the conditions are near the economizer on point, a dead band is used. At the ERS a 1 kJ/kg dead band was used for the enthalpy control. Thus the experimental results show the economizer was disabled for a longer period of time than was modeled by the programs. On the fourth day of the test, the models more closely match the economizer control since the conditions were more abrupt with regards to whether the economizer was enabled or disabled.

The cooling coil heat transfer rate for both TRNSYS and DOE2.1E closely follow the experiment. Mechanical cooling was not required during this test until the afternoon of the third day of the test and then used in the morning and afternoon on the fourth day of the test.

Table 4.5 Statistical comparison of AHU-A parameters.

Statistical Parameter	Supply airflow rate, m <sup>3</sup> /hr			Outside airflow rate, m <sup>3</sup> /hr			Return air/outdoor air enthalpy difference, kJ/kg			Cooling coil heat transfer rate, kW		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{X}$	1723.6	1611.6	1947.1	939.8	876.3	1061.0	13.4	13.3	14.0	1.8	1.5	1.9
$\sigma$	76.3			24.6			0.3			0.8		
S	564.9	477.8	724.6	641.7	608.4	762.7	9.8	9.2	9.6	3.1	2.5	3.2
X <sub>max</sub>	3218.0	2873.0	3305.0	2576.0	2471.0	3179.0	26.5	25.4	26.6	11.2	8.4	11.0
X <sub>min</sub>	1200.0	1196.0	1214.0	82.0	0.0	0.0	-6.8	-6.3	-5.1	0.0	0.0	0.0
$\bar{D}$		112.0	-223.6		63.5	-121.2		0.1	-0.6		0.3	-0.1
D <sub>max</sub>		679.0	793.0		2111.0	2449.0		2.1	2.5		2.8	1.9
D <sub>min</sub>		0.0	9.0		2.0	1.0		0.0	0.0		0.0	0.0
D		136.9	245.6		228.8	248.6		0.6	0.8		0.3	0.3
D <sub>rms</sub>		212.5	333.5		393.4	516.7		0.8	1.1		0.8	0.5
SE		7.0	-11.5		7.3	-11.4		1.0	-3.9		22.1	-6.3
IE		8.5	12.6		26.1	23.4		4.9	6.0		22.3	13.3

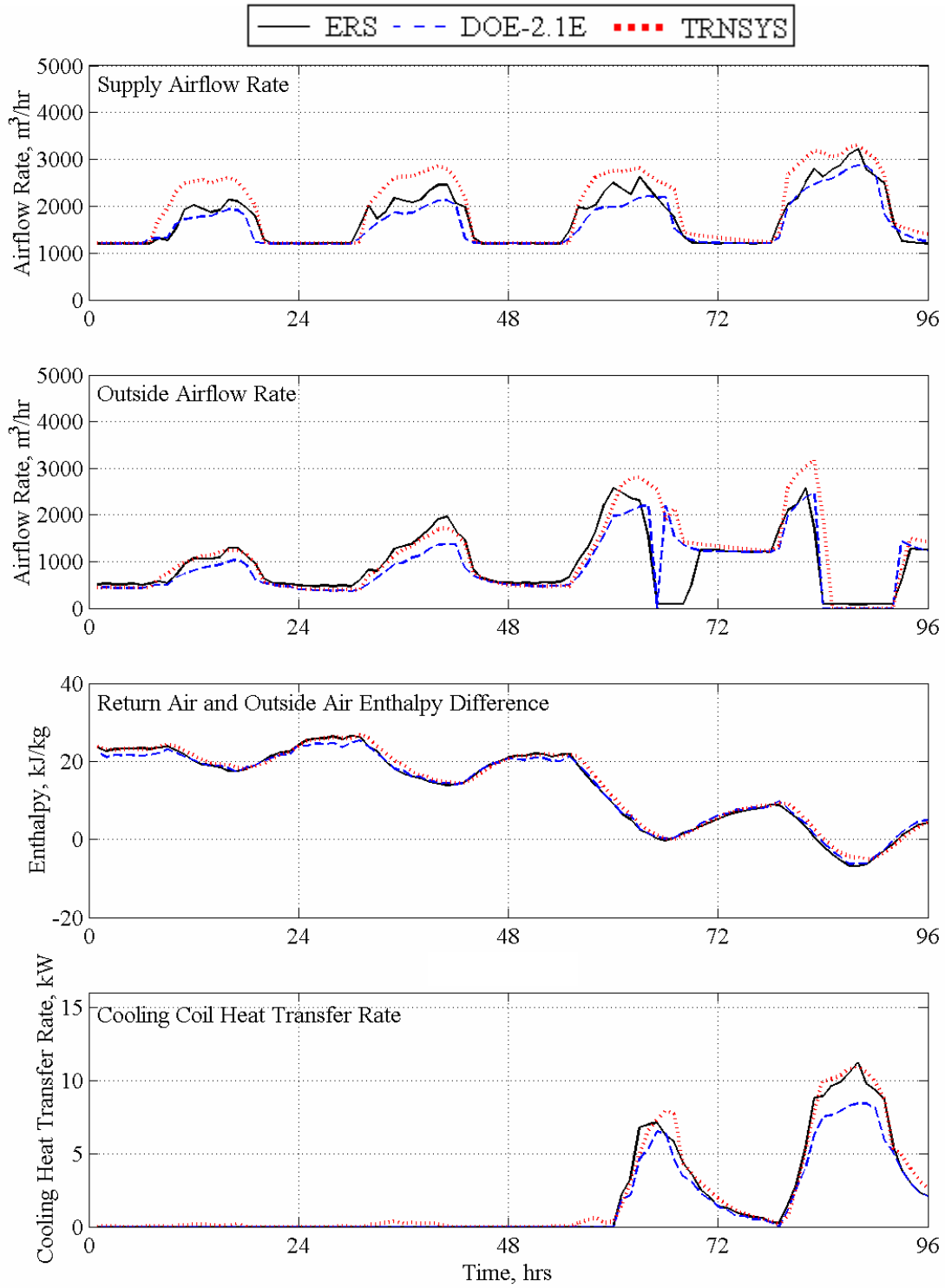


Figure 4.4 AHU-A parameters.

Table 4.6 provides a statistical summary of additional system parameters, which include the leaving coil air temperature, mixed air temperature, and return air temperature for air handling unit “A”. The graphical results for these parameters are shown in Figure 4.5. The statistical summary and the graphical results provide valuable tools comparing the additional parameters for air handling unit “A”.

Because the leaving cooling coil temperature is very close related to the supply air temperature (the temperature rise across the supply fan was supplied in the test specifications), good predictions for this parameter were seen by both TRNSYS and DOE2.1E on the first three days. On the last day of the test, the predicted leaving cooling coil temperature for the DOE2.1E is well above the experiment. Both TRNSYS and DOE2.1E closely predict the mixed air temperature during the first two days of the test when there was no mechanical cooling required and the last two days when mechanical cooling was required. TRNSYS predicts the return air temperature within the range seen in the experiment. During the first two test days, the DOE2.1E fluctuates below the actual return air temperature, while on the last two days of test; DOE2.1E over-predicts the return air temperature.

Table 4.6 Statistical comparison of additional AHU-A parameters.

Statistical Parameter	Leaving coil air temperature, °C			Mixed air temperature, °C			Return air temperature, °C		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.5	13.9	13.5	16.1	16.1	15.8	23.0	22.8	22.9
$\sigma$	0.2			0.2			0.2		
$S$	0.2	0.3	0.0	3.6	3.7	3.7	0.2	0.8	0.2
$x_{\max}$	14.0	15.0	13.5	23.3	24.2	23.7	23.6	24.2	23.3
$x_{\min}$	13.0	13.7	13.5	13.4	13.7	13.0	22.6	21.2	22.5
$\bar{D}$		-0.4	0.0		0.0	0.4		0.2	0.2
$D_{\max}$		2.0	0.5		1.8	3.2		1.9	0.7
$D_{\min}$		0.0	0.0		0.0	0.0		0.0	0.0
$ D $		0.4	0.2		0.3	0.6		0.7	0.3
$D_{\text{rms}}$		0.6	0.2		0.5	0.9		0.9	0.3
$SE$		-3.0	0.0		0.2	2.4		0.9	0.8
$IE$		3.1	1.1		2.0	3.5		3.0	1.1

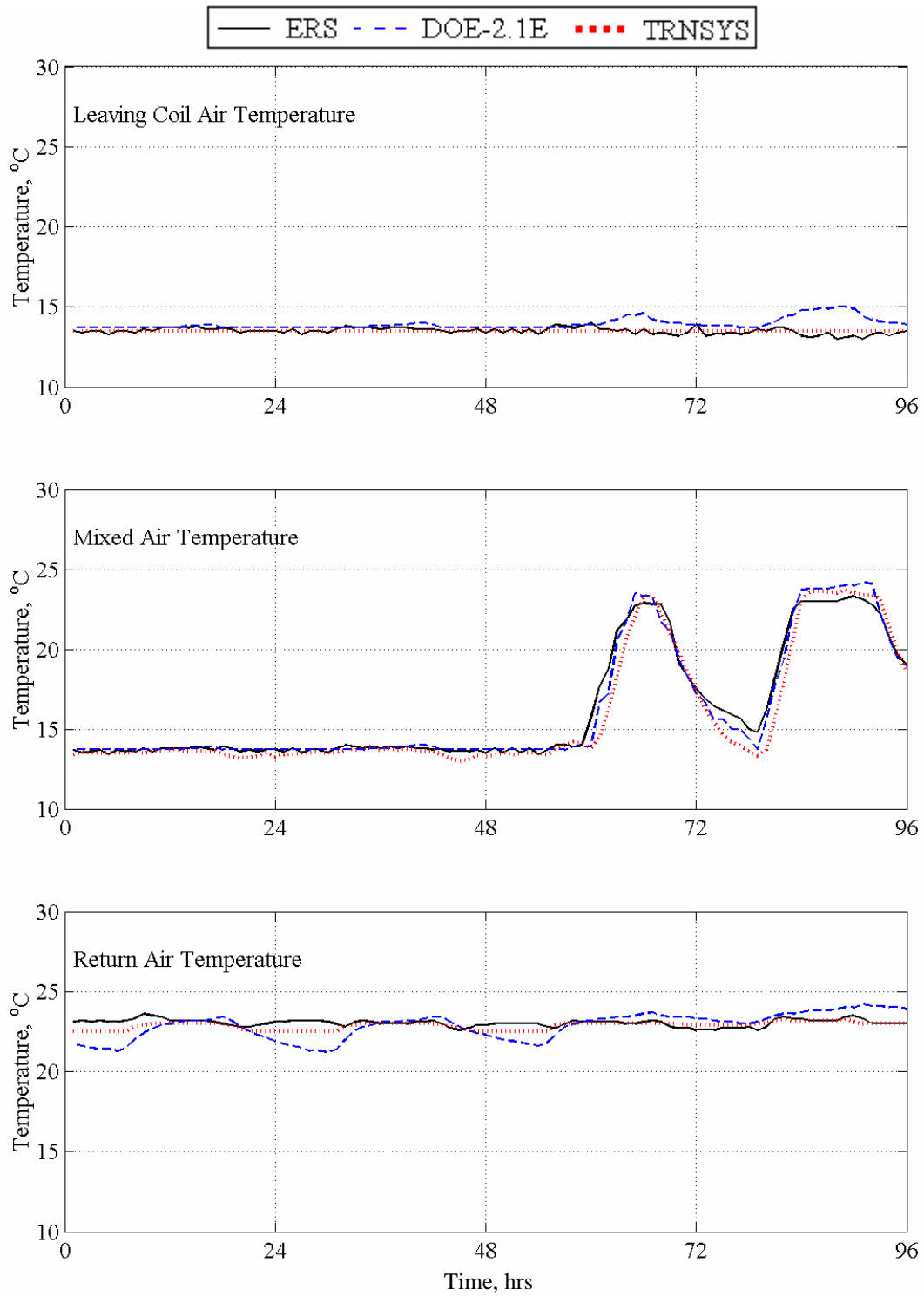


Figure 4.5 Additional AHU-A parameters.

#### 4.2.2.2. System level results for the “B” system

Air handling unit “B” supplies air to the “B” test rooms. As was shown Table 1.2, the parameters generally used for system-level comparison are the supply airflow rate, the outside airflow rate, the temperature of air entering cooling coil, the temperature of air leaving cooling coil, the temperature of return air, and the cooling coil energy heat transfer rate.

Table 4.7 provides a statistical summary of supply airflow rate, outside airflow rate, return and outside dry-bulb temperature difference, and cooling heat transfer rate for air handling unit “B”. The graphical results for the four-day test are shown in Figure 4.6. From the statistical summary and the graphical results some general trends are apparent between the simulations and the experiment for air handling unit “B” parameters. Similar to the results seen for the air handling unit “A”, both TRNSYS and DOE-2.1E over-predict the supply airflow rate.

There was an unexplainable discrepancy in the TRNSYS value for return and outside air enthalpy, which may possibly be an output error. If this value were the value used for the cooling heat transfer rate calculations, larger discrepancies not seen in the results would have been expected.

Both TRNSYS and DOE2.1E both over-predict the cooling coil heat transfer rate. The amount of cooling energy used was significantly higher compared with the “A” system where the economizer control was enabled.

Table 4.7 Statistical comparison of AHU-B parameters.

Statistical Parameter	Supply airflow rate, m <sup>3</sup> /hr			Return air/outdoor air enthalpy difference, kJ/kg			Cooling coil heat transfer rate, kW		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	1670.7	1711.2	1970.6	13.3	13.7	24.6	4.9	5.0	5.7
$\sigma$	112.1			0.3			1.1		
S	511.5	526.1	717.2	9.8	9.2	11.9	1.8	1.6	2.2
$x_{\max}$	3018.0	2913.0	3270.0	26.3	25.7	39.2	10.1	8.5	9.9
$x_{\min}$	1207.0	1232.0	1239.0	-6.9	-6.0	2.4	2.8	3.0	3.4
$\bar{D}$		-40.5	-299.9		-0.4	-11.3		-0.1	-0.9
$D_{\max}$		609.0	1020.0		1.7	15.5		2.2	3.2
$D_{\min}$		0.0	6.0		0.0	6.5		0.0	0.0
$ D $		115.5	315.3		0.8	11.3		0.5	0.9
$D_{\text{rms}}$		173.7	419.2		0.9	11.6		0.6	1.2
SE		-2.4	-15.2		-2.6	-46.0		-2.0	-15.0
IE		6.7	16.0		5.8	46.0		9.3	15.9



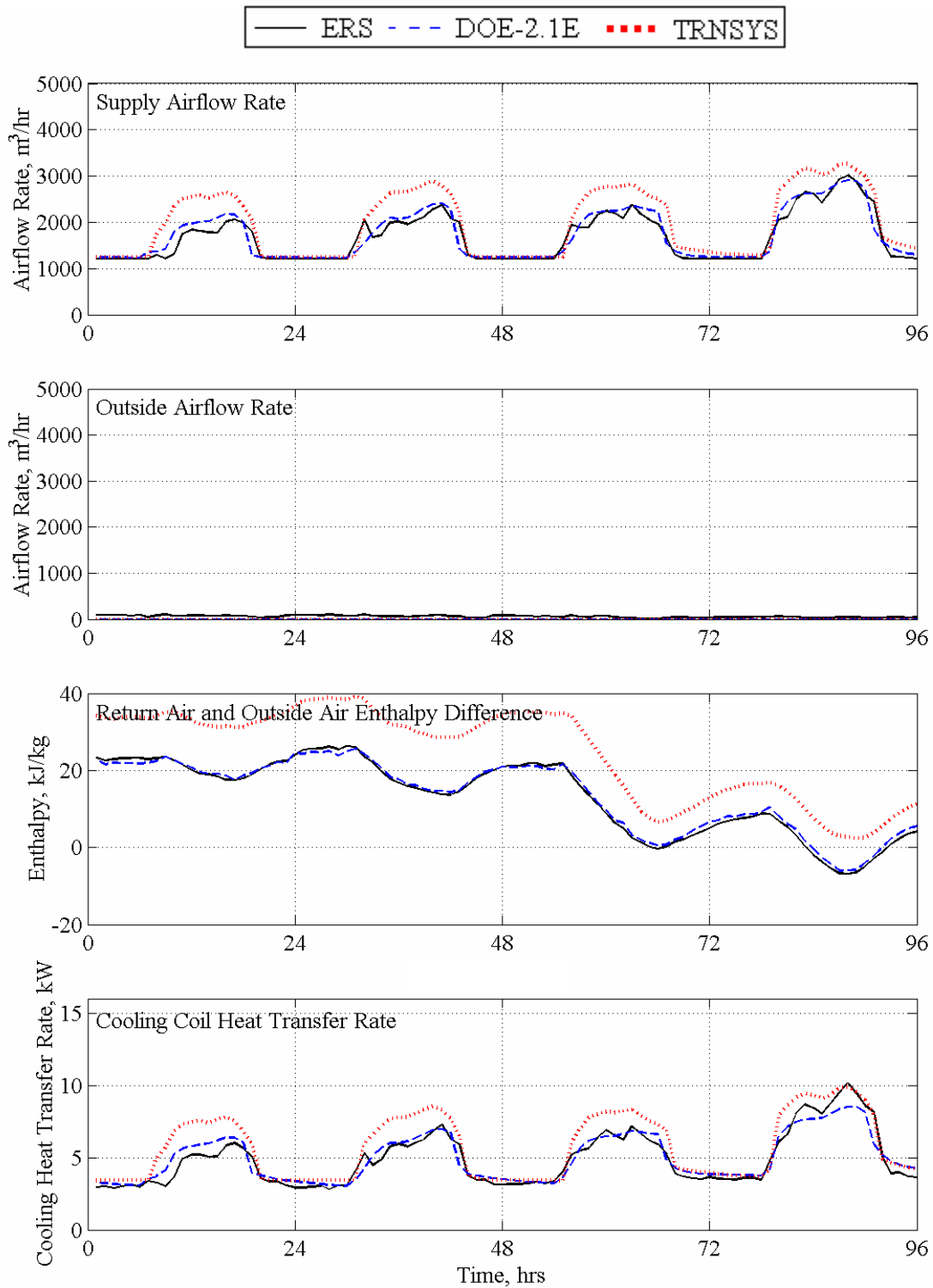


Figure 4.6 AHU-B parameters.

Table 4.8 provides a statistical summary of additional parameters, which include the leaving coil air temperature, mixed air temperature, and return air temperature for air handling unit “B”. The graphical results for these parameters are shown in Figure 4.7. The cooling coil leaving temperature in the DOE2.1E predictions was consistently about 1°C higher during the entire experiment.

TRNSYS over-predicts the mixed air temperature during most of the test. The predicted mixed air temperature for DOE2.1E fluctuates up and down from day to night for the first two days of test and is remains higher than the actual temperature during the last two days of test. The mixed air temperature predicted from TRNSYS and measured at the ERS remains relatively constant during the four-day test. The same trend is also seen for the return air temperature.

Table 4.8 Statistical comparison of additional AHU-B parameters.

Statistical Parameter	Leaving coil air temperature, °C			Mixed air temperature, °C			Return air temperature, °C		
	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS	ERS	DOE2.1E	TRNSYS
$\bar{x}$	13.2	14.3	13.5	22.6	22.9	23.2	22.9	22.9	23.0
$\sigma$	0.2			0.2			0.2		
S	0.1	0.3	0.0	0.2	0.8	0.3	0.2	0.8	0.3
$x_{\max}$	13.4	15.0	13.5	23.3	24.2	23.8	23.4	24.2	23.6
$x_{\min}$	12.8	14.0	13.5	22.1	21.3	22.8	22.4	21.3	22.6
$\bar{D}$		-1.1	-0.3		-0.3	-0.6		0.0	-0.1
$D_{\max}$		2.2	0.7		1.4	1.2		1.7	0.7
$D_{\min}$		0.6	0.1		0.0	0.1		0.0	0.0
$ D $		1.1	0.3		0.7	0.6		0.7	0.3
$D_{\text{rms}}$		1.1	0.3		0.8	0.6		0.8	0.3
SE		-7.4	-2.1		-1.3	-2.5		0.0	-0.5
IE		7.4	2.1		3.2	2.5		2.9	1.2

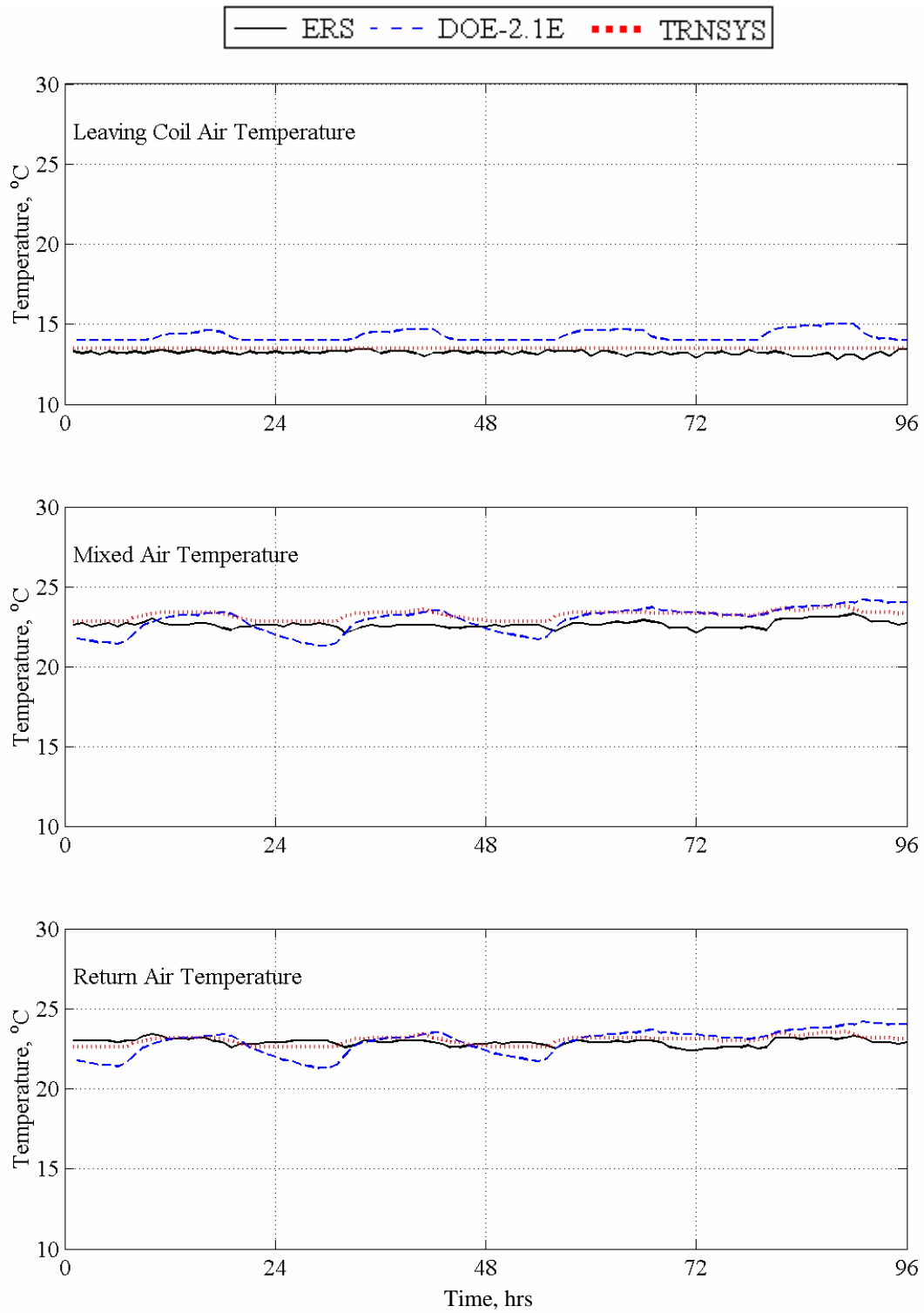


Figure 4.7 Additional AHU-B parameters.

## 5. Conclusions

During all three tests, both TRNSYS and DOE2.1E demonstrated a fundamental ability to predict parameters associated with enthalpy and temperature economizer control strategies. The major shortcoming of the models was not readily apparent when the simulations were in economizer mode, but rather when the system operated at a minimum damper position from the first test. These models currently do not have the ability to model complexities associated with the dynamics of variable air volume systems.

The strengths and weaknesses of each building simulation package were also apparent during the three tests and are noted below.

TRNSYS seemed to be able to accurately predict leaving cooling coil, mixed air and return air temperatures consistently for all the tests. Large temperature fluctuations not seen in the experiment were predicted by DOE2.1E especially for the mixed and return air temperature parameters. There were also some discrepancies with the leaving cooling coil temperature.

DOE2.1e provided some very accurate supply airflow rate, while TRNSYS systematically over-predicted the supply airflow rates. Both TRNSYS and DOE2.1E accurately predicted the cooling coil heat transfer rates on some times, while over and under-predicting it at other times. When in economizer mode, DOE2.1E consistently under-predicted the outside air flow rate. There were also discrepancies in both TRNSYS and DOE2.1E determining when to disable or enable the economizer controls.

All of these results reveal the importance of empirical validation of building simulation software. Empirical validations provide direct feedback about the robustness and inadequacies inherent in any simulation software compared with how building HVAC system actually function.

# Appendix A Energy Resource Station Specification

This appendix contains information about the Energy Resource Station (ERS) which should provide sufficient detail to allow building energy simulation modelers to develop their own models for use in the validation exercises. The information is organized in a format similar to a DOE2 input file.

Section A.1 contains information necessary to describe the building. This information has been obtained from the architectural drawings and construction documents available from the ERS manager. AutoCad drawings of the ERS are located on the CD that accompanies this report. While information about the entire ERS is provided, it is the “A” and “B” test rooms that were modeled for the empirical validation exercises. Data from the exercises are only available for the HVAC systems AHU-A and AHU-B, the “A” and “B” test rooms and the ERS weather station.

Section A.2 contains information about the HVAC systems in the ERS. The information presented is generic since specific system parameters differ from one validation exercise to another. The detailed system specifications are presented along with the description of each exercise.

## A.1. Input for the load calculations

### A.1.1. Run Period

For each validation exercise, the starting and ending dates are specified. The run period is used to specify the initial and final dates of the desired simulation period. It is important that the run period coincide with the dates of the exercise so that the appropriate weather data are used in the simulation.

### A.1.2. Weather data

During the dates of a validation exercise, weather and solar measurements are recorded. These data are post-processed into TMY format. The TMY data created from the ERS weather replace specific fields in an original DESMOINE.TMY file. Of the 8,760 days of data in the original file, only the days that correspond to the dates of the exercise have modified values. A TMY data file contains many meteorological parameters which may or may not be used in building simulation software. The only data fields which are modified with ERS data include the following:

- Dry bulb temperature
- Dew point temperature
- Barometric pressure
- Total horizontal solar irradiation
- Direct normal solar irradiation
- Wind direction
- Wind speed

The weather files created for the empirical validation exercises are named according to the year in which the test was conducted. For example the file “IEA2002.tmy” contains modified data for validation tests that were conducted in 2002. TMY weather files for the validation exercises are provided on the CD provided with this report.

### **A.1.3. Building Location**

This specifies the location of the building and information about the time zone.

LATITUDE: 41.71 degree north

LONGITUDE: 93.61 degree west

ALTITUDE: 938.0 feet above sea level

TIME-ZONE: 6, central time zone in the US

DAYLIGHT-SAVINGS: YES/NO. Depending on the time of year this parameter is YES or NO. Generally daylight-saving time is in effect from early April until mid-October. This parameter is specified for each exercise. The parameter affects the relationship between the local time and solar time and is significant when defining time-based events such as light schedules, thermostat schedules, etc.

### **A.1.4. Building Shade**

There are no surrounding objects that significantly block solar irradiation on the ERS. A monument located south and east of the building does cast a small shadow on the east-facing test rooms during the early morning hours of clear days for the months from October to March. The shadow only occurs for a few minutes shortly after sunrise when solar irradiation is small. Because the shadow is small and does not remain in the same location for any significant time, the affect of the shadow on the solar irradiation striking the wall or glass is assumed to be insignificant. The shadow would have an impact on daylighting validation exercises if the shadow affected the amount of ambient light entering the test room. The surrounding ground cover is nearly all grass with a limited amount of concrete walkways approaching the doors.

### **A.1.5. Floor Plan**

The floor plan is used to identify each space for the building model. Figure A.1 is a simplified floor plan. Details of the floor plan are available on the CD.

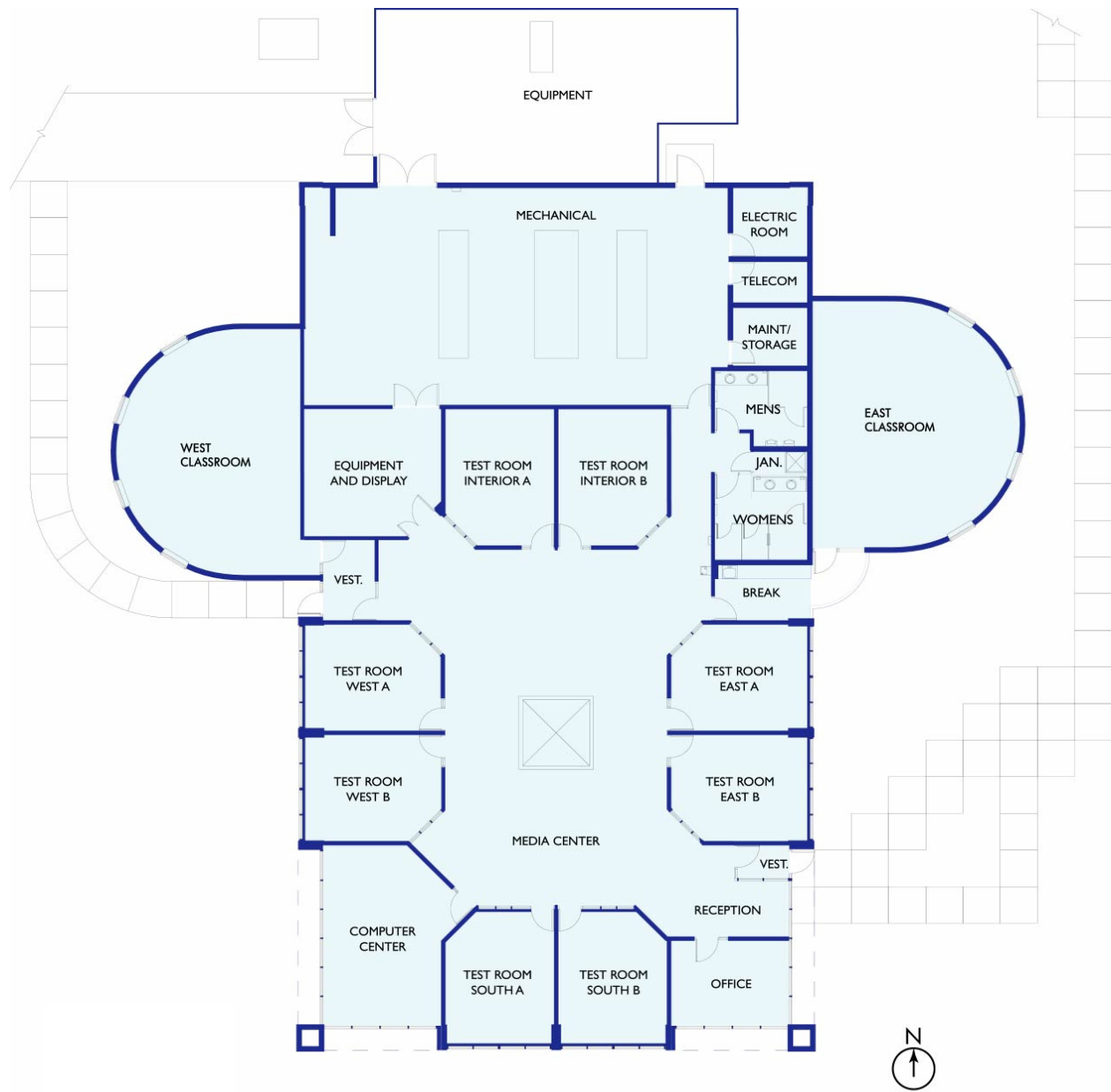


Figure A.1 A floor plan of the Energy Resource station

### A.1.6. Construction layer description

This specifies the material layers of each construction element in the model. These include; the cross section of an exterior wall, interior wall, ceiling, door, slab on grade floor and roof.

#### A.1.6.1. Layer type identification

There are 15 different construction layers used to describe the construction of the ERS. Table A.1 identifies the layer name and description/location for each layer.

#### A.1.6.2. Layer description

Each construction layer is composed of materials. The description of each material, the material thermal properties and the material thickness is described in Table A.2. The properties are given in terms of the following symbols:

- T: thickness, in inches
- K: conductivity, in Btu/(hr-ft-°F)
- D: density, in lb/ft<sup>2</sup>
- Cp: specific heat, in Btu/(lb-°F)
- R: resistance, in (hr-ft<sup>2</sup>-°F)/Btu.

Table A.1 Identification of construction layers used in the ERS building

Layer type	Description
LAY-R1	Layers for the roof of all spaces except for the classroom.
LAY-R2	Layers for the roof of the classroom.
LAY-W1	Layers for the lower portion of the exterior wall of the test rooms
LAY-W2	Layers for the upper portion of the exterior wall of the test rooms
LAY-W3	Layers for the spandrel wall in the lower portion of the computer room and office
LAY-W4	Layers for the upper portion of the exterior wall in the computer room and office
LAY-W5	Layers for the exterior wall of the classroom
LAY-W6	Layers for the lower portion of the exterior wall of other spaces
LAY-W7	Layers for the upper portion of the exterior wall of other spaces
LAY-P1	Layers for the 6-inch interior partition wall of all spaces
LAY-P2	Layers for the 4-inch interior partition wall of all spaces
LAY-P3	Layers for the 1/8-inch interior glass partition wall of test rooms
LAY-P4	Layers for the door of all spaces
LAY-C1	Layers for the ceiling of all spaces
LAY-F1	Layers for the slab on grade floor of all spaces



Table A.2 Thickness and thermal properties used for construction layers

Layer type	Description	T	K	D	Cp	R
LAY-R1	Inside surface					
	2 in heavy weight concrete	2.00	0.7576	140	0.2	0.22
	4 in horizontal air space	4.00	-	-	-	0.87
	2 in heavy weight concrete	2.00	0.7576	140	0.2	0.22
	Vapor barrier	-	-	-	-	0.06
	4 in insulation	4.00	0.0133	1.5	0.38	25.06
	Single-ply membrane	-	-	70	0.35	0.44
	Washed river rock	1.00	0.8340	55	0.4	0.10
Outside surface						
LAY-R2	Inside surface					
	22 gage steel deck	0.034	26.0	480	0.1	
	4 in insulation	4.00	0.0133	1.5	0.38	25.06
	Single-ply membrane	-	-	70	0.35	0.44
	Washed river rock	1.00	0.8340	55	0.4	0.10
Outside surface						
LAY-W1	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Vapor barrier	-	-	-	-	0.06
	3/8 in vertical air space	0.38	-	-	-	0.90
	1.5 in rigid insulation with foil face	1.50	0.0133	1.5	0.38	9.39
	4 in pre-cast conc.	4.00	0.7576	140	0.2	0.44
Outside surface						
LAY-W2	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	3/8 in vertical air space	0.38	-	-	-	0.90
	1 in rigid insulation with foil face	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
Outside surface						
LAY-W3	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Vapor barrier	-	-	-	-	0.06
	Metal stud framing with R13 batt insulation with foil face	3.50	0.0250	0.6	0.2	12.96
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	4.75 in vertical air space	4.75	-	-	-	0.92
	1 in spandrel glass	1.00	-	-	-	2.08
Outside surface						

Table A.2 (continued)

Layer type	Description	T	K	D	Cp	R
LAY-W4	Inside surface					
	Metal stud framing with R13 batt insulation with foil face	3.50	0.0250	0.6	0.2	12.96
	3/4 in vertical air space	0.75	-	-	-	0.90
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					
LAY-W5	Inside surface					
	3/4 in gypsum board	0.75	0.0926	50	0.2	0.67
	Vapor barrier	-	-	-	-	0.06
	Metal stud framing with R13 batt insulation with foil face	3.50	0.0250	0.6	0.2	12.96
	1 3/8 in vertical air space	1.38	-	-	-	0.89
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					
LAY-W6	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Vapor barrier	-	-	-	-	0.06
	Metal stud framing with R13 batt insulation with foil face	3.50	0.0250	0.6	0.2	12.96
	3/4 in vertical air space	0.75	-	-	-	0.90
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	4 in pre-cast conc.	4.00	0.7576	140	0.2	0.44
	Outside surface					
LAY-W7	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Metal stud framing with R13 batt insulation with foil face	3.50	0.0250	0.6	0.2	12.96
	3/4 in vertical air space	0.75	-	-	-	0.90
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					
LAY-P1	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Metal stud framing with fiberglass fill, insulation	3.50	0.0225	3.0	0.33	12.96
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
LAY-P2	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Metal stud framing with fiberglass fill, insulation	2.37	0.0225	3.0	0.33	8.78
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56

Table A.2 (continued)

Layer type	Description	T	K	D	Cp	R
LAY-P3	1/8 in glass with steel frame	1/8	0.797	138	0.18	0.013
LAY-P4	Door	1.75	-	-	-	4.16
LAY-C1	Ceiling	0.75	0.033	18	0.32	1.89
LAY-F1	Carpet	-	-	-	0.34	1.23
	4 in heavy weight conc.	4.00	0.7576	140	0.20	0.44
	Perimeter insulation, 2-inch width	-	-	-	-	5.00

A combined radiative and convective inside film resistance of 0.68 (hr-ft<sup>2</sup>-°F)/Btu is assumed for all interior surfaces (both vertical and horizontal). The outside film resistance should be based on the wind speed obtained from the TMY weather data. The assumed values for solar absorptances for the exterior walls and roofs are 0.6 and 0.29, respectively.

### A.1.7. Window type and description

This section specifies the fenestration for the building. Three types of window glazing are used throughout the building. All of the test rooms have double-pane clear glass while the remaining windows have double-pane tinted glass. A skylight is located above the media center which contains a translucent glass. The bottom of all windows located on an exterior wall is 3.5 feet (1.07 m) above the floor.

Table A.3 summarizes the fenestration for the ERS. For each type of window information is provided about the number of panes, shading coefficient, heat conductance of the total window (except for the outside film coefficient), width and height of the window. The glass conductance does not include the outside film coefficient but does include the frame.

### A.1.8. Space Description

This section identifies each space. Once all spaces have been identified, then each surface of the space is described in terms of orientation, width and height, and construction layer. Gross surface areas are presented in this section. Thus the areas include door and/or window areas. The size of a door is 3 feet (0.91 m) wide and 7 feet (2.13 m) high.

#### A.1.8.1. Space identification

All of the test rooms and most of the rooms in the remainder of the building have a plenum space and a conditioned space. The mechanical room and storage room do not have plenum spaces. The ceiling height of most rooms is 8.5 feet (2.59 m), and the plenum height is 5.5 feet (1.68 m). Detailed information about the size is illustrated in Section A.1.8.2. Since the “A” and “B” test rooms are matched pairs, information provided on each orientation applies to either room. Table A.4 identifies a space as either plenum space or conditioned space. Plenum space is designated with the prefix “P.”

Table A.3 Window identification and its characteristics with size

Type	Location	W	H	P	S	C
WIN-TEST	Exterior wall in test rooms	14.0	5	2	0.85	0.55
WIN-TYP1	Exterior wall east in the office	11.8	5	2	0.31	0.30
WIN-TYP2	Exterior wall south in the office	15.3	5	2	0.31	0.30
WIN-TYP3	Exterior wall south in the computer room	15.3	5	2	0.31	0.30
WIN-TYP4	Exterior wall west in the computer room	24.0	5	2	0.31	0.30
WIN-TYP5	Exterior wall south in the classroom	3.5	5	2	0.31	0.30
WIN-TYP6	Exterior wall west in the classroom	7.0	5	2	0.31	0.30
WIN-TYP7	Exterior wall north in the classroom	3.5	5	2	0.31	0.30
WIN-TYP8	Exterior wall east in the reception room	7.9	5	2	0.31	0.30
WIN-TYP9	Door in vest east and west	3.0	7.0	2	0.31	0.30
WIN-SKY	Roof of the media center	10.0	10	1	0.35	0.24

W: width, in feet H: height, in feet P: number of panes S: shading coefficient  
C: heat conductance of the total window, in Btu/(hr-ft<sup>2</sup>-°F)

Table A.4 Identification of plenum and conditioned space

Space-ID	Description
P-EAST	Plenum in the East test room
P-SOUTH	Plenum in the South test room
P-WEST	Plenum in the West test room
P-INTE	Plenum in the Interior test room
P-BREAK	Plenum in the break room, restrooms of women and men
P-RECEPT	Plenum in the reception room
P-OFFICE	Plenum in the office
P-COMPUTE	Plenum in the computer center
P-CLASS	Plenum in the classroom
P-DISPLAY	Plenum in the display room
P-MEDIA	Plenum in the media center
EASTROOM	Conditioned space in the East test room
SOUTHROOM	Conditioned space in the South test room
WESTROOM	Conditioned space in the West test room
INTEROOM	Conditioned space in the Interior test room
BREAKROOM	Conditioned space in the break room, restrooms of women and men
RECEPTION-RM	Conditioned space in the reception room
OFFICE	Conditioned space in the office
COMPUTE-RM	Conditioned space in the computer center
CLASSROOM	Conditioned space in the classroom
DISPLAY-RM	Conditioned space in the display room
STORAGE-RM	Conditioned space in the storage room, elec./comm. room
MEDIA-CENTER	Conditioned space in the media center
MECH-ROOM	Conditioned space in the mechanical room

### A.1.8.2. Space description

From the ERS floor plan (Figure A.1) one sees that the test rooms are not rectangular in shape. However, for simplification the rooms are assumed to be rectangular. Therefore, each test room has six surfaces: 4 walls, a ceiling (above) and a floor (below). Above each test room is a plenum space. The plenum space is also assumed to have six surfaces: 4 walls, a roof (above) and a ceiling (below). For a better understanding of the surface geometry, a capital letter representing the position of the surface is used. Refer to Figures A.2(a) and A.2(b) which illustrate the surface arrangements.

- C: a horizontal surface used for the *ceiling*
- E: a vertical surface used for the *wall east*
- F: a horizontal surface used for the *floor*
- N: a vertical surface used for the *wall north*
- R: a horizontal surface used for the *roof*
- S: a vertical surface used for the *wall south*
- W: a vertical surface used for the *wall west*

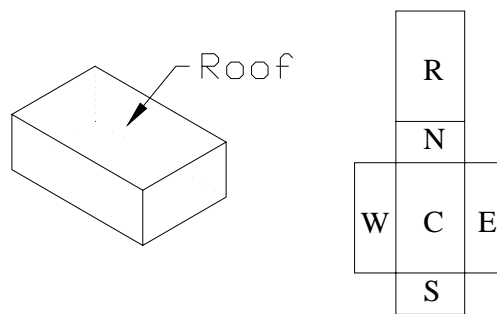


Figure A.2(a) Geometry presentation for plenum spaces

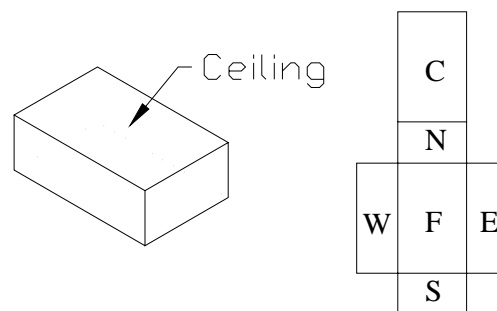


Figure A.2(b) Geometry presentation for conditioned spaces

Table A.5 describes the spaces with detailed information about the surfaces. The ERS is oriented with respect to true north/south. In the same way, the spaces identified in Table A.5 are described by surface orientation such as north, east, south and west. For example, consider the

space “P-EAST” that defines the plenum space above the East test room. P-EAST is located on the east side of the building at an elevation of 8.5 feet (2.59 m) above the floor level. The space is surrounded by six surfaces: one east-facing exterior wall, one interior north-facing wall, one interior south-facing wall, one interior west-facing wall, one ceiling and one roof. Once the surface orientations are specified, detailed information about the six surfaces which make up “P-EAST” must be provided. This includes the dimensions of the surface, the construction layer of the surface, and any windows or doors, if present.

As another example, consider the conditioned space called “SOUTHROOM” that is located on the south side of the building at the floor level. This space also is surrounded by six surfaces: one south-facing exterior wall that has a window, one north-facing interior wall that has a door, one east-facing interior wall, one west-facing interior wall that is adjacent to the computer room, one ceiling that is adjacent to the plenum space called “P-SOUTH”, and one floor.

Table A.5 Description of the space and details of its six surfaces

Space	Orientation	Width (ft)	Height (ft)	Layer	Window	Door
P-EAST	R	17.74	15.50	LAY-R1	-	-
	C	17.74	15.50	LAY-C1	-	-
	N	17.74	5.50	LAY-P2	-	-
	E	15.50	5.50	LAY-W2	-	-
	S	17.74	5.50	LAY-P2	-	-
P-SOUTH	W	15.50	5.50	LAY-P1	-	-
	R	15.50	17.74	LAY-R1	-	-
	C	15.50	17.74	LAY-C1	-	-
	N	15.50	5.50	LAY-P2	-	-
	E	17.74	5.50	LAY-P2	-	-
P-WEST	S	15.50	5.50	LAY-W2	-	-
	W	17.74	5.50	LAY-P1	-	-
	R	17.74	15.50	LAY-R1	-	-
	C	17.74	15.50	LAY-C1	-	-
	N	17.74	5.50	LAY-P2	-	-
P-INTE	E	15.50	5.50	LAY-P1	-	-
	S	17.74	5.50	LAY-P2	-	-
	W	15.50	5.50	LAY-W2	-	-
	R	15.50	17.74	LAY-R1	-	-
	C	15.50	17.74	LAY-C1	-	-
P-BREAK	N	15.50	5.50	LAY-P2	-	-
	E	17.74	5.50	LAY-P2	-	-
	S	15.50	5.50	LAY-P2	-	-
	W	17.74	5.50	LAY-P1	-	-
	R	10.66	36.60	LAY-R1	-	-
P-RECEPT	C	10.66	36.60	LAY-C1	-	-
	N	10.66	6.00	LAY-P2	-	-
	E	36.60	6.00	LAY-W7	-	-
	S	10.66	6.00	LAY-P2	-	-
	W	36.60	6.00	LAY-P2	-	-
P-OFFICE	R	17.74	13.00	LAY-R1	-	-
	C	17.74	13.00	LAY-C1	-	-
	N	17.74	5.50	LAY-P2	-	-
	E	13.00	5.50	LAY-W4	-	-
	S	-	-	-	-	-
P-OFFICE	W	-	-	-	-	-
	R	16.40	12.10	LAY-R1	-	-
	C	16.40	12.10	LAY-C1	-	-
	N	-	-	-	-	-
	E	12.10	5.50	LAY-W4	-	-
P-OFFICE	S	16.40	5.50	LAY-W4	-	-
	W	12.10	5.50	LAY-P1	-	-

Table A.5 (continued)

Space	Orientation	Width (ft)	Height (ft)	Layer	Window	Door
P-COMPUTE	R	16.30	25.10	LAY-R1	-	-
	C	16.30	25.10	LAY-C1	-	-
	N	16.30	5.50	LAY-P2	-	-
	E	25.10	5.50	LAY-P1	-	-
	S	16.30	5.50	LAY-W4	-	-
	W	25.10	5.50	LAY-W4	-	-
P-CLASS	R	22.20	34.67	LAY-R2	-	-
	C	22.20	34.67	LAY-C1	-	-
	N	22.20	1.00	LAY-W5	-	-
	E	-	-	-	-	-
	S	22.20	1.00	LAY-W5	-	-
	W	34.67	1.00	LAY-W5	-	-
P-DISPLAY	R	17.83	17.74	LAY-R1	-	-
	C	17.83	17.74	LAY-C1	-	-
	N	17.83	5.50	LAY-P2	-	-
	E	17.74	5.50	LAY-P1	-	-
	S	-	-	-	-	-
	W	-	-	-	-	-
P-MEDIA	R	30.00	60.80	LAY-R1	-	-
	C	30.00	57.20	LAY-C1	-	-
	N	-	-	-	-	-
	E	-	-	-	-	-
	S	-	-	-	-	-
	W	6.00	5.50	LAY-W7	-	-
EASTROOM	C	17.74	15.50	LAY-C1	-	-
	F	17.74	15.50	LAY-F1	-	-
	N	17.74	8.50	LAY-P2	-	-
	E	15.50	8.50	LAY-W1	WIN-TEST	-
	S	17.74	8.50	LAY-P2	-	-
	W	15.50	8.50	LAY-P3	-	LAY-P4
SOUTHROOM	C	15.50	17.74	LAY-C1	-	-
	F	15.50	17.74	LAY-F1	-	-
	N	15.50	8.50	LAY-P3	-	LAY-P4
	E	17.74	8.50	LAY-P2	-	-
	S	15.50	8.50	LAY-W1	WIN-TEST	-
	W	17.74	8.50	LAY-P1	-	-
WESTROOM	C	17.74	15.50	LAY-C1	-	-
	F	17.74	15.50	LAY-F1	-	-
	N	17.74	8.50	LAY-P2	-	-
	E	15.50	8.50	LAY-P3	-	LAY-P4
	S	17.74	8.50	LAY-P2	-	-
	W	15.50	8.50	LAY-W1	WIN-TEST	-
INTEROOM	C	15.50	17.74	LAY-C1	-	-
	F	15.50	17.74	LAY-F1	-	-
	N	15.50	8.50	LAY-P2	-	-
	E	17.74	8.50	LAY-P2	-	-
	S	15.50	8.50	LAY-P3	-	LAY-P4
	W	17.74	8.50	LAY-P1	-	-
BREAKROOM	C	10.66	36.60	LAY-C1	-	-
	F	10.66	36.60	LAY-F1	-	-
	N	10.66	8.00	LAY-P2	-	-
	E	36.60	8.00	LAY-W6	-	-
	S	10.66	8.00	LAY-P2	-	-
	W	36.60	8.00	LAY-P2	-	LAY-P4
RECEPTION-RM	C	17.74	13.00	LAY-C1	-	-
	F	17.74	13.00	LAY-F1	-	-
	N	17.74	8.500	LAY-P2	-	-
	E	13.00	8.50	LAY-W4	WIN-TYP8	-
	S	17.74	8.50	LAY-P2	-	-
	W	-	-	-	-	-

Table A.5 (continued)

Space	Orientation	Width (ft)	Height (ft)	Layer	Window	Door
OFFICE	C	16.40	12.10	LAY-C1	-	-
	F	16.40	12.10	LAY-F1	-	-
	N	16.40	8.50	LAY-P2	-	LAY-P4
	E	12.10	8.50	LAY-W3	WIN-TYP1	-
	S	16.40	8.50	LAY-W3	WIN-TYP2	-
	W	12.10	8.50	LAY-P1	-	-
COMPUTER-RM	C	16.30	25.10	LAY-C1	-	-
	F	16.30	25.10	LAY-F1	-	-
	N	16.30	8.50	LAY-P2	-	-
	E	25.10	8.50	LAY-P1	-	LAY-P4
	S	16.30	8.50	LAY-W3	WIN-TYP3	-
	W	25.10	8.50	LAY-W3	WIN-TYP4	-
CLASSROOM	C	22.20	34.67	LAY-C1	-	-
	F	22.20	34.67	LAY-F1	-	-
	N	22.20	9.00	LAY-W5	WIN-TYP7	-
	E	34.16	9.00	LAY-P1	-	LAY-P4
	S	22.20	9.00	LAY-W5	WIN-TYP5	-
	W	34.67	9.00	LAY-W5	WIN-TYP6	-
DISPLAY-RM	C	17.83	17.74	LAY-C1	-	-
	F	17.83	17.74	LAY-F1	-	-
	N	17.83	8.50	LAY-P2	-	-
	E	17.74	8.50	LAY-P1	-	-
	S	17.83	8.50	LAY-P2	-	LAY-P4
	W	17.74	8.50	LAY-P2	-	-
STORAGE-RM	C	10.55	25.30	LAY-C1	-	-
	F	10.55	25.30	LAY-F1	-	-
	N	10.55	14.00	LAY-W6	-	-
	E	25.30	14.00	LAY-W6	-	-
	S	10.55	14.00	LAY-P2	-	-
	W	15.30	14.00	LAY-P2	-	LAY-P4
MEDIA-CENTER	R	10.50	10.50	LAY-R1	WIN-SKY	-
	C	30.00	57.20	LAY-C1	-	-
	F	30.00	60.80	LAY-F1	-	-
	N	-	-	-	-	-
	E	-	-	-	-	-
	S	-	-	-	-	-
MECH-ROOM	W	6.00	8.50	LAY-W6	WIN-TYP9	-
	R	66.30	30.60	LAY-R1	-	-
	F	66.30	30.60	LAY-F1	-	-
	N	57.80	14.00	LAY-W7	-	-
	E	25.30	14.00	LAY-P2	-	-
	S	57.80	14.00	LAY-P2	-	LAY-P4
	W	25.30	14.00	LAY-W7	-	-

### A.1.9. Test rooms operations

The operation of the test rooms is specified for each validation exercise. The operational parameters includes: lighting, internal loads, thermostat schedules, special window coverings, etc.



## A.2. Input for system model

Information in this section provides an over view of the HVAC air-side system used for conditioning the test rooms. A dedicated air-distribution system is used to condition the “A” test rooms while a second dedicated air-distribution system is used to condition the “B” test rooms. The air handling units are referred to as AHU-A and AHU-B. The remaining spaces in the ERS are conditioned from a third air-distribution system referred to as AHU-1. The focus on the information presented here is for the HVAC systems that serve the “A” and “B” test rooms.

The air handling units contain chilled water coils and heating water coils. Chilled water can be provided from an air-cooled chiller or from district chilled water provided by the campus facility. Heating water is provided by a natural gas-fired boiler. Each air handling unit is equipped with a supply fan and a return fan, both of which have variable frequency drives, and each unit is instrumented to provide operational data such as temperatures and flow rates. Figure A.3 illustrates the air-handling unit and sensors

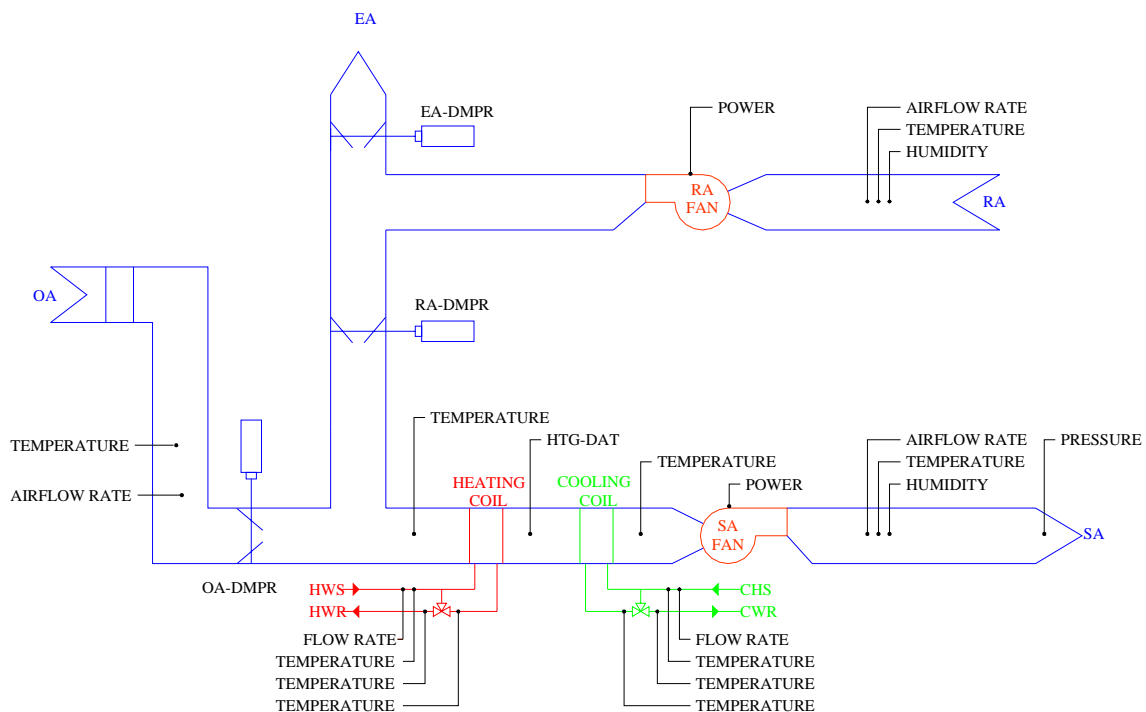


Figure A.3 Air handling unit

The building automation system provides for a great variety of system operational modes and parameter control. Each validation exercise requires a complete control and operational specification to assure the system is properly configured for the desired test.

The air-distribution system for the test rooms is illustrated in Figure A.4. The figure illustrates some of the flexibility available for testing. Again, the building automation system provides for flexibility in the specification of the operational and control parameters for each test room. For example, reheat can be provided either from an electrical resistance coil or a hydronic coil. Although not shown in the figure, another zone level system that can be used for space conditioning includes a four-pipe fan coil unit. Each validation exercise requires a complete control and operational specification to assure the zone level systems are configured properly.

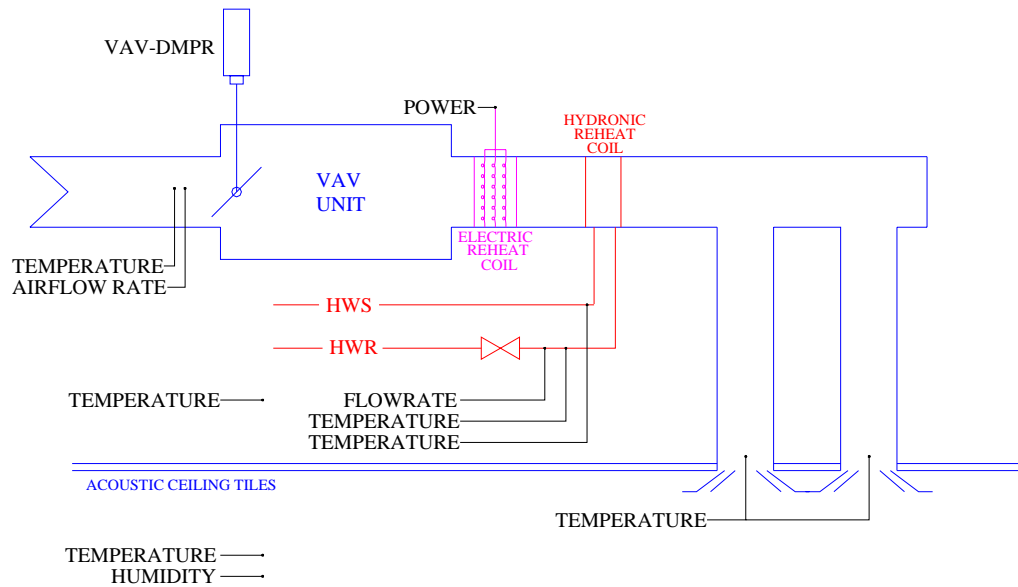


Figure A.4 Zone level HVAC system

## Appendix B Uncertainty Analysis

For every experiment, there are errors that are associated with the measured parameters. Experimental error is the variation among observations and measurements that are treated alike. The errors for the experimental parameters measured at the ERS were quantified using information obtained from calibrations and corrections, manufacturer information, and current literature. The error values were used to estimate the experimental error for calculated quantities in the experiment. This was done using a Propagation of Error formulation.

### B.1 Calibration Information

An extensive set of calibrations was performed at the ERS for the resistant temperature devices (RTD) at the ERS (Wen and Smith, 2001). In this procedure, the measurements from the individual RTDs were compared with a Hart 1522 thermometer, the so-called gold standard. The calibration results from this endeavor were used to quantify the portion of the error for the RTDs. A sample of the temperatures used for the final calibration check was used for regression to perform a regression analysis. Ninety-five percent uncertainty bands were calculated to quantify the part experimental error linked to the calibration. Figure B1 shows the plot with a linear regression analysis and the uncertainty bands for the mixed air temperature for the “A” system.

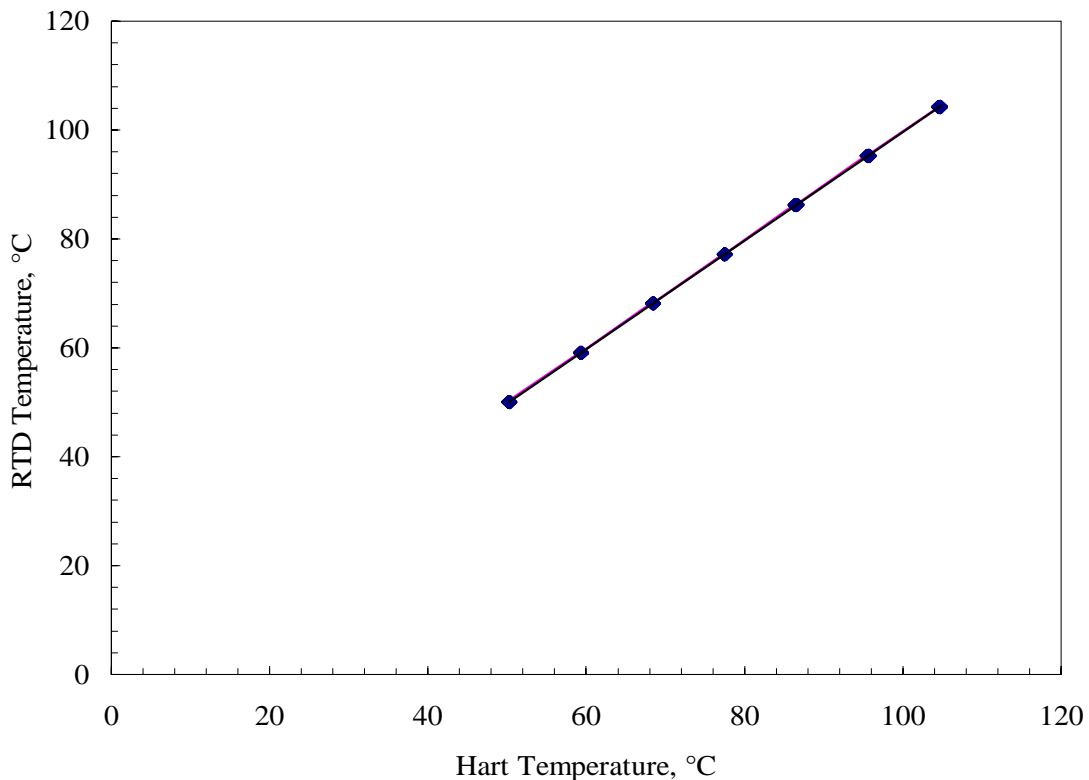


Figure B.1 Hart temperature versus RTD temperature with 95% uncertainty bounds.

From Figure B1, the uncertainty bands are small, primarily due to good correlations. The linear relationship between the Hart and the RTD temperatures is shown in Equation B.1. Tables B.1, B.2, and B.3 contain information from the regression analysis for the temperatures.

$$T_{RDT} = 0.9967529 T_{HART} - 0.063006 \quad (B.1)$$

where

$T_{RDT}$  is the temperature of the RTD, in °C.

$T_{HART}$  is the temperature of the Hart thermometer, in °C.

Table B.1 Summary of the fit for the temperature calibration.

Term	Estimate
R-Square	0.999975
R-Square Adjusted	0.999974
Root Mean Square Error	0.091288
Mean of Response	77.29286
Observations	216

Table B.2 Analysis of variance for the temperature calibration.

Source	Degrees of Freedom	Sum of Squares	Mean Square
Model	1	70,050	70,150.21
Error	214	1.781	0.0083823
Corrected Total	215	70,152	

Table B.3 Parameter estimates for the temperature calibrations.

Term	Estimate	Standard Error	t Ratio	Prob> t
Intercept	-0.063006	0.027358	-2.30	0.0222
X-Component	0.9967529	0.000343	2903.2	0.0000

The associated error from the RTD was calculated from a 95% uncertainty bands. The temperature variance with respect to the gold standard was calculated using Equation B.2.

$$\sigma_{Hart} = \frac{\pm N \sqrt{MSE}}{\beta_1} \quad (B.2)$$

where

$N$  is the Gaussian distribution quantity for a 97.5% quantile.

$MSE$  is the mean squared error value.

$\beta_1$  is the slope of the line from the regression analysis.

There were also small measurement errors for the Hart thermometer quantifies by the manufacturer. The manufacture error values are for the ERS are shown in Table B.7. To assign a 95% interval of uncertainty for the temperature parameter, Gleser (1998) proposed a method for dealing with different types of errors variances, which is shown in Equation B3.

$$\sigma_{Total} = \sqrt{\sigma_{Hart}^2 + 1.96^2 \sigma_{Hart,error}^2} / 3 \quad (B.3)$$

where

$\sigma_{Hart,error}$  is the error bounds for the Hart thermometer provided by the manufacture.

Similar analyses for two additional RTDs were performed. There were very minute discrepancies. Therefore, the relationship developed for the mixed air RTD for the “A” system was used for the all the RTDs in the experiments.

## B.2 Corrected Data

Immediately following a daylight test performed at the same facility, discrepancies were realized for the room airflow rates. An experimental apparatus was assembled to measure the airflow rates in the duct using a pitot tube traverse at low airflow rates and a flow hood for high airflow rates. These values were compared with the building control’s airflow rate measurements. A correlation with building control measurements and a regression analysis was performed to correct measurement errors. The linear relation from the regression analysis was used to post-process the room airflow measurements. Figure B2 shows the results of the regression analysis for the East “A” airflow rates. Ninety-five percent uncertainty bounds were used for the error calculations.

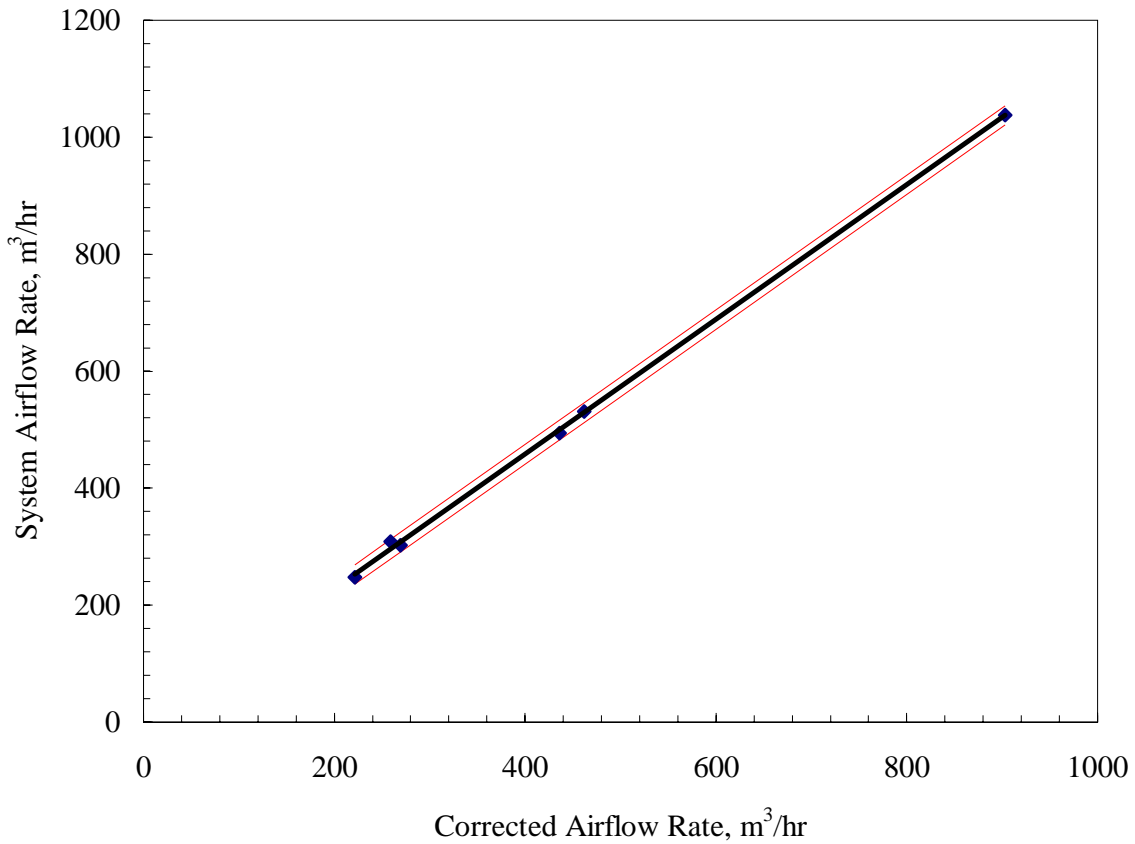


Figure B.2 East “A” test room airflow rate correction curve.

Equation B.4 is the linear fit from the regression analysis. Tables B4, B5, and B6 contain the results from the regression analysis.

$$Q_{system} = -2.565086 + 1.151116 Q_{Cor} \quad (B.4)$$

where

$Q_{Cor}$  is the airflow rate measured by the system in  $m^3/hr$ .

Table B.4 Summary of the fit for the airflow rate correction.

Term	Estimate
R-Square	0.999361
R-Square Adjusted	0.999201
Root Mean Square Error	8.276338
Mean of Response	486.8506
Observations	6

Table B.5 Analysis of variance for the airflow correction.

Source	Degrees of Freedom	Sum of Squares	Mean Square
Model	1	428,496.32	428,496
Error	4	273.99	68
Corrected Total	5	428,770.32	

Table B.6 Parameter estimates for the airflow correction.

Term	Estimate	Standard Error	t Ratio	Prob> t
Intercept	-2.565086	7.05027	-0.36	0.7344
X-Component	1.15116	0.014554	79.09	<.0001

Similar regressions analyses were performed to correct the airflow rates for the other test rooms. The error from post-processing of the data is estimated by Equation B.5. A 95% uncertainty bound was used to calculate the error value.

$$\sigma_{Flow} = \frac{\pm t\sqrt{MSE}}{\beta_1} \quad (B.5)$$

where

$t$  is the student distribution quantity for a 97.5% quantile.

$MSE$  is the mean squared error value.

$\beta_1$  is the slope of the line from the regression analysis.

Base on literature about airflow rate measurement with a pitot tube traverse and flow hoods, the error is 1-5% of the measured value (Schroeder et al, 2000). Therefore, the total error for the airflow rates for Daylight Case II was estimated in a similar manner as the temperatures. This relationship is shown in Equation B.6.

$$\sigma_{Total Flow} = \sqrt{\sigma_{Flow}^2 + (1.96(0.01Q_0))^2} \quad (B.6)$$

The statistical parameter used to calculate the 95% uncertainty bounds for the test rooms are shown in Table B.7.

Table B.7 Statistical parameters for uncertainty bound calculations for zone airflow rates.

Location	n	MSE	$\beta_l$
East "A"	6	68	1.151116
East "B"	6	342	1.2283747
South "A"	6	279	1.1173097
South "B"	5	218	1.108725
West "A"	6	178	1.1540728
West "B"	5	144	1.1849076
Interior "A"	6	408	1.0939741
Interior "B"	6	1319	1.1321554

### B.3 Propagation of Error

Several parameters that were compared with output from the building simulation software were not measured directly during the experiment. These values were later calculated as functions of measured experimental parameters. The calculated quantities included: room reheat power and cooling heat transfer rate. The calculation for the cooling heat transfer rate is described in Equation 2.1.

Ninety-five percent error bounds were calculated using a propagation of the error analysis. The methodology used for to calculate these error bounds for the cooling coil heat transfer rate is shown in Equation B7.

$$\sigma_{HTR}^2 = \left( \frac{\partial HTR}{\partial \dot{m}_{SA}} \sigma_{\dot{m}_{SA}} \right)^2 + \left( \frac{\partial HTR}{\partial \dot{m}_{OA}} \sigma_{\dot{m}_{OA}} \right)^2 + \left( \frac{\partial HTR}{\partial h_{RA}} \sigma_{h_{RA}} \right)^2 + \left( \frac{\partial HTR}{\partial h_{OA}} \sigma_{h_{OA}} \right)^2 \quad (\text{B.7})$$

Preliminary variances of the mass flow rates and the enthalpies were calculated using the propagation of error analyses, manufacturers' information, and calibration data. These calculations were done using a variant of Equation B.7 and are not shown in this report.

The average error for a given experiment was calculated by taking the arithmetic mean of the hourly errors. These values are provided in the comparison tables from the results section of each compared parameter contained within the main body of the report. For many quantities, it was impossible to perform statistical analyses and estimate of uncertainty. Therefore, many error values were estimated using manufactures information or information from current literature. This information is contained in Table B.8.



Table B.8 Accuracy of ERS instrumentation.

Name	Units	Uncertainty
HART 1522 Thermometer	°C	$\pm 0.0025$
Outside Airflow Rate	ft <sup>3</sup> /min	$\pm 2\%$ of Reading ( $> 500$ ft <sup>3</sup> /min) $\pm 10\%$ of Reading ( $< 500$ ft <sup>3</sup> /min)
Room Airflow Rates	ft <sup>3</sup> /min	$\pm 2\%$ of Reading
Room Light Power	W	$\pm 0.2\%$ of Reading
Barometric Pressure	millibars	$\pm 0.75$ millibars
Outside air humidity	% RH	$\pm 2\%$ of RH
Pyranometer	Btu/(hr-ft <sup>2</sup> )	$\pm 0.5\%$ of Reading
Pyrheliometer	Btu/(hr-ft <sup>2</sup> )	$\pm 0.5\%$ of Reading
Wind Direction	°	$\pm 1^\circ$
Wind Speed	mph	$\pm 1$ mph
Constant Specific Heat for Air	kJ/kg-K	$\pm 2\%$ of Reading

## Appendix C Hourly Averaged Experimental Data

This appendix describes the data found on the CD-ROM that accompanies this report. The data can be used by modelers who wish to make comparisons with the daylighting tests conducted in IEA Task 22 Subtask D. The CD contains two ASCII text files, three Microsoft Excel files and a pdf version of this report.

### C.1. Weather Data

The ASCII text files are TMY weather files that contain the processed weather information collected at the Energy Resource Station during the tests. The test dates for Economizer Test 1 were: May 2, 2002 through May 5, 2002. The weather file is called “IEA2002tmy.txt”. The test dates for Economizer Test 2 were: March 25, 2003 through March 28, 2003. The weather file is called “IEA2003tmy.txt”. The test dates for Economizer Test 3 were: March 29, 2003 through April 1, 2003. The weather file is called “IEA2003tmy.txt”. Although each TMY file is for a full year, only the specified test dates contain data based on weather measured at the ERS. The remainder of the TMY file is from a standard Des Moines, IA TMY file.

It is important to note that ERS modified weather information included in the TMY file does not replace all weather related data. For example, the sky conditions, amount of rain fall, etc. are not altered from their original values. The only TMY fields that are modified to reflect weather data measured at the ERS are shown in Table C.1

Table C.1 Fields modified in the TMY weather files

Field Number	Position	Element
003	006 - 015	Solar Time
102	024 – 028	Direct Radiation
108	054 – 058	Total Horizontal Radiation
206	099 – 103	Station Pressure
207	104 – 111	Temperature
208	112 – 118	Wind

### C.2. Hourly averaged data

The Microsoft Excel files contain hourly averaged values of data collected during each daylighting test. During a test, information is recorded on a one-minute time interval. For comparison purposes, the data are averaged over a one-hour period. The graphs in this report illustrating ERS results are based on the hourly-averaged values found in these files. The Excel file names for the three tests are called “Economizer Test 1.xls”, “Economizer Test 2.xls” and “Economizer Test 3.xls”, respectively.

The Excel spreadsheet files are organized using tabs. Each tab is a worksheet that contains values for a particular air handling unit system or a particular test room.

### C.3. Air Handling Unit Data

Figure C.1 is a schematic of an air handling unit that serves the test rooms at the ERS. The “point names” in the figure represent locations where measurements are made; however, not all of these measurements are relevant for the daylighting tests. Table C.2 provides a list of the point names and their description that are relevant for the daylighting tests. These names appear as column headings for the spreadsheets labeled as “System A” and “System B” in the Excel files.

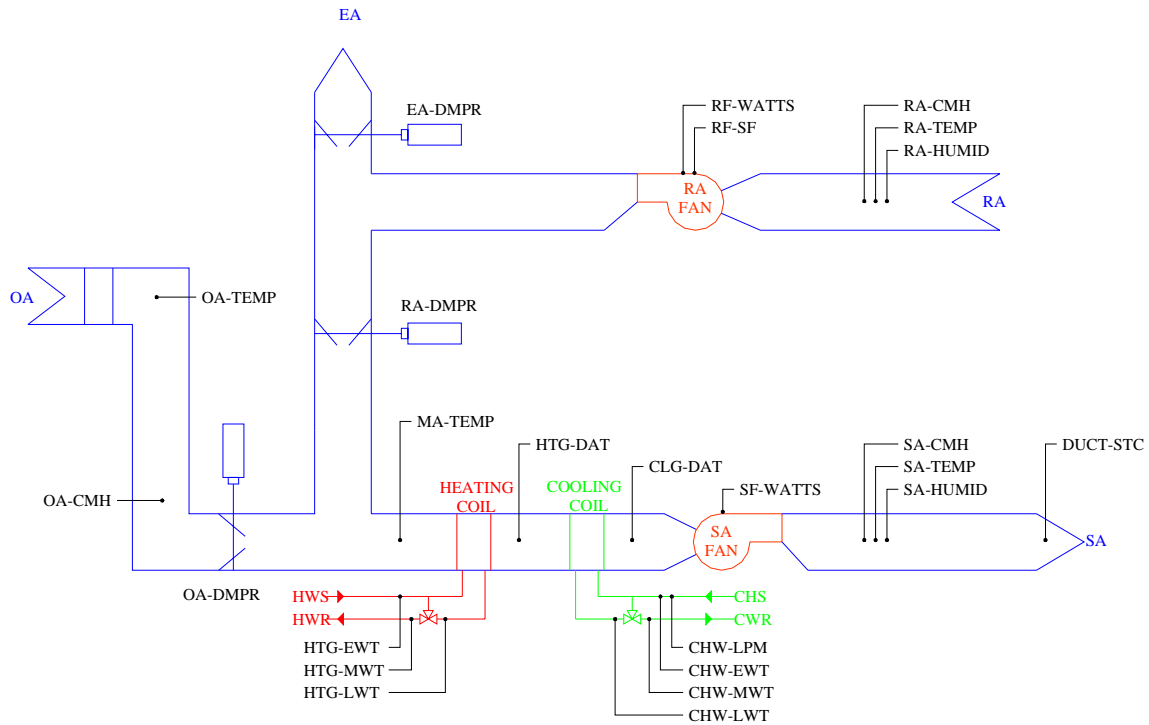


Figure C.1 Air handling unit schematic

Table C.2 AHU System A and System B Nomenclature

OA-CMH	Outside air flow rate [m <sup>3</sup> /hr]
OA-TEMP	Outside air temperature [°C]
OA-DMPR	Outside air damper position [% open]
CHW-LPM	Cooling coil water flow rate [liter/min]
CHW-EWT	Cooling coil entering water temperature [°C]
CHW-MWT	Cooling coil mixed water temperature [°C]
CHW-LWT	Cooling coil leaving water temperature [°C]
CLG-DAT	Cooling coil discharged air temperature [°C]
RA-TEMP	Return air temperature [°C]
RA-HUMID	Return air humidity [%]
RF-WATTS	Return fan power [Watts]
RF-SF	Return fan speed as a percent of supply fan speed
RA-DMPR	Return air damper position [% open]
EA-DMPR	Exhaust air damper position [% open]
MA-TEMP	Mixing air temperature [°C]
SA-CMH	Supply air flow rate [m <sup>3</sup> /hr]
SA-TEMP	Supply air temperature (after supply fan) [°C]
SA-HUMID	Supply air relative humidity (after supply fan) [%]
SF-WATTS	Supply fan power [Watts]
DUCT-STC	Supply duct static pressure [kPa]

## C.4. Test Room Data

Figure C.2 is an HVAC schematic of a test room at the ERS. The “point names” in the figure represent locations where measurements are made; however, not all of these measurements are relevant for the daylighting tests. Table C.3 provides a list of the point names and their description that are relevant for the economizer tests. These names appear as column headings for the spreadsheets labeled as test rooms in the Excel files. The spreadsheet tab names for the test rooms are East A, East B, Interior A, Interior B, South A, South B, West A and West B.

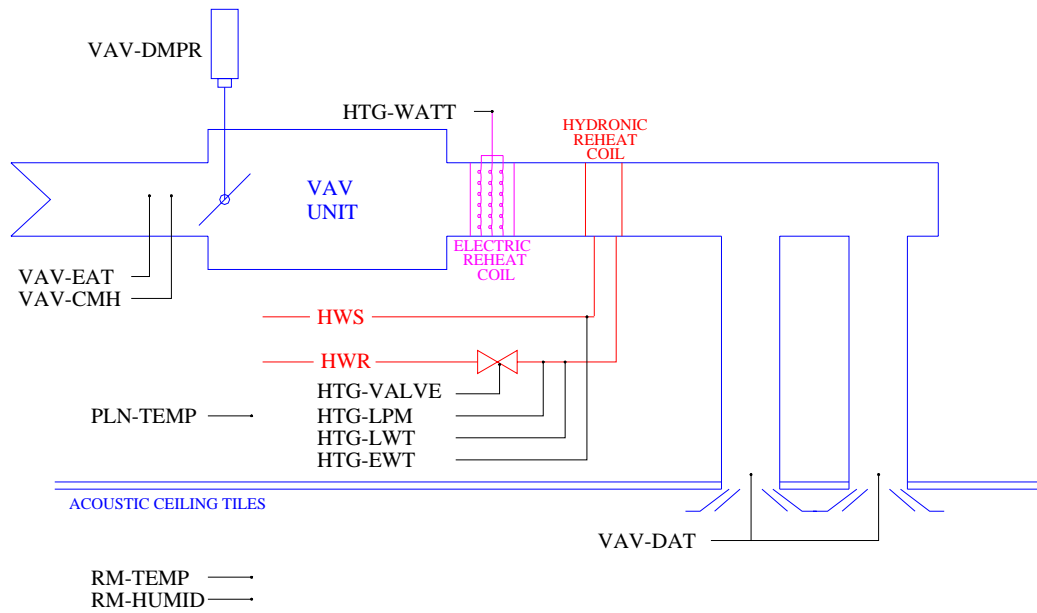


Figure C.2 Test Room HVAC Schematic

Table C.3 Test rooms (East, South, West, Interior) nomenclature

HTG-VALVE	Hydronic reheat coil control valve position [% closed]
HTG-LPM	Hydronic reheat coil water flow rate [liter/min]
HTG-LWT	Hydronic reheat coil entering water temperature [°C]
HTG-EWT	Hydronic reheat coil leaving water temperature [°C]
VAV-CMH	VAV air flow rate [m <sup>3</sup> /hr]
VAV-EAT	VAV discharge air temperature [°C]
VAV-DAT	VAV entering air temperature [°C]
VAV-DMPR	VAV damper position [% open]
PLN-TEMP	Room plenum temperature [°C]
RM-TEMP	Room temperature [°C]
LIGHT-WATT	Room electric light power [Watts]

## **Appendix D Modelers' Reports**

This appendix contains the Modelers' Reports from the organizations that participated in the IEA Task 22 Subtask D. These reports address any information that the modelers wish to share which explains or clarifies their model validation results.

**Modeler's Report**  
Clemens Felsmann, PhD  
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March 2004

## **1. Model and simulation program**

All the tests were done with TRNSYS TUD a modification and rewritten version of TRNSYS 14.2. At the Dresden University the original TRNSYS program source code was subjected to a lot of changes as well as additions to create a tool characterized by very specific properties in regard to the simulation and analysis of both operation and control of HVAC-systems in buildings.

The building model is the standard TRNSYS multizone model. All information (zone dimensions, orientations, materials, etc.) that are required to build a TRNSYS model of the ERS were taken from a large set of architect's plans. It is a time consuming procedure to get all the data from the plans and put them into the model because there are a lot of details that have to be considered.

The model of the HVAC system only consists of a series of basic energy and mass flow balance equations dealing with heat and moisture transfer. The components (chiller, cooling coil, reheat, economizer) are not described in physical detail. Due to the simplified modeling it is also not necessary to calculate the pressure drops in the duct system.

With the assumption that the cooling load always can be served the chiller leaving air temperature was set to a fixed value. This fixed value was calculated from the supply air set point temperature minus a (constant) temperature rise caused by the supply fan.

Both building and HVAC system model were already validated during former empirical tests conducted at the ERS.

The simulation time step is fixed to 0.005 h. This low value is necessary to get robust control signals from the PI-controllers inside the VAV boxes (air flow and hydronic reheater).

## **2. Test cases**

There are at all three economizer tests which can be divided into two categories. The first category consists of single case (1) whereas the second one covers two cases (2-3). The main difference between the categories is the minimum outside air flow rate:

- Case 1: When the economizer was disabled it was set to a fixed minimum damper position. In a first simulation run also the outside air flow was misleadingly set to a constant value. Due to the pressure balance this is not correct. That is why the real, i.e. measured, data of outside air flow were defined as an input during the succeeding simulation runs because the simulation program was not able to calculate the outside air flow in dependence on the pressure balance inside the duct system.

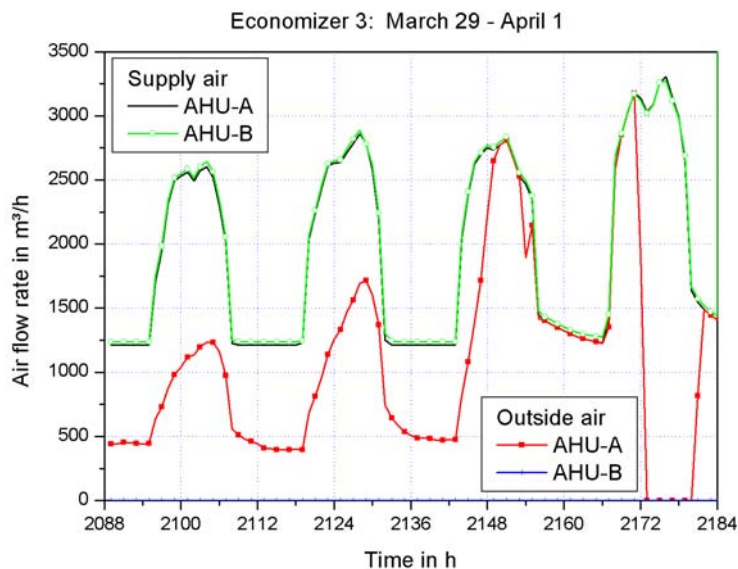
- Case 2-3: When the economizer was disabled it was set to 0% damper position. At this point there is a 100% re-circulation of exhaust air.

All the tests include either return temperature or return enthalpy controlled economizer mode. The information that are necessary to build the simulation models could be taken from the detailed specifications. Once the models of the building and the HVAC system were created it was very easy to change the simulation models accordingly to specific test parameters.

### 3. Results

Three different types of output information were analyzed: global, system and zone data. All output data required to fill out the pre-formatted data sheets are available in TRNSYS-TUD.

The simulation results do match the measurement quite well even though there are sometimes uncertainties in predicting supply flow rates and cooling coil heat transfer rate. A big deviation occurred in the prediction of the B-system's return enthalpy in the IEA Economizer Test Cases 2 and 3. This was probably caused by some incorrect moisture calculations and may also lead to inaccurate latent cooling load results. The model has to be improved referring to its moisture calculation method. Regarding the supply air flow rates there are no differences between A and B-system. In fact that means room temperature and/or room cooling load have to be identical. The different outside air flow rates are caused by the economizer control.



### 4. Summary

Regardless the simulations do not always completely match the experiments the economizer tests are excellent examples to study and analyze real physical effects and how to incorporate them in the simulation model.

The tests are a very useful addition to the validation procedures at TUD.



## **Modelers' Report**

Peter Loutzenhiser and Gregory Maxwell  
Iowa State University  
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The main objective of this report was to describe the modeling strategy used for the empirical validation exercise developed at the Iowa Energy Resource Station (ERS) by Iowa State University, Ames, Iowa, using DOE-2.1E.

The LOADS model was developed for the matched set of test rooms at the ERS. A system model was created for the "A" and "B" test rooms. Building construction documentation was used to obtain information about the wall, roof, and slab construction layers as well as windows. The walls separating the test rooms from the remainder of the ERS were modeled as adiabatic.

After the first iteration, it was discovered that DOE-2.1E did not have the capability of modeling a fixed outside air damper position in a variable air volume system. Therefore the minimum outside airflow rates for both the "A" and "B" systems in Case 1 were inputted into the program via a schedule that used the experimental outside airflow rate for the "B" system.

The thermal mass of the test rooms presented a problem for the first iterations of the economizer tests for the baseboard heat load. The best results were obtained when the load was modeled as an instantaneous convective load. Information from the window manufacturer coupled with the DOE-2.1E windows library helped create a more sophisticated window model. Many default values provided by the program were used when specific values could not be obtained.

## References

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