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Charting a Course to Energy Independence

Providence, RI
August 9-12, 2009

M&V as a Continuous Learning Process: Whiteman AFB

M&V as Continuous Learning

- Lessons Learned at Whiteman AFB
  - M&V through modeling – it's **all** in the details
  - M&V surprises lead to understanding of building dynamics
  - Ongoing M&V aids ECM performance
  - Ongoing M&V builds customer relationship and trust

Whiteman AFB – JCI – ESPC Objectives

- Multi-Phase Long Term Strategy
  - Infrastructure and equipment upgrades;
  - Improved facility environmental control;
  - Operations and Maintenance Reduction;
  - Addition of energy meters;
  - Networking of additional buildings to facilitate energy awareness.

Energy Conservation Measures

- **Energy Management Control System** *(17 bldgs)*
  - Central Workstation
    - Efficient management of HVAC Equipment
  - Unoccupied Setup/Setback or Shutdown
  - Discharge Air Reset on Air Handler Units
  - Hot Water/Chilled Water Reset
  - Heating and Cooling Outside Air Temperature Lockouts

- **Lighting**
  - T12 → T8 lamps, Metal Halide → T5 lamps *(15 bldgs)*
  - Motion Sensors *(9 bldgs)*

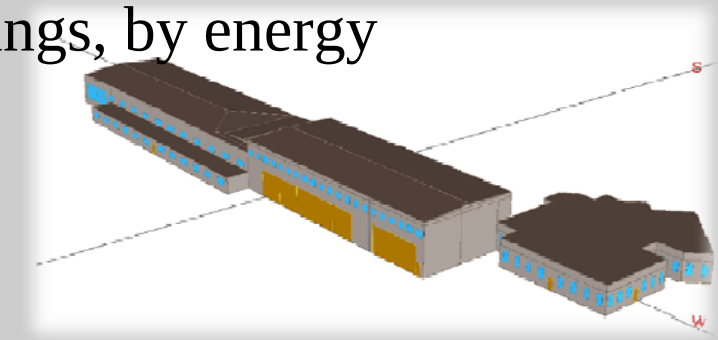
Energy Conservation Measures (cont'd)

- **Ground coupled-heat pumps** *(10 bldgs)*
  - Replaced aging DX units
  - 29 GCHP Heat Pumps; 135 Total Tonnage

- **5 Well Fields + 1 Fluid Cooler**
  - Main Loop, 3 Sub-Loops *(5 buildings)*
  - Temporary Lodging Facilities Loop *(4 apt buildings)*
  - Building 59 Loop *(1 building)*
- **Average EER = 18.8, Average COP = 4.2**

Project Strategy

1. Create eQuest models for 14 buildings to predict baseline and post-retrofit energy use.
2. Install steam and electric meters on four typical, high-energy usage buildings.
3. Post-calibrate eQuest models with Performance Year measured steam and electric data.
4. Determine savings by retroactively backing out installed ECMs from Year 1 Calibrated Models.
5. Apply percentage of verified savings from four metered buildings to remaining buildings, by energy source, to determine project savings.



Achieved Energy Savings

- ***Energy actually saved as a percentage Baseline Energy Usage)***

Metered Building	% Electric Energy Saved	% Natural Gas Saved
709	30%	41%
159	43%	43%
139	19%	34%
14	21%	55%

- ***Saved $312,477 in fiscal year 2008***
- ***Reduced energy consumption by 33,579,000 BTUs.***

Savings Evaluation

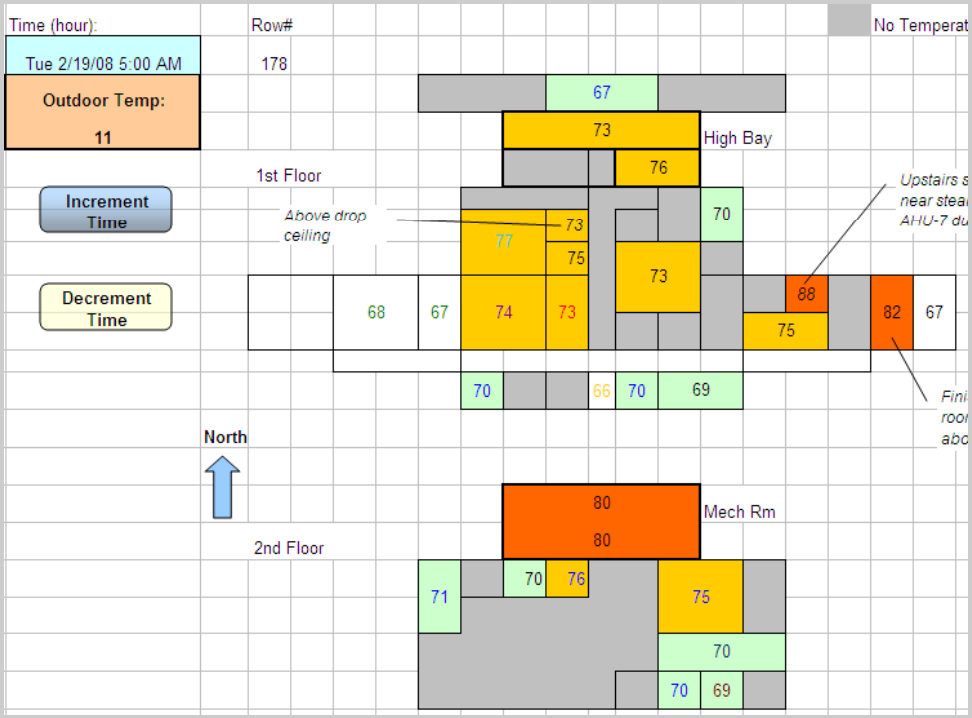
- Actual first year savings were short of projections.
  - Johnson Controls honored their annual guarantee.
  - JCI Measurement and Verification team initiated joint effort with WAFB to investigate.

Shortfall Analysis

- Software modeling errors;
- Inappropriate default parameters;
- Failure to anticipate effect of adjacent uncontrolled spaces on controlled spaces;
- Unexpected heat flow to spaces from steam lines and steam-filled condensate lines.

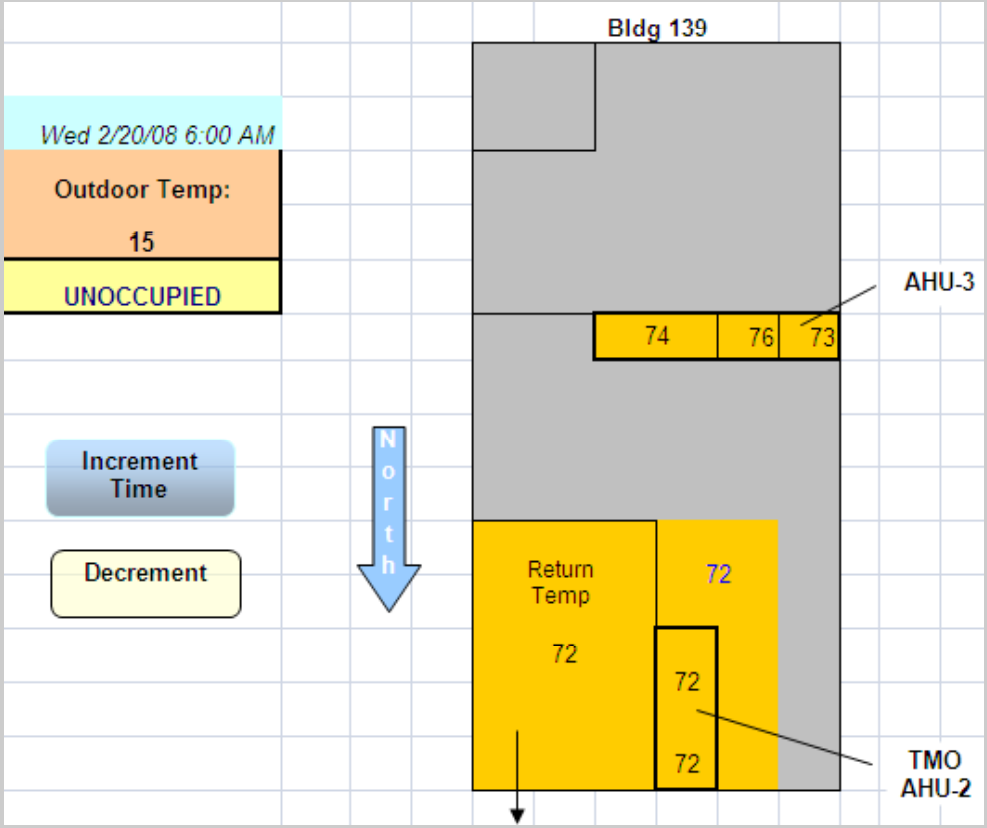
Unexpected Heat Sources

- **Heat sources negate night setback**
  - Steam and Condensate piping
  - Central Mechanical Room
  - Uncontrolled steam unit heaters
  - Computers and office equipment on 24/7



Mixed-Use Building Dynamics

- **Mixed-Use Building**
  - Uncontrolled 24/7 unit heaters in warehouse spaces transfer heat to adjacent office spaces.



Resulting Improvements

- Knowledge and understanding of building dynamics leads to targeted improvement
  - JCI: Replaced steam water heater to allow building steam shut off in summer;
  - JCI: Added controls to warehouse area unit heaters;
  - WAFB: Steam trap repair/replacement;
  - WAFB: Radiant heater installation in bays and shop areas.

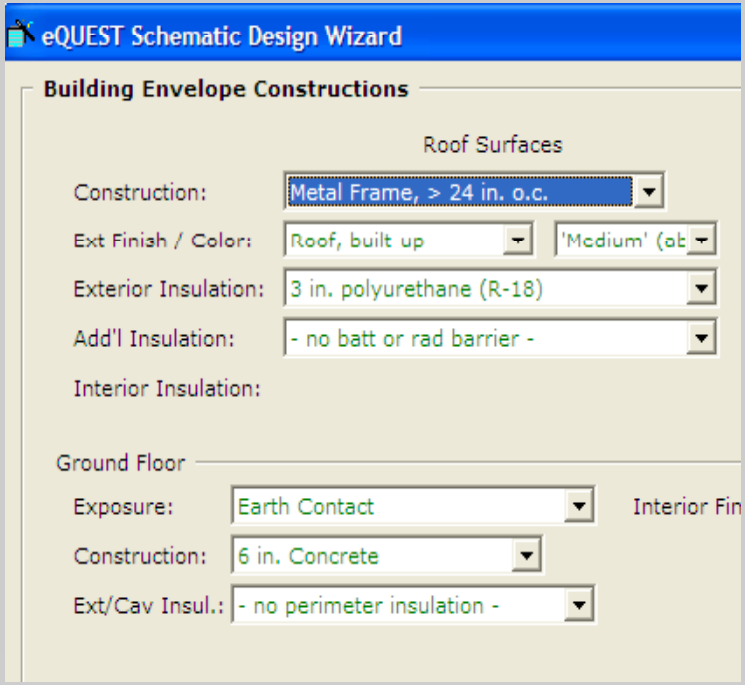
eQuest Modeling:

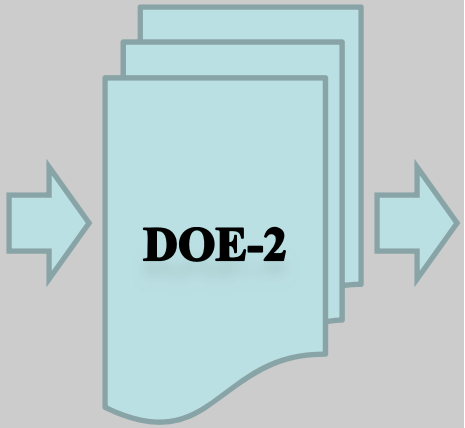
FIVE LESSONS LEARNED

What is eQuest?

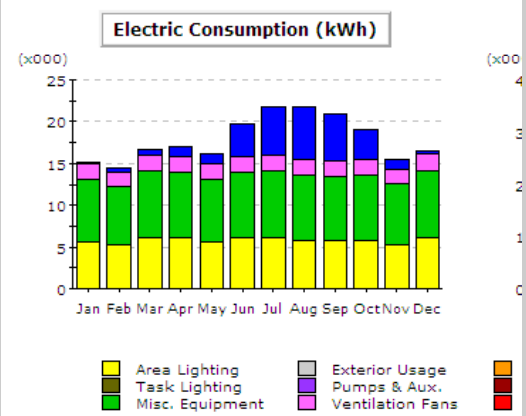
eQuest is a graphical, Windows-based, front end for DOE-2.2

eQuest Input





eQuest Output



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun
Space Cool	0.17	0.42	0.61	1.15	1.29	3.78
Heat Reject.	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-
Vent. Fans	1.78	1.69	1.96	1.96	1.78	1.96
Pumps & Aux.	0.07	0.05	0.06	0.01	0.01	-
Ext. Usage	-	-	-	-	-	-
Misc. Equip.	7.58	7.04	7.99	7.87	7.58	7.87
Task Lights	-	-	-	-	-	-
Area Lights	5.53	5.24	6.05	6.04	5.53	6.04
Total	15.14	14.44	16.67	17.04	16.20	19.65

Behind the eQuest Curtain

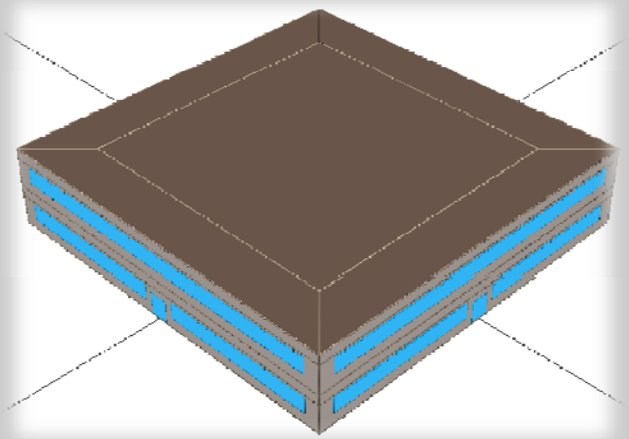
eQUEST

…is DOE-2.2

1. Know When Defaults are Dangerous

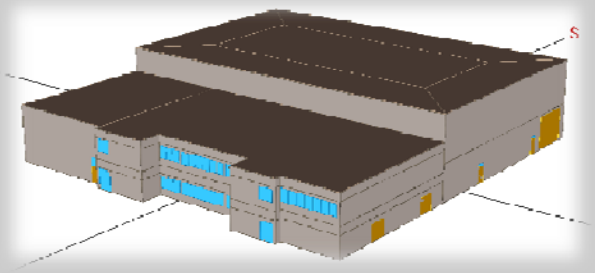
What eQuest does best …

- Many defaults for each building-type template allow quick and easy evaluation of energy saving measures
  - Office Building Defaults: Common office construction, windows, schedules, occupancy, lighting …



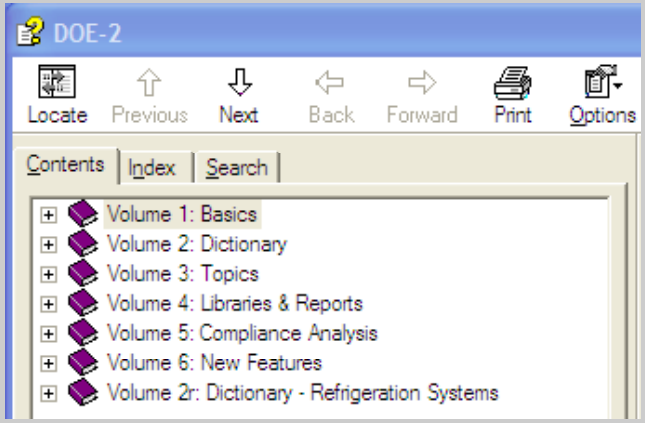
Caution: Human Intervention Required!

1. Modeling an existing building (especially an older one) to be calibrated with measured energy data;
2. Complex buildings:
   - Multi-use building with offices, shops, warehouse or storage areas
   - Library, Vehicle Maintenance, Training Facility, etc.



2. Always Review the DOE-2.2 Input and Output Files

- The *.inp* is the actual input text file for DOE-2, containing all of the DOE-2 commands.
- The Input File makes you smarter!
  - Six-*Chapter book* in the Help File
  - Complete explanation of system types and commands,
  - Pictures!



Input Example

```
..
"Supply Admin Computer Zn (G.E2)" = ZONE
   TYPE              = CONDITIONED
   MIN-FLOW-RATIO    = 0.3
   FLOW/AREA         = 0.5
   OA-FLOW/PER       = 60
   DESIGN-HEAT-T     = 72
   HEAT-TEMP-SCH     = "S1 Sys1 (PIU) Heat Sch"
   DESIGN-COOL-T     = 75
   COOL-TEMP-SCH     = "S1 Sys1 (PIU) Cool Sch"
   ZONE-FAN-T-SCH    = "S1 S1 Sys1 (PIU) ZFTemp"
   SIZING-OPTION     = ADJUST-LOADS
   TERMINAL-TYPE     = PARALLEL-PIU
   REHEAT-DELTA-T    = 32
   SPACE             = "Supply Admin Computer (G.E2)"
```

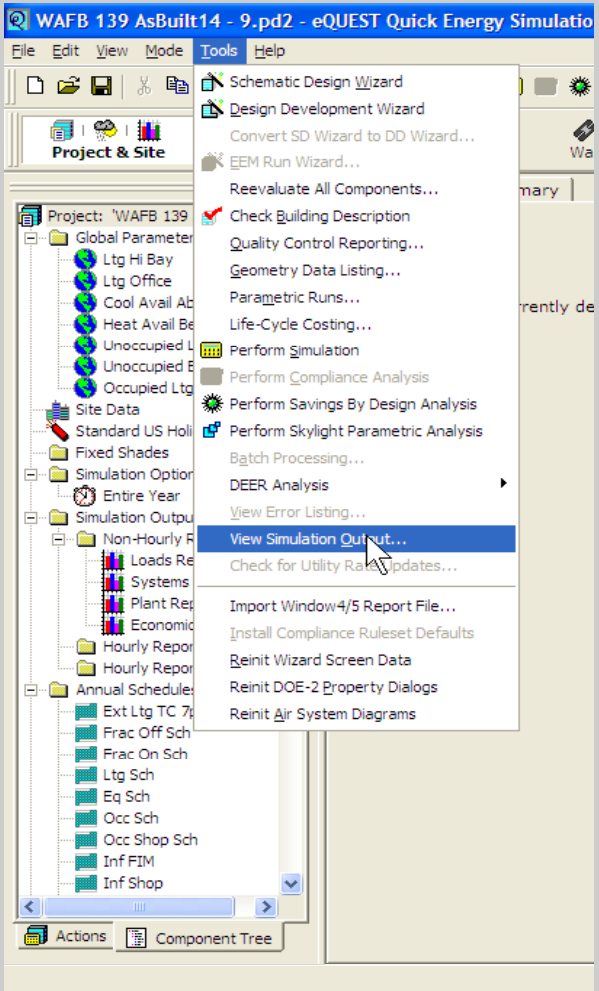
FLOW/AREA: Sets the zone flow rate as a ratio of zone area

OA-FLOW/PER: Zone Outside Air Flow cfm per occupant (Occupancy will default by building and space type, if not specified)

DOE-2 Output File (Sim File)

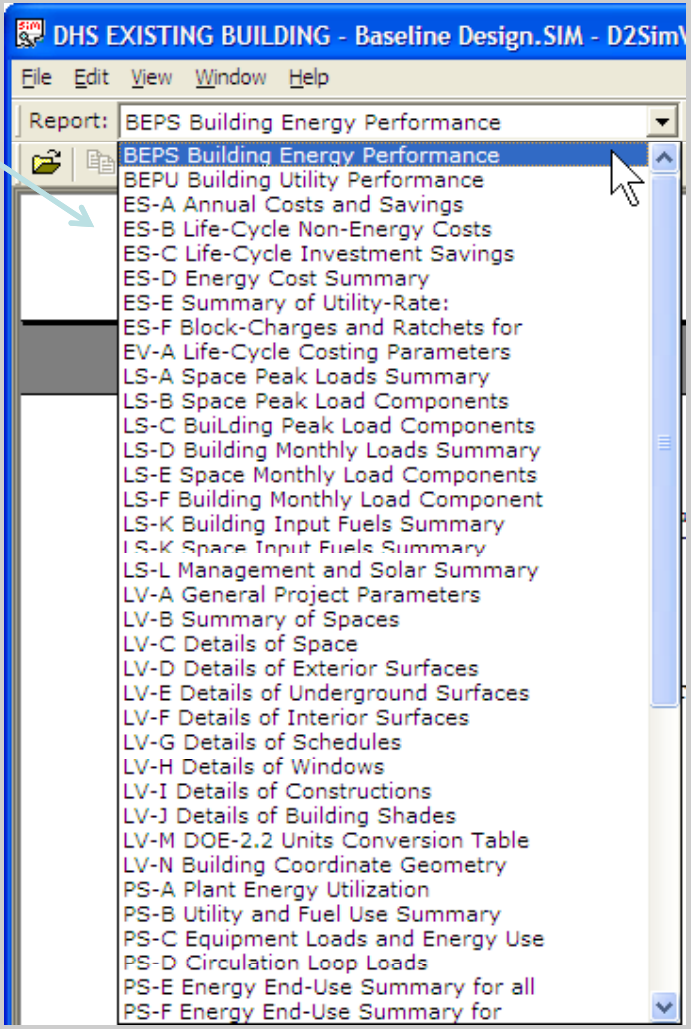
- ***A "Gold Mine" of information, but you may not be able to open it!***
  - MS.DOS file format
  - ***Very*** large text file
  - Will lock up on large projects

- ***Reduce Sim file size by deleting the Hourly Report under Project & Site***



Mining the Sim File

- **Over 50 reports in the Sim File**
  - DOE-2 Help, Volume 4, Reports, Report Map



Report Map

This section consists of four tables, one each for LOADS, SYSTEMS, PLANT and EONOMICS, that show in which reports you can find various calculated quantities, like space loads, cooling peaks, temperatures, etc.

LOADS SUMMARY REPORTS

		Space Peak Loads	Space Peak Load Components	Bldg Peak Load Components	Building Monthly Loads	Space Monthly Load Components	Bldg Monthly Load Components	Space Daylighting Summary
	Bldg Level Info	LS-A		LS-C	LS-D		LS-F	
	Space Level Info	LS-A	LS-B			LS-E		LS-G
THERMAL LOAD	Total (Sens&Lat) Heat/Cool Space Load		P	P		T	T	
	Sensible Heat/Cool Space Load	P	P	P	P/T	T	T	
	Latent Cooling Space Load		P	P		T	T	
	Heat/Cool Space Load Components		P	P		T	T	

Report: ATTN Simulation Messages for Review

- Cryptic warnings all mean *something* … review carefully

Report: ATTN Simulation Messages For Review | Component:

```
WAFB 14 Lighting4                                                    DOE-2.2-44e

REPORT- ATTN Simulation Messages For Review HVAC        Program
-----------------------------------------------------------------------------------

 **WARNING*****************************************************************
            PREHEAT/HEATING-CAPACITY in SYSTEM HVU-1
            is too low to provide the requested supply temperature for
            the calculated mixed air temperature using total ZONE loads
            (on LS-A/B) and SYSTEM design parameters, plus outside air
            conditions (on LS-C), and specified capacities & air flows.
            Requested temperature is 110.00 calculated is  72.00
            Check HEATING-CAPACITY, HEAT-SET-T, PRE-HEAT-T, MAX-SUPPLY-T,
            DESIGN-HEAT-T, and ZONE loads for consistency.

 **WARNING*****************************************************************
            PREHEAT/HEATING-CAPACITY in SYSTEM UH's Hi-Bay
            is too low to provide the requested supply temperature for
            the calculated mixed air temperature using total ZONE loads
            (on LS-A/B) and SYSTEM design parameters, plus outside air
            conditions (on LS-C), and specified capacities & air flows.
            Requested temperature is 110.00 calculated is  72.00
            Check HEATING-CAPACITY, HEAT-SET-T, PRE-HEAT-T, MAX-SUPPLY-T,
            DESIGN-HEAT-T, and ZONE loads for consistency.
```

Report LS-B: Space Peak Load Components

Heating and Cooling Load components for each zone

REPORT- LS-B Space Peak Load Components Greenhouse East (ML.E1) WEATHER FILE- Columbi

SPACE Greenhouse East (ML.E1)
SPACE TEMPERATURE USED FOR THE LOADS CALCULATION IS 70 F / 21 C

MULTIPLIER	1.0	FLOOR MULTIPLIER	1.0
FLOOR AREA	574 SQFT	53 M2	
VOLUME	8180 CUFT	232 M3	

	COOLING LOAD		HEATING LOAD	
TIME	AUG 24 3PM		FEB 3 7AM	
DRY-BULB TEMP	99 F	37 C	1 F	-17 C
WET-BULB TEMP	75 F	24 C	-1 F	-18 C
TOT HORIZONTAL SOLAR RAD	279 BTU/H.SQFT	879 W/M2	0 BTU/H.SQFT	0 W/M2
WINDSPEED AT SPACE	7.2 KTS	3.7 M/S	10.8 KTS	5.5 M/S
CLOUD AMOUNT 0(CLEAR)-10	3		0	

	SENSIBLE (KBTU/H)	SENSIBLE (KW)	LATENT (KBTU/H)	LATENT (KW)	SENSIBLE (KBTU/H)	SENSIBLE (KW)
WALL CONDUCTION	1.183	0.346	0.000	0.000	-3.371	-0.988
ROOF CONDUCTION	0.986	0.289	0.000	0.000	-1.344	-0.394
WINDOW GLASS+FRM COND	13.595	3.983	0.000	0.000	-14.445	-4.232
WINDOW GLASS SOLAR	9.466	2.774	0.000	0.000	1.368	0.401
DOOR CONDUCTION	0.000	0.000	0.000	0.000	0.000	0.000
INTERNAL SURFACE COND	0.000	0.000	0.000	0.000	0.000	0.000
UNDERGROUND SURF COND	-0.342	-0.100	0.000	0.000	-4.175	-1.223
OCCUPANTS TO SPACE	0.025	0.007	0.000	0.000	0.010	0.003
LIGHT TO SPACE	1.336	0.391	0.000	0.000	1.336	0.391
EQUIPMENT TO SPACE	0.000	0.000	0.000	0.000	0.000	0.000
PROCESS TO SPACE	0.000	0.000	0.000	0.000	0.000	0.000
INFILTRATION	1.741	0.510	1.151	0.337	-4.171	-1.222
TOTAL	27.990	8.201	1.151	0.337	-24.793	-7.264
TOTAL / AREA	0.049	0.154	0.002	0.006	-0.043	-0.136
TOTAL LOAD	29.141 KBTU/H		8.538 KW		-24.793 KBTU/H	-7.264 KW
TOTAL LOAD / AREA	50.77 BTU/H.SQFT		160.115 W/M2		43.193 BTU/H.SQFT	136.223 W/M2

Report SS-O: Zone Temperature Summary

Total Hours and Time of Day at Temperature Levels for each zone

- SS-O Space Temperature Summary for Hi Bay Zn (G.W1) WEATHER FILE- Columbia MO TMY2

TOTAL HOURS AT TEMPERATURE LEVEL AND TIME OF DAY

HOUR	1AM	2	3	4	5	6	7	8	9	10	11	12	1PM	2	3	4	5	6	7	8	9	10	11	12	TOTAL
ABOVE 85	0	0	0	0	2	3	7	12	25	31	40	41	44	49	50	51	51	45	0	0	0	0	0	0	451
80-85	0	0	0	0	23	23	31	38	30	30	26	28	27	24	27	26	24	22	0	0	0	0	0	0	379
75-80	0	0	0	0	36	36	28	25	21	19	22	24	24	34	33	37	28	29	2	0	0	0	0	0	398
70-75	0	0	0	0	53	157	161	155	157	160	154	145	151	139	138	133	143	149	108	0	0	0	0	0	2103
65-70	0	0	0	0	14	24	20	20	19	12	11	16	8	8	6	8	8	8	6	0	0	0	0	0	188
60-65	0	0	0	0	10	11	7	6	5	6	5	6	6	7	7	6	7	8	0	0	0	0	0	0	97
BELOW 60	0	0	0	0	7	7	7	5	4	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0	38

Report SV-A: System Design Parameters

HVAC System Design for each system, showing airflow and load for each zone served by that system.

709 AsBuilt23 DOE-2.2-44e4 12/31/2008 9:07:35 BDL RUN 1

REPORT- SV-A System Design Parameters for AHU-5 (SZRH) WEATHER FILE- Columbia MO TMY2

SYSTEM TYPE	ALTITUDE FACTOR	FLOOR AREA (SQFT)	MAX PEOPLE	OUTSIDE AIR RATIO	COOLING CAPACITY (KBTU/HR)	SENSIBLE (SHR)	HEATING CAPACITY (KBTU/HR)	COOLING EIR (BTU/BTU)	HEATING EIR (BTU/BTU)	HEAT PUMP SUPP-HEAT (KBTU/HR)
SZRH	1.030	13536.0	27.	0.030	95.951	0.758	-153.216	0.000	0.000	0.000

FAN TYPE	CAPACITY (CFM)	DIVERSITY FACTOR (FRAC)	POWER DEMAND (KW)	FAN DELTA-T (F)	STATIC PRESSURE (IN-WATER)	TOTAL EFF (FRAC)	MECH EFF (FRAC)	FAN PLACEMENT	FAN CONTROL	MAX FAN RATIO (FRAC)	MIN FAN RATIO (FRAC)
SUPPLY	2974.	1.00	0.678	0.73	1.0	0.50	0.62	DRAW-THRU	CONSTANT	1.10	0.30

ZONE NAME	SUPPLY FLOW (CFM)	EXHAUST FLOW (CFM)	FAN (KW)	MINIMUM FLOW (FRAC)	OUTSIDE AIR FLOW (CFM)	COOLING CAPACITY (KBTU/HR)	SENSIBLE (FRAC)	EXTRACTION RATE (KBTU/HR)	HEATING CAPACITY (KBTU/HR)	ADDITION RATE (KBTU/HR)	ZONE MULT
Engineering Zn (G.C12)	2472.	0.	0.000	1.000	74.	0.00	0.00	51.84	0.00	-124.42	1.
Vault Ex Fuel Zn (G.NW13)	275.	0.	0.000	1.000	8.	0.00	0.00	5.77	-10.09	-5.19	1.
Office Zn (G.N14)	227.	0.	0.000	1.000	7.	0.00	0.00	4.75	-8.32	-4.28	1.
EL1 Core Pl Zn (G.C28)	0.	0.	0.000	0.000	0.	0.00	0.00	0.00	0.00	0.00	1.
EL1 NW Perim Pl Zn (G.NW2	0.	0.	0.000	0.000	0.	0.00	0.00	0.00	0.00	0.00	1.
EL1 North Perim Pl Zn (G.)	0.	0.	0.000	0.000	0.	0.00	0.00	0.00	0.00	0.00	1.

3. Details, Details, Details

The more things you "pin down" at the beginning for an existing building model, the easier calibration will be at the end

- Actual kW/sq ft of lighting. Note % burnouts, lighting schedules
- Parking lot, Exterior lighting kW.
- People density, Occupied Hours
- Number of computers. Left on at night & weekends? (ask IT Dept)
- Office equipment, foot heaters
- Domestic Hot Water heating
- HVAC equipment nameplate data, general condition
- Space Temperatures
- Building control strategies
  - Setback/Setup
  - Central control or zone autonomy
- **Outside Air**
  - Get as much feel for OA as possible
    - OA Dampers
    - Economizer?
    - Building Pressure
- **VAV Box flow, Minimums**
- **Infiltration**

4. Use the Latest Version

- eQuest and DOE-2.2 are constantly being updated; bugs are getting fixed.
- Latest versions, available online, are *better* than the previous versions.
- http://www.doe2.com

eQUEST Version 3.63 Download:

Current Release (posting date: 5/14/2009, ~44 MB):

5. Do Not Attempt This at Home

- EQuest is not transparent.
- Modeling is complex.
- Post-calibration of models is an accepted M&V practice, but risky.

Jackass, The Movie

Continuous Improvement

- Ongoing M&V has clarified actual facility dynamics, and enhanced the relationship between Whiteman AFB and Johnson Controls

Quarterly Report

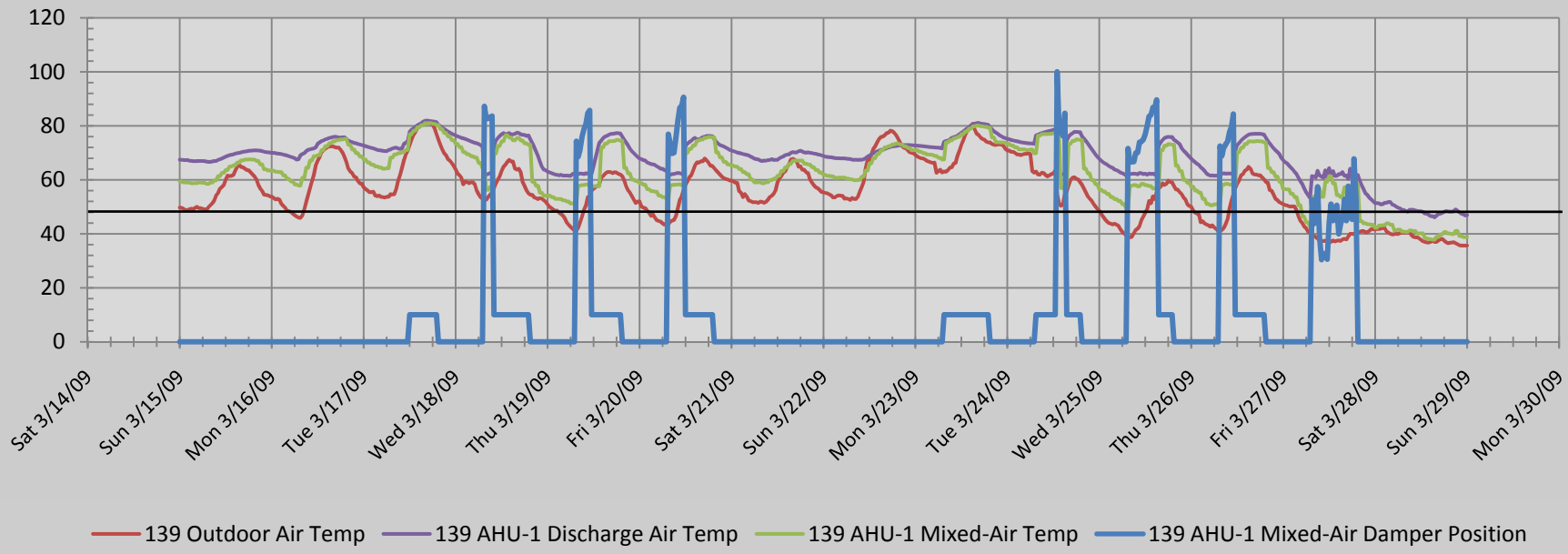
Building	Equipment Parameter Monitored	Cooling/ Heating/ Econ	Schedule in Place	Occupied Setpoint	Un-occupied Setpoint	Enable/ Lockout Spt	Econ Enable Spt	Reset	Overrides/ Comments
159	Dispatch VAV	Heating	Yes	68°	60°				Occupants complain that the Dispatch Area runs two s HVAC schedules are for single shift. Advised to cont: VAV-19 and VAV-9 seem to be under-heating. Occupied schedule should probably be moved up 1-2 h morning--temperature recovery is too slow, especially morning. Technician thought there might be some blockage in H Dispatch Area. After leaving last High Bay, line grew could not detect much flow.
159	MAU-1	Htg Only	Yes	70°	60°			w/ Zone Temp	Operating as Intended
159	HP-8	Htg/Clg	Yes	70°/74°	65°/80°				Operating As Intended
159	HP-10	Htg/Clg	Yes	70°/74°	65°/80°				Computer room, always in cooling

Maintaining the Project

- *Use Building Automation System trend data to verify that Energy Conservation control strategies are in place and working as intended.*

This graph verifies:

- Economizer operation
- Economizer enable setpoint
- Damper minimum position
- Scheduled, Damper closed unoccupied

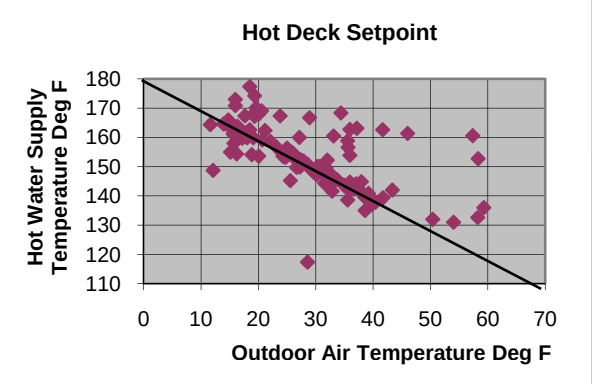


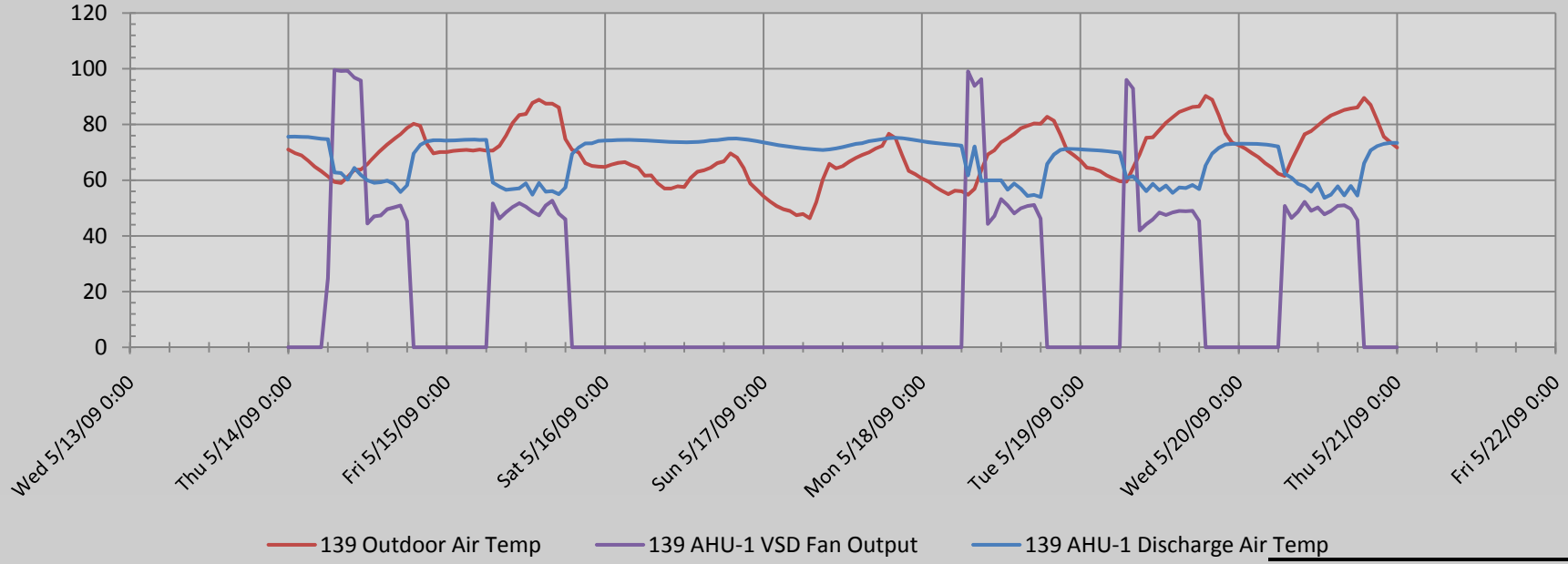
AHU Controls Verification

- ***Analyze no more than 4 buildings each quarter***
- ***Present and discuss findings with maintenance staff***
- ***Follow up the next quarter***

Verified:

- VFD backing off
- Fan Off during Unoccupied
- Chilled Water setpoint
- Hot Deck Reset





Summary

- ESPC Project met Whiteman AFB requirements and financial goals
  - Springboard for long-term energy improvement;
  - Trusted partnership between JCI and Whiteman AFB.
- Detailed M&V Analysis clarified actual facility dynamics
  - ECM refinements and building improvements by JCI;
  - Additional energy savings projects initiated by base.
- Ongoing M&V maintains maximum benefit from Energy Conservation Measures