Energy Modeling of Dedicated Outdoor Air Systems for a Small Commercial Pilot Project

BUILDING ENERGY SIMULATION FORUM, AUGUST 17, 2016
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Overview

→ Pilot project: energy efficient replacement options for end-of-life packaged rooftop units on small commercial buildings
  → Dedicated Outdoor Air Systems (DOAS) with Heat Recovery Ventilation (HRV)
→ Energy modeling as a tool to quantify savings
→ Share progress and lessons learned
Target Building Sector:

- Small commercial (< 25,000 ft²)
- Includes small office, retail, schools, restaurants, small assembly
- Makes up approx. half of the commercial building floor area in the Pacific Northwest.
- Smaller HVAC systems; typically not engineered.
Pilot Project Overview

Exhaust Air

Return Air

Ventilation + Heating (or Cooling)

Outdoor Air

Packaged Rooftop Unit
Provides fresh air for occupants

Controls space temperature

Ventilation + Heating (or Cooling)
Pilot Project Overview

Dedicated Outdoor Air System

Heat Recovery

Exhaust Air

Outdoor Air

Heat Pump

Zone-Level Heating (or Cooling)

Ventilation

Exhaust Air

Dedicated Outdoor Air System
Pilot Project Overview

→ Dedicated Outdoor Air System (DOAS) with Heat Recovery in Small Commercial Building Sector

→ Successful DOAS conversion depends on several factors, including:
  › Reduction in ventilation air volumes; demand controlled ventilation (DCV)
  › Very low ventilation fan power (0.5 Watts/cfm or less)
  › Very high ventilation heat/energy recovery efficiency

→ Minimal uptake due to lack of a cost-effective high efficiency ventilation solution
Pilot Project Overview

→ Early pilot work funded by the Northwest Energy Efficiency Alliance (NEEA)
  → New high efficiency Heat Recovery Ventilation (HRV) unit
  → Vertical mounting for existing RTU ductwork
  → 1000 cfm max flow
  → Greater than 80% sensible heat recovery efficiency
Pilot Project Overview

→ PART 1: Establish Baseline Conditions
→ PART 2: Calibrated Baseline Energy Model
→ PART 3: DOAS Conversion
→ PART 4: Establish Post-Conversion Conditions
→ PART 5: Calibrated Post-Conversion Energy Model

Savings
→ **PART 1: Establish Baseline Conditions**
   
   → Site Review
   
   → Baseline Air Leakage Testing
   
   → Installation of Monitoring Equipment
PART 2: Calibrated Baseline Energy Model

- Actual Operating Conditions (occupancy, schedules, heating and cooling setpoints, etc.)
- Baseline Air Tightness
- Monitoring Data
- Historic Utility Data
PART 3: DOAS Conversion

- New HRV unit
- Zone-level heating and cooling
- Local design teams and contractors
PART 4: Establish Post-Conversion Conditions

- Site Review
- Post-Conversion Air Leakage Testing
- Additional Monitoring Equipment
→ **PART 5:** Calibrated Post-Conversion Energy Model

→ Maintain Baseline Operating Conditions
→ Post-Conversion Air Tightness
→ Monitoring Data
→ 1 Year Post Conversion Utility Data
→ Project timeline: **Year 1**

- Recruiting Pilot Project Participants
- Prototype Modeling

**PART 1:** Establish Baseline Conditions

**PART 2:** Calibrated Baseline Energy Model

**PART 3:** HRV Conversion

**PART 4:** Establish Post-Conversion Conditions
→ Project timeline: **Year 2**

**PART 1:** Baseline

**PART 2:** Baseline Model

**PART 3:** HRV Conversion

**PART 4:** Establish Post-Conversion Conditions

**PART 5:** Calibrated Post-Conversion Energy Model
Prototype Modeling
→ Perform energy modeling of small commercial building prototypes to demonstrate savings potential

→ Prototype buildings
  › Office
  › Retail
  › School
  › Restaurant

→ Climate zones
  › CZ4C Portland OR
  › CZ5B Boise ID
  › CZ6B Helena MT
A few notes on prototypes:

- Geometry and majority of operating inputs from DOE
- Commercial Prototype Building Models
A few notes on prototypes:

→ How to reflect existing small commercial building stock?
  › DOE Pre-1980s Building enclosure inputs (4C/5B/6B)
    » R-5/R-6/R-7 walls
    » R-11/R-14/R-17 roof
    » U-0.55 windows
  › Downgraded baseline equipment efficiencies by 10%
  › No motorized damper controls on baseline rooftop units
    » Fixed damper position at 20%
Office Building

- 5,500 ft$^2$
- Defined as perimeter (70%) and core (30%) areas
Office Baseline

→ Rooftop Unit (RTU) with Gas-Fired Heating and DX Cooling
Office Conversion

→ Dedicated Outdoor Air System (DOAS) with Heat Recovery Ventilation (HRV) and Zone-Level Heat Pumps
Whole building modeled EUI of 55 kBtu/ft². Results in 22 kBtu/ft² energy savings over the baseline model.
HVAC systems represent 57% or 32 kBtu/ft² of the overall energy use.

HVAC systems represent 29% or 10 kBtu/ft² of the overall energy use.
Prototype Modeling

Small Office Prototype

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Baseline EUI (kBtu/ft²)</th>
<th>Conversion EUI (kBtu/ft²)</th>
<th>Savings (kBtu/ft²)</th>
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<td>55</td>
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<tr>
<td>CZ5B</td>
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<td>27</td>
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<tr>
<td>CZ6B</td>
<td>69</td>
<td>39</td>
<td>30</td>
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</tbody>
</table>

- **Baseline CZ4C**
- **Conversion CZ4C**
- **Baseline CZ5B**
- **Conversion CZ5B**
- **Baseline CZ6B**
- **Conversion CZ6B**

Graphical representation:

- 44% Savings
- 40% Savings

Legend:
- Heating
- Cooling
- Fans
- Equipment, Lighting, DHW
Prototype Modeling

→ Sit-Down Restaurant
  → 5,500 ft² floor area
  → Includes dining area (73%) and kitchen (27%)
Sit-Down Restaurant Baseline

- Rooftop Unit (RTU) with Gas-Fired Heating and DX Cooling; Kitchen Exhaust with 100% Outdoor Air Make-up
Prototype Modeling

Sit-Down Restaurant Conversion

→ Dedicated Outdoor Air System (DOAS) with Heat Recovery Ventilation (HRV) and Zone-Level Heat Pumps; Kitchen Exhaust Heat Recovery
Prototype Modeling

→ Sit-Down Restaurant Prototype Results

Baseline

Annual Energy Consumption Profile

Whole building modeled EUI of 435 kBtu/ft².

Conversion

Annual Energy Consumption Profile

Whole building modeled EUI of 307 kBtu/ft². Results in 128 kBtu/ft² energy savings over the baseline model.
Prototype Modeling

→ Sit-Down Restaurant Prototype Results

Baseline

HVAC systems represent 39% or 169 kBtu/ft² of the overall energy use.

Conversion

HVAC systems represent 13% or 41 kBtu/ft² of the overall energy use.
## Restaurant Prototype

### Climate Zone Results

<table>
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<tr>
<th>Climate Zone</th>
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<td>CZ6B</td>
<td>523</td>
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</table>

### Energy Use Intensity

- **Baseline**: Red
- **Conversion**: Blue
- **Fans**: Green
- **Equipment, Lighting, DHW**: Gray

- **35% Savings**
- **32% Savings**
- **29% Savings**
Retail

- 3,750 ft²
- End unit of strip mall
- 100% retail space
Retail Baseline

→ Rooftop Unit (RTU) with Gas-Fired Heating and DX Cooling
Retail Conversion

- Dedicated Outdoor Air System (DOAS) with Heat Recovery Ventilation (HRV) and Zone-Level Heat Pumps
Prototype Modeling

→ Retail Prototype Results

**Baseline**

**Conversion**

Whole building modeled EUI of 71 kBtu/ft².

Whole building modeled EUI of 44 kBtu/ft². Results in 27 kBtu/ft² energy savings over the baseline model.
Baseline

Annual Energy Consumption Profile

- Heating (Gas): 34%
- Lighting: 33%
- Fans: 12%
- Exterior Lighting: 4%
- Misc. Equipment: 8%
- Cooling: 5%
- DHW: 4%

HVAC systems represent 52% or 37 kBtu/ft² of the overall energy use.

Conversion

Annual Energy Consumption Profile

- Exterior Lighting: 7%
- Heating (Elec): 6%
- Fans: 7%
- Cooling: 9%
- Misc. Electricity: 13%
- Lighting: 52%

HVAC systems represent 22% or 10 kBtu/ft² of the overall energy use.
Prototype Modeling

Retail Prototype

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<tr>
<td>CZ6B Helena MT</td>
<td>74</td>
<td>46</td>
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Graph showing:
- 38% Savings
- 39% Savings
- 41% Savings

Legend:
- Red: Heating
- Blue: Cooling
- Green: Fans
- Gray: Equipment, Lighting, DHW
→ Primary School
  → 74,600 ft²
  → Includes classrooms (50%), office & amenity (27%), and circulation and service areas (23%)
Prototype Modeling

Primary School Baseline

→ Gas-Fired Boiler, Rooftop Unit (RTU) with Hydronic Heating and DX Cooling, and Zone-Level Hydronic Re-Heating
Prototype Modeling

Primary School Conversion

→ Dedicated Outdoor Air System (DOAS) with Heat Recovery Ventilation (HRV) and Zone-Level Heat Pumps
Prototype Modeling

→ Primary School Prototype Results

Baseline

Annual Energy Consumption Profile

Whole building modeled EUI of 61 kBtu/ft².

Conversion

Annual Energy Consumption Profile

Whole building modeled EUI of 41 kBtu/ft². Results in 20 kBtu/ft² energy savings over the baseline model.
HVAC systems represent 42% or 26 kBtu/ft² of the overall energy use.

HVAC systems represent 14% or 6 kBtu/ft² of the overall energy use.
Prototype Modeling

Primary School Prototype

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- **33% Savings**
- **35% Savings**
- **38% Savings**
→ 30% to 40% predicted whole building savings for DOAS conversion
→ 10 pilot projects to date
→ Highlight first pilot projects
  → Office 1, Portland OR
  → Office 2, Corvallis, OR
  → Office 3, Libby, MT
  → Restaurant 1, Corvallis, OR

→ Progress report
→ General lessons learned to reconcile energy model and in-service energy performance
→ **Office 1**

→ Existing heritage building

→ Second floor of a 2-storey building

→ Private offices

→ Intermittent occupancy in meeting and conference rooms

→ Monday through Friday day time operation
- **Office 1**
- **Baseline**
  - 9 RTUs, total 35 tons cooling, 650,000 Btu/h heating
- **Conversion**
  - 4 HRVs
  - 8 zone-level VRF fan coil units, tons cooling, 215,000 Btu/h heating
→ Office 1

→ Pre-Conversion Air Leakage Testing

→ Air Leakage Test Result: 0.616 cfm/ft² at 75 Pa

  › Air leakage noted at operable windows, HVAC dampers, and mechanical chases between floors.

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<td>Equivalent Leakage Area [ft² @ 75Pa]</td>
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<td>Air Changes [per Hour @ 50Pa]</td>
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<tr>
<td>Air Leakage Test Coefficient (C) [cfm/Pa']</td>
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<tr>
<td>Flow Exponent (n) [dimensionless]</td>
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<tr>
<td>Squared Correlation Coefficient (r²) [dimensionless]</td>
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</table>
→ **Office 1**

→ Preliminary baseline modeling results

→ EUI 51 kBtu/ft²
→ Office 1
→ Post-Conversion Air Leakage Testing
→ Air Leakage Test Result: 0.506 cfm/ft$^2$ at 75 Pa

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<td>Squared Correlation Coefficient ($r^2$) [dimensionless]</td>
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</table>
Pilot Project

→ Office 1
→ Preliminary DOAS conversion modeling results
  → EUI 30 kBtu/ft²
  → ~ 40% savings

NOT CALIBRATED
→ **Office 1**

→ **Preliminary Monitoring Data**

![Graph showing Outdoor Air Temperature and Heat Pump Energy (Cooling Mode)]
→ Office 1

→ Preliminary Monitoring Data

Outdoor Air Temperature

VRF Fan Coil Units

HRV Fans
→ **Office 1**

→ **Preliminary Monitoring Data**

![Graph showing temperature data over time with markers indicating specific dates and temperatures.](image-url)
→ **Office 1**

→ **What’s next?**
    → Fine tuning DOAS conversion
    → Collect more utility data and monitoring data
    → Calibrate DOAS conversion model

→ **General “lessons learned” for reconciling metered and modeled energy performance:**
    → Commissioning matters!
    → Expect and mitigate anomalies in monitoring data
→ **Office 2**
→ Single storey office building
→ Private offices, conference room, storage & library
→ Monday through Friday day time operation
→ DOAS conversion for 2 out of 5 zones
→ **Office 2**

→ **Baseline**
  
  → 5 RTUs, total 20 tons cooling, 227,000 Btu/h heating

→ **Conversion**
  
  → 3 RTUs remain, total 14 tons cooling, 152,000 Btu/h heating
  
  → 1 HRV
  
  → 2 zone-level multi-split indoor units and 1 outdoor unit, 4 tons cooling, 54,000 Btu/h heating
Pilot Project

→ Office 2

→ Pre-Conversion Air Leakage Testing

→ Air Leakage Test Result: 0.295 cfm/ft² at 75 Pa
  › Air leakage noted at office entry doors, operable windows, exhaust fans with gravity dampers (under positive pressure).

<table>
<thead>
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<th>TABLE 21 - SUMMARY OF AIR LEAKAGE TEST RESULTS</th>
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<tr>
<td>Test Condition</td>
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<tr>
<td>Enclosure Airtightness [cfm/ft²@75Pa]</td>
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<tr>
<td>Equivalent Leakage Area [ft³ @ 75Pa]</td>
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<td>Air Changes [per Hour @ 50Pa]</td>
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<td>Air Leakage Test Coefficient (C) [cfm/Pa²]</td>
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<td>Flow Exponent (n) [dimensionless]</td>
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<tr>
<td>Squared Correlation Coefficient (r²) [dimensionless]</td>
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</table>
→ **Office 2**
→ Preliminary baseline modeling results
→ EUI 60 kBtu/ft²
→ **Office 2**
→ **DOAS conversion in spring/summer 2016**
Office 2

Post-Conversion Air Leakage Testing

Air Leakage Test Result: 0.266 cfm/ft² at 75 Pa

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<thead>
<tr>
<th>Test Condition</th>
<th>Depressurize</th>
<th>Pressurize</th>
<th>Average</th>
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<td>0.998</td>
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</table>
→ Office 2
→ Preliminary DOAS conversion modeling results
→ EUI 50 kBtu/ft²
→ **Office 2**

→ **Preliminary Monitoring Data**

24 hour period showing time averaged difference between post-conversion CO$_2$ levels and pre-conversion CO$_2$ levels.
Pilot Project

→ Office 2

→ What’s next?
  → Collect more utility data and monitoring data
  → Calibrate DOAS conversion model

→ General “lessons learned” for using energy modeling as a tool to evaluate performance:
  → Modeling evaluates energy consumption; don’t forget the non-energy benefits.
Pilot Projects

Office #3
Libby MT
→ **Office 3**
→ Single storey office with attached garage + shop area
→ Monday through Friday day time schedule
Office 3

Baseline
- 1 RTU, total 7 tons cooling, 76,000 Btu/h heating
- Hydronic heating (electric)

Conversion
- 1 HRV
- 9 zone-level multi-split indoor units and 2 outdoor units, 4 tons cooling, 54,000 Btu/h heating
→ Office 3

→ Pre-Conversion Air Leakage Testing

→ Air Leakage Test Result: 0.746 cfm/ft² at 75 Pa
  
  Air leakage noted at roof to wall joints in garage, operable windows and overhead sectional doors in garage, ductwork.

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<td>Squared Correlation Coefficient (r²) [dimensionless]</td>
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</table>
Pilot Projects

→ **Office 3**
→ Preliminary baseline modeling results
  → EUI 79 kBtu/ft²
→ Office 3
→ DOAS conversion scheduled for summer 2016
-> Office 3
-> Preliminary DOAS conversion modeling results
-> EUI 67 kBtu/ft²
→ Office 3

→ Preliminary Monitoring Data

Electric boiler energy consumption (secondary axis)

IT room heat pump (primary axis)

RTU???
→ **Office 3**

→ **Preliminary Monitoring Data**

Actual electricity consumption and modeled electricity consumption per month for the year 2013.

---

**Monthly Electricity Usage**

- **Electricity Use (kWh)**
  - Jan: 22,000
  - Feb: 23,000
  - Mar: 19,000
  - Apr: 16,000
  - May: 15,000
  - Jun: 14,000
  - Jul: 12,000
  - Aug: 11,000
  - Sep: 10,000
  - Oct: 18,000
  - Nov: 20,000
  - Dec: 20,000

- **Month**
  - Jan
  - Feb
  - Mar
  - Apr
  - May
  - Jun
  - Jul
  - Aug
  - Sep
  - Oct
  - Nov
  - Dec

- **Legend**
  - Actual-2013
  - Calibrated-Model
→ **Office 2**

→ **What’s next?**
  
  → Install DOAS conversion
  
  → Post-conversion air leakage testing and monitoring equipment install
  
  → Collect more utility data and monitoring data
  
  → Calibrate DOAS conversion model

→ **General “lessons learned” for reconciling metered and modeled energy performance:**
  
  → Expect and incorporate seasonal and other building-specific operating characteristics.
Pilot Projects

Restaurant #1
Corvallis OR
→ **Restaurant 1**

→ Busy sit-in & take-out restaurant

→ Dining area, kitchen, basement storage

→ Operating hours from 9AM to midnight, daily
→ **Restaurant 1**

→ **Baseline**

  → **Dining area:**
    - Previously had 1 RTU, 7.5 tons cooling, 88,000 Btu/h heating
    - Currently no ventilation
    - Ductless split heat pumps for heating and cooling

→ **Conversion**

  → **Dining area:**
    - Install 1 HRV to reinstate ventilation at low energy penalty
    - Use existing ductless split heat pumps for heat and cooling
Restaurant 1

Pre-Conversion Air Leakage Testing

Air Leakage Test Result: 1.634 cfm/ft² at 75 Pa

Air leakage noted at existing RTU supply and return registers, around doorway to basement, exhaust fans.

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</table>
Pilot Project

→ **Restaurant 1**
→ Preliminary baseline modeling results
→ EUI 651 kBtu/ft²
Pilot Project

→ Restaurant 1
→ Post-Conversion Air Leakage Testing
  → Air Leakage Test Result: 1.644 cfm/ft² at 75 Pa

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→ Restaurant 1
→ Preliminary Monitoring Data

- Interior Air Temperature (front and back)
- Outdoor Air Temperature

![Graph showing temperature data over time with three lines representing Outdoor Temp, Back Temperature, and Front Temperature.]
→ Restaurant 1
→ Preliminary Monitoring Data

**Interior Air Temperatures ≠ Temperature at HRV Exhaust Inlet**

Duct Leakage in Unconditioned Attic
Pilot Project

→ **Restaurant 1**

→ What’s next?
  
  → Collect more utility data and monitoring data
  
  → Create and calibrate DOAS conversion model

→ General “lessons learned” for reconciling metered and modeled energy performance:
  
  → Expect and mitigate system losses.
Summary and Next Steps
Summary and Next Steps

→ Summary – progress thus far
Project timeline: Year 1

- Recruiting Pilot Project Participants
- Prototype Modeling

**PART 1:** Establish Baseline Conditions

**PART 2:** Calibrated Baseline Energy Model

**PART 3:** HRV Conversion

**PART 4:** Establish Post-Conversion Conditions
→ Summary – some early lessons learned for connecting modeled energy performance with in-service building performance

→ Commissioning matters!

→ Expect and mitigate anomalies in monitoring data.

→ Expect and incorporate building-specific and seasonal operational schedules.

→ Expect and mitigate system losses.

→ Also, don’t forget the non-energy benefits.
Project timeline: Year 2

PART 1: Baseline

PART 2: Baseline Model

PART 3: HRV Conversion

PART 4: Establish Post-Conversion Conditions

PART 5: Calibrated Post-Conversion Energy Model
Summary and Next Steps

- **PART 1:** Establish Baseline Conditions
- **PART 2:** Calibrated Baseline Energy Model
- **PART 3:** DOAS Conversion
- **PART 4:** Establish Post-Conversion Conditions
- **PART 5:** Calibrated Post-Conversion Energy Model

Reliably Estimate and Validate Savings

Market Transformation
RDH Building Engineering Ltd. and Building Science Consulting Inc. have merged. Effective November 1, 2015, we now operate as one integrated firm. The merger brings two of the leading building science firms in North America together to provide a combination of cutting-edge research with leading design and implementation capabilities. The result is a unique offering for our clients—an ability to explore new and innovative ideas based on science and our practical knowledge of what can be built. We are excited about the possibilities as we launch the new firm.

Discussion + Questions

FOR FURTHER INFORMATION PLEASE VISIT

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