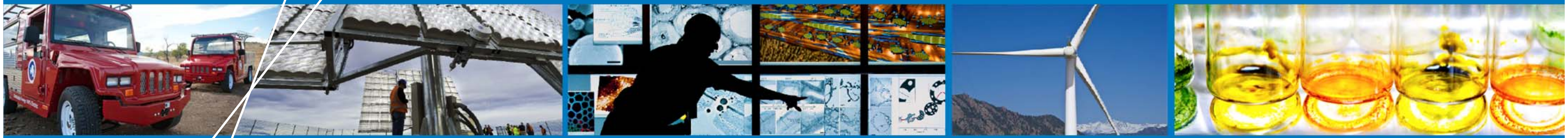
Laboratory Performance Testing of Residential Window Mounted Air Conditioners



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April 29, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

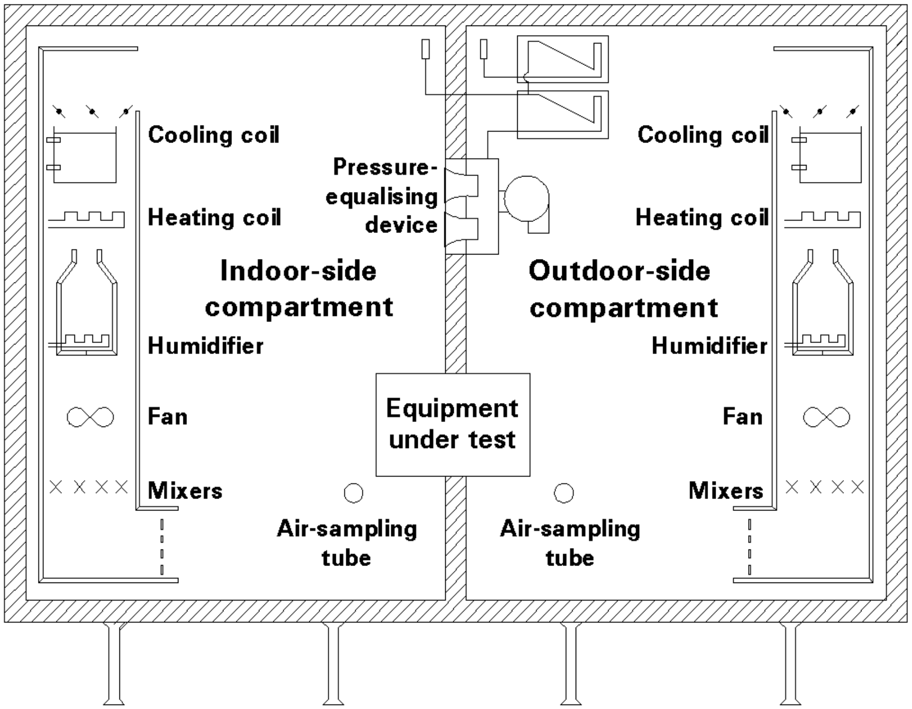
Why should we care?

- **Window AC unit sales dominate US market**
  - 7.5 million units sold in 2011
    - – 36% more than ducted systems
    - – Approx. 30% of installed capacity
  - Inexpensive relative to central units
  - Easy installation
  - Attractive for retrofits
- **Need accurate models in whole-building tools**
  - Costs/savings relative to other solutions can be quantified
  - Spot cooling can reduce energy use, but when, where and by how much?
  - Window A/Cs potentially more cost effective than central A/C
- **Ratings test methods insufficient for accurate modeling**

Standard Ratings Test Method

Shortcomings that prevent accurate simulation:

- Acceptable for rating; insufficient data for simulation
- Does not account for manufacturer-recommended installation methods/materials
- Does not account for additional leakage from window being open
- No cycling tests
- Limited opportunity for identifying improvements & characterizing their impacts



ASHRAE 16 Standard Test Configuration

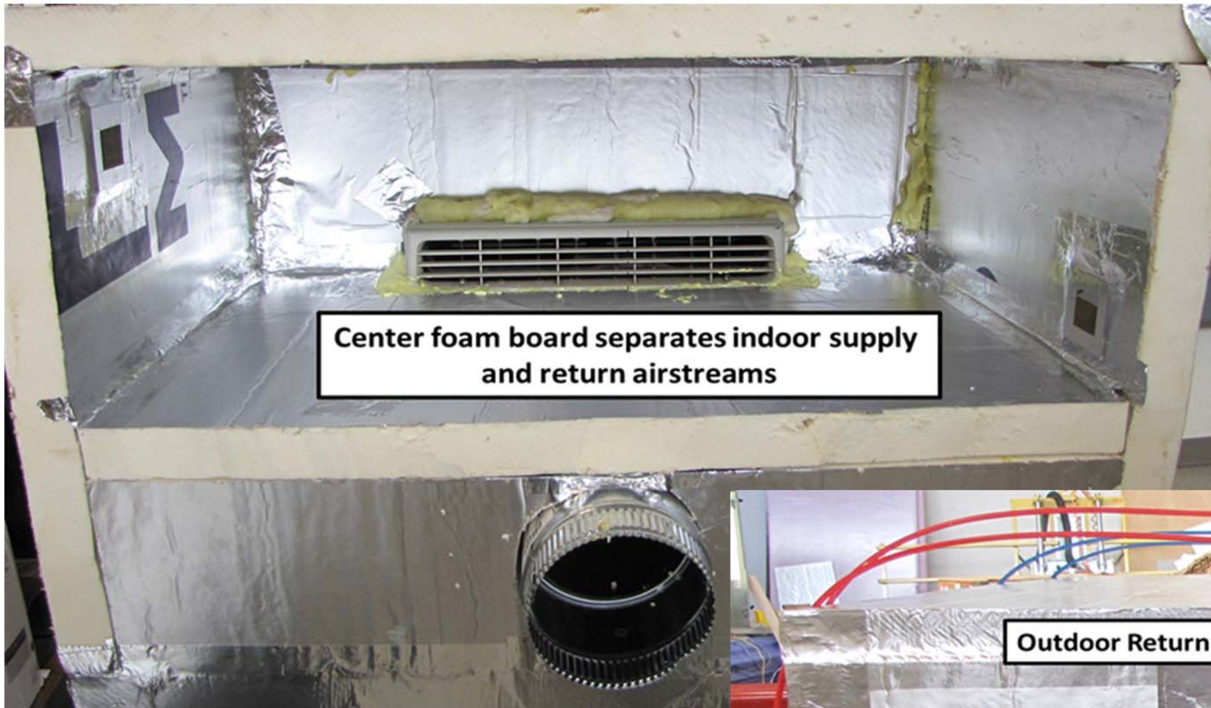
Our Approach

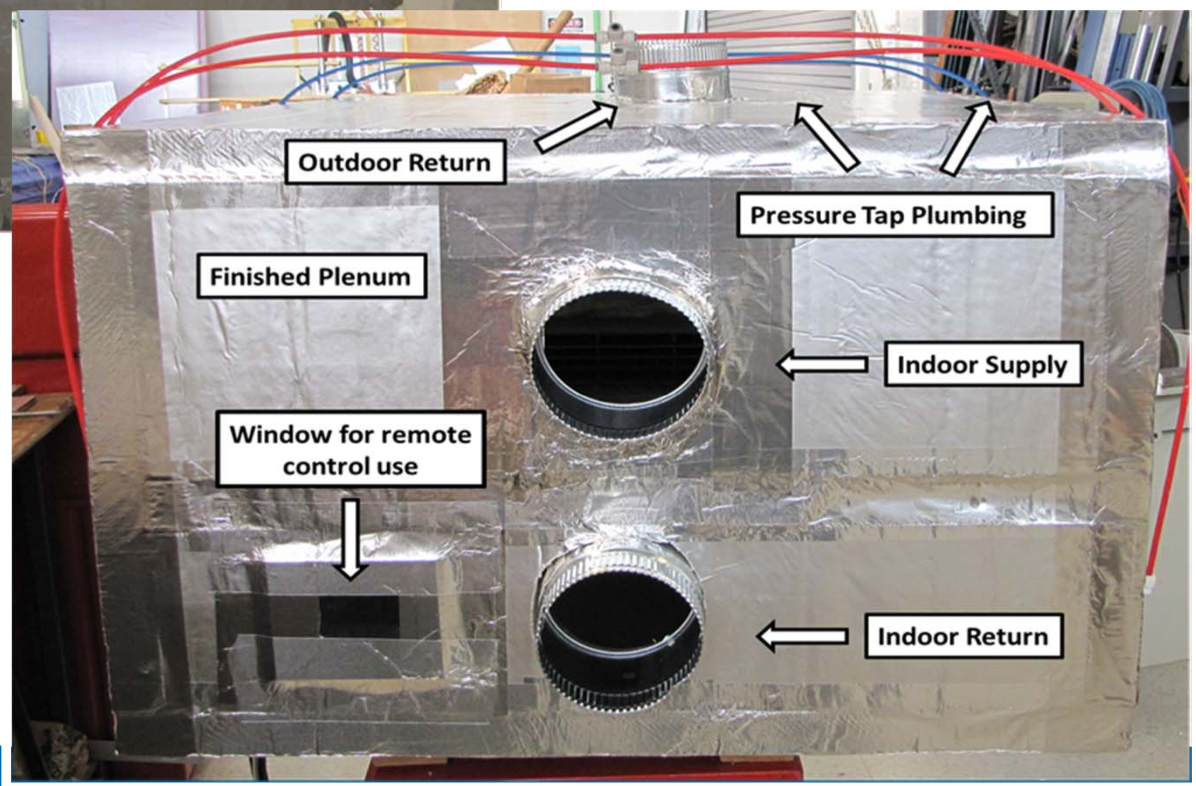
- **Performance Mapping**
  - How does steady state performance depend on operating temperatures?
  - How does the unit perform under part-load conditions?
- **Infiltration Testing**
  - What is the installed room air leakage and where does it come from?
- **Recirculation Testing**
  - How much of the supply air gets sucked into the returns? This reduces efficiency and capacity.
- **Recommendations**
  - How can users/manufacturers improve performance?

Brand Name	Model #	Capacity[1] (kBtu/h)	EER[1] (Btu/Wh)	Airflow Rate[2] (cfm)	ENERGY STAR® Qualified	Date of Manufacture
Frigidaire	FRA103BT1	10	9.8	231/260/290	No	11/2011
Frigidaire	FRA106CV1	10	10.7	231/260/290	Yes	10/2011
Haier	HWR-5XCL	5	9.7	115/125/135	No	Unknown[4]
General Electric (GE)	AGD06LAG1	6	9.7	N/A[3]	No	02/2001

[1] Performance at the rated return condition of 80°F DB, 67°F WB and outdoor condition of 95°F.
[2] Airflow rates correspond to low, medium and high fan speeds, respectively, when available.
[3] Rated airflow rate data was not available for this unit due to its age.
[4] This unit did not have a nameplate to identify manufacture date. It is likely of recent manufacture, as it was purchased at a local big box store where product turnover is high.

Our Approach (continued)





End-of-Life Unit

- **Tested unit in as-found condition to determine performance degradation**

NREL/PIX 23653
Credit: Jeff Tomerlin, NREL

NREL/PIX 23652
Credit: Jeff Tomerlin, NREL

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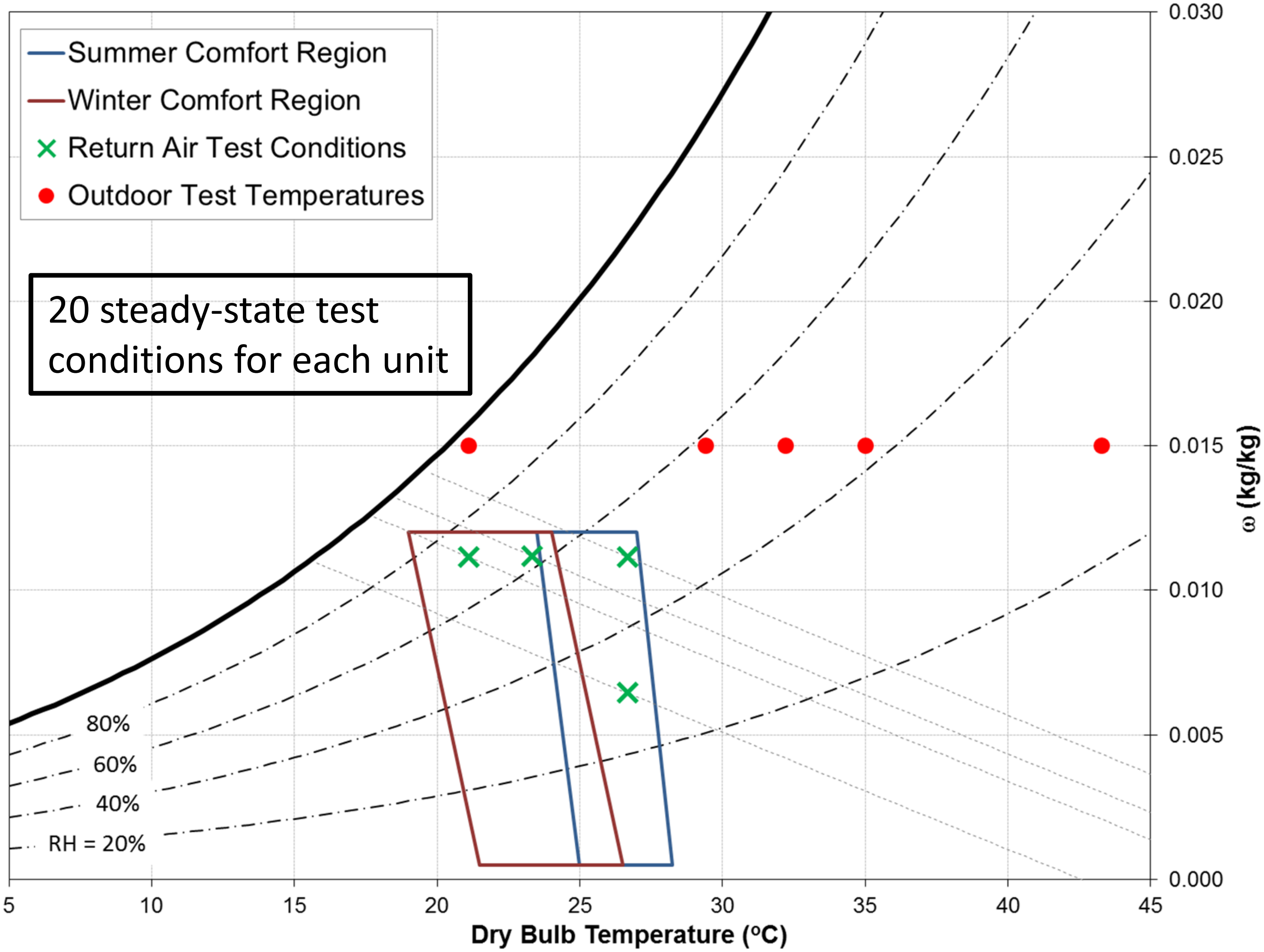
Performance Mapping

Test Matrix



Summer Comfort Region
Winter Comfort Region
Return Air Test Conditions
Outdoor Test Temperatures
20 steady-state test conditions for each unit
80%
60%
40%
RH = 20%
5
10
15
20
25
30
35
40
45
Dry Bulb Temperature (°C)
0.030
0.025
0.020
0.015
0.010
0.005
0.000
ω (kg/kg)

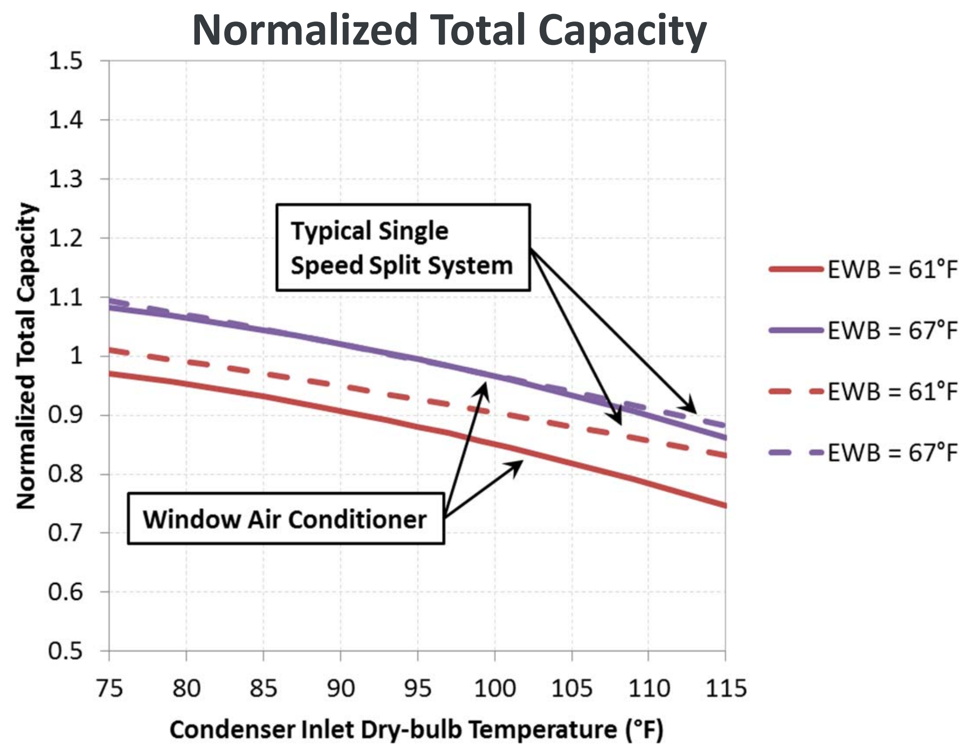
Steady State Performance Results

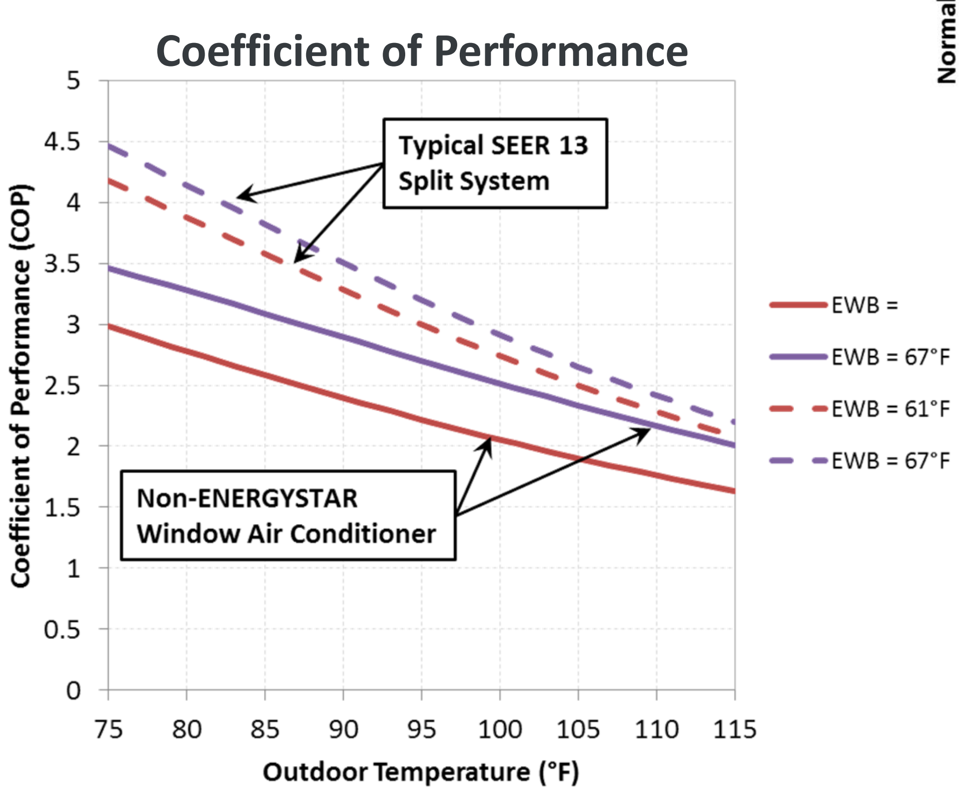
Window Air Conditioner	Manufacturer Rated Performance		Measured Performance Estimates		
	Capacity (Btu/h)	EER (Btu/Wh)	Capacity (Btu/h)	EER (Btu/Wh)	SHR
Frigidaire	10,000	9.8	9,547 ± 473	8.9 ± 0.4	0.65 ± 0.01
Frigidaire (ENERGY STAR)	10,000	10.7	10,256 ± 529	11.0 ± 0.5	0.66 ± 0.02
Haier	5,000	9.7	4,937 ± 213	9.0 ± 0.4	0.63 ± 0.01
GE (End-of-Life Unit)	6,000	9.7	3,497 ± 222	4.3 ± 0.3	0.72 ± 0.02

- **ENERGY STAR unit slightly exceeded manufacturer rating**
- **GE had significant fouling and very low flow rates**
- **Units had surprisingly low sensible heat ratios (SHR)**

Steady State Performance Curves (Temperature)

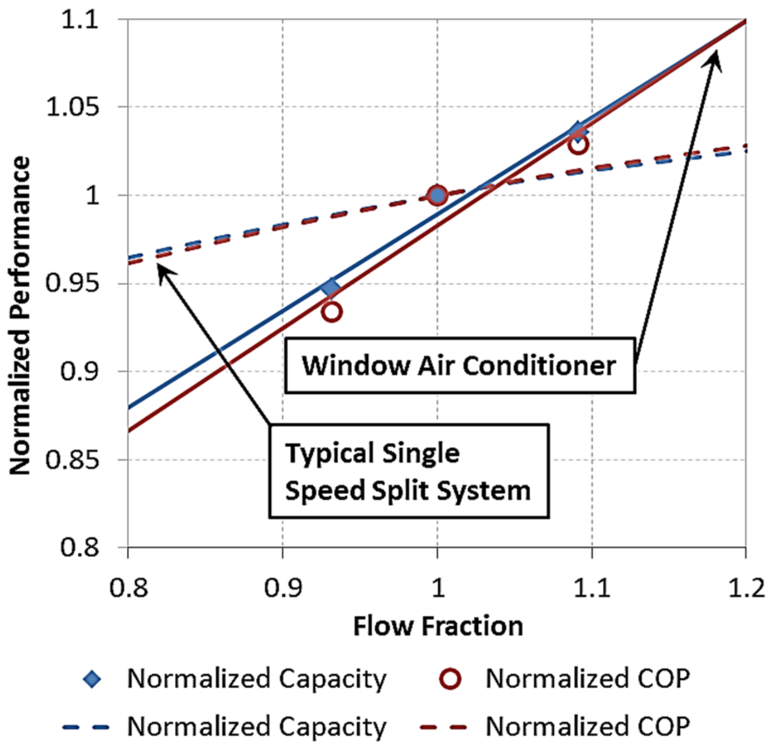
- **Window AC performance compared to a typical split system**





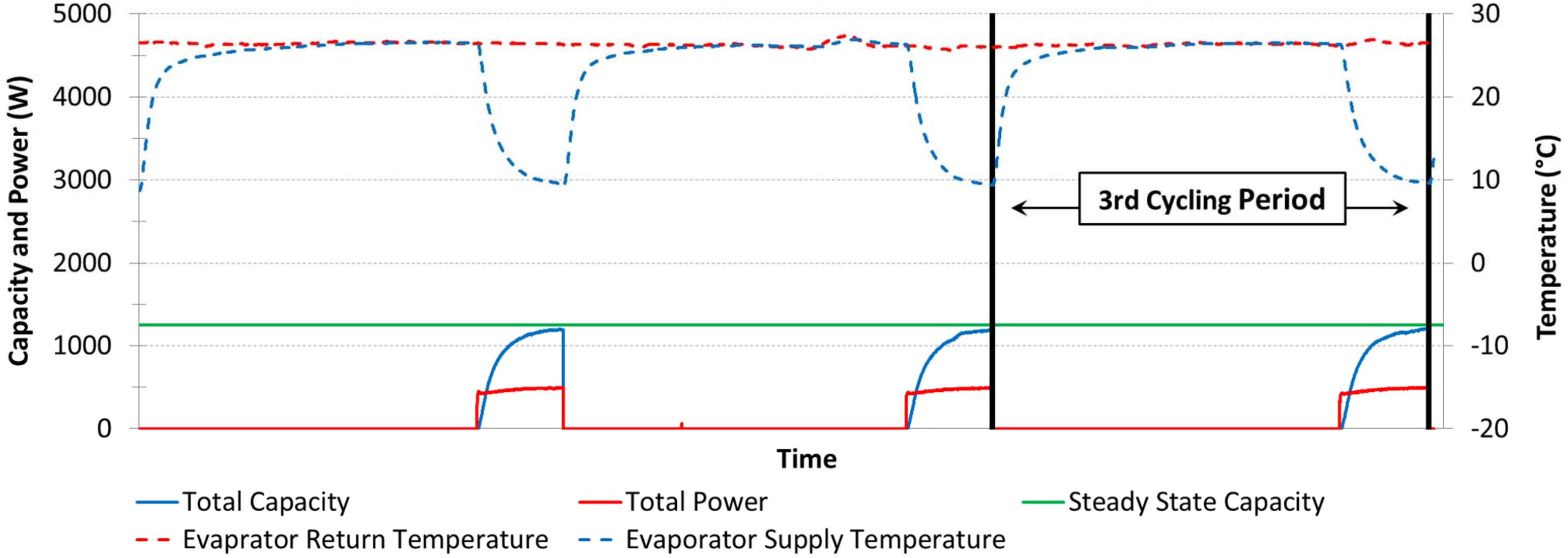
Steady State Performance Curves (Airflow)

- Window ACs have one fan motor
- Performance is more sensitive to fan setting than split systems



Flow Fraction =
Airflow Rate/Rated Airflow Rate

Cyclic Performance



Window AC	EER_{cyc} (Btu/Wh)	$EER_{ss,}$ (Btu/Wh)	CLF	C_D
Frigidaire	8.04	9.75	0.20	0.22
Frigidaire (ENERGY STAR)	8.07	9.92	0.15	0.22
Haier	6.88	8.23	0.16	0.20
GE (End-of-Life)	3.02	5.51	0.13	0.52

Maximum value: 0.25

Typical values: 0.05-0.10

$$EER_{cyc} = \frac{\int_{\tau_1}^{\tau_2} \left[\frac{\dot{m}_{evap,in}(\tau) + \dot{m}_{evap,out}(\tau)}{2} \right] \left[h_{evap,in}(\tau) - h_{evap,out}(\tau) \right] d\tau}{\int_{\tau_1}^{\tau_2} \dot{P}(\tau) d\tau}$$

$$CLF = \frac{q_{cyc}}{\dot{Q}_{ss} \cdot \Delta\tau_{cyc}}$$

$$C_D = \frac{1 - \frac{EER_{cyc}}{EER_{ss}}}{1 - CLF}$$

Source: AHRI Standard 210/240

Estimating Seasonal Energy Efficiency Ratio (SEER)

- **Steady state performance testing coupled with cyclic testing allows us to estimate SEER**

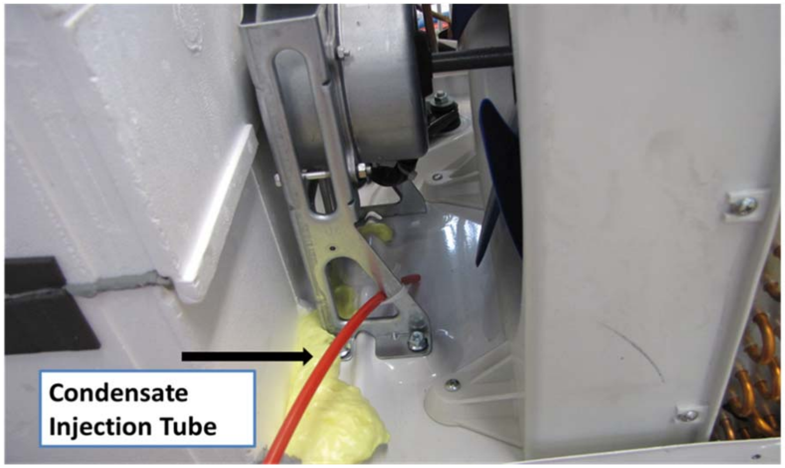
Window Air Conditioner	Equivalent SEER[1] (Btu/Wh)
Frigidaire	9.3
Frigidaire (ENERGY STAR)	12.1
Haier	9.9
GE (End-of-Life Unit)	4.7

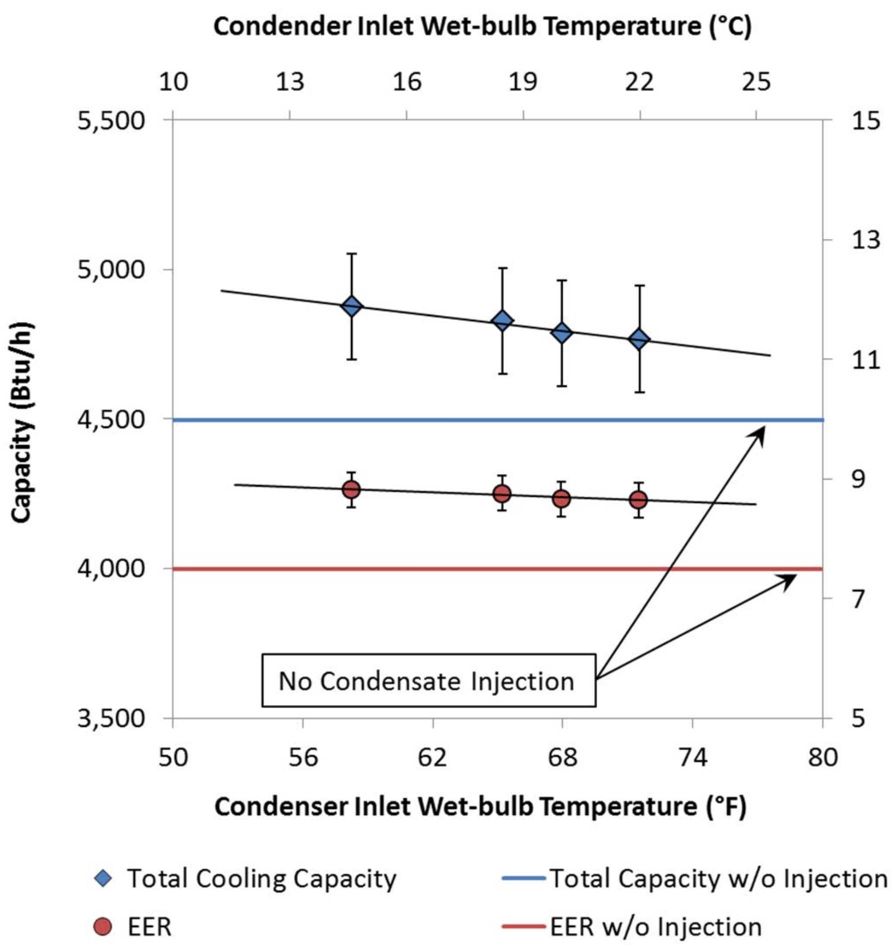
[1] Neglects air infiltration, but includes air recirculation

- **Standard rating test procedures do not facilitate the calculation of an SEER**

$$SEER = \left(1 - 0.5 \cdot C_D\right) \cdot EER_B$$

Condensate Injection



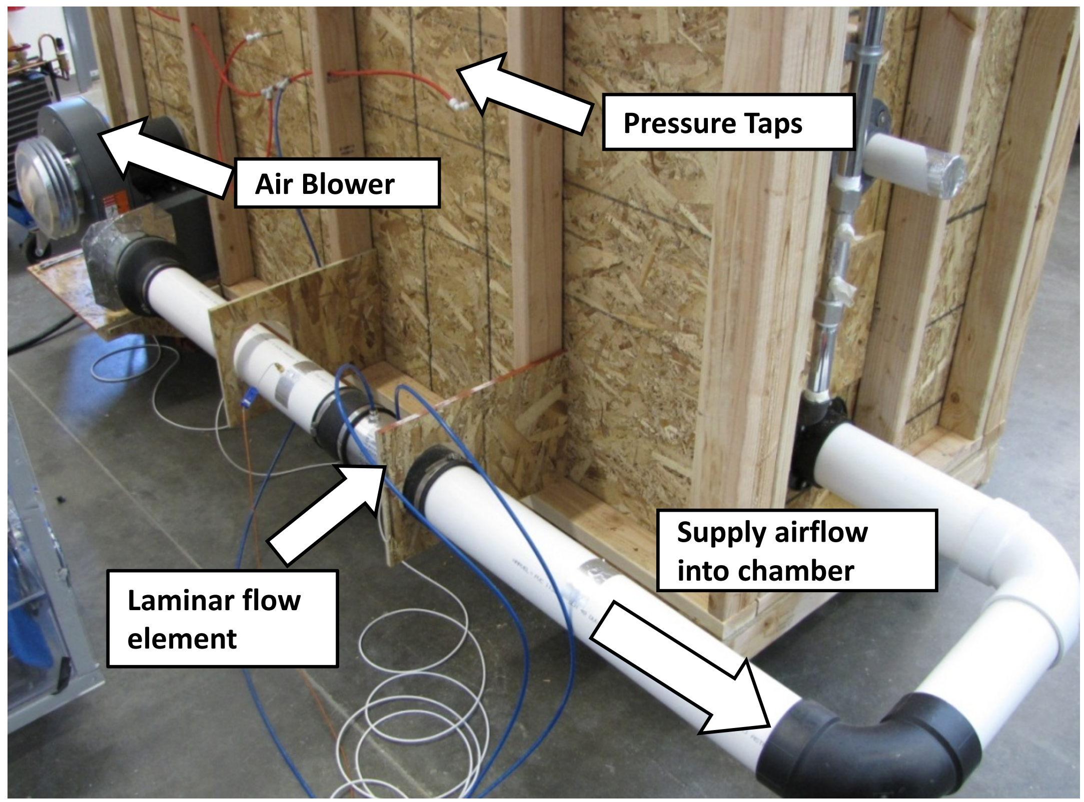


All tests conducted at 95°F outdoor dry-bulb, 80°F return dry-bulb, and 67°F return wet-bulb temperatures

Infiltration Testing

Infiltration Test Chamber

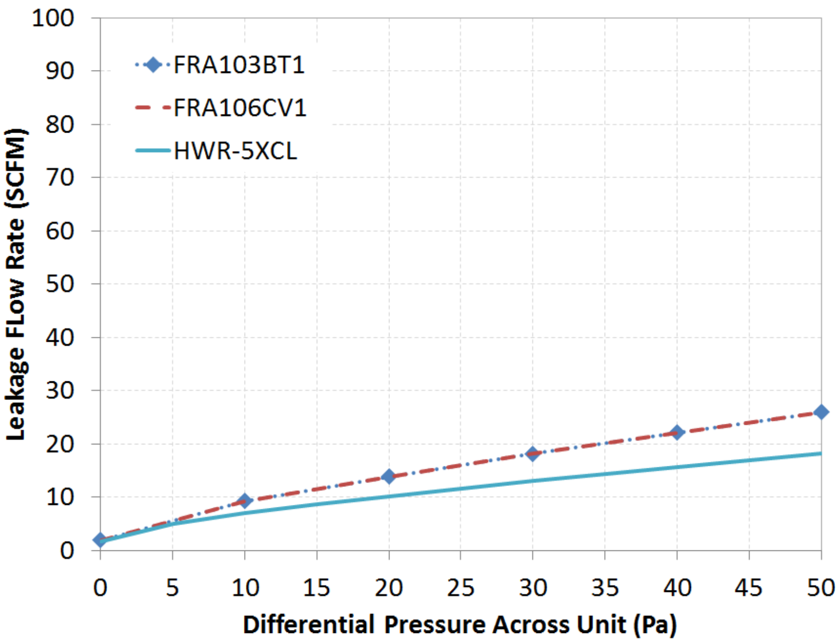
- Pressurized chamber
- Measure leakage
- Configurable A/C installation



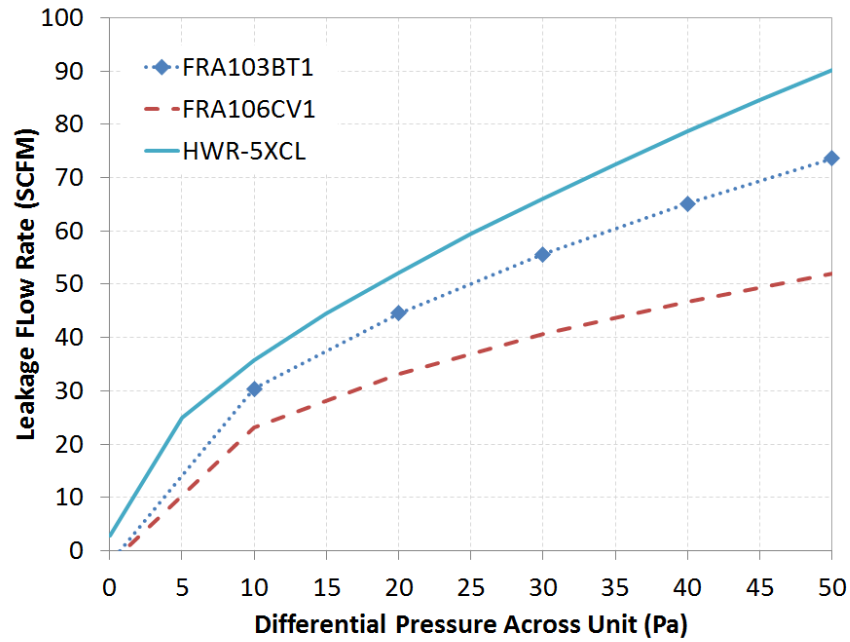
Infiltration Testing

Results – Infiltration

Leakage Through Unit



Leakage Due to Installation



- **Installation leakage not captured in standard test method**
- **Total leakage ~2 ACH50, ~10-20% more leakage for a 1960's 1,280 sq. ft. house**

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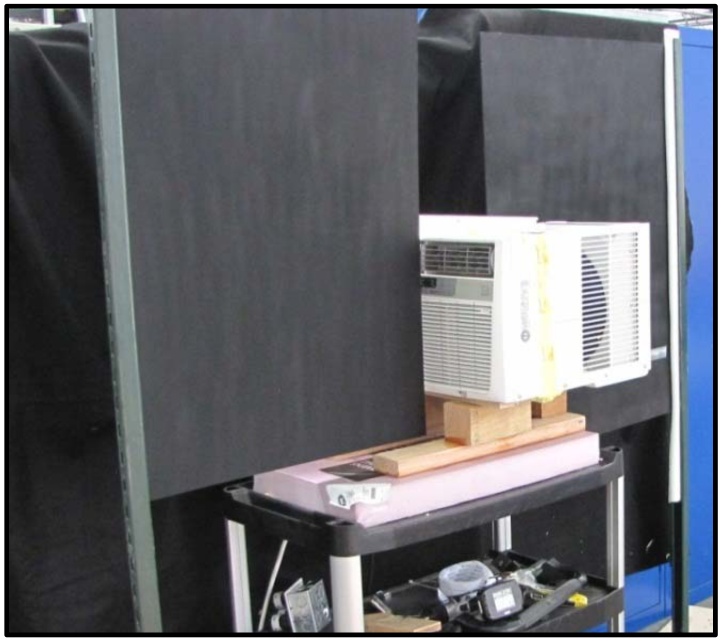
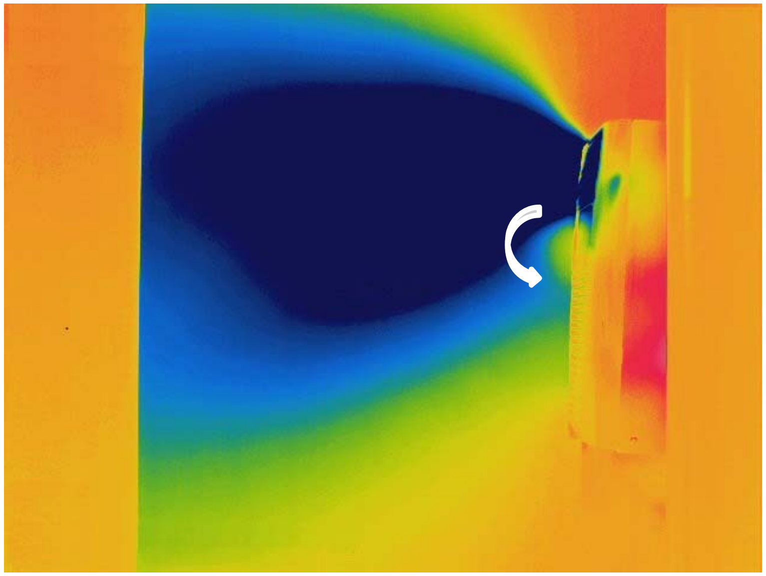
Recirculation Testing

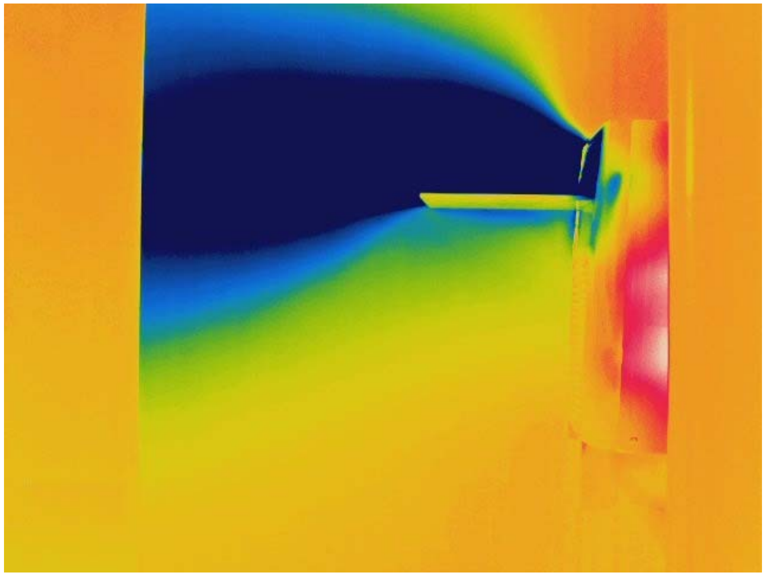
Recirculation Analysis

- Innovative measurement technique developed for these tests
- Capture IR images of a plane parallel to the flow
- Conjugate heat transfer analysis at the imaged plane to calculate local air temperature (inverse heat conduction problem)
- Requires point velocity measurement at supply/return



Fixing the Problem





- Easily eliminate most recirculation
- Many forms possible for diverter
- Easy to manufacture, no changes to current tooling or assembly lines

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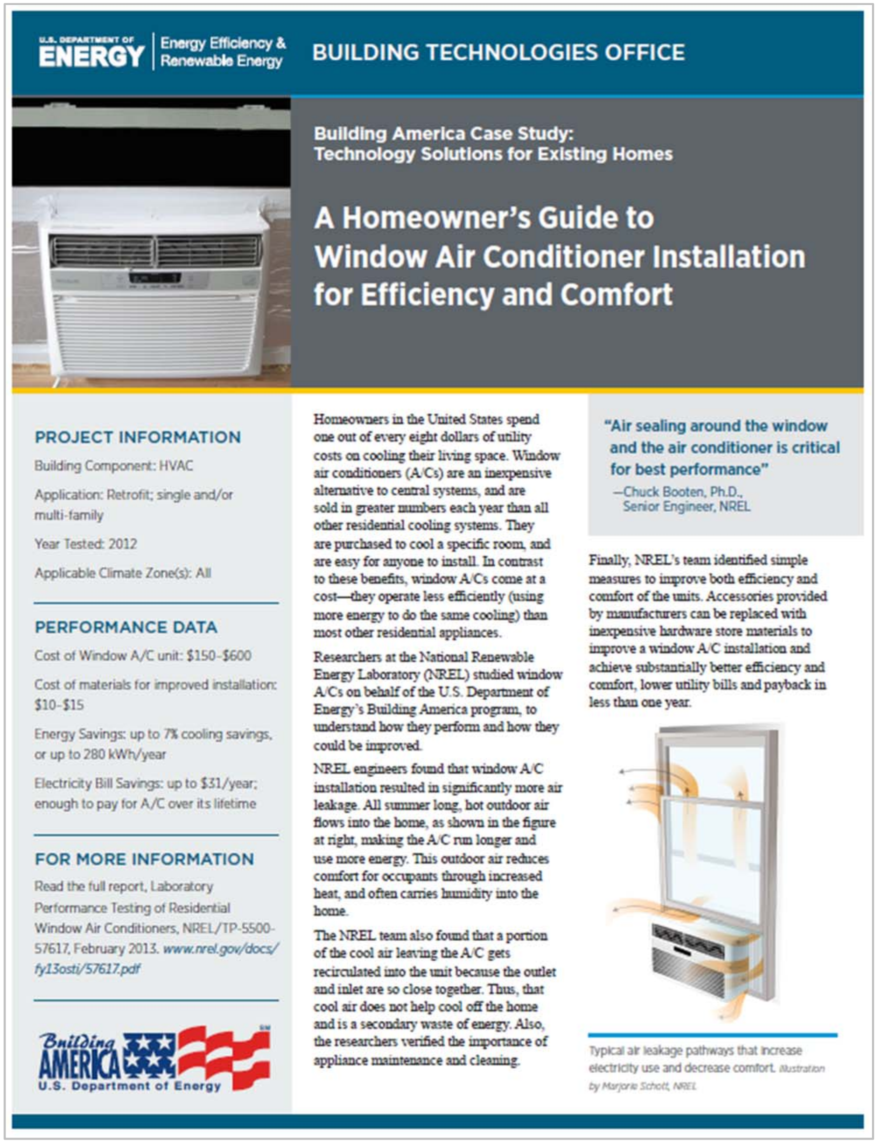
Installation Guide

Homeowner Installation Guide



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BUILDING TECHNOLOGIES OFFICE

Building America Case Study: Technology Solutions for Existing Homes

A Homeowner's Guide to Window Air Conditioner Installation for Efficiency and Comfort

PROJECT INFORMATION

Building Component: HVAC

Application: Retrofit; single and/or multi-family

Year Tested: 2012

Applicable Climate Zone(s): All

PERFORMANCE DATA

Cost of Window A/C unit: $150-$600

Cost of materials for improved installation: $10-$15

Energy Savings: up to 7% cooling savings, or up to 280 kWh/year

Electricity Bill Savings: up to $31/year; enough to pay for A/C over its lifetime

FOR MORE INFORMATION

Read the full report, Laboratory Performance Testing of Residential Window Air Conditioners, NREL/TP-5500-57617, February 2013. *www.nrel.gov/docs/fy13osti/57617.pdf*

Building AMERICA U.S. Department of Energy

Homeowners in the United States spend one out of every eight dollars of utility costs on cooling their living space. Window air conditioners (A/Cs) are an inexpensive alternative to central systems, and are sold in greater numbers each year than all other residential cooling systems. They are purchased to cool a specific room, and are easy for anyone to install. In contrast to these benefits, window A/Cs come at a cost—they operate less efficiently (using more energy to do the same cooling) than most other residential appliances.

Researchers at the National Renewable Energy Laboratory (NREL) studied window A/Cs on behalf of the U.S. Department of Energy's Building America program, to understand how they perform and how they could be improved.

NREL engineers found that window A/C installation resulted in significantly more air leakage. All summer long, hot outdoor air flows into the home, as shown in the figure at right, making the A/C run longer and use more energy. This outdoor air reduces comfort for occupants through increased heat, and often carries humidity into the home.

The NREL team also found that a portion of the cool air leaving the A/C gets recirculated into the unit because the outlet and inlet are so close together. Thus, that cool air does not help cool off the home and is a secondary waste of energy. Also, the researchers verified the importance of appliance maintenance and cleaning.

"Air sealing around the window and the air conditioner is critical for best performance"

—Chuck Booten, Ph.D., Senior Engineer, NREL

Finally, NREL's team identified simple measures to improve both efficiency and comfort of the units. Accessories provided by manufacturers can be replaced with inexpensive hardware store materials to improve a window A/C installation and achieve substantially better efficiency and comfort, lower utility bills and payback in less than one year.

Typical air leakage pathways that increase electricity use and decrease comfort. *Illustration by Marjorie Schott, NREL*

BUILDING TECHNOLOGIES OFFICE: WINDOW AIR CONDITIONER INSTALLATION

1 2 3 4 5

Five Easy Steps to Limit Window A/C Infiltration

1. Remove accordion panels. Typically a sliding keeper can be removed. Pull the frame out, then remove another keeper from the side of the A/C. Do not remove top and bottom braces. *Note: The top and bottom braces must remain attached to the A/C, as they hold the unit into the window.*
2. Cut and install rigid foam panels to fill the spaces beside the A/C, measure the thickness of the window sash to determine foam thickness; 1-1 ½ in. thickness will fit most window frame channels. Some foams have a skin to help protect the foam from weather.
3. Foam strips provided by the manufacturer for sealing between sashes are prone to air leaks. Instead, use backer rod (closed cell cylindrical foam) between sashes.
4. No matter what foam is used, it is important to also plug the top of the side channels.
5. Use tape to secure the foam panels and prevent air leaks around joints. Tape the foam panels to the window, window frame, and A/C; tape the top and bottom of the A/C, too. White duct tape is available, as shown in the photo at left.

Go Further: Address Cool Air Recirculation

To further enhance performance, install a diverter between the cool air supply (top) and room air return (bottom) of the air conditioner. This maximizes the amount of cool air that goes into the room.

The Bottom Line

- Air leakage wastes energy and costs money, but homeowners can reduce this leakage easily
- Recirculation of air near the unit lowers efficiency and can be easily reduced
- Periodic cleaning of intake and exhaust grills on both the indoor and outdoor portion of the unit can help maintain efficient performance
- Remove unit from window or seal it up completely on the inside after cooling season is over, otherwise, air will leak through the unit itself.

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For more information, visit: www.buildingamerica.gov

The U.S. Department of Energy's Building America program is engineering the American home for energy performance, durability, quality, affordability, and comfort.

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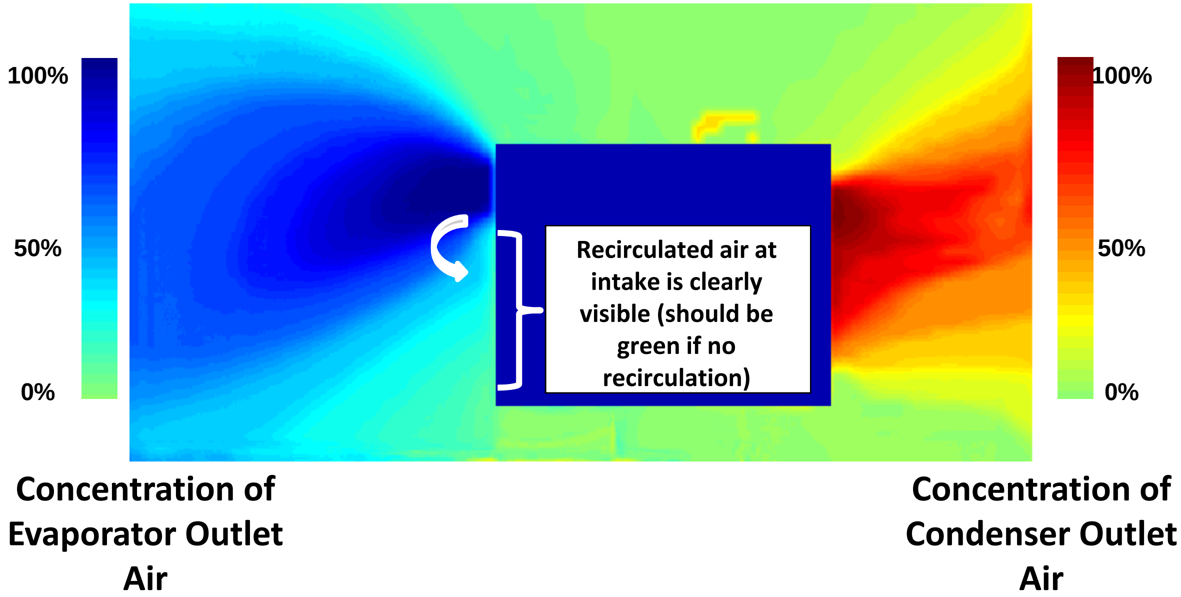
Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post consumer waste.

Recirculation Results



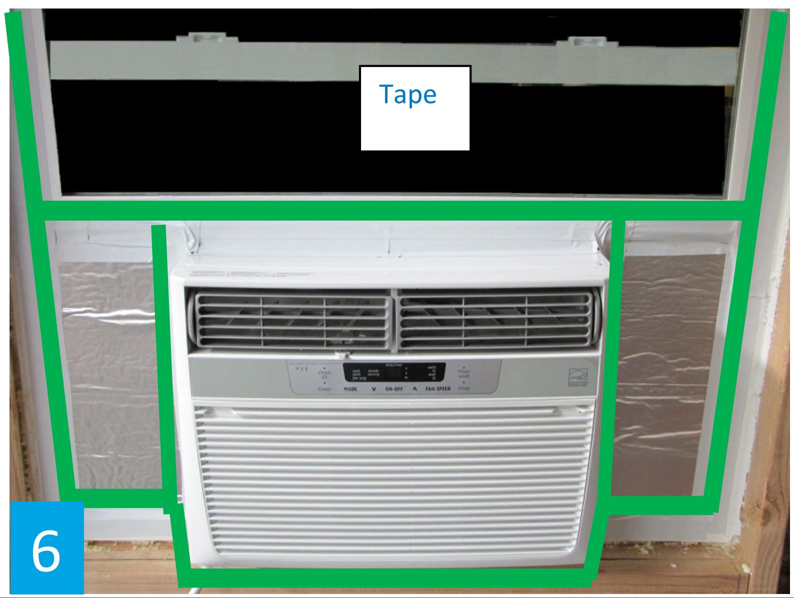
- **Most recirculation is on evaporator side**
- **20% recirculation reduces COP by ~10%**

Brand Name	Recirculation				
	Evaporator (%)			Condenser (%)	
	Low	High	Uncertainty	Typical	Uncertainty
Frigidaire	22	26	2.0	4.0	2.7
Frigidaire (ENERGY STAR)	19	20	3.5	4.0	2.7
Haier	28	22	2.8	-	3.5
GE (End-of-Life Unit)	27	24	5.1	11.2	1.3

Recommended Installation

1. **Remove unit from the window**
2. **Remove accordion panels**
3. **Replace with foam to help insulate and air seal**

Recommended Installation



4. **Use backer rod between sashes**
5. **Seal side channels as well**
6. **Tape foam, A/C and window frame to complete air sealing**

Recommended Installation

Standard

Better - Air Sealed

Best – Sealed with Diverter

Potential Low-Cost Improvements

Recommended Design Modification	Method to Achieve	Potential Performance Improvement
Reduce Installation Infiltration	• Provide better installation attachments such as closed-cell foam weather stripping, removable tape, and similar.	Infiltration reduced by up to 47 in^2 or 90 CFM_{50} (65-80%)
Reduce Air Recirculation	• Invert interior components so evaporator supply is at the bottom. • Supply an attachment fin to separate supply and return airflows.	At least 1 EER (~20%)
Reduce the Barriers to Excellent Maintenance	• Provide better air filters. • Provide air filter for condenser. • Provide a cage or grille to limit damage to condenser fins. • Provide a means to clean the refrigerant coils using a vacuum.	Up to 4 EER (towards end-of-life)
Increase Airflows	• Better fan blade design, including scalloped trailing edges.	At least 1 EER Lower noise
TOTAL IMPACT	• Save up to $30/year • Pay for unit over its life • $190M/year potential consumer savings	

Questions?

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