Better Buildings Residential Network
Peer Exchange Call Series

Right-Sizing Equipment vs. Wrong-Sizing – How Not to Waste Energy

February 9, 2023

Agenda and Ground Rules

- Moderator
  - **Jonathan Cohen,** Better Buildings Residential Network, DOE Residential Buildings Integration Program (RBI)
- Agenda Review and Ground Rules
- Residential Network Overview and Upcoming Call Schedule
- Opening Poll
- Featured Speakers
  - **Jon Winkler,** National Renewable Energy Laboratory (NREL)
  - **Shengming Zhu,** MaGrann Associates
  - **Karen Fenaughty,** FSEC, University of Central Florida
  - **Bryan Orr,** Kalos Services, HVAC School
- Open Discussion
- Closing Poll and Announcements

Ground Rules:

1. **Sales of services and commercial messages are not appropriate** during Peer Exchange Calls.
2. Calls are a safe place for discussion; **please do not attribute information to individuals** on the call.

The views expressed by speakers are their own, and do not reflect those of the Dept. of Energy.

Join the Network

Member Benefits:

- Recognition in media, social media and publications
- Speaking opportunities
- Updates on latest trends
- Voluntary member initiatives
- One-on-One brainstorming conversations

Commitment:

- Members only need to provide *one number*: their organization's number of residential energy upgrades per year, or equivalent.

Upcoming Calls (2nd & 4th Thursdays):

- *2/23: The Deep Retrofit Warranty – A Game Changer?*
- *3/9: Topic Coming Soon*

Peer Exchange Call summaries are posted on the Better Buildings website a few weeks after the call

Jon Winkler

National Renewable Energy Laboratory (NREL)

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Residential HVAC Sizing Considerations

Jon Winkler, PhD
Senior Research Engineer
Residential Buildings Research Group
National Renewable Energy Laboratory

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NREL at-a-Glance

2,926

Workforce, including

219 postdoctoral researchers

60 graduate students

81 undergraduate students

World-class

facilities, renowned technology experts

More than 900

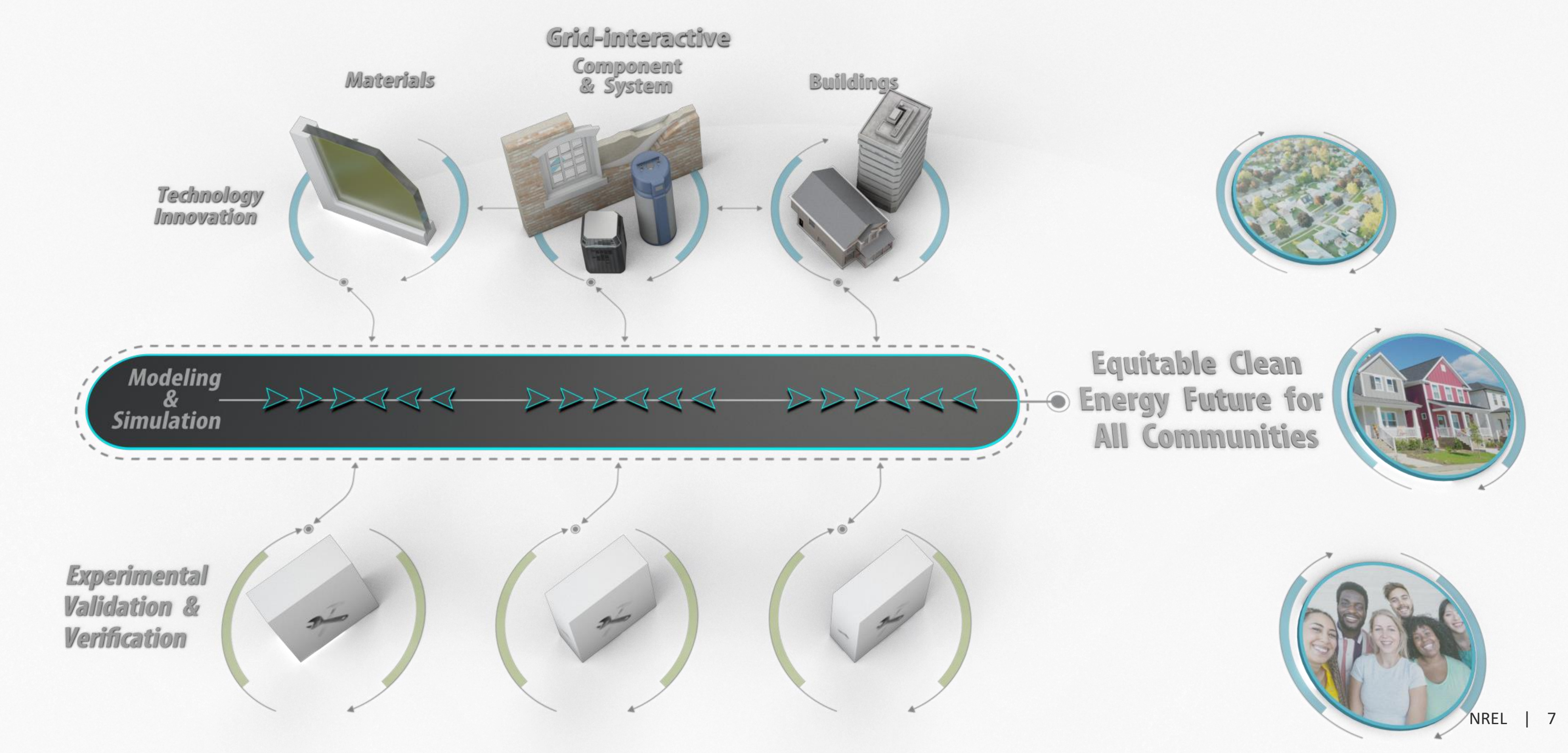
Partnerships

with industry, academia, and government

Campus

operates as a living laboratory

Our Integrated R&D Enables an Equitable and Decarbonized Energy Future

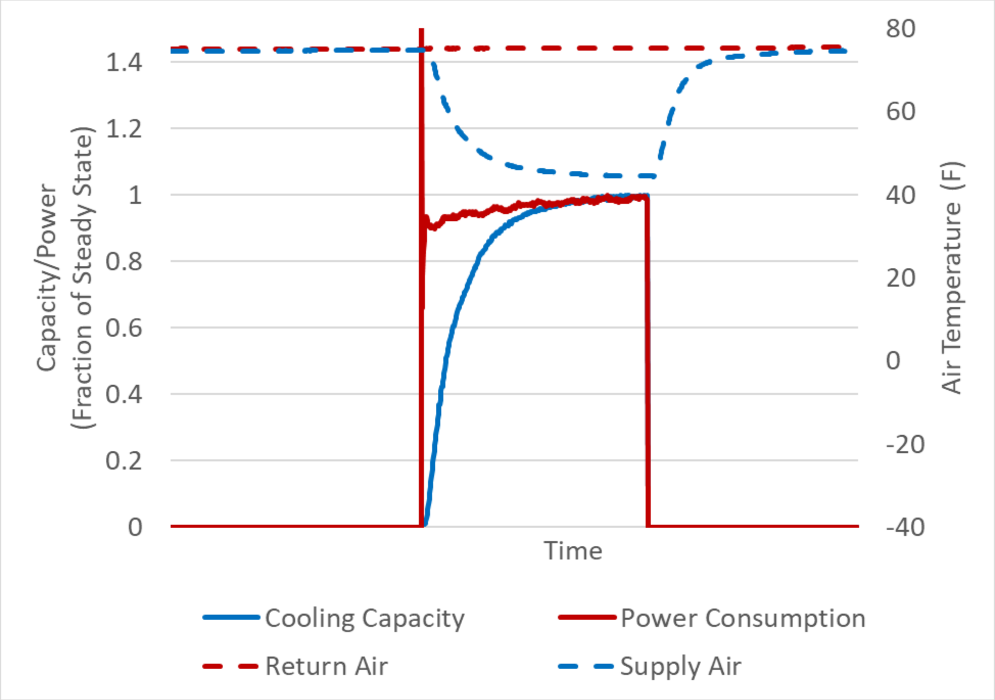


Oversizing Impacts

Oversizing Energy Penalties

- Start-up losses/cyclic degradation
- Blower power
- Duct leakage
- Parasitic power

Startup Losses

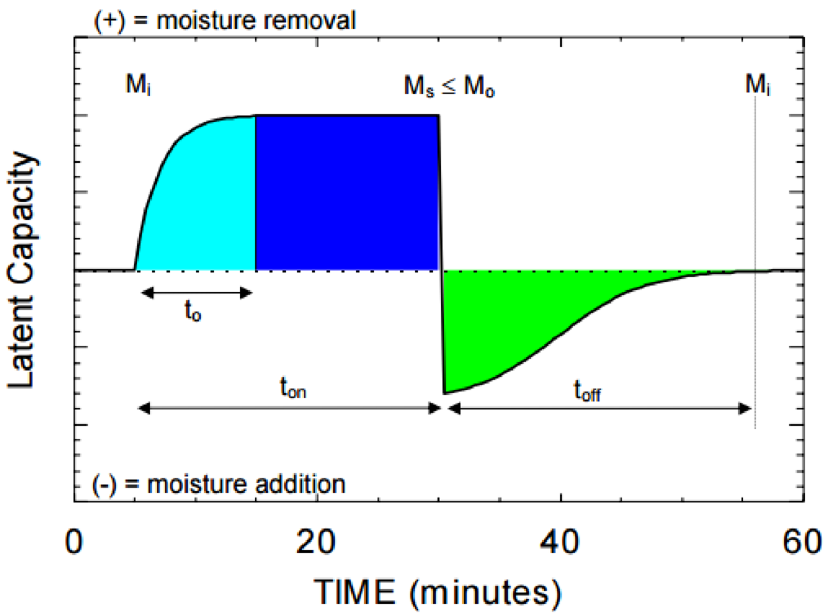


- Causes
  - Refrigerant migration
  - Material thermal mass
- Start-up losses in modern equipment are generally considered to be small [1]

[1] https://www.energy.gov/sites/prod/files/2018/06/f53/bto-ResidentialHVACLitReview-06-2018.pdf

Blower Off Delay

- Blower setting to utilize cold thermal mass of the indoor coil
  - Evaporative cooling due to condensate evaporation
- Negligible cooling energy impact (-2% to +1% change) [1]
- Fairly significant impact on indoor humidity levels [1]



Source: Shirey, D. B., III, Henderson, H. I., III, and Raustad, R. A. 2006. Understanding the Dehumidification Performance of Air-Conditioning Equipment at Part-Load Conditions. FSEC-CR-1537-05.

[1] Winkler, Jon, Jeffrey Munk, and Jason Woods. *Effect of Occupant Behavior and Air-Conditioner Controls on Humidity in Typical and High-Efficiency Homes*, 2018.

Non-Energy Benefits to Right Sizing

- Equipment/life cycle cost
- Peak demand
- Comfort
  - Temperature changes
  - Humidity control
  - Air mixing
- Noise
- Durability

Oversizing Appears Common

Residential HVAC Installation Practices: A Review of Research Findings (2018)

Table 2: Field Measured Data by Fault Type

Fault Type	Reports	States	Recommended Range[5]	% of Systems Testing Higher than Recommended Range	% of Systems Testing Lower than Recommended Range
Equipment Sizing	Appx A: 1, 2, 3, 5, 8, 12, 13, 18, 24	AZ, CA (south), FL, NJ, NV, TX, WI	33-48% oversize compared to Manual J	31-93%	0-9%

- Audited ~5,000 homes in 2009-10
- 31% of systems are oversized
- 41 MW of excess peak demand

Source: https://www.energy.gov/sites/prod/files/2018/06/f53/bto-ResidentialHVACLitReview-06-2018.pdf

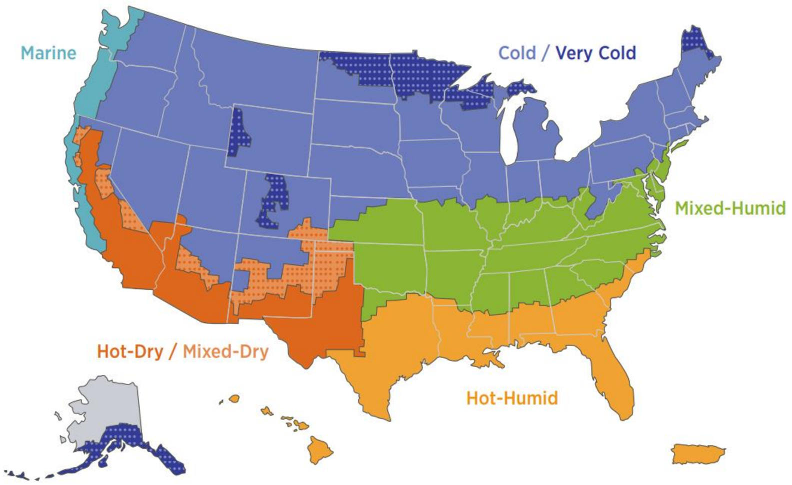
Building America Fault Prevalence Study

Field testing of 400 newly installed residential HVAC systems.

- Central ducted split systems
- Air conditioners and air source heat pumps
- Installed within the past year

Performance parameters/faults of interest:

- Indoor unit performance: airflow rate, power consumption, and static pressure
- Refrigerant charge
- Refrigerant non-condensable gases
- Duct leakage
- Control configuration
- **System sizing**



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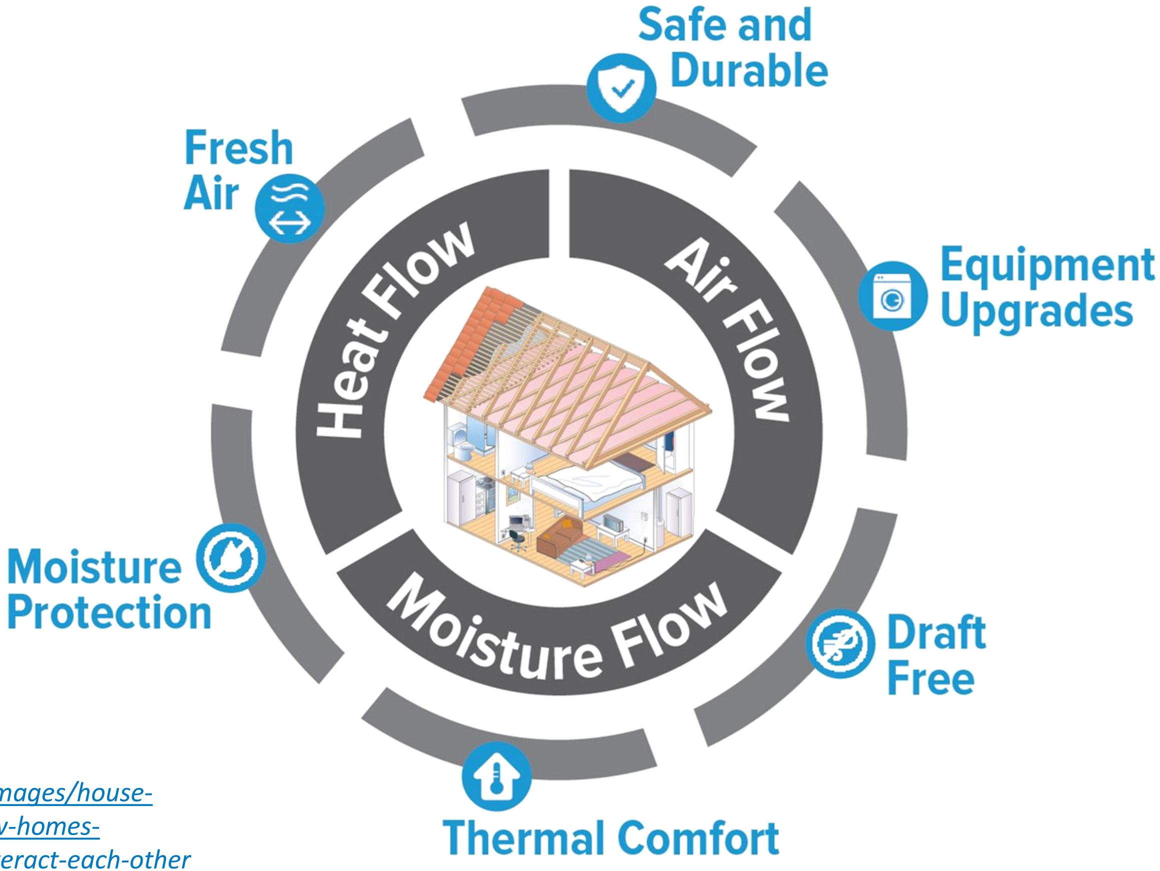
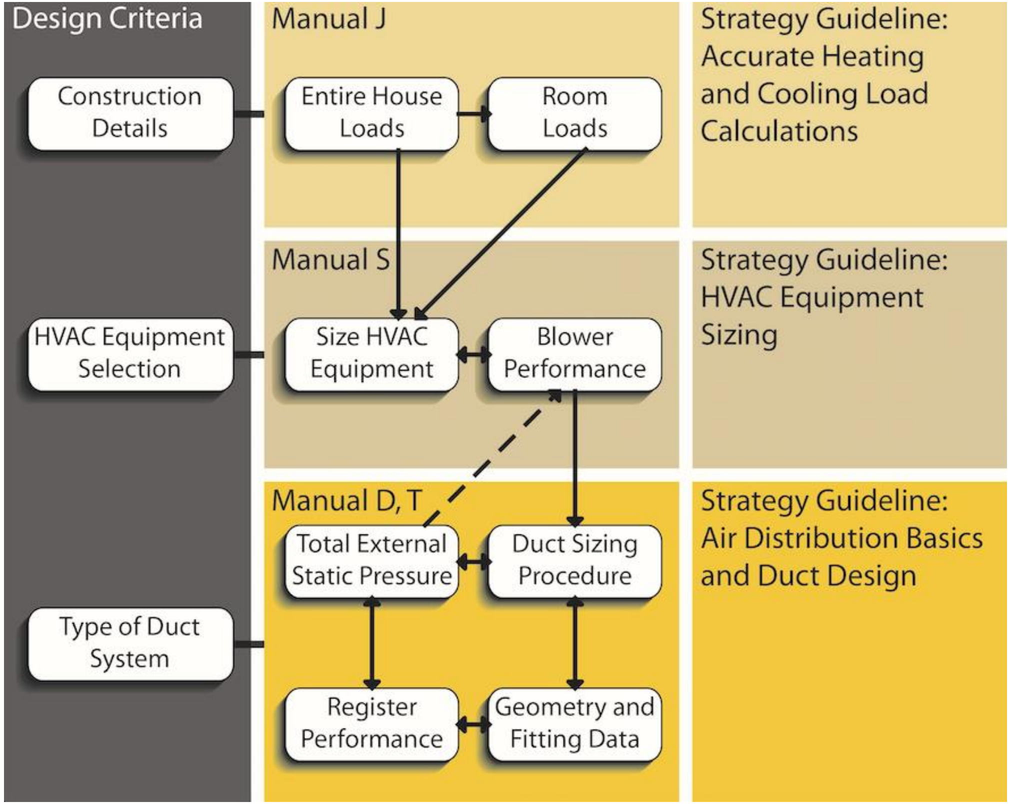
Avoiding Oversizing

House as a System



Source: *https://basc.pnnl.gov/images/house-system-approach-considers-how-homes-components-and-equipment-interact-each-other*

Residential HVAC Design Process



Source: https://www.nrel.gov/docs/fy11osti/51603.pdf

Home Sensible and Latent Cooling Loads

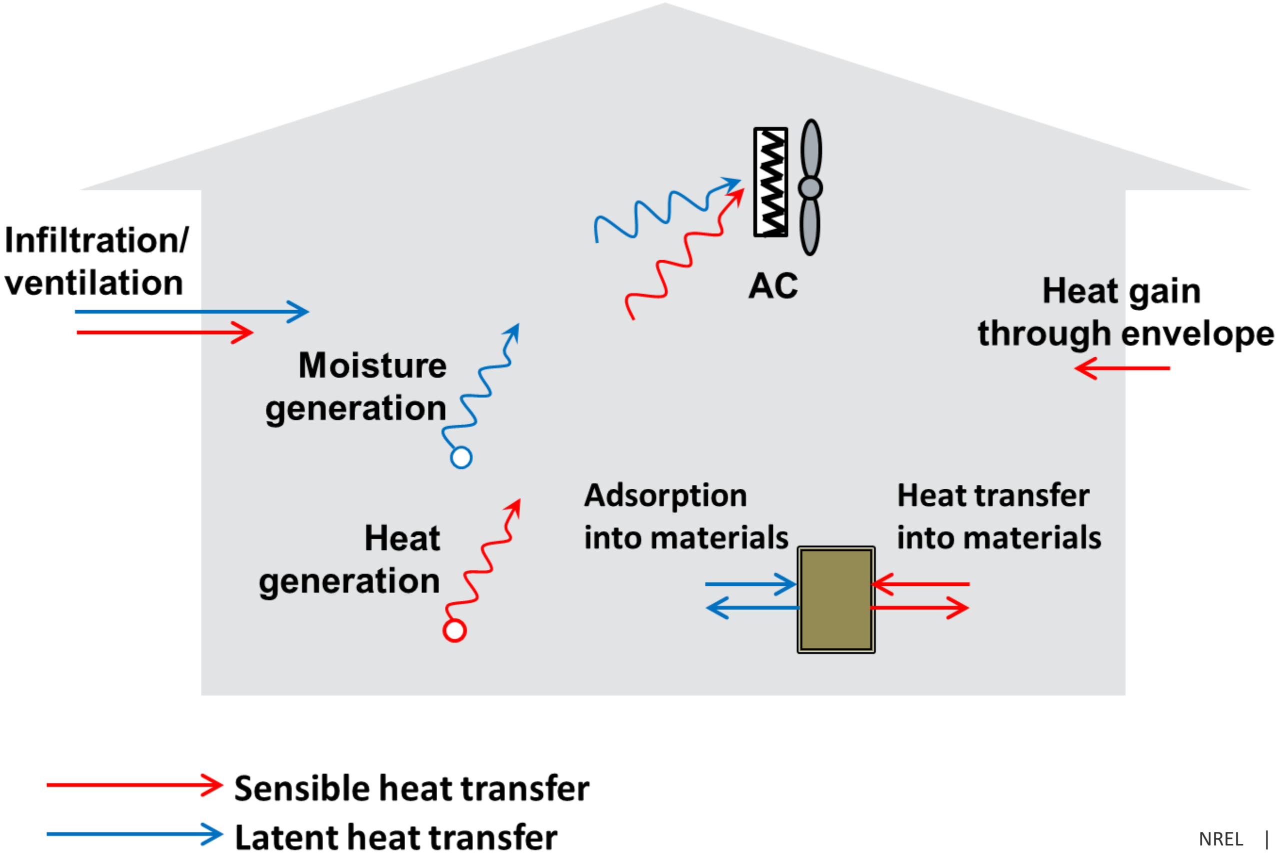
Envelope
- Window SHGC ●
- Wall/roof R-value ●

Infiltration/ventilation ● ●

Level of furnishings ● ●

Air conditioner
- Blower off delay ●
- Sizing ●
- Indoor air flow rate ●

Occupants
- Internal gains ● ●
- Window shading ●
- Cooling set point ● ●

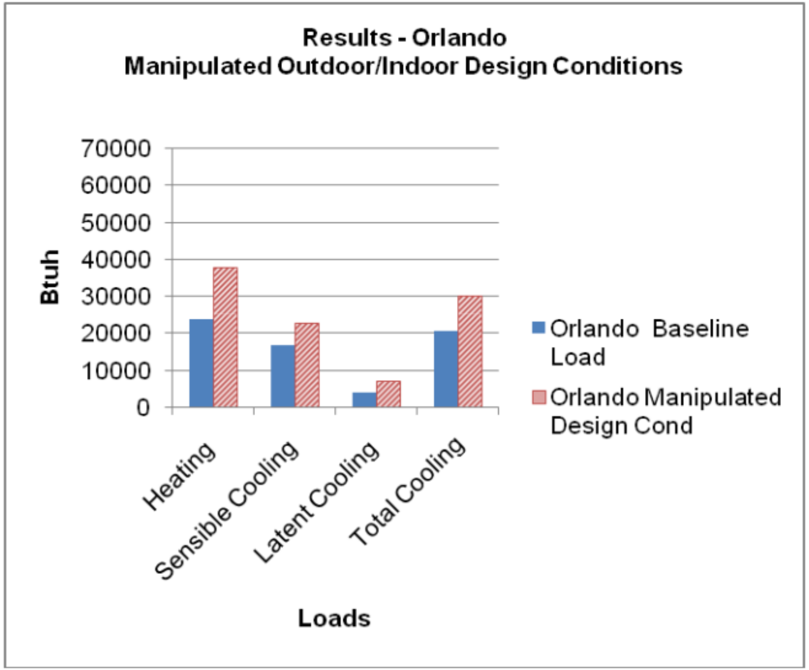


Accurate load calculations are important!

- Be cautious of simple tools or rules of thumb, such as sq. ft. per ton
- Garbage in = garbage out
- Small manipulations → Exaggerated loads

<u>ACCA Manual J on safety factors:</u>

“Manual J calculations should be aggressive, which means that the designer should take full advantage of legitimate opportunities to minimize the size of estimated loads.”



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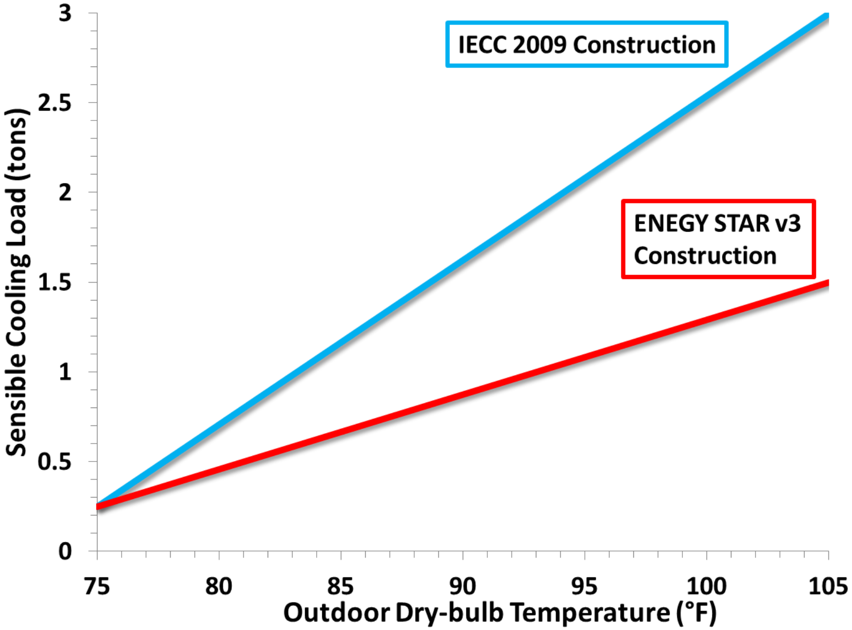
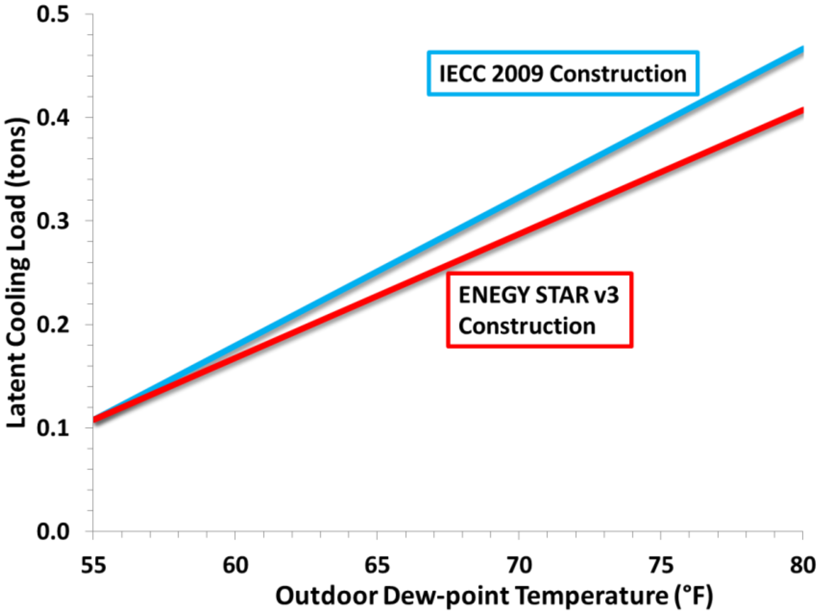
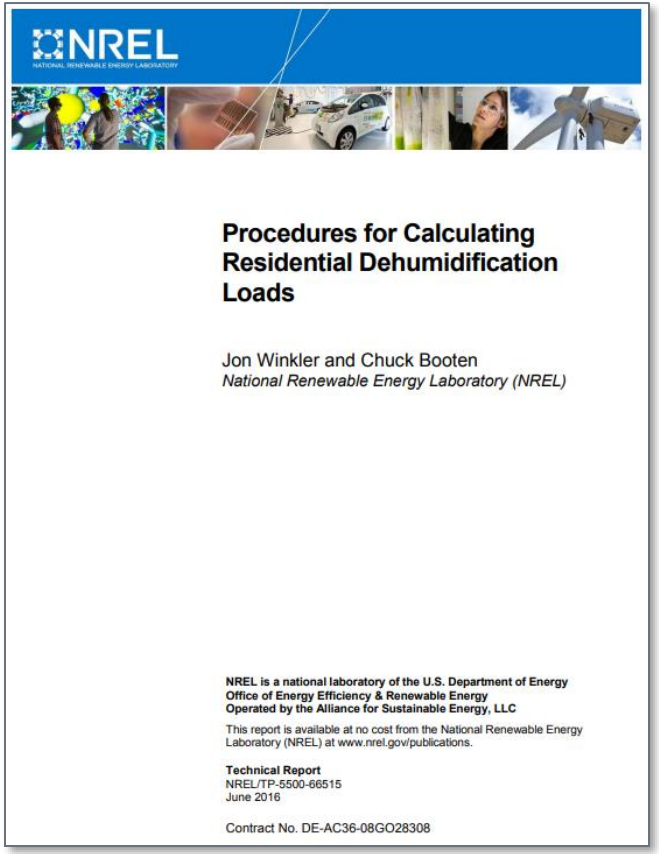
New Construction Sensible Load Ratios





Dehumidification Loads



Procedures for Calculating Residential Dehumidification Loads

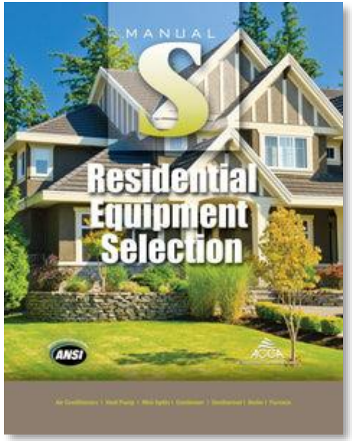
Jon Winkler and Chuck Booten
National Renewable Energy Laboratory (NREL)

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

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5500-66515
June 2016

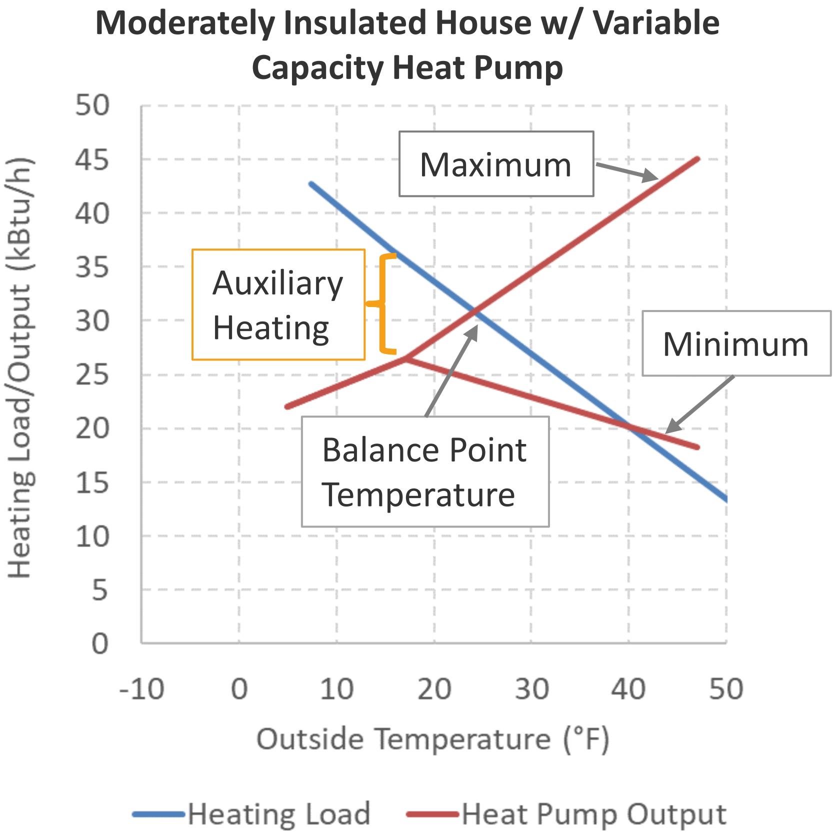
Contract No. DE-AC36-08GO28308

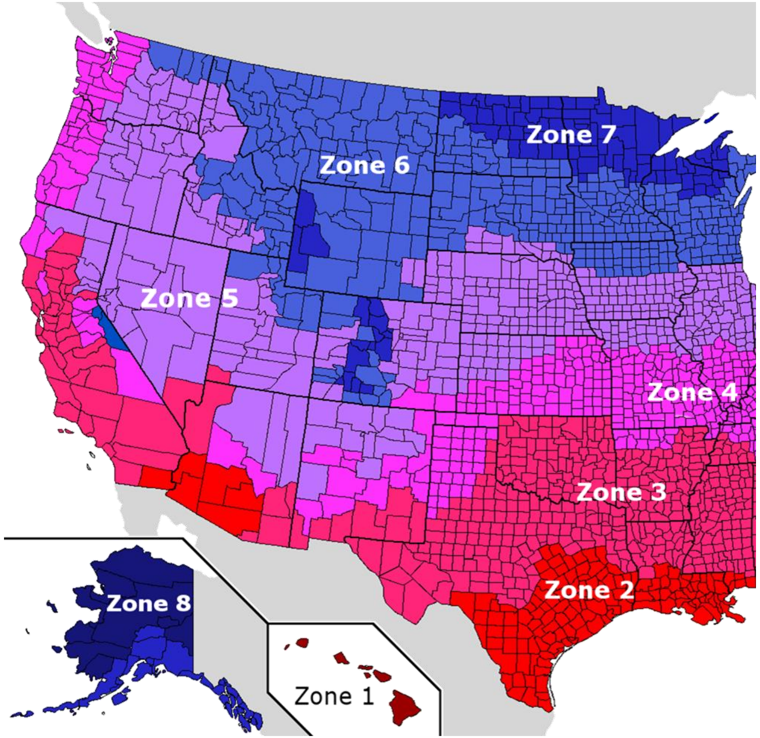


<u>ACCA Manual S:</u>

"It should be noted that NREL published an excellent white paper on the process to calculate residential dehumidifier loads. This white paper was influential in the dehumidifier sizing guidance contained ACCA's Manual for Low Load Home."

Heating Loads and Heat Pumps





Conclusion

- Proper HVAC design and equipment selection will improve comfort, reduce installation cost, improve durability, and save energy

- Important to accurately and aggressively follow standardized load calculation methods

Thanks!

www.nrel.gov

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University of Central Florida, FSEC

Maximizing the Effectiveness of Ductless Mini-Splits in Existing Homes

Shengming Zhu, MaGrann Associates
Karen Fenaughty, FSEC

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February 2023

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Centsible House

Why Integrated Controls?

- Inefficient central heating systems provide inadequate comfort.

- There is a trend to install efficient ductless ASHP to supplement legacy systems.

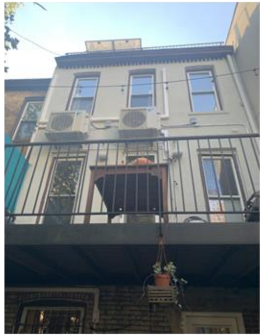
- ASHPs not reaching full potential because existing central heating systems operate more than necessary.

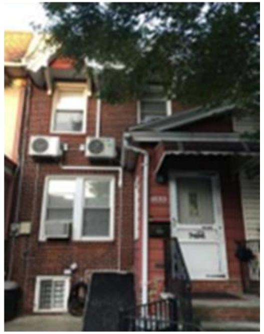
- This project investigated the potential to maximize energy savings from supplemental ASHPs by using integrated controls.

Sites

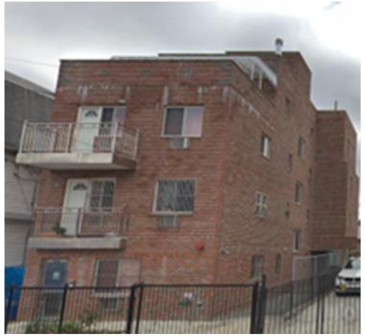
- 12 Sites
- 1-2 family buildings
- Owner-occupied, some with rental units
- Masonry attached; wood frame detached
- 5 gas sites, 7 oil sites
- Hydronic and forced-air heating







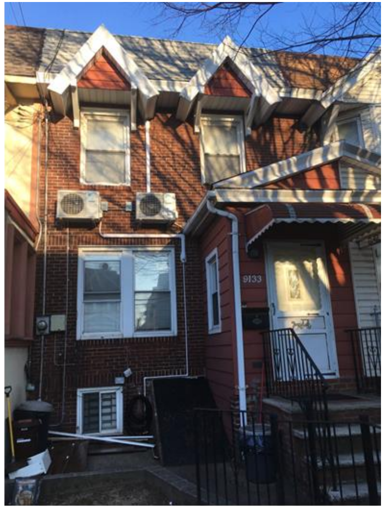


Retrofit Scope

- Low-ambient equipment (NEEP listed ccASHPs)
- Legacy heating system remains in place
- Integrated controllers
- Configure control

Heat Pump Equipment

- Mostly Daikin/Mitsubishi/Fujitsu equipment
- 1-3 condensing units
- 1-7 air handlers
- Wall mounted mini and



Integrated Control Strategies

1. Outdoor Switchover

Heat pump shuts down and central heat turns on when outdoor temperature drops below threshold (typically 23F).

2. Indoor Droop

Central system turns on when indoor temperature falls more than a preset number of degrees (known as the “droop") below the setpoint (typically 5F).

(Optional) Smart sensors enable occupancy sensing and allow control strategy to factor in rooms without heat pump indoor heads when calculating average room temperature.

Control Equipment

Resideo (Outdoor switchover + indoor droop)

- Resideo T10 thermostat + Smart sensors
- Resideo D6 wireless controller

Flair (Outdoor switchover only)

- Flair Puck Pro

Daikin (Outdoor switchover + indoor droop)

- DKN Wi-Fi adapter

Control Equipment Cost

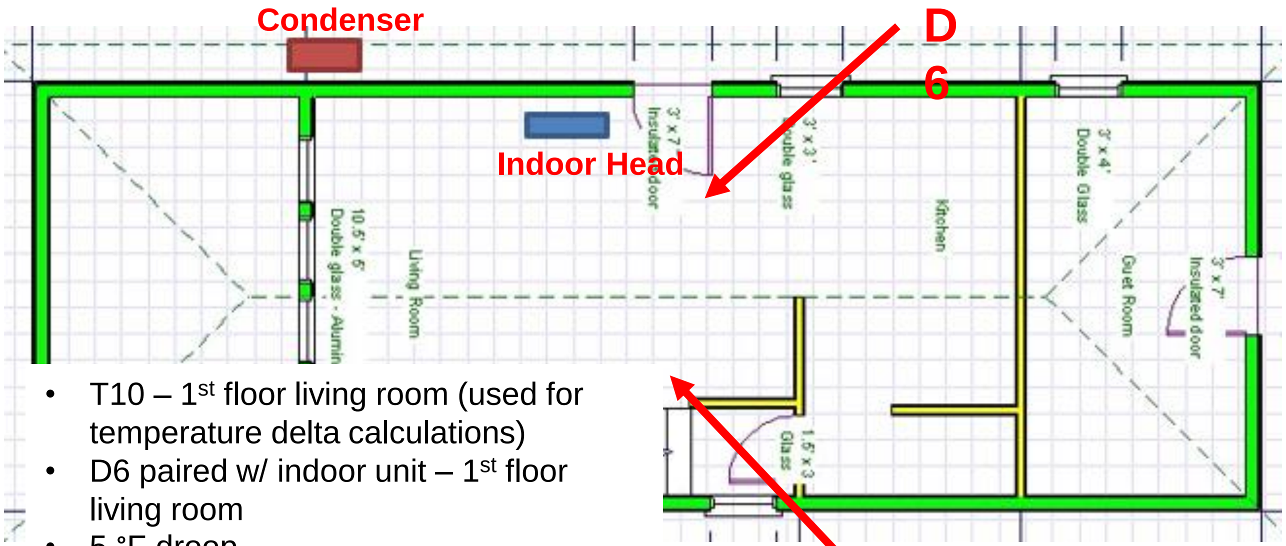
Central T-stat one per site; Averaged three Wi-Fi controllers per site

	Central T-stat		Wi-Fi Controller			
Site	Model	Unit Price	Model	Unit Price	Qty.	Total Cost
1	T10	$243	D6	$100	2	$443
2	T10	$243	D6	$100	1	$343
3	T10	$243	D6	$100	2	$443
4	T10	$243	D6	$100	1	$343
5	T10	$243	D6	$100	1	$343
6	DKN Plus	$295	DKN Wi-Fi	$260	6	$1,855
7	T10	$243	D6	$100	3	$543
8	DKN Plus	$295	DKN Wi-Fi	$260	4	$1,335
9	T10	$243	D6	$100	3	$543
10	DKN Plus	$295	DKN Wi-Fi	$260	4	$1,335
11	Honeywell	N/A (existing)	Flair Puck Pro	$129	6	$774
12	DKN Plus	$295	DKN Wi-Fi	$260	6	$1,855
Average		**$262**		**$187**	**3**	**$846**

Barriers

- **Cost:** Controllers and labor are expensive
- **Communication:** Internet connection affects the Integrated Control.
- **Compatibility:** Control product incompatible with the legacy system.
- **Service:** Software update ceased. Hard to get customer service
- **Design:** Lack of reliable products on the market.
- **Savings/Payback:** Electrification results in higher bills for space heating; the integrated control alone may or may not result in energy savings.
- **Awareness/Education:** Awareness is limited. Perceived comfort difference.

Example 1-Head Configuration (Site 4)



- T10 – 1st floor living room (used for temperature delta calculations)
- D6 paired w/ indoor unit – 1st floor living room
- 5 °F droop
- 15 °F changeover temperature
- No occupancy sensing

Research Method

- **Flip-flop design**
  - Baseline: Systems operated independently by occupant
  - Integrated Control (IC): Programmed by contractor, occupant adjust set points/schedules
- **Like-temperature range data for both periods**
- **Weather normalized to TMYx (2004-2018)**
- **Evaluated total heating energy use & electricity and fossil fuel independently**
- **Predictions**
  - Not full season: Limited to temperatures used for modeling
  - Not directly comparable from site to site

Findings: Small ASHP Installations

Site #	Compressors/Fan Heads	Change over Temp. (°F)	Temp. Range (°F)	Modeled FOSSIL FUEL Use Prediction (kBtu/range)			Modeled ELECTRICTY Use Prediction (kBtu/range)			Combined Model Savings
				Baseline	Integrated Control	Savings	Baseline	Integrated Control	Savings	
1	2/2	15	26-62	Poor statistical modeling			4,687	4,843	-3%	16%
2	1/1	15	25-68	29,437	28,438	3%	6,739	6,961	-3%	1%
3	1/2	15	24-74	48,406	40,552	16%	3,025	2,819	7%	14%
4	1/1	15	35-61	46,903	30,315	35%	Poor statistical modeling			32%
5	1/1	15	21-61	16,354	14,606	11%	4,835	3,538	27%	10%
7	1/3	15	24-50	Poor statistical modeling			6,574	5,820	11%	Poor mod

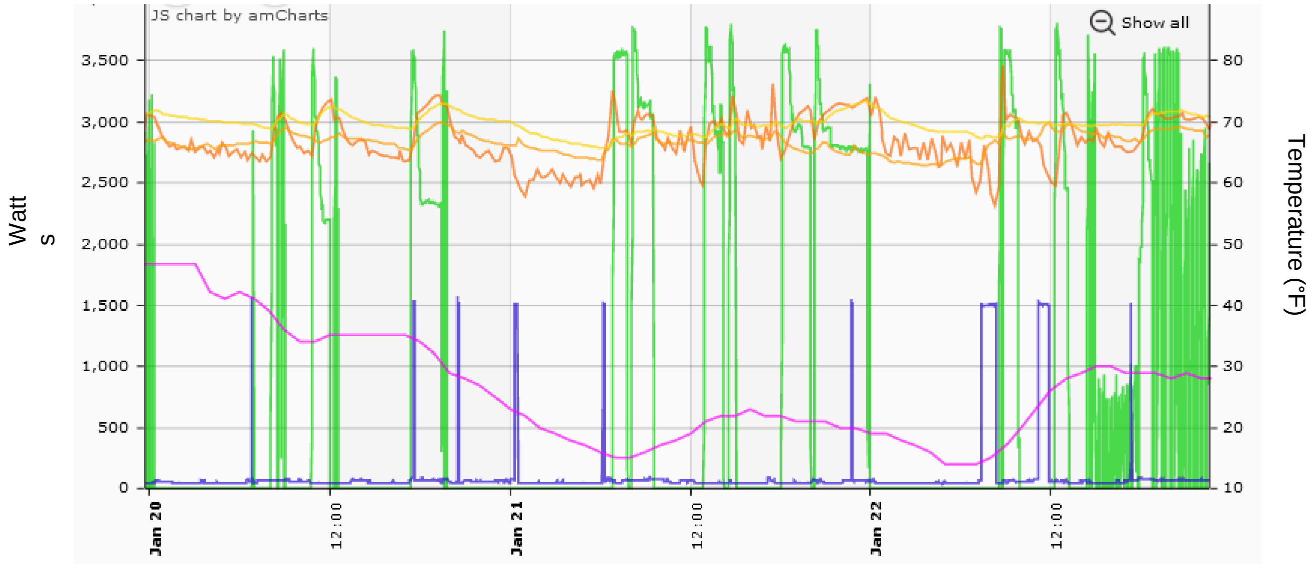
- **Fossil fuel use: +3% to +35% savings during IC**
- **Electricity use: -3% to +27% savings during IC**
  - Expected to increase, decreases during IC associated with lower indoor temperatures
- **Poor statistical gas use modeling associated with very low use**

Findings: Larger ASHP Installations

- **5 Sites with 4-7 fan coils installed**
- **4 with high outdoor changeover temperatures of 23°F**
- **Slight to moderate increase in fossil fuel use with IC**
  - Baseline conditions had no or very little gas use at 3 sites
  - IC controller appeared to trigger gas use when otherwise not used
  - Statistical evaluation hindered by few days with gas use
- **Electricity use change range 30% increase to 2% decrease during IC**
  - Notably higher interior temperatures found during IC, set point changes apparent

Site 4: Furnace Failure

Acceptable interior conditions maintained during cold front with furnace failure



Power: ASHP Supplemental Heat

Temperatures: Interior 1 Interior 2 Interior 3 Outdoor

Conclusions

Integrated control may or may not decrease fossil fuel use

- Supplemental type ASHP retrofit, IC indicated savings
  - Fossil fuel savings outweighed (or at least balanced out) increases in electricity use
- Near complete ASHP retrofit, systems already operated to greatly limit fossil fuel use
  - Often electricity use also increased during IC, but with increased interior temperature
- Outdoor changeover should be carefully selected according to climate

Caveats

- **New ASHP installations with occupants adjusting to newness**
- **Case-study in nature**
  - Temperature ranges evaluated, not entire winters
  - Some very short flip/flop periods only
  - ASHP vary in efficiency and cold climate performance
- **Unrelated changes in interior conditions obscured findings**
- **Colder weather data not always available for both conditions: limited ASHP/legacy switchover observations**

Thank You!

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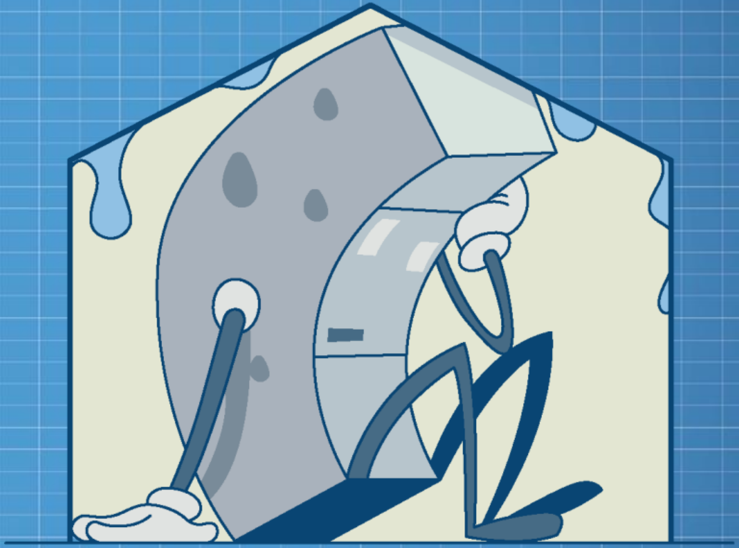
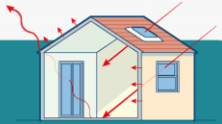
Right-Sizing Equipment vs. Wrong-Sizing

How Not to Waste Energy



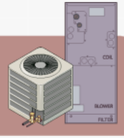
Manual J & Manual S Basics

MANUAL J



- **Load calculation based on the heat gains and losses in a structure**
- **Consists of:**
  - Heating & cooling BTUs (Gains & Losses)
  - Sensible & Latent Heat
- **Contractors must consider:**
  - Building envelope/duct leakage
  - Insulation
  - Shade
  - Ventilation
- Only as useful as the information we put into it and the assumptions we make

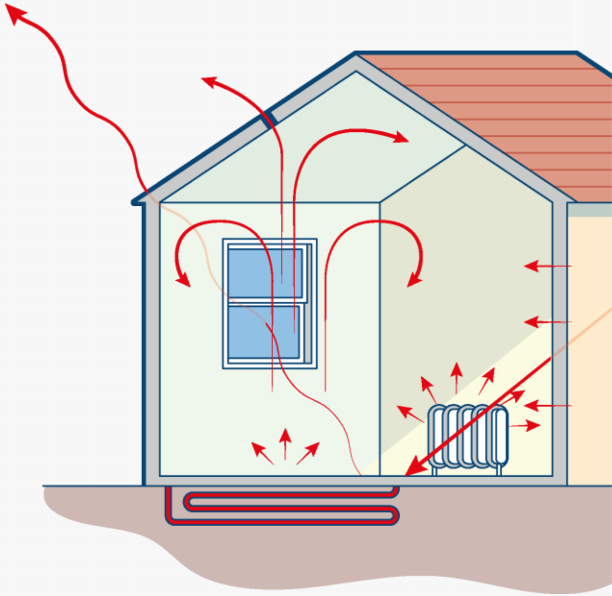
MANUAL S



- **Equipment selection based on Manual J load calculations**
- **Undersized equipment:** may fail to heat or cool properly
- **Oversized equipment:** may fail to handle latent heat loads properly

Undercooling & Overcooling

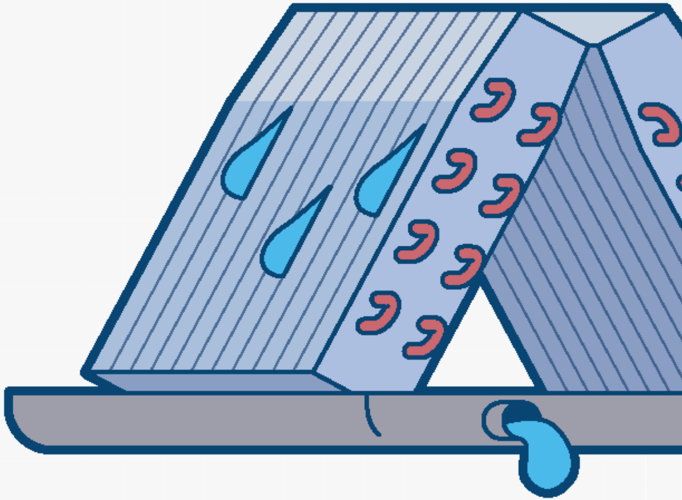
- **Indoor-to-outdoor delta T**
  - BTU losses and gains become greater the greater the delta
- **Conduction - Heat enters/leaves via direct contact**
  - Walls
  - Floors
  - Insulation
- **Convection - Heat enters/leaves via a fluid**
  - Open windows
  - Open doors
  - Cracks
- **Radiation - Heat enters/leaves via electromagnetic waves**
  - Passing through glass windows
  - Radiant Losses / Gains Occur "Line of Sight"



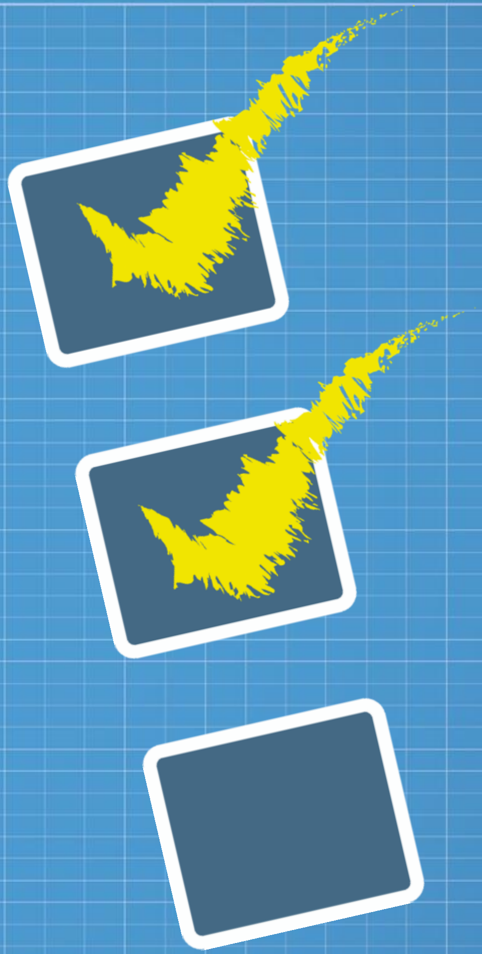
Bring the Load to the Equipment

Short-Cycling

- **Oversizing equipment decreases runtime**
- **Straight-cool and heat pump cooling mode**
  - It takes a while for the evaporator to get down to temperature
    - Short-cycling prevents it from reaching the dew point
    - Decreased dehumidification
    - Wear and tear due to many start and stops
- **Heat pump heating mode**
  - It is difficult in some climates to size a unit properly for heating without drastically oversizing for cooling. Electric heat is highly electrically inefficient.

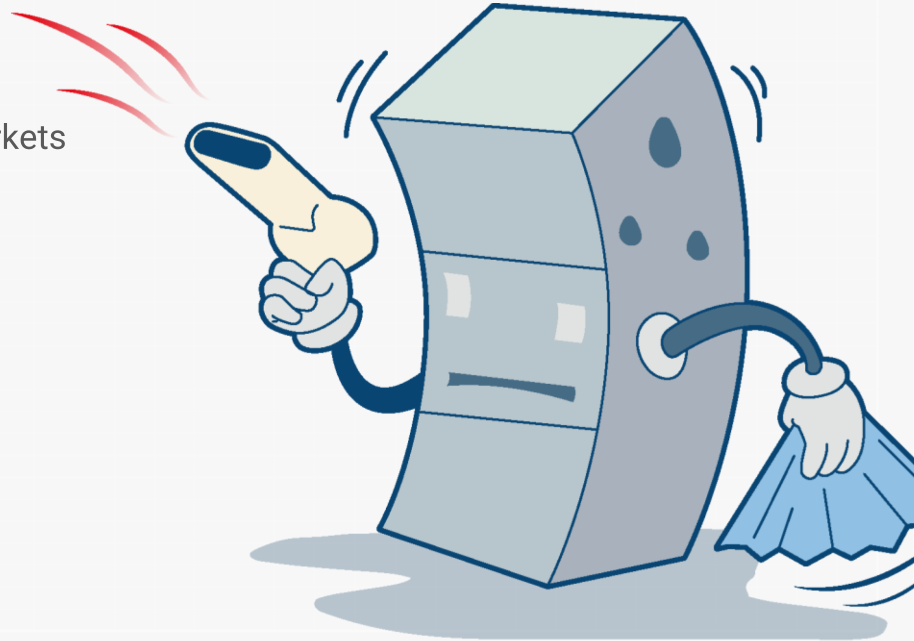


Challenges



Different Heating & Cooling Markets

- **Heating loads**
  - High during the winter in northern markets
  - Low to none in some southern markets
- **Cooling loads**
  - High and exist year round in some southern markets
  - Highly volatile during the summer in some northern markets
- **Latent loads**
  - High in Southeast and other “green grass” markets
  - Low in Southwest and at high elevations



Sensible Heat Ratio (SHR)

- **High SEER, high SHR**
  - High-efficiency units, especially ductless, have high SHR
  - Excellent for removing sensible heat, not great at removing latent heat
- **Lower SEER, better dehumidification**
  - Longer runtimes with colder evaporator coils are “less efficient” but remove more latent heat
- **Cost concerns**
  - Lower efficiency = higher power bills
  - Lower-SEER operation modes are **necessary** in humid climates

Unreasonable Expectations

- **Clients think that feeling uncomfortable = undersized unit**
  - Clients often mistakenly think a bigger unit will make them feel cooler
  - They often don't understand the negative consequences of upsizing equipment

- **Contractors have no power or protection in these situations**
  - Contractors often end up with negative feedback and even legal actions because clients won't accept reasonable temperature setpoints swings during extreme weather conditions.
  - Oversizing to solve a comfort complaint usually leads to more comfort complaints

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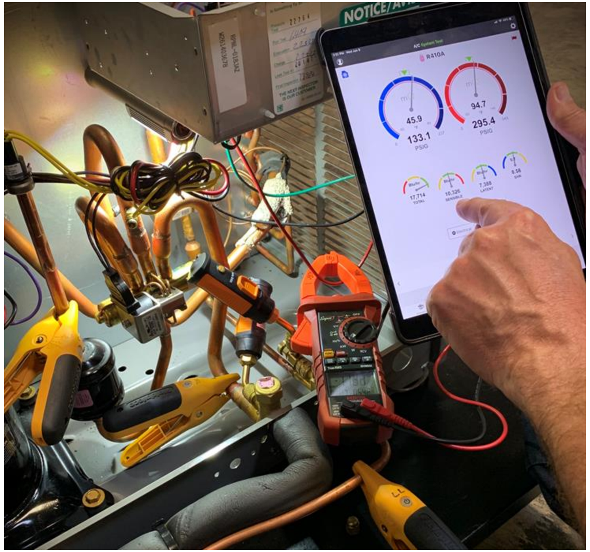
Heat Pumps, an Asterisk, and a Solution

Q: How do we decarbonize residential heating loads?

A: Heat Pumps*

*Improper installations reduce system performance, resulting in energy waste and comfort issues:

- One or more energy-wasting HVAC fault in 70–90% of homes[1]
- Estimated 9% residential HVAC energy waste nationally due to installation faults in CAC/ASHP[2]



Solution: Smart diagnostic tools help ensure heat pumps are installed properly, resulting in realized energy-efficiency and reduced energy waste.

1. EERE, 2019. Residential HVAC Installation Practices: A Review of Research Findings
2. Winkler et al. 2020. Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage. Applied Energy, Volume 278

Smart Tools for Efficient HVAC Performance (STEP) Campaign

Scan this QR code to visit our website

Contact: christian.valoria@pnnl.gov

The STEP Campaign aims to increase adoption of smart diagnostic tools to streamline HVAC system performance testing and troubleshooting, reducing energy-wasting faults and improving occupant comfort.

To join the STEP Campaign, visit: bit.ly/3DFmEaE

HVAC Contractors and Technicians

- Reduce callbacks, improve consistency and quality, streamline processes
- Find out where to get training on smart diagnostic tools
- Be recognized for successful adoption of smart diagnostic tools!

Utilities and Program Implementers

- Streamline quality installation and quality maintenance programs
- Improve engagement with your contractors
- Be recognized for programs that utilize smart diagnostic tools!

HVAC Training Organizations

- Offer qualified training on System Performance with smart diagnostic tools
- Promote your training events
- Be recognized for providing training!

Weatherization Organizations

- Ensure your ASHP/CAC installations are operating at optimized efficiency
- Develop pilot with PNNL team
- Be recognized!

ORGANIZING PARTNERS

Storm Window and Insulating Panel (SWIP) Campaign

Scan this QR code to visit our website

Contact: christian.materia@pnnl.gov

Residential Storm Window and Insulating Panel Virtual Summit
March 9, 2023 (3-5pm EST)

Gain insights from utilities and weatherization organizations that have included cost-effective and energy-rated storm windows and insulating panels in their programs.

Register for the SWIP Summit:
http://bit.ly/3Y1WQOb

Buildings UP

The Buildings Upgrade Prize

AMERICAN MADE
U.S. DEPARTMENT OF ENERGY

Building capacity to transform U.S. buildings into energy-efficient and clean energy-ready homes, commercial spaces, and communities

Upgrading existing buildings to efficiently run on clean energy will help address climate change. This means transitioning **residential and commercial buildings** to efficient electric equipment, such as **heat pumps and heat pump water heaters**, and ensuring comfort with measures such as **insulation and air sealing**.

Teams participating in **Buildings UP** will develop innovative plans to leverage the billions of dollars through the Bipartisan Infrastructure Law, the Inflation Reduction Act, utility rebate programs, and many other funding sources available and capitalize on this unprecedented opportunity to improve our homes, businesses, and communities.

Buildings UP will award more than **$22 million** in cash prizes and expert technical assistance to bring winning ideas to life.

www.heroX.com/buildingsUP

Form Your Team and Submit Your Application by July 2023!

- Community-based organizations
- Local governments
- Utilities
- Non-profit organizations
- For-profit energy efficiency companies
- and more!

Multi-stakeholder teams are encouraged

Application support available for new and under-resourced teams

Follow Buildings UP on HeroX for prize info and updates

Questions: buildingsUP@nrel.gov

Explore the Residential Program Guide

Resources to help improve your program and reach energy efficiency targets:

- Handbooks - explain *why* and *how* to implement specific stages of a program.
- Quick Answers - provide answers and resources for common questions.
- Proven Practices posts - include lessons learned, examples, and helpful tips from successful programs.
- Technology Solutions NEW! - present resources on advanced technologies, **HVAC** & **Heat Pump Water Heaters**, including installation guidance, marketing strategies, & potential savings.
- Health + Home Performance Infographic NEW! – spark homeowner conversations.

https://rpsc.energy.gov

Health + Home Performance Infographic

DOE's new Health + Home Performance Infographic reveals the link between efficiency and health – something everyone cares about. Efficiency programs and contractors can use the question-and-answer format to discover a homeowner's needs.

The infographic is ideal for the "kitchen table" conversations where people decide what to do – and who they want to do it. It also has links for homeowners to find a qualified contractor if they do not already have one.

Download this infographic from DOE's Better Buildings Residential Network.

Looking for photos to help tell your energy efficiency story? Visit our image libraries: https://www.energy.gov/eere/better-buildings-residential-network/articles/image-libraries

Thank You!

Follow us to plug into the latest Better Buildings news and updates!

Better Buildings Twitter with #BBResNet

Better Buildings LinkedIn

Office of Energy Efficiency and Renewable Energy Facebook

Please send any follow-up questions or future call topic ideas to:
bbresidentialnetwork@ee.doe.gov