U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Low-Load Space-Conditioning Needs Assessment

Srikanth Puttagunta
Consortium for Advanced Residential Buildings

May 2015

Building America
U.S. Department of Energy

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Low-Load Space-Conditioning Needs Assessment

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

Golden, CO 80401

NREL Contract No. DE-AC36-08GO28308

Prepared by:

Srikanth Puttagunta

Steven Winter Associates, Inc.

of the

Consortium for Advanced Residential Buildings (CARB)

61 Washington Street

Norwalk, CT 06854

NREL Technical Monitor: Stacey Rothgeb

Prepared under Subcontract No. KNDJ-0-40342-05

May 2015

The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

Contents

List of Figures

Unless otherwise noted, all figures were created by CARB.

List of Tables

This table was created by CARB.

Definitions

AHU	Air Handler Unit
ASHP	Air-Source Heat Pump
CARB	Consortium for Advanced Residential Buildings
ERV	Energy Recovery Ventilator
HRV	Heat Recovery Ventilator
HVAC	Heating, Ventilating, and Air Conditioning
kBtu/h	1,000 British Thermal Units per Hour
SWA	Steven Winter Associates, Inc.

Executive Summary

Heating, ventilating, and air-conditioning (HVAC) equipment must be right-sized to ensure energy performance and comfort. With limited low-load options in the HVAC market, many new-construction housing units are being fitted with oversized equipment that creates system efficiency, comfort, and cost penalties. To bridge the gap between currently available HVAC equipment that is oversized or inefficient and the rising demand for low-load HVAC equipment in the marketplace, HVAC equipment manufacturers need to be fully aware of the needs of the multifamily building and attached single-family (duplex and townhouse) home market. Over the past decade, Steven Winter Associates, Inc. (SWA) has provided certification and consulting services for hundreds of housing projects and has accrued a large pool of data that describe multifamily and attached single-family home characteristics. The U.S. Department of Energy's Building America research team Consortium for Advanced Residential Buildings (CARB) compiled and analyzed these data to outline the characteristics of low-load dwellings such as the heating and cooling design loads.

Design loads and the full complement of desired building characteristics were available for 941 dwellings from SWA's recent work on multifamily and attached single-family homes across the Northeast and Mid-Atlantic regions. Information about dwelling characteristics, design loads, and the specifications for installed mechanical equipment was analyzed to determine trends for typical design heating and cooling loads and to identify specification needs for new low-load HVAC equipment. These trends were investigated through simple regressions for quantitative variables and box plots and frequency analyses for qualitative variables.

Of the 941 dwellings, CARB found that only 1% had right-sized heating equipment and 6% had right-sized cooling equipment (within 25% or less of design load). In all these analyses the magnitudes of the heating and cooling design loads for low-load dwellings are becoming increasingly similar even in the cold climate region. More than 75% of the heating and cooling design loads for multifamily apartments in the data set were lower than 12 kBtu/h. For the attached single-family homes, more than 75% of the heating design loads were 25 kBtu/h or lower; the cooling design loads were similar to those in the multifamily apartments. No statistically significant trends could be determined for the quantitative physical characteristics such as floor area, volume, enclosure area, and exposed enclosure area. Even so, some trends could be inferred. The best correlations were for heating loads with respect to dwelling volume and enclosure area.

With currently available technologies, CARB has successfully used an all-electric approach that uses inverter-driven air-source heat pumps and heat recovery ventilators or energy recovery ventilators. With this approach, a whole-house ventilation system can be configured to also serve as an internal distribution system for point-source or minimally distributed space-conditioning systems. Still, more low-load HVAC options are necessary to provide more flexibility to builders and designers. A low-load HVAC specification has been outlined for equipment manufacturers based on the findings of this research and SWA's HVAC consulting experience. The intent is to provide a roadmap for developing more appropriate HVAC equipment for low-load dwellings.

1 Introduction

Steven Winter Associates, Inc. (SWA) frequently recommends efficient in-unit space-conditioning systems for dwellings with modest space-conditioning loads. The typical systems in residential construction are: (1) furnace with split air conditioner; (2) heat pump; (3) combined (combi) hot water system (hydro-air) with split air conditioner; and (4) packaged terminal air conditioner. These are typically not ideal solutions because

- Furnaces are often too large.
- Heat pumps switch to electric resistance heat when outside conditions are the coldest (though new technologies are addressing this issue—but at a price).
- Combi systems have been demonstrated to be less efficient because they have high return water temperatures from the hydro-coil (Schoenbauer et al. 2012).
- Packaged terminal air conditioners are inefficient.

These heating, ventilating, and air-conditioning (HVAC) options are not appropriate for low-load dwellings because of overcapacity and performance issues. Still, the market need for appropriate solutions at these lower loads is growing. So why haven't HVAC manufacturers addressed this market?

A common definition for a "low-load" home is one in which the design heating and cooling loads do not exceed 10 Btu/h-ft^2 of conditioned floor area. At this rate a 1,200-ft^2 dwelling would have a design heating load of 12 kBtu/h and a 2,000-ft^2 dwelling would have a design heating load of 20 kBtu/h. The smallest furnaces typically available have capacities of 38 or 57 kBtu/h. When considering the market of low-load dwellings, the first thought might be to consider a newly constructed and highly efficient single-family home such as a zero energy ready home. In this market niche, too few houses fall into this category for any HVAC manufacturer to consider investing research and development time and money toward effective solutions to these specific mechanical system needs (heating, cooling, and ventilation). The low-load single-family market may grow over time (because of codes or for other reasons); however, the multifamily market need for low-load space-conditioning solutions is immediate and the market is substantial.

At 33.5 million housing units (according to the 2010 Census data), multifamily dwellings comprise 25% of the total U.S. housing stock. Figure 1 represents multifamily buildings as a percentage of total residential units across the United States. This figure shows that areas densely populated with multifamily housing are scattered throughout the nation. Multifamily housing also accounted for 35% of all new housing starts midway through 2014 (Conerly 2014). New construction starts demonstrate a particular area where low-load HVAC will be in high demand because these buildings are likely to meet or exceed the stringent International Energy Conservation Code efficiency requirements. The market increasingly desires air conditioning and owners increasingly desire occupants to be directly responsible for their energy bills; thus, the multifamily housing market has shifted to decentralized mechanical systems. An already large multifamily housing stock is being updated as equipment approaches the end of its serviceable life and the new-construction rate is accelerating; therefore, the multifamily building construction market needs low-load HVAC systems that are tailored to its requirements.

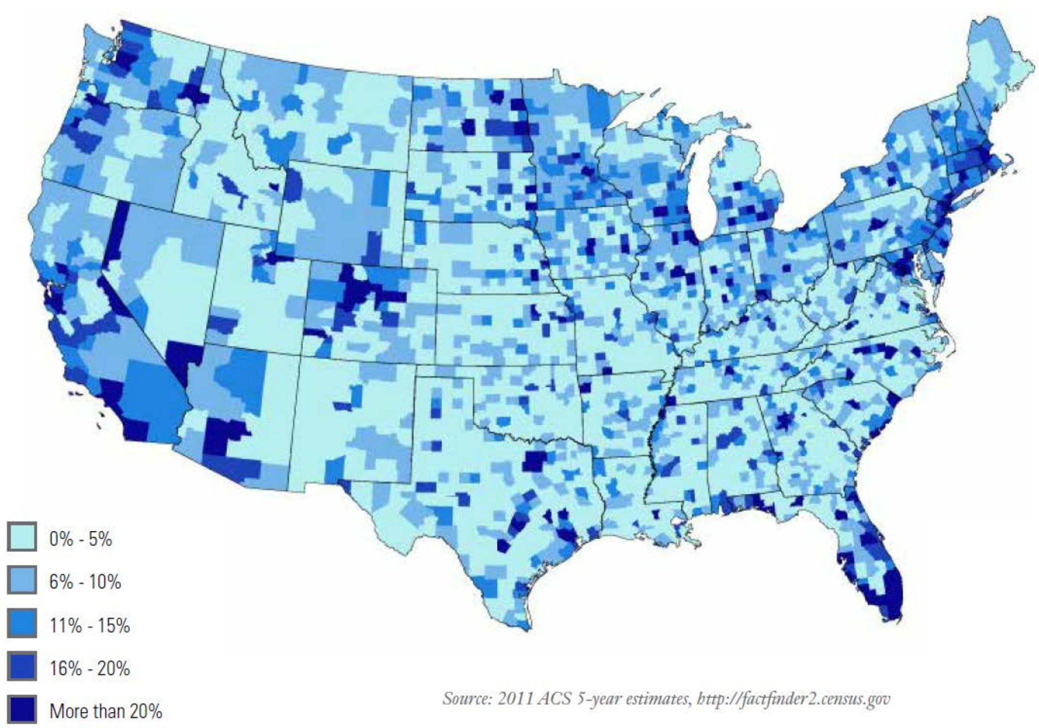


Figure 1. Percentage of multifamily properties (five or more units) across the United States

Initial conversations with HVAC equipment manufacturers indicate that (1) desired equipment specifications for low-load equipment are unknown and (2) the market demand is uncertain because oversized products are being used. To better characterize the low-load HVAC market, an extensive data set of 941 dwellings from SWA's certified projects over the past decade were compiled and analyzed. This work was conducted by researchers who sought to summarize which space-conditioning systems are currently being used, provide initial characterization of low-load housing unit needs, and determine sizing requirements for a new generation of low-load space-conditioning equipment.

1.1 Background

HVAC equipment must be right-sized to ensure energy performance and comfort. Given the currently available options on the HVAC market, many new-construction housing units are being fitted with oversized equipment that creates system efficiency, comfort, and cost penalties. Table 1 shows typical minimum capacities for several equipment types. These system options are in line with Lstiburek (2006). This report discusses methods of providing compartmentalized HVAC systems in multifamily apartments. Some have variable-capacity options that allow for a turndown ratio of up to 3:1, but these systems are premium-priced products and the ductwork still needs to be sized for full capacity, which takes up valuable real estate in small dwellings.

Figure 2 displays design loads from one of SWA's ongoing multifamily projects. The load magnitude shows that most of the HVAC equipment in these low-load dwellings would be oversized (especially on the cooling side, which has a high latent-to-sensible heat ratio requirement) when the smallest available capacity equipment on the market is used.

Table 1. Minimum Available Capacity of Various Space-Conditioning Technologies

HVAC Equipment	Typical Minimum Heating Capacity (Btu/h)	Typical Minimum Cooling Capacity (Btu/h)
Air Conditioner	–	18,000
Air-Source Heat Pump (ASHP)	16,000	18,000
Mini-Split Heat Pump	9,000	8,500
Through-Wall Heating/Cooling	36,000	12,000
Central Furnace	38,000	–
Boiler	50,000	–
Packaged Terminal Air Conditioner or Heat Pump	7,000	7,000

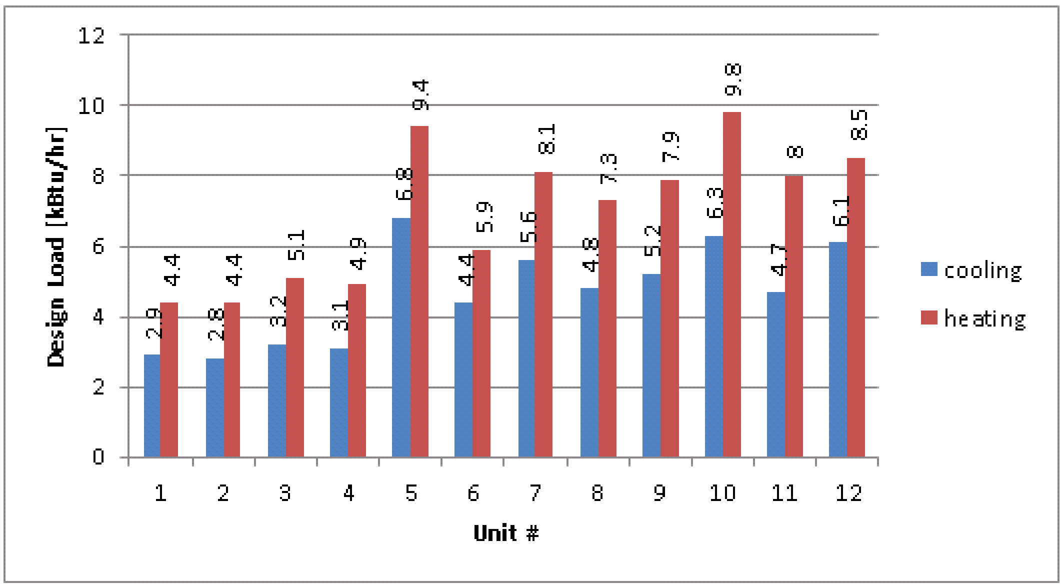


Figure 2. Heating and cooling design loads for a recently constructed 12-unit code-compliant apartment building in New York State

Building America teams and others have performed research on currently available HVAC systems used on low-load homes; however, the Consortium for Advanced Residential Building (CARB) is unaware of any published research that quantifies typical heating and cooling loads of various multifamily apartment types. Pacific Northwest National Laboratory is currently researching this topic but with a greater focus on attached single-family low-load homes (Brown et al. 2013).

1.2 Impact

Low-load HVAC equipment has economic advantages at the time of initial equipment purchase because its capital and annual operating costs are lower. Smaller capacity equipment should reduce operating costs. The distribution ductwork can also be downsized, which allows for easier integration into floor plans. This downsizing has cost benefits in installation materials and labor; some additional value may accrue in terms of market appeal (potential for higher ceilings, fewer soffits, smaller mechanical rooms, etc.).

Although short-cycling may not adversely affect sensible heating and cooling, its effects on moisture removal can be detrimental with respect to comfort and condensation risks. In low-load housing units these risks can be significant because latent loads are typically derived from internal sources and are not substantially reduced by energy-efficiency measures. From an energy-conservation standpoint short cycling can reduce the operating efficiency of HVAC equipment. These adverse effects can be easily avoided by correctly sizing the equipment at the time of installation. However, with currently available market options, this is not always possible.

1.3 Research Questions

To successfully implement low-load HVAC equipment into the multifamily marketplace, equipment manufacturers need reliable information about market demand, building size, HVAC equipment, and space-conditioning loads. At least one HVAC equipment manufacturer has expressed concern about the lack of available information on market potential and low-load space-conditioning data for multifamily buildings. This research effort was aimed at answering the following questions:

- What are typical design heating and cooling loads in a variety of multifamily and low-load dwellings in the Northeast and Mid-Atlantic?
- What are the ideal specifications for low-load HVAC that account for different housing types, fuel types, and components in the cold and mixed-humid climate zones?

2 Technical Approach

To bridge the gap between currently available HVAC equipment—which is oversized or inefficient—and the rising demand for low-load HVAC equipment in the marketplace, HVAC equipment manufacturers need to be fully aware of the needs of the multifamily building and attached single-family home market. Over the past decade, SWA has provided certification and consulting services for hundreds of housing projects and has accrued a large pool of low-load dwelling data. CARB compiled and analyzed these data to understand the building load ranges in various multifamily apartments and attached single-family home types and to assess the HVAC equipment that is currently being specified for these low-load dwellings. Figure 3 provides the geographic locations of the projects included in this database.

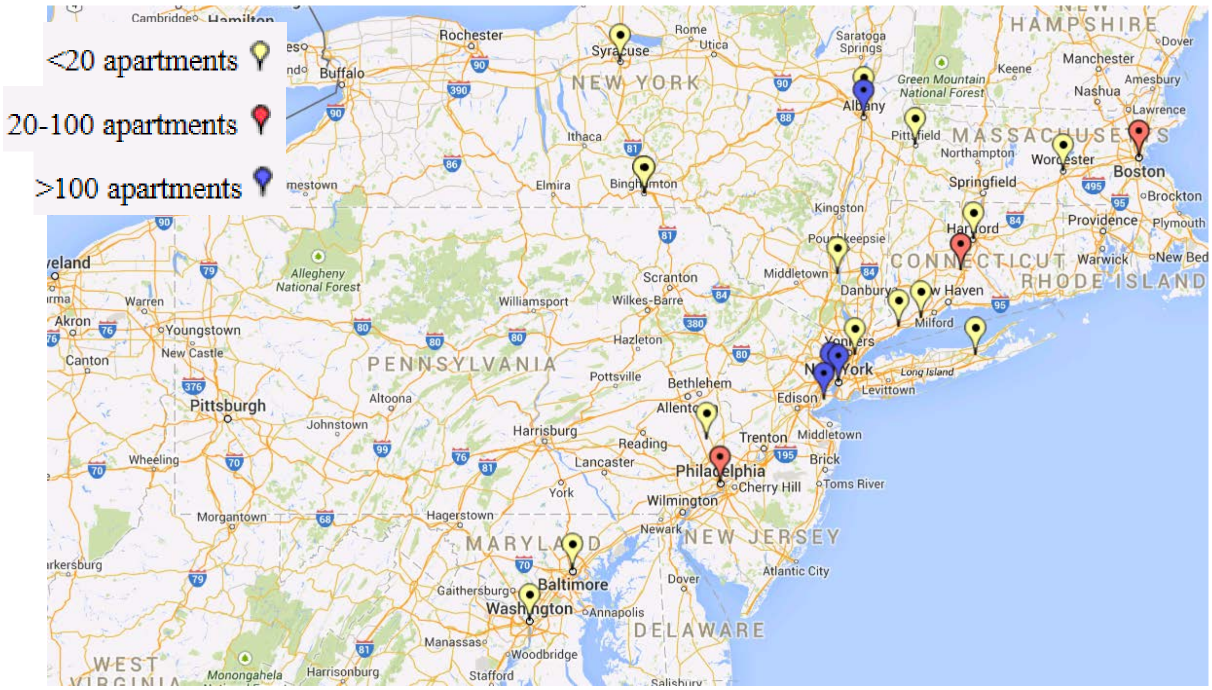


Figure 3. Geographic locations of projects in CARB's low-load HVAC database

CARB's database of low-load projects includes the following information:

- Dwelling unit characteristics:
    - Location
    - Year built
    - Apartment type (low-rise, midrise, high-rise, garden, etc.)
    - Apartment location (first floor, middle floor, top floor)
    - Apartment position (interior unit, exterior unit)
    - Number of bedrooms and baths
    - Square footage

  - Volume
  - Total and exposed enclosure area
  - Window-to-wall ratio
  - Construction type (masonry, wood, steel, etc.)
  - Unguarded blower door results (CFM50, CFM50/ft^2 of enclosure area, ACH50)
  - Insulation performance levels (R-value)
  - Glazing performance levels (U-value, solar heat gain coefficient)
  - Design heating and cooling load from REM/Rate
- Installed whole-house HVAC equipment make, model, efficiency, and capacity.

Information about the apartment building characteristics, design load, and specifications of installed mechanical equipment was analyzed to determine any trends in the data set. These trends were investigated through simple regressions between quantitative variables and box plots and frequency analyses for qualitative variables. The slopes of the regressions quantify the validity of the trends. The box plots and frequency analyses provide a pictorial understanding of the relationship between the qualitative building characteristics and numerical items such as design load or equipment capacity range.

3 Results

In total, design loads and the full complement of desired building characteristics were available for 941 dwellings from SWA's recent multifamily and attached single-family work across the Northeast and Mid-Atlantic. REM/Rate energy modeling software was used to determine design heating and cooling loads. Although the software is not an approved Air Conditioning Contractors of America Manual J software tool, it provides a usable estimate of loads. The installed capacity was documented in field inspection notes and the REM/Rate equipment inputs.

Figure 4 provides the results of comparing the heating design load to the equipment capacity. All data points would be on the red line if design loads perfectly matched equipment capacity. Data points above the red line indicate oversized equipment and data points below the red line indicate undersized equipment (no data points appear under the red line). The typical heating design loads for these dwellings was typically 20 kBtu/h or lower, but most equipment capacity was 20 kBtu/h or higher. The average installed heating capacity for heat pumps, furnaces, and boilers was 20 kBtu/h, 44 kBtu/h, and 84 kBtu/h, respectively. The fact that the boilers were the highest capacity equipment is reasonable because these units typically provide space heating and hot water. Add-on hydro-coils to air handler units (AHU) are typically oversized and not configured (delivered water set point, controls, etc.) to have a sufficient temperature drop across the coil to allow condensing operation with higher performance boilers.

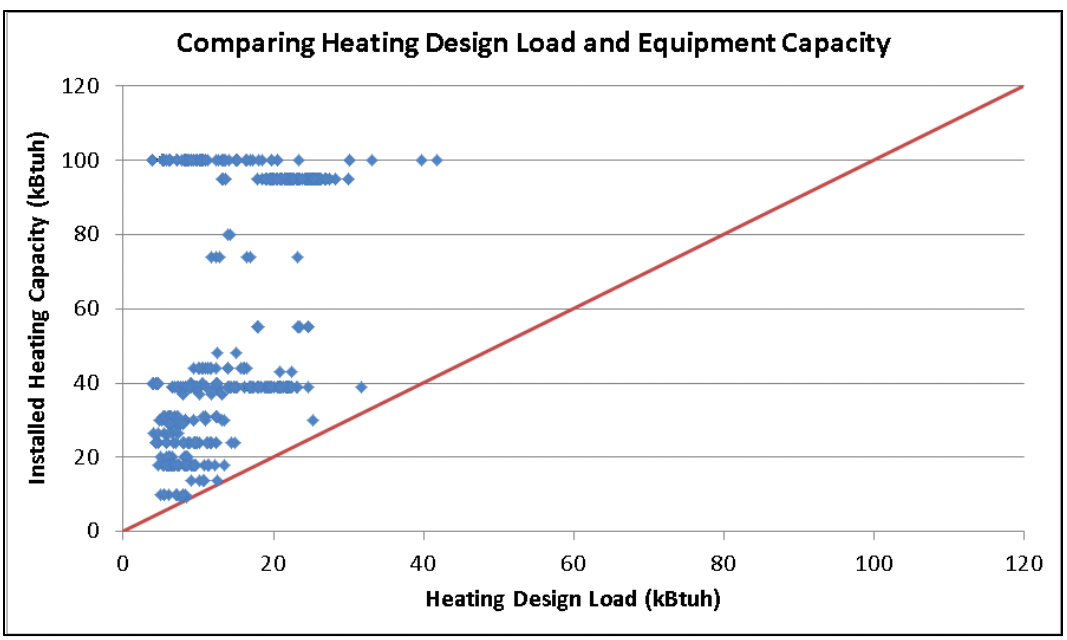


Figure 4. Comparing heating design load versus equipment capacity

In SWA's database, 507 of the dwellings included cooling systems (Figure 5). The average installed cooling capacity for air conditioners and heat pumps was 20 kBtu/h and 16 kBtu/h, respectively. Most units were air conditioners that had 1.5- to 2-ton (18- to 24-kBtu/h) capacities because these are the smallest available size for central units depending on the product line and pairings with the heating system. This market limitation resulted in most of these units being oversized by at least 100% (especially in low-load dwellings, which have a high latent-to-sensible heat ratio requirement). The dwellings with installed cooling capacity of about 9 kBtu/h used through-wall air conditioners. These matched the cooling loads more closely but were inefficient.

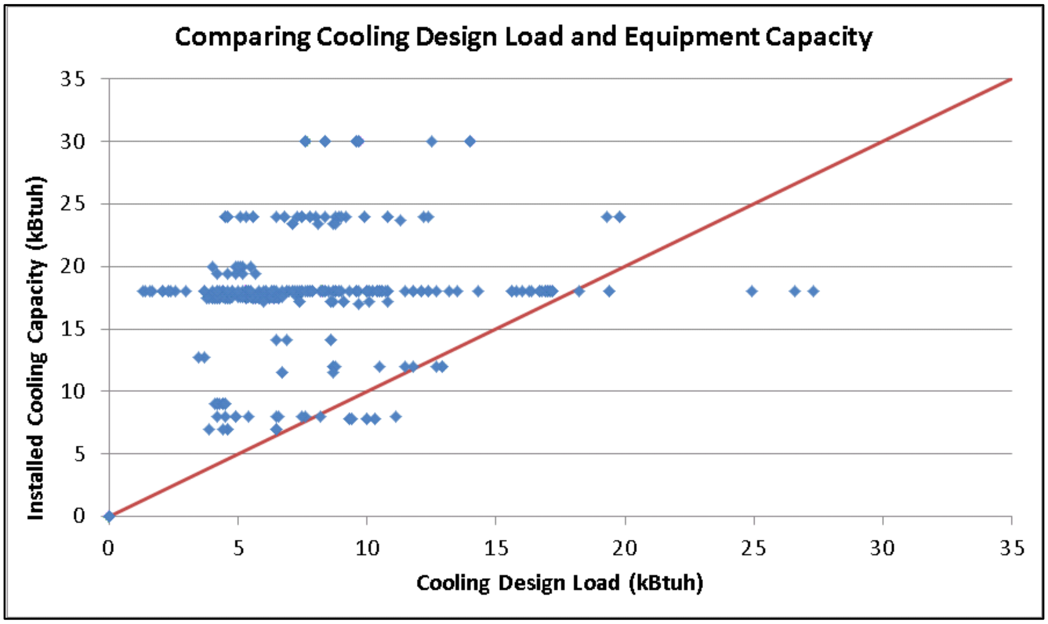


Figure 5. Comparing cooling design load versus equipment capacity

In addition to the cooling data from SWA's database, data for 203 Florida apartments consisting of nine unique floor plans were provided by the Building America Partnership for Improved Residential Construction (see Figure 6). Similar oversizing results of at least 100% were found for these low-load dwellings.

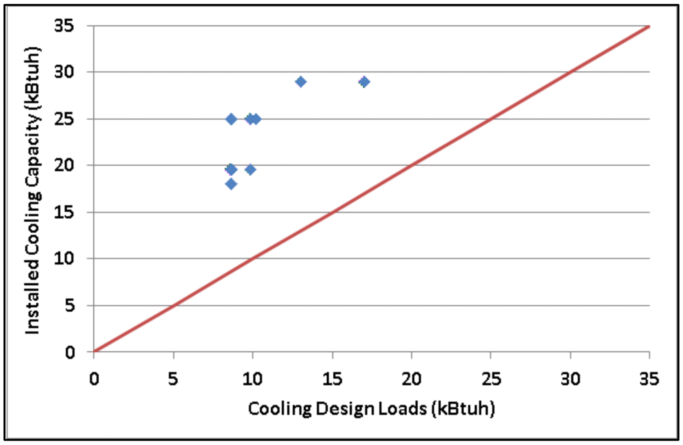


Figure 6. Comparing cooling design load versus equipment capacity for Florida data set

3.1 Dwelling Design Loads Based on Physical Characteristics

In an attempt to estimate design loads based on quantitative physical characteristics of the various dwellings, the research team compared heating and cooling design loads to floor area (Figure 7), volume (Figure 8), enclosure area (Figure 9), and exposed enclosure area (Figure 10). HVAC manufacturers indicated that they are not seeking regionally specific data, so the analyses were done on the entire data set in an attempt to determine broad trends. Although general trends can be inferred, the R^2 (interpreted as the proportion of the variance in y attributable to the variance in x) for the trend lines is poor (particularly on the cooling side). This is likely because the data set covers three climate zones (4A, 5A, and 6A) and the construction code requirements vary. Comparing design loads to the exposed enclosure area showed the least correlation of the four characteristics evaluated. This indicates that builders are effectively addressing exterior thermal and air barrier issues that are being pushed by more stringent codes and certification programs but are still not effectively compartmentalizing the dwellings. The best correlations were for heating design loads with respect to dwelling volume and enclosure area.

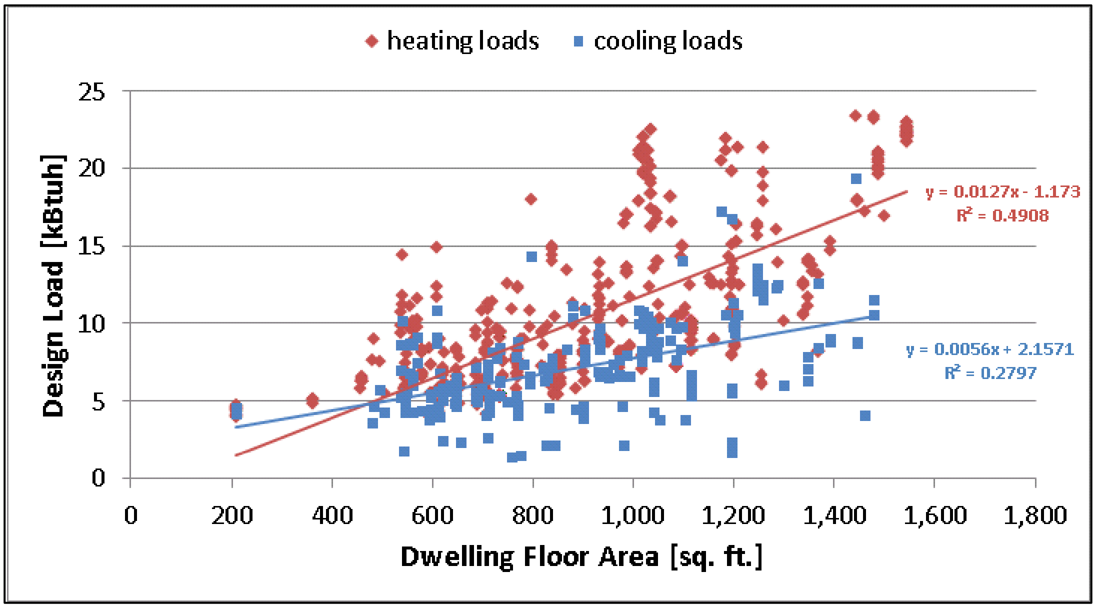


Figure 7. Comparing floor area versus design load

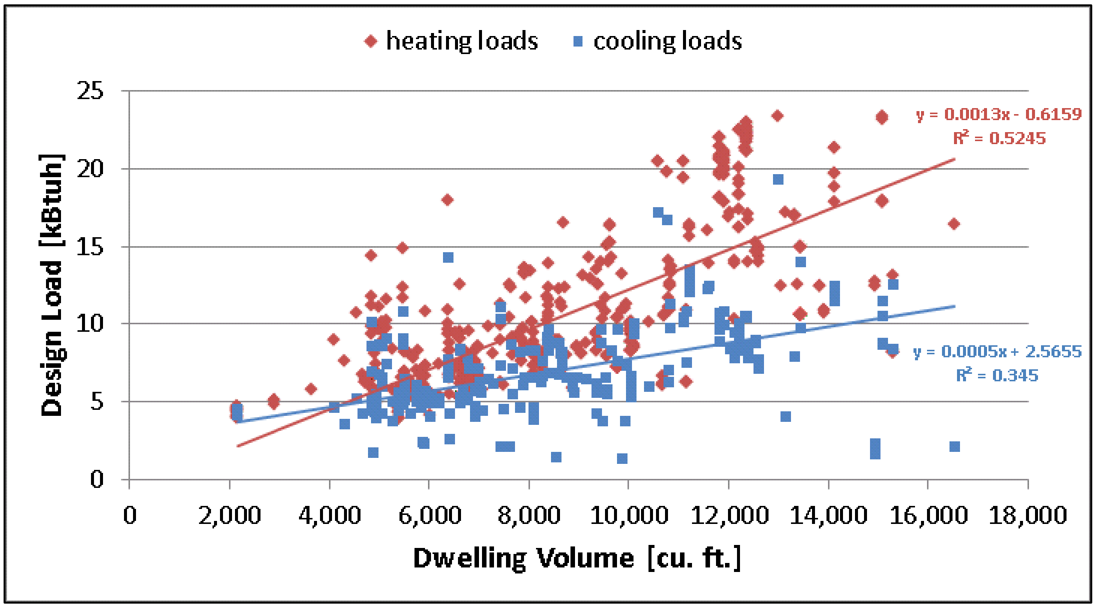


Figure 8. Comparing volume versus design load

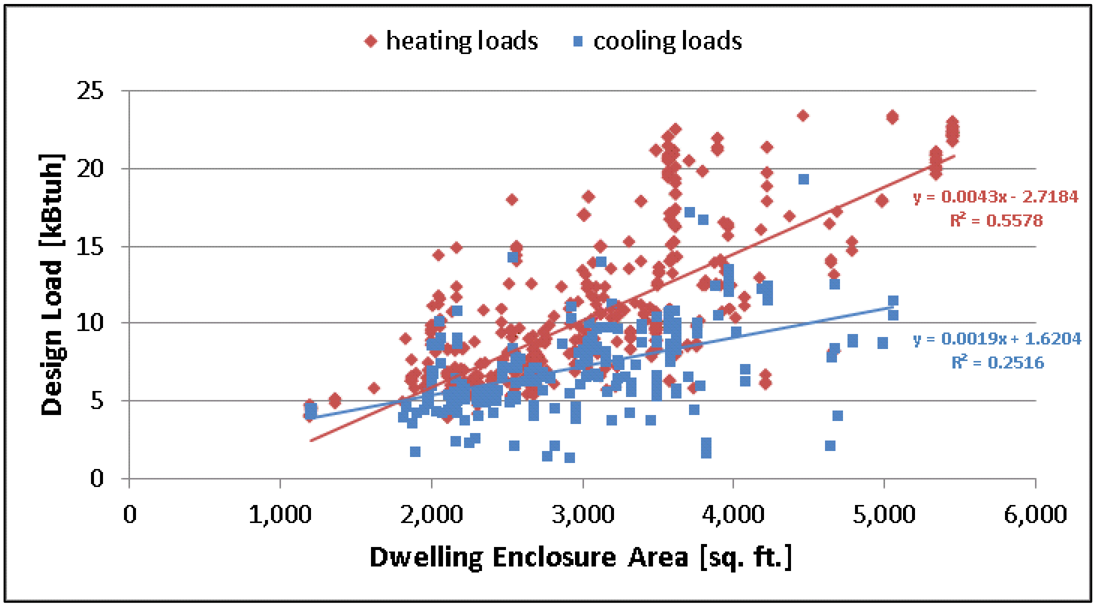


Figure 9. Comparing enclosure area versus design load

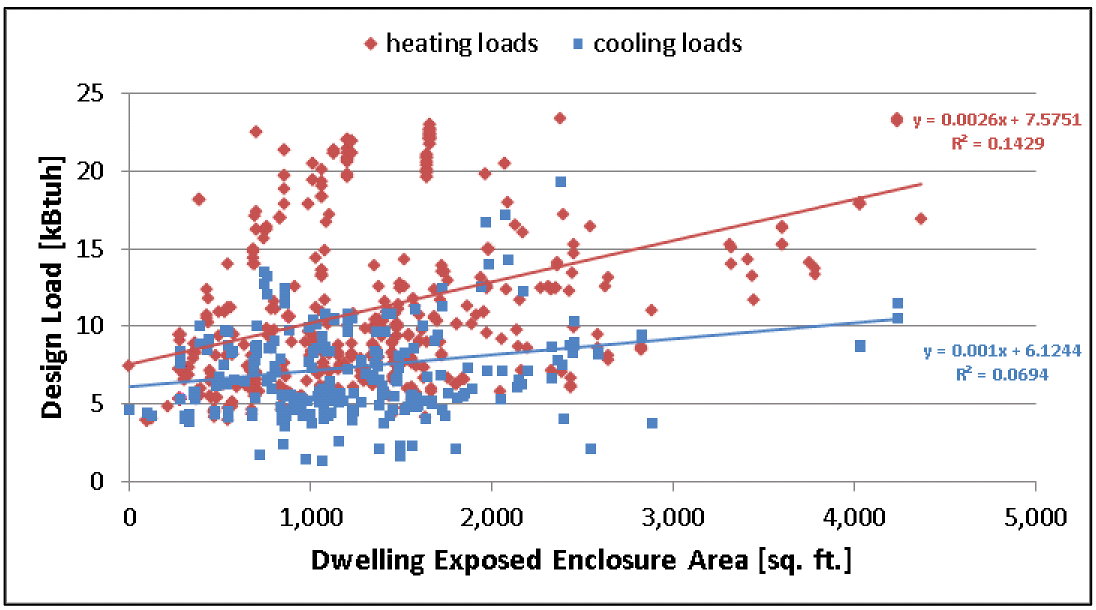
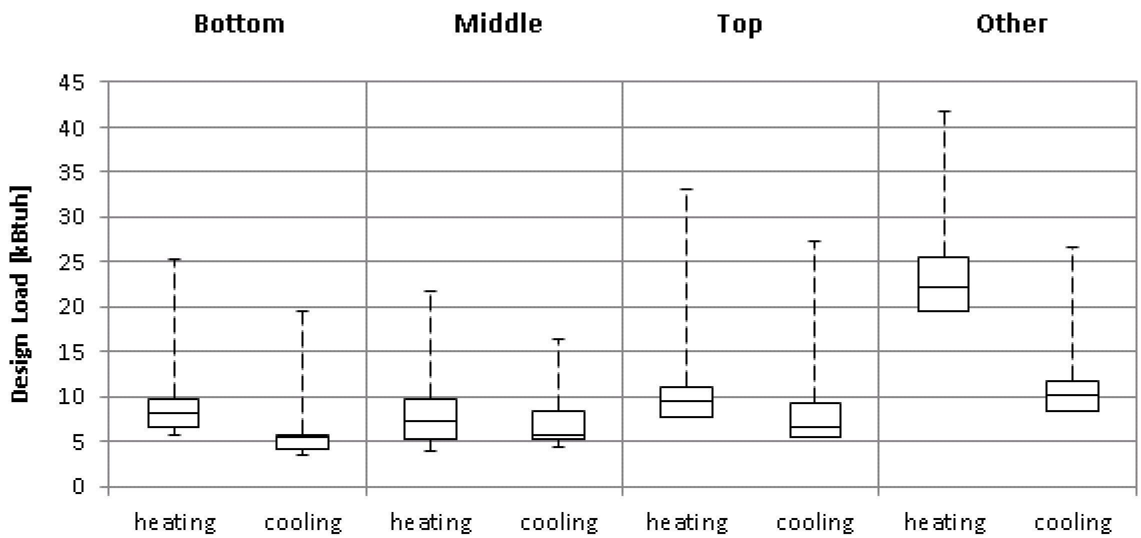


Figure 10. Comparing exposed enclosure area versus design load

3.2 Dwelling Design Loads Based on Qualitative Characteristics

Qualitative characteristics such as the location of the dwelling in the overall building were evaluated. These data are presented in box-and-whisker diagrams in Figure 11 through Figure 13. The box defines the middle half of the data points bounded by the upper and lower quartiles. All whiskers represent the highest and lowest data values excluding outliers (defined as more then 1.5 times above or below the difference between the upper and lower quartiles). Minimum, maximum, mean, and median values are listed below each plot. The percent outliers describe the percentage of the data collected that lie outside the whiskers.

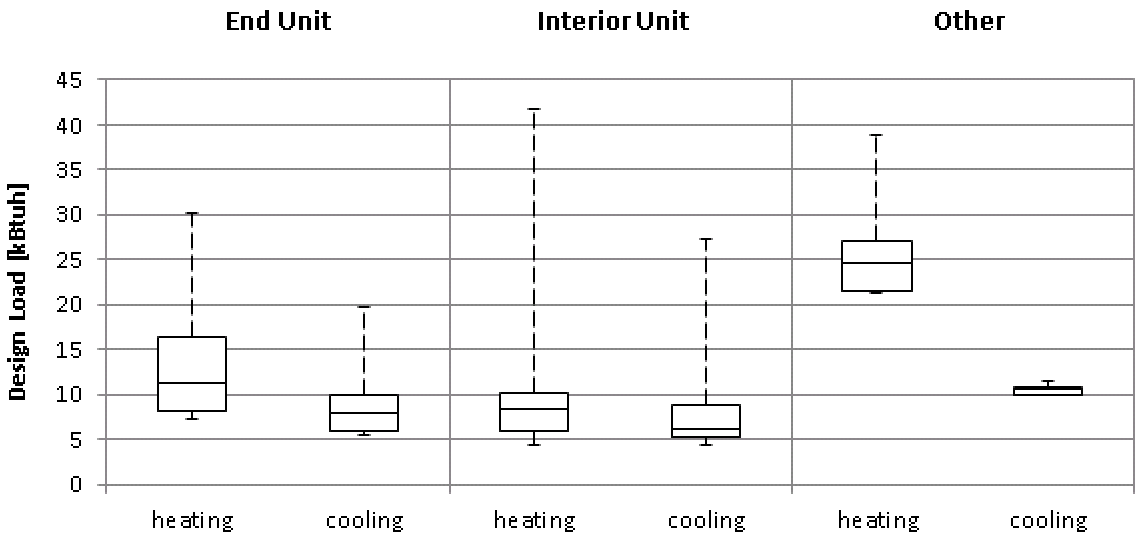
Figure 11 shows design loads for bottom (ground floor only), middle (all floors between the lowest and highest floors), and top (highest floor only) apartments in multifamily buildings. The "other" category refers to attached single-family homes. For the multifamily apartments, more than 75% of the design loads were lower than 12 kBtu/h and the design loads showed no significant difference based on the location (story) in a building. For the attached single-family homes, cooling design loads were similar to the multifamily apartments, but heating design loads were typically 20–25 kBtu/h.



Count	117	73	215	194	168	124	441	116
Min	4.6	1.4	3.9	2.1	4.1	1.3	4.0	4.2
Max	25.2	19.4	21.8	16.4	33.1	27.3	41.8	26.6
Mean	8.8	5.5	8.0	7.0	9.9	7.9	22.2	10.9
Median	8.1	5.4	7.2	5.8	9.4	6.7	22.1	10.2
% Outliers	7.7%	11.0%	4.7%	4.6%	4.8%	4.8%	0.9%	13.8%

Figure 11. Comparison of story location versus design load

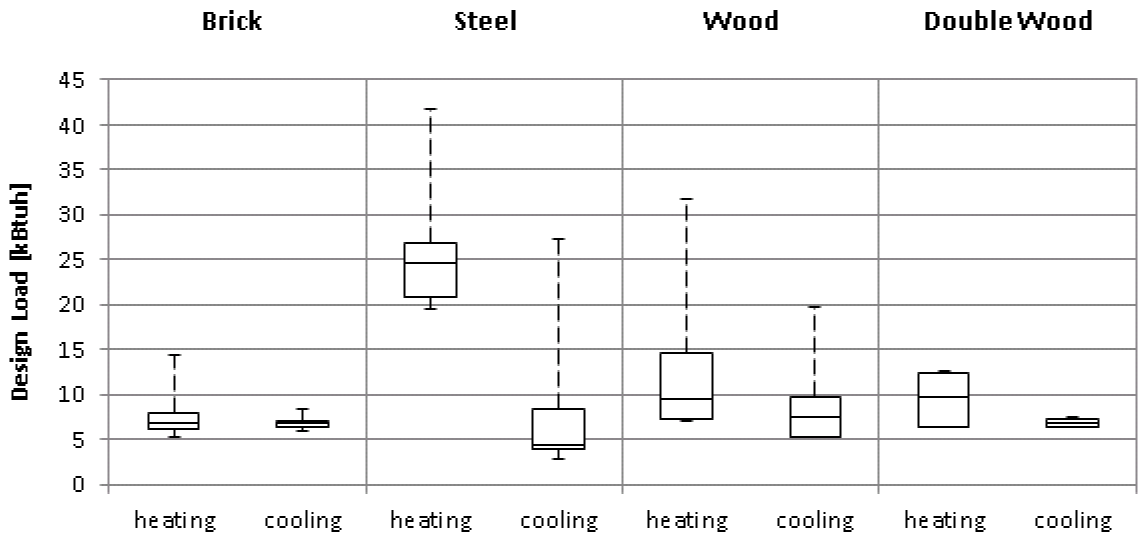
Figure 12 shows design loads for interior and end unit apartments in multifamily buildings and other units (attached single-family homes). In all cases, the cooling design loads still suggest that 9–12 kBtu/h cooling systems would be ideal for these low-load dwellings. Multifamily end units had a slightly higher heating design load because they have larger exposed enclosure areas. The attached single-family homes had heating design loads more in line with a 20–30 kBtu/h system capacity.



Count	276	190	370	310	293	7
Min	4.3	2.1	3.9	1.3	6.1	8.4
Max	30.2	19.8	41.8	27.3	38.8	11.5
Mean	12.5	8.5	9.7	7.4	24.2	10.3
Median	11.2	8.0	8.3	6.1	24.6	10.5
% Outliers	0.7%	4.2%	0.5%	7.4%	0.7%	0.0%

Figure 12. Comparison of dwelling location versus design load

Finally, Figure 13 shows design loads for various exterior wall types. The steel-framed walls had the highest design loads because the steel members had conductive thermal bridging. The brick and double-wood-framed walls had the lowest design loads. Even though the double-wall construction (R~38 in wall cavities) makes intuitive sense, the brick wall assembly may not. In this database, the brick wall dwellings consisted mostly of double-brick walls with R-9 continuous insulation on the interior side prior to wood-framed walls with an additional R-15 in the wall cavities. The double-wall dwellings also had larger floor areas than the brick dwellings.



Count	75	7	315	26	541	468	10	6
Min	4.8	6.4	3.9	1.3	3.9	1.7	6.1	6.1
Max	14.3	8.3	41.8	27.3	31.8	19.8	12.5	7.5
Mean	7.5	6.9	23.7	7.7	11.2	7.9	9.4	6.8
Median	6.9	6.8	24.5	4.4	9.5	7.5	9.8	6.9
% Outliers	13.3%	14.3%	4.8%	15.4%	0.6%	5.3%	0.0%	0.0%

Figure 13. Comparison of dwelling construction type versus design load

4 Discussion

In the past, heating design loads would be two to four times larger than cooling design loads in cold climates and some mixed-humid climates. All these analyses show that even in the cold climate region the heating and cooling design loads for low-load dwellings are trending toward similar magnitudes. Building owners also increasingly want occupants to be directly responsible for their energy bills so many owners of existing buildings are considering decentralized or compartmentalized mechanical systems. This suggests that—based on currently available equipment in the market—single-energy source systems such as electric heat pumps (which offer fairly similar heating and cooling capacities) may be a better match to low dwelling loads than dual-fuel source systems. Such systems include furnaces or boilers (hydro-coil) paired with air conditioners, four-pipe AHUs with chilled-water and hot-water coils, or packaged terminal air conditioners with hydronic heat kits. More low-load HVAC equipment options are needed to provide more flexibility to builders and designers.

4.1 Low-Load HVAC Specification

Based on the findings of this research and SWA's HVAC consulting experience, the following performance specifications for low-load HVAC needs have been outlined for manufacturers:

- AHU with electronically commutated motor fan:
    - Airflow rate: up to 450 CFM @ 0.5-in. external static pressure
    - Power consumption: 20–100 Watts (depending on airflow)
    - 1-in. minimum efficiency reporting value 8 filter minimum
- Heating performance:
    - Heat pump:
        - ≥12,000 Btu/h @ 0°F (at maximum capacity operation) with variable capacity with modulation down to 3,000 Btu/h
        - Coefficient of performance @ 5°F >2 (at maximum capacity operation)
    - Furnace:
        - 4,000–20,000 Btu/h (variable capacity)
        - Sealed combustion
        - 94+% annual fuel utilization efficiency
- Cooling performance of heat pump/air conditioner:
    - 3,000–12,000 Btu/h @ 95°F (variable capacity)
    - Seasonal energy-efficiency ratio ≥18, energy-efficiency ratio ≥13
    - Sensible heat ratio: ~65% for humid climates/~85% for dry climates
    - Dry mode operation to enhance dehumidification without overcooling (need dry mode control algorithm that is integrated with humidity set point).

Suitable whole-house ventilation is another required component, whether integrated with the AHU or as a standalone device. Performance specifications for a balanced whole-house ventilator are provided here for energy recovery ventilator (ERV) or heat recovery ventilator (HRV) with electronically commutated motor fan(s):

- Airflow rate: up to 80 CFM @ 0.2-in. external static pressure (variable ventilation rate that is user/contractor specified)
- Power consumption: 10–50 Watts (depending on airflow)
- Efficient heat recovery:
    - Apparent sensible effectiveness: 80% min @ 32°F
    - Total recovery efficiency: 60% min @ 95°F
- Single-wall penetration by using concentric or tandem ducting
- Air filtration for all airstreams.

Ideally, all HVAC equipment would have integrated fault detection to ensure optimal performance of the units over time.

4.2 Current Solutions: All-Electric Option

CARB believes a promising solution is electric heating and cooling systems, specifically ASHPs. Inverter-driven ASHPs can provide efficient heating in cold climates (at temperatures lower than 0°F) and excellent control of sensible and latent cooling loads. Because many of these systems have small capacities (starting at 6,000 Btu/h) and can effectively modulate to even lower capacities, they are an excellent match for low-load dwellings. Many ASHP systems also provide point-source heating and cooling (e.g., ductless heat pumps) or have limited distribution systems. These smaller, simpler systems often cost much less than conventional heating and cooling systems. Such cost savings are very appealing to builders who invest in superior building envelopes or who build multifamily dwellings in which loads are small even for code-level enclosures.

Efficient electric space-conditioning systems can make all-electric dwellings quite practical even in cold climates. Builders and developers can save a great deal by eliminating natural gas infrastructure and plumbing. Going all-electric also simplifies the zero energy equation, because all electricity consumed can be directly offset by an onsite photovoltaic system. The modulating capacity of these ductless heat pumps provides greater tolerance for system misapplication, which minimizes the penalty for oversizing.

The remaining issue for all-electric dwellings is how to provide whole-house ventilation and water heating. In cold climates, exhaust-only ventilation is still the predominant strategy—except in extremely tight enclosures—because its first cost is low. For balanced ventilation strategies, the use of sub-80-CFM ERVs and HRVs is increasing. One effective design strategy is to integrate the ERV as an internal distribution system for point-source space-conditioning units by pulling return air from the spaces that are not directly connected to the room in which the space-conditioning unit is located (such as bedrooms) and then supplying the tempered outdoor air supply to directly above the return of the space-conditioning unit (Figure 14).

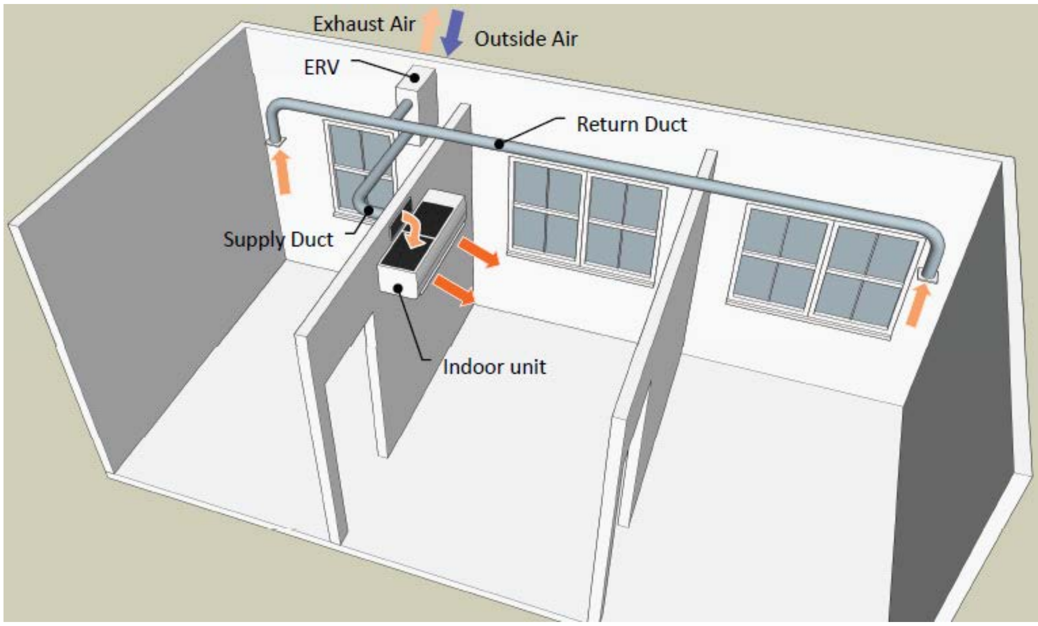


Figure 14. Potential configuration of balanced whole-house ventilation system to provide some internal circulation with a point-source heating system

For hot water, electric resistance water heaters still remain the primary option. Although heat pump water heaters can provide efficient hot water, they have minimum volume requirements (typically 750 ft^3 or greater) and are not ideally situated for conditioned space such as in apartment dwellings. Internationally some ASHPs have a single outdoor unit and connect to an indoor fan coil unit and a water heater (removing the impact of having the heat pump inside the dwelling). This would be an ideal solution in many low-load applications, but ASHPs are not currently available in the U.S. market.

Figure 15. In a less-than-ideal situation, an electric space heater was placed next to a heat pump water heater within an apartment because the unit was overcooling the living space.

5 Conclusions

Of the 941 dwellings in the data set that were evaluated, CARB found that only 1% and 6% of the dwellings had right-sized (within 25% or less of design load) heating and cooling equipment capacities, respectively. These data provide further evidence that new and appropriately sized equipment needs to be developed. In this research study, more than 75% of the heating and cooling design loads were lower than 12 kBtu/h. For the attached single-family dwellings in this study, more than 75% of the heating design loads were 25 kBtu/h or lower; the cooling design loads were similar to the multifamily apartments. These should be the starting criteria for manufacturers as they develop solutions for low-load dwellings.

With respect to wall assembly types, steel-framed walls predictably had the highest design loads because the steel members had conductive thermal bridging. The heating loads were 20–40 kBtu/h for these dwellings. The brick (typically double-brick walls with R-9 continuous insulation on the interior side prior to wood-framed walls with an additional R-15 in the wall cavities) and double-wood-framed walls had the lowest design loads (5–15 kBtu/h).

With respect to quantitative physical characteristics of the dwelling units, such as floor area, volume, enclosure area, and exposed enclosure area, no statistically significant trends could be determined. Even so, some general trends can be inferred. The best correlations were for heating loads with respect to dwelling volume and enclosure area. Comparison of design loads to the exposed enclosure area had the least correlation of the four characteristics evaluated.

All these analyses show that the heating and cooling design loads for low-load dwellings—even in the cold climate region—are approaching similar magnitudes. For multifamily apartments and attached single-family dwellings, the cooling design loads suggest that 9–12 kBtu/h would be an ideal cooling system capacity. A slightly larger range was observed on the heating side; however, a heating system with a maximum capacity range of 9–18 kBtu/h would fit the needs of most low-load dwellings.

With currently available technologies, CARB has successfully used an all-electric approach that employs inverter-driven ASHPs and HRVs/ERVs. With this approach, the whole-house ventilation system is configured to also serve as an internal distribution system for point-source or minimally distributed space-conditioning systems. Still, more low-load HVAC equipment options are needed to provide more flexibility to builders and designers. A low-load HVAC specification has been outlined for equipment manufacturers based on the findings of this research and SWA's HVAC consulting experience. The intent is to provide a roadmap for developing more appropriate HVAC equipment for low-load dwellings.

References

Brown, S.; Thornton, B.; Widder, S. (2013). *Review of Residential Low-Load HVAC Systems*. Richland, WA: Pacific Northwest National Laboratory, PNNL-22244 letter report.

Conerly, B. (2014). Multi-Family Real Estate Forecast: 2014-2020. Forbes. May 19, 2014. Accessed November 2014: http://www.forbes.com/sites/billconerly/2014/05/19/multi-family-real-estate-forecast-2014-2020/.

Lstiburek, J. (2006). "HVAC in Multifamily Buildings." BSD-110. Somerville, MA: Building Science Corporation. Accessed April 16, 2014: http://www.buildingscience.com/documents/digests/bsd-110-hvac-in-multifamily-buildings.

Schoenbauer, B.; Bohac, D.; Huelman, P.; Olson, R.; Hewett, R. (2012) *Retrofitting Combined Space and Water Heating Systems: Laboratory Tests*. Golden, CO: National Renewable Energy Laboratory. DOE/GO-102012-3694. Accessed January 12, 2015: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/labtests_combi_spacewh.pdf.

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102015-4670 ▪ May 2015