A Report Prepared for
Urban Green Council
by Steven Winter Associates
April 2011

THERE ARE HOLES IN OUR WALLS

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Urban Green Council
U.S. Green Building Council New York
40 Fulton Street, Suite 802
New York, NY 10038

PRINTING

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WHY THIS REPORT?

The quality of the building envelope drives the heating and cooling loads of most buildings and advanced envelopes have demonstrated that proper design can lead to dramatic reductions in these loads. In the case of Passive House for small buildings, energy use for heating and cooling may be 90% lower than conventional construction. But typical buildings suffer from substantial air leakage, thermal loss, and solar heat gain, leading to high heating and cooling loads and energy costs.

While many aspects of envelope performance are invisible to the naked eye, some are right in front of us. Huge numbers of building throughout the U.S. have numerous penetrations in their envelope in the form of room air conditioners that are installed in windows or included in the wall assembly. We have wondered what impact they might have on energy consumption for heating and cooling. A review of the literature, however, found little direct study of a question that could have a substantial impact either on actual building performance or on the accuracy of models used to predict that performance.

Consequently, Urban Green Council issued a competitive “Call for Building Envelope Research” in 2010, seeking engineers or building scientists to produce a research paper on the impact of room air conditioners (ACs) on building envelope performance. A Research Advisory Committee was set up to help formulate the “Call,” review responses, review the actual report and propose recommendations. The committee members are listed in the Credits section of this report.

Steven Winter Associates, a building science consulting firm, was selected to undertake the effort. Their paper, which follows, is the core product of this effort. It presents their findings and details the basic design considerations of room air conditioners, the human factors in their application, the negative impacts on building envelope efficiency, and possible responses to those impacts, both available and proposed.

Based on the findings in the report, a subset of the Advisory Committee developed several recommendations for policymakers. Since these recommendations represent the views of the committee, they are presented in a separate section after the paper itself.

Urban Green Council is grateful to the members of the Advisory Board for their time and input, and owes an enormous “Thank You” to Marc Zuluaga and his team at Steven Winter Associates for a truly outstanding piece of research, experimentation, and analysis.

CREDITS

Authors

Marc Zuluaga, Sean Maxwell, Jason Block and Liz Eisenberg
Steven Winter Associates

Research Advisory Committee

Leo Baez
Director of Construction,
Enterprise Community Partners

Greg Bauso
Co-Principal,
Monadnock Construction

Scott Frank
Partner,
Jaros, Baum & Bolles

Richard Leigh
Director of Research,
Urban Green Council

Charlotte Matthews
Vice President for Sustainability,
Related Companies

Mo Siegel
President/Co-CEO,
Ice Air, LLC

Russell Unger
Executive Director,
Urban Green Council

ABSTRACT

This study examines the impact on thermal performance of building envelope penetrations associated with distributed heating, ventilating, and air conditioning (HVAC) equipment such as window air conditioners (ACs), sleeved ACs, and packaged terminal air conditioners and heat pumps (PTACs and PTHPs). Physical testing of sixteen different AC and PTAC units in eleven buildings revealed that the infiltration losses through leaks and poorly-fitting installations are far greater than might be expected, and that the leakage area associated with the average unit in this sample was six square inches, the size of the rectangle on the cover of this report. Extrapolated to the New York City residential housing stock, this corresponds to a hole equal to 60% of a city block. The associated heating losses are estimated to cost in the neighborhood of $150 million per year in excess fuel use, and result in the emission of around 400,000 tons of CO_2 annually – about 1% of the city's annual total. In some individual buildings, the estimated average cost of fuel to make up for winter thermal losses is comparable to the cost of electric energy used in the summer for cooling.

The study finds the primary cause of the leakage to be a lack of long-term integrity in the installation kits for window ACs and poor fit and sealing for sleeved units and PTACs, especially in retrofit and replacement situations. The causes of this poor performance start with the Energy Efficiency Ratio (EER) standard, which measures cooling performance but provides no constraints that would encourage designs incorporating efficient air sealing. Other causes include split incentives, where the building owner may supply the equipment but the resident pays the electric bill, or the resident makes the installation, but the building supplies the heat. Poor understanding of cost effectiveness plays a role, since residents will often purchase a less expensive window AC to either use in or replace a sleeve AC, with worse fit, greater infiltration, and greater electric and fuel costs in either case.

Finally, the study evaluates a variety of off-the-shelf products that can reduce infiltration and thermal losses, in some cases dramatically, and describes various alternative technologies that appear practical but have not yet been widely deployed or, in some cases, developed. Innovations in operations and maintenance, including improved installation kits, are found to offer the most immediate benefits, while development of suitable split systems to minimize wall penetrations offer the possibility of greater improvement long-term. These proposals were integrated into the recommendations of the Advisory Committee, which follow the study.

THERE ARE HOLES IN OUR WALLS

INTRODUCTION

This paper presents the findings of our work on the impact of room air conditioners (ACs) on building envelope performance and details the basic design considerations of room air conditioners, the human factors in their application, the negative impacts on building envelope efficiency, and the possible solutions to those effects, both available and proposed.

We use “room air conditioner” as an umbrella term here to describe three types of cooling systems: window-mounted (“window AC”), through-the-wall (“sleeve AC”), and packaged terminal systems such as packaged terminal heat pumps and packaged terminal air conditioners (“PTHPs” and “PTACs”). All constitute a permanent or semi-permanent penetration through the building envelope. The infrared image of a multi-family building with through-the-wall sleeves shown in Figure 1 qualitatively illustrates the nature of the problem. This image was taken during winter from the exterior of a building. The red and orange colors indicate warmer exterior surface temperatures and areas of concentrated heat loss.

A room air conditioner’s Energy Efficiency Ratio (EER) rating is the sole industry standard used to compare the efficiency of different units. It allows a simple way for building owners, designers, and consumers to distinguish between units of different cost and design. Still, as we discuss below, since this rating applies only to cooling performance, it falls far short of properly characterizing the total energy impact of room air conditioners for a number of reasons. Room air conditioners pose two main problems for the building envelope:

1. They result in air leakage pathways that increase the uncontrolled movement of air through buildings (infiltration).

2. They are a thermal bridge, meaning that they conduct heat very efficiently around other building materials such as insulation, which are designed to resist heat flow.

Both of these effects contribute to an increase in the winter heating requirements of a building and have an impact on energy performance in multi-family buildings, hotels, and many small commercial buildings.

The primary objective of this study is to provide a framework for understanding the impact that room air conditioners have on building heating requirements. To this end, we have quantified the additional winter heating energy use resulting from the installations of room air conditioners. Based on field testing results from a variety of New York City (NYC) room air conditioner configurations, we have:

1. Estimated the energy penalty associated with typical applications

2. Evaluated the energy savings potential of both off-the-shelf solutions and potential solutions that have not been widely implemented.

The focus of this paper is on the multi-family sector, since in NYC, room air conditioners are most prevalent in multi-family buildings and because addressing this problem comprehensively is most difficult in occupied residential buildings. The findings of this paper are also relevant to many hotels and some commercial buildings.

Above all, this paper recognizes that the technical obstacles that must be overcome to reduce the heating energy penalty of room air conditioners are dwarfed by human factors. A root cause of many of these issues is the disconnect found in NYC multi-family buildings where a building owner, not the actual apartment residents, pays for heat but the individual residents are partially or fully responsible for the installation and maintenance of room air conditioners. In our evaluation of best-practice approaches, we acknowledge the difficulty of implementing the cultural changes that may be required in multi-family buildings. Although these human challenges are significant, the scale of the problem citywide justifies a concerted effort to further identify and evaluate improved approaches.

According to the 2008 New York City Housing Vacancy Survey (NYCHVS), there are more than 3.3 million total residential housing units with 13.3 million rooms in NYC. If 30 percent of all rooms are cooled with room air conditioners, that would represent 4 million punctures in building envelopes. According to the NYCHVS, an average of 20,000 new units were developed in NYC every year from 2002 to 2008. While new construction is more of a blank slate for implementing improved practices, it is clear that our existing stock represents by far the greatest problem and opportunity that must be addressed. In the NYC multi-family sector alone, we estimate that the leakage area associated with room air conditioners is equivalent to a 167,000 square foot hole — an area almost as large as a typical Manhattan block. On an annual basis, this gaping opportunity translates into an operating cost penalty of between $130 million and $180 million for owners and the discharge of 375,000 to 525,000 tons of CO_2 into the atmosphere.

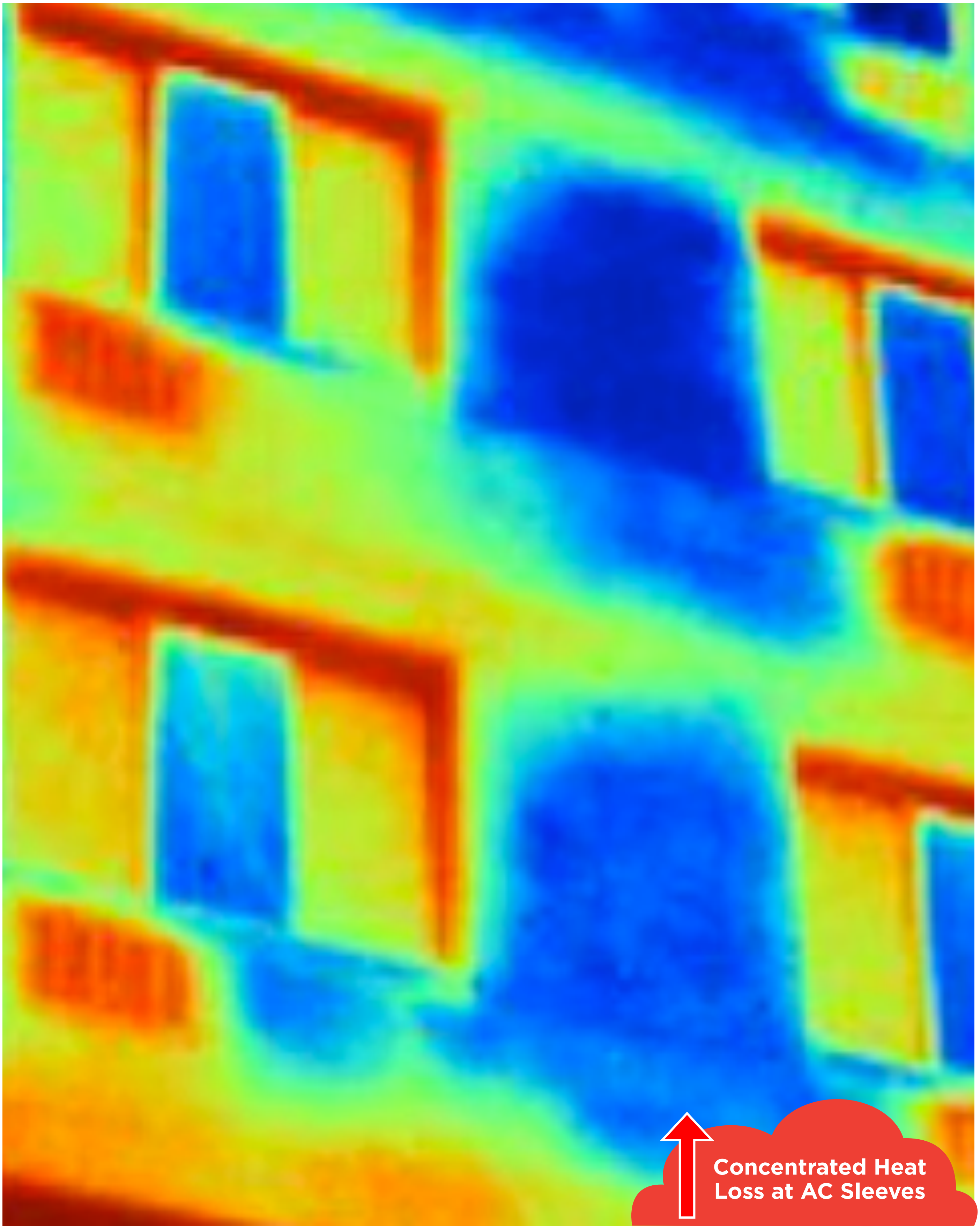

Fig. 1: **Infrared image of a building with through-the-wall sleeves (exterior view)**

BASIC CHARACTERISTICS OF ROOM AIR CONDITIONERS

Fig. 2: **Good double-hung window installation**

Fig. 3: **Bad double-hung window installation**

WINDOW AIR CONDITIONERS

Window air conditioners are extremely common in all types of housing. They can be installed in double-hung, single-hung or casement windows. In multi-family buildings, they may be installed by residents or maintenance staff and are typically not installed in all of the rooms. The units themselves are usually purchased by residents. However, in some cases where the building owner pays the apartment electricity bill, an owner may provide, install, and maintain window air conditioners as part of an additional service charge. Typical dimensions for window air conditioners range from 11 to 18 inches in height, 18 to 26 inches in width, and 15 to 30 inches in depth. On the exterior, where they protrude from the building facade, they have louvers on three sides to allow air to flow through the outdoor coil section when operated during the summer. Manufacturers usually include window gasket seals and adhesive foams with the unit to prevent air leakage via unsealed joints around the unit perimeter and the window frame. With double-hung windows, accordion panels can be installed and adjusted accordingly when the window frame is significantly wider than the unit itself. Separate installation kits are available for horizontal sliding and casement windows. In NYC multi-family buildings, it is very typical for window air conditioners to be left in place year-round, since 1) winter storage space is usually not available, 2) residents typically do not pay for heat, and 3) no one enjoys lifting the units out of windows. Air-leakage pathways exist both through and around the window AC units. In double-hung windows, the installation of a window unit also results in a gap between the two sashes (red arrow in Figure 3).

The impact of window air conditioners on thermal bridging is minimal, since they represent a penetration within an already (highly conductive) window penetration and do not displace any insulation.

SLEEVE AIR CONDITIONERS

Sleeve or through-the-wall air conditioners are similar in design to window air conditioners in that they are a self-contained unit that can be installed and removed by a tenant. They are mounted in a metal sleeve that has been installed through a rough opening in the wall, typically under a window. Sleeves have been installed in buildings at the time of construction since the 1950s and may also be retrofitted into buildings that were not otherwise designed with a cooling system. Sleeve dimensions vary slightly by manufacturer as shown in Table 1.

Because they must fit in a sleeve and not protrude beyond the building façade, sleeve air conditioner condenser coils are exposed to the outside only from their exterior face in the rear; they do not have louvered sides the way that window air conditioners do. For this reason, they are sometimes called “rear-breathing” units. Sleeve air conditioners are also more expensive — they can cost twice as much as a window unit of the same size. In multi-family buildings, the sleeves are also typically installed in every bedroom and living area, and these penetrations through the building’s envelope will be there year-round. The amount of air leakage through the sleeve may vary, depending on whether or not an air conditioner unit is installed and, if one is, whether it is a proper sleeve unit or just a window unit stuck in the opening. The air leakage can come from a few different sources: the joint between the unit and its sleeve, the joint between the sleeve and the drywall finish, and through the air conditioner unit itself. One advantage that sleeve air conditioners have is that they can be permanently installed, unlike window air conditioners, which are typically more temporary in nature. The gaps between the rough opening and the sleeve, and between the sleeve and the unit itself can be thoroughly sealed to reduce air leakage. The metal sleeves themselves result in a thermal bridge that bypasses any insulation that may exist in the wall assembly or any insulation located within the air conditioner unit itself.

PACKAGED TERMINAL AIR CONDITIONERS AND HEAT PUMPS

Packaged terminal air conditioners (PTACs) and packaged terminal heat pumps (PTHPs) started to be installed in New York City buildings in the 1970s. Both types of units are similar to sleeve air conditioners in that they are mounted in a metal sleeve that has been installed through a rough opening in the wall; however, in this case only the outdoor section fits into the sleeve itself. PTACs are professionally installed at the time of construction, usually in every bedroom and living room and almost always maintained by the building owner.

Table 1: **Sleeve dimensions of major manufacturers**[1]

Sleeve Dimensions	**Friedrich USC Sleeve**	**Amana**	**Carrier** (51S Series)	**Emerson/ Fedders**	**GE/ Hotpoint**	**Whirlpool**
Height (inches)	15 1/2	15 5/8	16 7/8	15 3/4	15 5/8	16 1/2
Width (inches)	25 7/8	26	25 3/4	26 3/4	26	25 7/8
Depth (inches)	16 3/4	16 7/8	18 5/8	15	16 7/8	17 1/8 or 23

Fig. 4: **Sleeve with AC installed**

Fig. 5: **Sleeve with metal cover instead of AC installed**

Fig. 6: **PTAC**

The indoor section extends well into the living space in a cabinet. Whereas PTHPs provide heat to a space by reversing the flow of refrigerant and/or using electric resistance during the winter, PTACs sometimes provide heat through hot water or steam coils that are fed by a central boiler plant, if they provide heat at all. These hot water coil-equipped PTACs make up only 6% of the national market, but they dominate in the NYC region. Other PTACs provide heat via a gas-fired furnace section, although the NYC Department of Buildings does not allow these to be located in bedrooms. While not very common in the Northeast, PTACs that utilize electric resistance coils for space heating can still be found in many buildings constructed in the 1960s despite their high operating cost and large carbon footprint. At the time it was thought that electricity was going to be "too cheap to meter."

Typical PTAC and PTHP units are roughly 26 to 42 inches in width, 16 inches in height, and 21 inches in depth, although there is some variation between manufacturers and models. Air leakage through PTACs and PTHPs is similar to that of sleeve ACs: There may be gaps between the rough opening and the sleeve, and between the sleeve and the AC unit itself. PTACs and PTHPs may also have holes within the units themselves, such as penetrations for refrigerant and electrical lines, as well as dedicated outside air dampers.

THE ROOM AIR CONDITIONER MARKETPLACE

There are major differences in the way that room air conditioners are marketed and purchased. PTACs are in a separate class altogether in this respect, in that the decision for their inclusion in the building is made early in the design process. Their efficiency is a design decision made by a developer or designer and not by an individual resident. They are not easily or cheaply retrofitted into existing buildings. Window and sleeve units are most often purchased by individual tenants and lend a more direct comparison. In terms of cost, sleeve units are much more expensive due to design factors and the comparatively smaller volume of units produced annually. For example, a typical Friedrich 8,000 Btu per hour window unit costs approximately $200, while an equivalent sleeve unit from the same company costs about $400. To sell window air conditioners, major appliance manufacturers are often paired with big-box retailers in order to corner large segments of the market (e.g. LG with The Home Depot, GE with Wal-Mart and Frigidaire with Lowes). These major manufacturers and retailers market the air conditioner units less like HVAC equipment and more like convenience appliances. Their lowest-price models sell for less than $100 and come with very little in the way of support.

HUMAN AND REGULATORY FACTORS

There are a variety of human factors that cannot be ignored in any discussion of potential solutions to minimize the impact of room air conditioners on heating energy use. Underlying the problem is the fundamental disconnect in almost all NYC residential buildings between owners who pay to operate central boilers and tenants who are not individually metered for heat but whose behavior can have a great impact on the heating requirements of a building. In general, when a building owner maintains a room air conditioner unit, the quality of the installations is more controlled. And even if there is room for improvement in this typical practice, implementing such improvements is well within the control of the owner.

At the other end of the spectrum, with tenant-supplied window air conditioners, there is a wide variation in the quality of installations, and building owners find it more difficult to alter or affect the installation of equipment owned by tenants. When tenants are responsible for installing window ACs, they generally do not opt to provide air conditioners in every room, which makes the impact of window ACs on envelope performance less severe than it could be. Dunn Development, an affordable housing developer and owner that tracks tenant behavior regarding window ACs, has found that tenants opt to install AC units in only one-third of the rooms in their buildings. In market-rate buildings with window ACs, it is likely that a greater percentage of rooms have window air conditioners. The ideal scenario with window air conditioners is to remove them in the winter. But high-rise co-ops may require that a resident hire a “professional” to remove or reinstall window air conditioners. The realities of apartment access, lack of storage space and residents not being metered for heat all combine to making any maintenance programs to remove window air conditioners in the winter extremely difficult to implement in any building. From an owner’s standpoint, any increases in annual maintenance costs associated with improved room air conditioner maintenance practices must be weighed against the potential energy savings. At the same time, it is important to keep in mind that all adjustments to routine maintenance activities do not necessarily add “cost” to the owner of a building with an in-house maintenance staff.

Fig. 7: **Window AC installed in a sleeve**

Fig. 8: **Window AC above sleeve**

In the case of sleeve air conditioners, there are of course through-wall penetrations in every room. If the building owner provides the sleeve air conditioners, the sleeves are all essentially plugged with mechanical equipment. Even if these sleeve ACs do not result in a perfectly airtight seal, as is discussed in a later section of this study, the equipment has at least been installed by a professional contractor or maintenance person. In some cases, building owners have chosen to provide and maintain sleeve air conditioners in selected rooms (i.e. bedrooms) while leaving the installation of ACs in living room sleeves up to the tenants. In cases where neither building owner nor residents use sleeves for cooling, interior metal cover panels are installed. These panels may or may not provide an airtight seal.

Wherever a building provides sleeves but no sleeve air conditioners, residents must purchase and install their own equipment if they want cooling in that room. Residents are often unaware of the fundamental difference between sleeve and window ACs (other than cost). Even if a resident is willing to pay a premium for a sleeve AC, purchasing the appropriate unit that will fit tightly into the sleeve is not a straightforward exercise due to the slight variations in sleeve dimensions from the different manufacturers presented in Table 1. There are “universal fit” through-wall units on the market, but even these are limited to a certain range. This problem of nonstandard dimensions constitutes another barrier to the purchase of appropriate sleeve units. Customers who change apartments may not be able to use their sleeve unit when they move. A window air conditioner constitutes an investment that retains at least some of its value if the resident moves, which explains why we often see window ACs installed either in sleeves or in windows above sleeves.

PTACs, like AC sleeves, result in through wall penetrations in every room. However, since these sleeves are almost always fitted with mechanical units maintained by the building, the potential impacts of tenant behavior are minimized.

It is important to note that in addition to letting air pass through them, any openings through room air conditioner installations also provide a pathway for outside noises from the street and other sources to enter the living space. In one example of housing near the Minneapolis-St. Paul International Airport, a retrofit program designed to improve the acoustic performance of homes located near the airport found that in some cases meeting noise-reduction targets for an entire home was possible simply by retrofitting the existing PTAC with a new unit that was installed properly.[2] And even if residents don’t pay for heating bills, drafts felt through these holes are a comfort issue that they do feel directly. Such potential non-energy, quality-of-life benefits may be important considerations that will help broaden the appeal of strategies to reduce leakage through room air conditioners to both residents and owners.

IMPACT OF ROOM AIR CONDITIONERS ON ENERGY USE

OVERVIEW

Room air conditioners pose two main problems for the building envelope that are captured by the above infrared image:

1. They result in air-leakage pathways that increase infiltration

2. They are a thermal bridge, meaning that they conduct heat very efficiently around other building materials such as insulation that are designed to resist heat flow.

Of these two effects, the impact of increased infiltration results in the greater impact on heating load, increased building energy use, and occupant comfort, as will be discussed below. Technically, the inferior envelope performance associated with room air conditioners results in both additional heating and cooling loads. However, as is discussed below, since the summer cooling load impact is significantly smaller than the winter heating load impact, the results of this analysis focus only on heating.

To assess the impact of room air conditioners on infiltration, Steven Winter Associates (SWA) developed a field protocol for measuring the effective leakage area in square inches of a particular room air conditioner, using a modified “blower door” test. This protocol has been implemented in 11 NYC buildings on 16 room air conditioners. While further research is necessary to identify and test a true statistically representative sample of room air conditioners, the field results presented in this paper are a reasonable starting point for estimating the nature and extent of this problem.

The energy penalty due to the thermal bridging associated with room air conditioners is a relative concept and raises the question: “Compared to what?” A sleeve retrofitted in an uninsulated pre-war masonry wall assembly will not result in as great an energy penalty as a sleeve that effectively displaces a significant amount of insulation in an otherwise high-performance wall assembly. Three representative NYC wall assembly R-values have been defined to gauge the relative impact of thermal bridging in different scenarios. Based on this assumption, a range for the resulting annual heating load

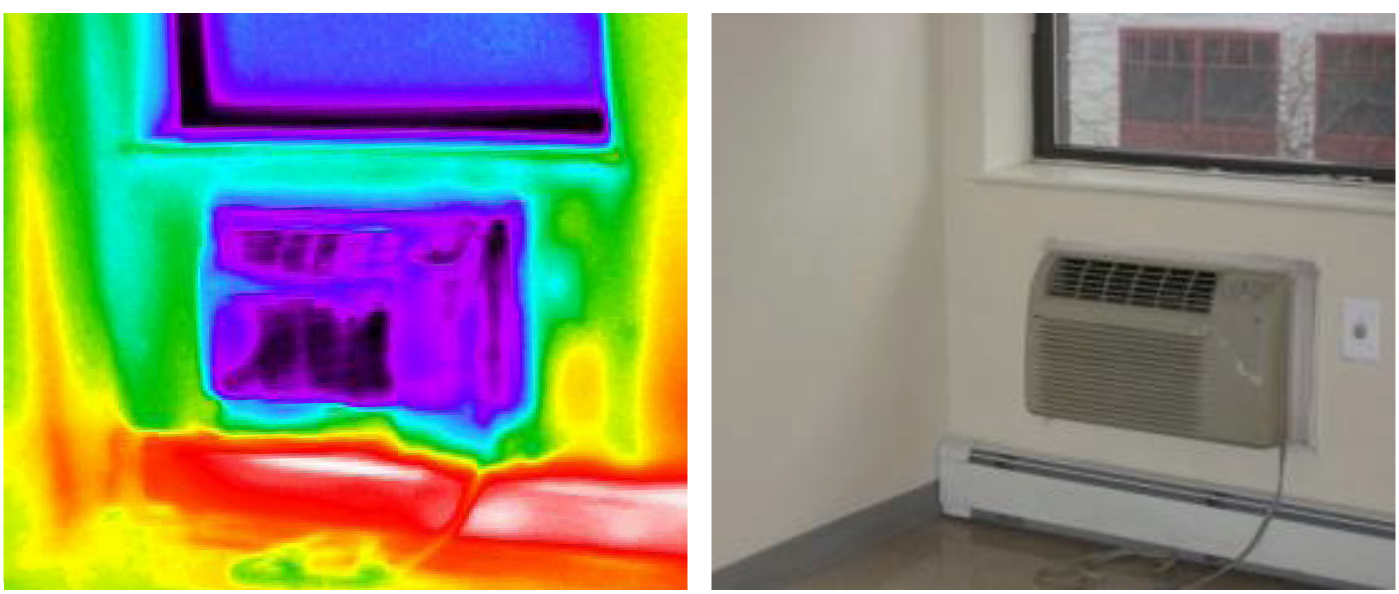

Fig. 9- 10: **Heat loss through a sleeve AC**

penalty due to a metal AC sleeve has been calculated for the NYC climate. Our analysis has demonstrated that, typically, the heating energy penalty due to air infiltration is an order of magnitude greater than the penalty due to thermal bridging.

IMPACT OF ROOM AIR CONDITIONERS ON AIRTIGHTNESS

Room air conditioners of all types have some effective leakage area. There are three primary types of air leakage pathways:

1. Intentional leakage through equipment (i.e. outdoor air dampers)
2. Unintentional leakage through equipment
3. Unintentional leakage around equipment (i.e. between a sleeve AC and the sleeve)

To better quantify the amount of air leakage that occurs through room air conditioners, SWA has conducted tests of multiple room air conditioners in a variety of different NYC multi-family buildings. These results are presented in Tables 2 to 5 and are expressed in terms of square inches of leakage area.

SWA tested three new buildings with window ACs. Building 1 had window ACs installed throughout the building by the building maintenance staff. While we only tested one apartment, installations throughout the building appeared relatively uniform, since all installation work was done in one period of time by a small number of staff. Buildings 2 and 3 were fixed window panels with an opening cut by building maintenance staff to receive the window AC. We did not have the opportunity to test any of the "cardboard contraptions" or other less-professional installations more commonly found in buildings with air conditioners installed by residents. Test results are presented in Table 2 on page 10. The three (relatively professional) installations tested averaged 7.6 square inches of leakage area.

Table 2: **Air leakage testing results for window AC buildings**

Test Building #	Year Built	Affordable or Market Rate	Description	Total Leakage Area (sq. in.)
1	2010	Affordable	Double-Hung Window with AC	5.7
2	2010	Affordable	Fixed Window Panel with AC	9.6
3	2010	Affordable	Fixed Window Panel with AC	9.1
			Average	**7.6**

Table 3: **Air leakage test results for sleeve AC buildings (with ACs installed in sleeves)**

Test Building #	Year Built	Affordable or Market Rate	Description	Total Leakage Area
4	2010	Affordable	Sleeve AC	7.1
5 (Sleeve 1)	1999	Affordable	Sleeve AC	4.6
5 (Sleeve 2)	1999	Affordable	Sleeve AC	5.2
6	1983	Affordable	Sleeve AC	1.9
7	1991	Affordable	Sleeve AC	0.7
8	1928	Affordable	Window AC in Sleeve	11.7
			Average	**5.2**

Table 4: **Air leakage test results for sleeve AC buildings with metal panel fitted to interior**

Test Building #	Year Built	Affordable or Market Rate	Description	Total Leakage Area
4	2010	Affordable	Interior Metal Panel (No AC)	0.1
6	1983	Affordable	Interior Metal Panel (No AC)	7.2
			Average	**3.6**

SWA tested five buildings of various vintages with sleeve ACs. Test results for cases where an air conditioner was installed in the sleeve are presented in Table 3 on page 11. The average leakage area for these cases was 5.2 square inches. The one installation tested with a small window AC installed in the sleeve was more than twice as leaky as the average unit tested. Ignoring the case of the window AC installed in the sleeve, there is a general trend of tighter installations in older buildings, probably due to years of paint covering up any gaps around the units. This trend implies that the majority of leakage in these types of installations is around the air conditioners and not through them. Moreover, the result from Building 7 demonstrates that it is possible for a sleeve AC installation to result in almost zero leakage.

Test results in Sleeve AC buildings for cases where no air conditioner was installed and the sleeve was fitted with an interior metal panel are presented in Table 4 on page 11. Building 4 was a recently completed building with the original metal panel provided by the sleeve manufacturer installed by the contractor at the time of construction. Since it was a newly constructed building, this sleeve had never been removed by a resident who wanted to install an AC and then replaced later if the next tenant did not want an air conditioner in that sleeve. The result from Building 4 demonstrates that a properly fitted interior panel can completely eliminate air leakage. The interior panel in Building 6 was visibly bent. While a wide variety of metal panel installations were not tested, it is logical to conclude that the leakiness of a metal panel is likely to increase over time unless regularly checking the fit of panels is part of an O&M program.

SWA tested three buildings constructed in the last 20 years with PTACs. The results are presented in Table 5 on page 13. All of the PTAC buildings were market rate rentals. All of the sleeve and window AC buildings tested were affordable housing. The average leakage area for all PTAC cases was 6.7 square inches, which is not significantly different from the average results for sleeve ACs with air conditioners installed or window ACs.

IMPACT OF ROOM AIR CONDITIONERS ON INFILTRATION AND HEATING ENERGY USE

The average room air conditioner tested resulted in a leakage area of 6 square inches. Air flow through a hole of a known size can be calculated if the pressure difference across that hole is known. In real buildings, pressure differences across the envelope continually fluctuate in response to the dynamic interactions between wind, stack (“chimney”) effect, and mechanical ventilation. Even at a given instant in time, the pressure difference across a building envelope can vary significantly at different locations and heights along the facades. The impact of a fixed leakage area on whole building infiltration has been calculated by others,

Fig. 11: **Metal panel installed in Building 4**

Fig. 12: **Metal panel installed in Building 6**

Table 5: **Air leakage test results for PTAC test buildings**

Test Building #	Year Built	Affordable or Market Rate	Description	Total Leakage Area (sq. in.)
9 (PTAC 1)	1990	Market Rate	PTAC McQuay P.DN S.2.015.C.Z.63.12AR.1 4.C.I.C.I	5.2
9 (PTAC 2)	1990	Market Rate	PTAC Ice Cap, CTC09200 CAFLDA	5.6
10	1986	Market Rate	PTAC Retroair, RC3509A0A	4.2
11 (PTAC 1)	1994	Market Rate	PTAC Ice Cap 5RSCT12WNC	11.6
11 (PTAC 2)	1994	Market Rate	PTAC Ice Cap 5RSCT09WNC	7.0
			Average	**6.7**

Table 6: **Increase in infiltration (cubic feet per minute) associated with a 6 square inch hole**

Average Room AC Leakage Area (sq. in.)	**CFM Leakage @ 5 Pa Indoor-Outdoor Pressure Difference** (Basis for Low-End Estimate)	**CFM Leakage @ 10 Pa Indoor-Outdoor Pressure Difference** (Basis for High-End Estimate)
6.0	13	19

Table 7: **Annual heating energy penalty associated with a 6 square inch hole**

Average Room AC Leakage Area (sq. in.)	**Annual Operating Cost Penalty**		**Annual Energy Penalty** (MMBtu)	
	(Low-End Estimate)	**(High-End Estimate)**	**(Low-End Estimate)**	**(High-End Estimate)**
6	$32	$45	2.3	3.2

assuming an average effective differential pressure of 5 Pa (0.02 in WC), to 10 Pa (0.04 in WC). [3] These two pressure bounds represent a low end and a high end for calculating the average seasonal increase in infiltration in cubic feet per minute associated with a 6 square inch hole.

Based on this differential pressure assumption, the correlation between one square inch of leakage area and the resulting annual heating load has been calculated for the NYC climate by making the following additional assumptions:

- Fuel cost of $14 per MMBtu (corresponds with an average rate for oil and gas)
- Heating Plant Seasonal Efficiency of 70%
- NYC climate (4,500 heating degree days)

It is important to note that in electrically heated buildings, operating cost penalties will be approximately 2 – 3 times higher than the results presented in Table 7 due to the significantly higher cost per MMBTU of energy in these buildings. Citywide, only 4% of apartments are in electrically heated buildings, but for any individual owner of these buildings, controlling heating expenses is a major issue. Moreover, a great opportunity for energy savings in some electrically heated buildings lies in submetering, so that tenants directly pay for apartment electricity use (including heating) and adjust their behavior accordingly to conserve. However, submetering can only be responsibly implemented if measures to minimize imbalances in heating loads (i.e. variability in the leakiness of sleeves throughout a building) are implemented.

IMPACT OF ROOM AIR CONDITIONERS ON THERMAL BRIDGING

Sleeve air conditioners and PTACs share the same thermal-performance issues because sleeve construction is very similar. Figure 13 on page 15 shows a typical section of a PTAC sleeve that illustrates the thermal bridging pathways for winter heat loss (red arrows).

Calculating the resistance to heat transfer (R-value) of a sleeve assembly requires either complex three-dimensional heat transfer modeling or controlled laboratory testing (or both), which were beyond the scope of this study. Instead, we have performed a “thought experiment” type of evaluation that estimates the thermal bridging penalty of a sleeve AC or PTAC by assuming that the assembly has an R-value comparable to that of a double-paned metal window with a non-thermally broken frame. This is a reasonable starting-point assumption, given that a sleeve AC or PTAC is basically a non-thermally broken metal frame that encloses an air cavity. With this starting point, an analysis has been performed utilizing the same assumptions for fuel cost, heating plant efficiency and NYC climate described above for the calculations of heating energy penalty due to infiltration. In addition, a sleeve cross-sectional area of 3.5 square feet has been assumed (average of 3 square feet for a typical through-wall AC and 4 square feet for a typical PTAC). Results of this thermal bridging analysis are presented in Table 8 and indicate that for all wall assemblies, the annual energy and operating cost penalty associated with thermal bridging is an order of magnitude less than the penalty due to infiltration (assuming a six square inch hole). In fact, these thermal bridging penalties are “in the noise” compared to the difference between low-end and high-end heating energy impact due to infiltration for a six square inch hole.

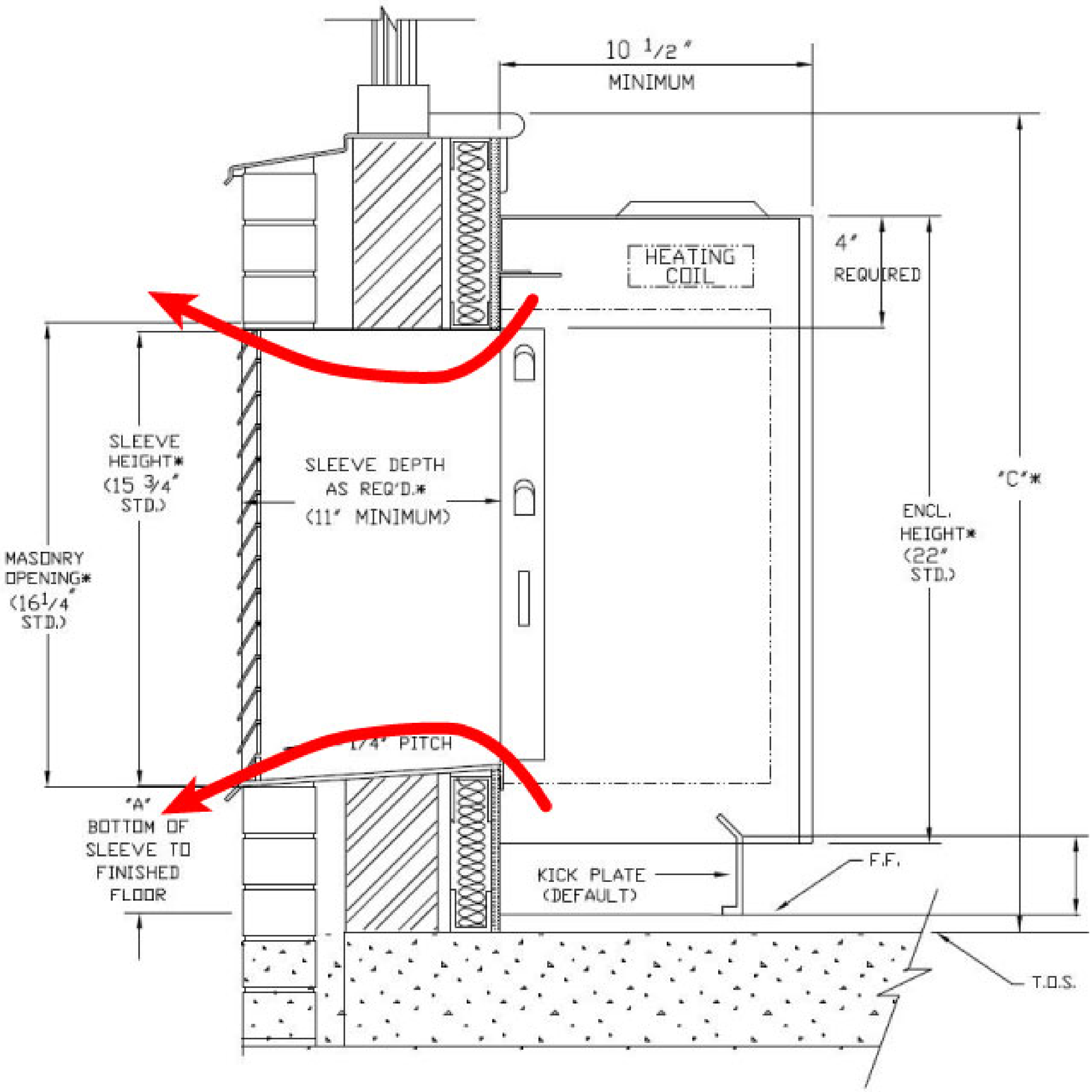

Fig. 13: **Thermal bridging pathway through a metal sleeve**

HEATING ENERGY PENALTY OF ROOM AIR CONDITIONERS – NYC CITYWIDE IMPACT

Assuming that one-third of all rooms have a room air conditioner installed in them, there are about 4 million of these envelope penetrations citywide. At six square inches of leakage per penetration, this adds up to a nearly 167,000 square foot hole — an area almost as large as a typical Manhattan block. Citywide, this translates to an operating cost penalty of between $130 million and $180 million and the release of between 375,000 and 525,000 tons of CO_2 into the atmosphere per year.

HEATING ENERGY PENALTY OF ROOM AIR CONDITIONERS COMPARED TO COOLING ENERGY USE

In six NYC affordable multi-family buildings, SWA obtained electricity bills from a 10% sample of apartments in order to estimate the amount of electricity used for cooling. All buildings were directly metered (i.e. tenants pay their own electric bills) and were cooled with either sleeve or window air conditioners. The average apartment was found to use 667 kWh per year for cooling, which translates into approximately $130 per year in operating costs. One reason that cooling energy use is relatively low in these buildings is that for either window or sleeve configurations, tenants must provide their own AC units and elect to do so only in a fraction of the rooms. The average per apartment cooling electricity use from Table 7 on page 14 (667 kWh per apartment) corresponds with operating a typical 1-ton AC for approximately five hours per day from June through August. At $32 to $45 in heating-energy operating costs per room air conditioner (Table 7), an apartment with two to three wall sleeves could have an annual operating cost penalty of $64 to $135 per year. These results indicate that, in an affordable housing building, the heating energy penalty of several room air conditioners may be comparable to the total annual cooling energy of an apartment.

HEATING ENERGY PENALTY OF ROOM AIR CONDITIONERS – SOME CAVEATS

In NYC, the vast majority of existing buildings do not have thermostatic zone valves that isolate individual

Table 8: **Annual heating energy and operating cost penalty due to a sleeve**

Steel Sleeve Assembly	Wall Assembly Types		
	Uninsulated Masonry	**Fiberglass Batt Insulation**	**Continuous Rigid Installation**
R-2	R-5	R-10	R-15
Annual Operating Cost Penalty of Sleeve Installed in Each Wall Assembly Type	$2.12	$2.82	$3.06
Annual Energy Penalty of Sleeve Installed in Each Wall Assembly Type (MMBTU)	0.15	0.20	0.22

apartments from the rest of the building when the space temperature in that apartment is satisfied. This reality is important for understanding the impact of room air conditioners on heating energy use for two reasons:

1. A central heating plant must supply the same temperature water or the same length of a steam cycle to all apartments in a building. Thus, any factors that result in unbalanced heating loads (such as 25% of apartments with much leakier room air conditioners than their neighbors) contribute to the classic balancing problem of having to overheat some apartments in order to provide sufficient heat to other apartments. The energy penalty associated with these balancing problems is impossible to quantify (especially when overheating may cause certain tenants to open windows) but necessary to note.

2. If heating load due to room air conditioners is significantly reduced on a building-wide basis without a corresponding adjustment of central heating plant set-points, there will likely not be enough of a feedback loop to realize optimal energy savings (i.e. the central boiler may not know it doesn't have to work as hard and to a certain extent, apartments will be overheated rather than boiler run-time being reduced). Therefore, as with any major heating load reduction in an existing building, central plant set-points must be appropriately adjusted to realize optimal energy savings.

AIR SEALING IN EXISTING BUILDING – SOME CAVEATS

In the building science community, the mantra of "build tight and ventilate right" is a common sense guideline for existing building interventions. While the focus of this study is on one particular building component, buildings operate as systems. Experienced practitioners recognize that it is not advisable to significantly tighten envelopes in buildings with ventilation systems that are not functioning properly. In NYC multi-family buildings, central roof exhaust "mushroom fan" type systems are most commonly used to provide ventilation. In SWA's experience, these systems are plagued with design, installation, and maintenance problems that all result in under-performance.

Significant building-wide air-sealing efforts should therefore be coordinated with any necessary retro-commissioning and upgrades to ensure proper ventilation system performance. There are, however, also many older buildings in NYC and beyond that have no mechanical ventilation system. These, usually pre-war, buildings with no mechanical ventilation also tend to be cooled with window air conditioners.

For further reference, the National Center for Healthy Homes has published guidelines for best-practice ventilation upgrades in multi-family buildings both with[4] and without[5] existing ventilation systems.

- Improving ventilation in existing or new buildings with no fan-powered ventilation: www.healthyhomestraining.org/GHMSMFP/Improving_Ventilation_Multi-family_Buildings_Fan_Powered.pdf
- Improving ventilation in existing or new buildings with central roof exhaust: www.healthyhomestraining.org/GHMSMFP/Improving_Ventilation_Central_Roof_Exhaust.pdf

Urban Green Council's Green Codes Task Force[6] has also taken a leadership role in defining improved standards for ventilation performance in multi-family residential buildings.

OFF-THE-SHELF SOLUTIONS

WINDOW AIR CONDITIONERS

As discussed earlier in this report, window air conditioners have become so prevalent and cheaply priced that they are now viewed as just another appliance. In the eyes of consumers, they are supposed to be plug-and-play, just like a television set or a refrigerator, and because of this, there is typically little thought given to their installation. The best, and perhaps only, way to reduce the energy loss that is associated with window air conditioners is to improve the quality of their installation. An improved window air conditioner installation can be performed by a qualified professional who knows how to properly and safely mount the unit in the window opening and, most importantly, seal all potential pathways for air leakage around it. This may involve the use of weather-stripping, closed cell foam and/or a more durable alternative to the common plastic accordion panels.

One way to ensure a more airtight installation in new construction is to use a special window assembly that includes a fixed glass pane below a standard double-hung window. For windows where tenants want to install air conditioners, the building owner replaces the lower fixed glass assembly with an insulated metal panel. The maintenance staff then uses a jig saw to cut out an opening in the insulated metal panel that is specifically tailored to the resident's window air conditioner. One significant benefit of this approach is that for windows where tenants elect to not install window air conditioners, they get the benefit of extra light in their apartments from the fixed third pane of glass, an outcome that is much more appealing than a sleeve penetration. The customized window assembly is of course more expensive than a standard double-hung window but this cost must be balanced against the avoided costs of not having to install sleeves. While this approach clearly takes an O&M commitment, it has been embraced by several NYC developers.

There are several products available on the market that can be used to cover the air conditioner during the winter. Most of these are a cloth-based cover with elastic sewn into the edge. Unfortunately, these products only cover either the evaporator or condenser portion of the air conditioner unit and leave the accordion wings, where the majority of the air leakage occurs, completely open.

Fig. 14: **Window AC installed in fixed panel below traditional double-hung window**

Fig. 15: **Soft cover for window AC**

One other possibility to reduce heat loss during the winter is to remove the air conditioners from the windows entirely as part of a building's operations and maintenance policy. Condo or co-op boards can require that air conditioners be removed from the windows during the heating season and may stipulate that the tenant must hire a professional to install them again in the spring. The existing building staff may be able to do this work as part of their regular duties and provide this service to the tenants "for free." While always an option, experience has demonstrated that this approach is difficult to actually implement.

SLEEVE AIR CONDITIONERS

There are a number of existing methods to address the heat loss through sleeve air conditioners. It is important to seal the joint between the sleeve and the rough opening well, and since the sleeves themselves are permanently installed into the building envelope, this air sealing need only be done once. New construction projects offer the best opportunity to thoroughly seal between the sleeve and the rough opening.

There are also products on the market that can help to reduce the amount of air leakage between the sleeve and the unit and also through the unit itself. One of these is the Chill STOP'R®, a hard plastic cover that fits around the entire sleeve.[7] These covers (and a similar product by Battic Door) do not provide a perfect seal around the edges since the air-sealing material at the connection to the wall is a porous foam. For this foam to be an effective air barrier, the unit must be tightly screwed to the wall — and this is not always the case. SWA suggests the product be modified to include a less-porous foam gasket around the edges.

These covers can be used with the air conditioner unit in place; however, the covers are bulky and a storage space must be reserved for them during the cooling season. For one example, covers were installed as part of a retrofit at two large multi-family buildings in Brooklyn with the intent of reducing the building energy loss during the winter. Unfortunately, when the tenants wanted to use their air conditioners, they had no place to store the covers for the summer and so they simply threw them away. In one building, only 60% of the sampled post-retrofit apartments still had their covers. This is, of course, better than 0%, but a plan for summer storage should be included as part of any project that uses these covers. Current retail price for a Chill STOP'R® is around $60.

Advantages:

- Requires little time to install and remove
- Does not require removal of the AC unit
- Durable

Disadvantages:

- Current designs have poor weather-stripping
- Bulky in storage

Another product that is available to reduce the amount of air leakage from sleeve air conditioners is the Sleeve Sentry.[8] Unlike the Chill STOP'R® and similar covers discussed above, this product is installed inside the sleeve itself. The Sleeve Sentry is a hard plastic panel with a foam gasket that provides a nearly airtight seal. The panel itself is filled with a closed-cell foam that has some insulating value; however, the highly conductive metal sleeve that surrounds it is a thermal bridge that effectively bypasses the panel. It has a relatively compact, flat profile that makes it easy to store. Initial testing results are excellent and indicate that air leakage due to an air conditioner sleeve can be reduced to virtually zero by using this product.

Advantages:

- Seals a sleeve virtually completely
- Easy to install in an empty sleeve
- Small profile — can be easily stored in a closet
- Foam gasket is replaceable

Disadvantages:

- Expensive — closed-cell foam insulation contained in product is compromised by thermal bridging and may not be very cost-effective. The price could likely be reduced by the use of less expensive and comparably effective insulation.

Fig. 16: **Chill STOP'R installed**

Fig. 17: **Sleeve Sentry installed**

- Seasonal installation of the product requires removal of air conditioners from sleeves, which may be labor-intensive.
- Air conditioners are not immediately usable should the weather change quickly. Operating an AC without removing the Sleeve Sentry could lead to damaging overheating of an air conditioner unit.

Another option for sealing air conditioner sleeves is a generic fabric sleeve cover. The fabric cover merely improves appearances and protects the less visually appealing air barrier, which is simply a plastic foam sheet. Included in the kit is a roll of tape to attach the plastic to the air conditioner and AC sleeve. Testing indicates that this product seals nearly as well as a Sleeve Sentry; however, this is a one-time-use product since the plastic sheet can easily be torn and becomes useless once removed for the season.

Advantages:

- Cheap, widely available
- Seals a sleeve virtually completely
- Straightforward installation

Disadvantages:

- Labor-intensive to install
- Not very durable — seal may fail fairly quickly
- New kit must be bought at least once every season

PACKAGED TERMINAL AIR CONDITIONERS

PTACs are installed in sleeves through the building envelope just like sleeve air conditioners, and it is important to seal the joint between the sleeve and the rough opening well. The joint between the sleeve and the drywall should be sealed with caulk to prevent any air leakage coming from around the sleeve. SWA's test results indicated that, in one test case, modest (15%) reductions in leakage area were possible through the one-time sealing of accessible penetrations. It is also possible to reduce the amount of air leakage coming through the PTAC or PTHP itself.

ALTERNATIVE SYSTEMS THAT MAY NOT YET EXIST OR ARE NOT WIDELY IMPLEMENTED

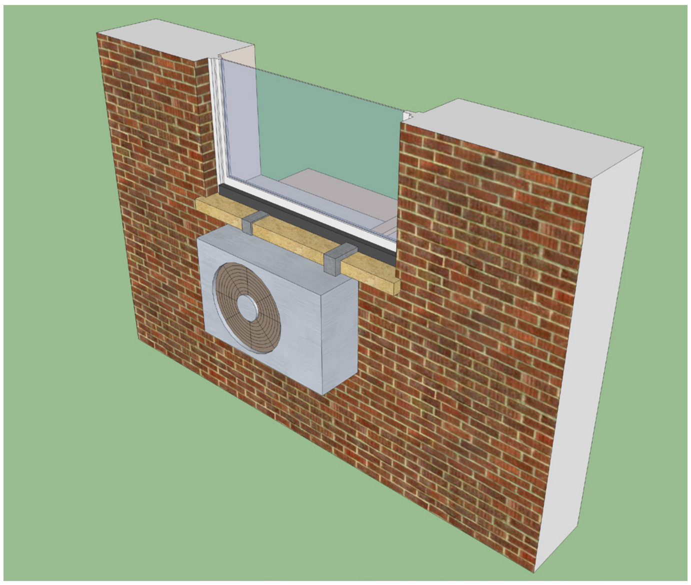

Fig. 18: **“Packaged-split” exterior view**

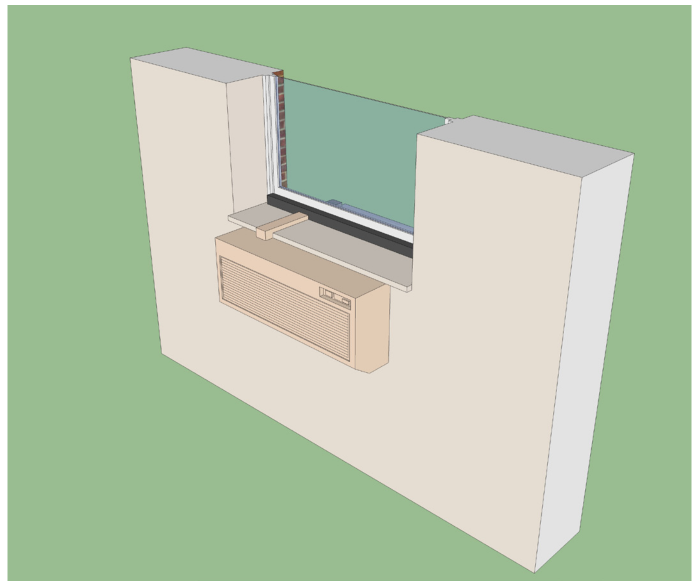

Fig. 19: **“Packaged-split” interior view**

A BETTER INSTALLATION KIT FOR WINDOW ACs IN DOUBLE-HUNG WINDOWS

Despite the sheer number of applications in NYC alone, an effective installation kit for window air conditioners installed in double- or single-hung windows does not exist. Such a kit would be applicable to the vast majority of buildings where winter removal of window air conditioners is not a viable option. This installation kit would need to incorporate effective gaskets to address all of the leakage area around window air conditioners. A fixed panel cut to the dimensions of the window opening (similar to Fig. 14) that houses the AC and can be sealed tightly to the window frame is one approach worth evaluating. In addition, the kit should also come with a flexible weather-stripping material for sealing the gap between the top and bottom sash of the windows created by the installation of a window air conditioner. Results from the sleeve AC testing indicate that leakage through an AC itself can be relatively minimal. If it is confirmed that leakage through window ACs is also minimal, then the retrofit kit would represent a one-time installation with no ongoing maintenance issues (i.e. installing and removing a cover for the AC two times per year). Since a window air conditioner, even if it is left in place for the winter, is still only a semi-permanent installation, the panel would have to be easily removable. To have the greatest impact on our existing building stock, this kit would need to be “universal.” And any kit that could also be used to rigidly secure the air conditioner in place would have a broader market appeal. In recent years, many NYC co-ops have installed brackets on all window air conditioners due to liability concerns. Price point and ease of installation are also important considerations.

A “PACKAGED-SPLIT” AC SYSTEM

AC systems where an indoor unit that cools a space is “split” from an outdoor unit that dissipates heat are very common in small homes and commercial buildings. The only connection between indoor and outdoor sections are two (usually less than 1” diameter) refrigerant lines that have a negligible impact on envelope performance where they penetrate an exterior wall. Window, sleeve and PTAC room air conditioners are all “packaged” equipment where the indoor and outdoor units are housed in one box. With packaged equipment, the box is basically dropped in place and no labor is required to run refrigerant lines based on site-specific requirements or to add refrigerant to the system in proportion to the additional refrigerant line length. Packaged systems therefore have a tremendous advantage over split systems in terms of minimizing the time and cost of installation. In addition, since packaged systems are factory “charged” with refrigerant per manufacturer’s requirements, there is no potential for a field technician to improperly add too much or too little refrigerant, which is very common and can have a negative impact on cooling performance and efficiency.[9]

Figures 18 and 19 on page 21 illustrate a “packaged-split” system alternative that attempts to combine the minimal impact on envelope performance associated with a traditional split system with the “drop-in” benefits of a packaged system.

The outdoor section is hung outside the window, and an indoor unit is mounted just inside. The two halves would be connected by power and refrigerant lines, but this penetration to the outside will be much smaller than those seen in existing package systems and could be more easily sealed to prevent infiltration.

These schematics are presented primarily as “concept cars” to further industry dialogue. A significant consideration associated with this type of approach is zoning. The schematics above represent a more permanent installation than a traditional window AC and therefore could be problematic if they extend beyond the lot line. It is important to note that this type of system is not without precedent. Figure 20 illustrates a small commercial split AC with a pliable refrigerant line connection between indoor and outdoor sections.[10]

Fig. 20: **“Packaged-Split” Installation in Europe**

INNOVATIONS IN OPERATIONS & MAINTENANCE (O&M)

While new technologies are important, especially given that window and sleeve ACs are replaced on a fairly regular cycle, innovations in O&M may represent the greatest opportunity for reducing the impact of room air conditioners on envelope performance in our buildings. For example, in its garden style properties with central heating plants and window air conditioners, a unique building owner in New Jersey has a policy to not investigate winter heat complaints in apartments that still have window air conditioners left in place. Implementing this type of policy requires:

1. A significant commitment from the owner (particularly from the property managers on the receiving end of tenant phone calls).
2. That the tenant of a small apartment find secure storage space for the window air conditioner(s). This approach may or may not be viable in the NYC market, but it is at least representative of the type of creative and common-sense approaches that are required.

This is not a hidden problem. A walk around a building could be used to spot many of the most egregious installation issues in order to identify and target the worst offenders. Since coordinating access to occupied apartments is a significant logistical challenge, incorporating a program to treat room air conditioner leakage at apartment turnover or as part of a periodic preventative maintenance program is another approach worth evaluating. To increase the likelihood of apartment access, these visits could be referred to as “draft-stopping” work. Alternatively, room air conditioner leakage treatment could be coordinated with upgrade work that a resident may not want to miss out on (e.g. new refrigerator delivery, etc.). In cases where room air conditioners are maintained by the building, a certain percentage of units are replaced every year over the life of the building. It is a lost opportunity not to incorporate best-practice installation requirements at the time of room air conditioner replacement. When a building owner is responsible for equipment maintenance, there is a much greater likelihood of being able to control the quality of the installation. In some cases, it is possible for building owners to provide and maintain air conditioners as an additional service to tenants. This type of service is successfully offered to the 14,000 residents of Peter Cooper Village / Stuyvesant Town. In these buildings, the building owner pays for all electricity used (including room air conditioners), so this arrangement is intended to recoup both the operating cost of the air conditioners and the cost of purchasing and maintaining the units.

CONCLUSIONS

Regardless of who pays the cooling bill, a building owner pays a significant portion of the true operating cost of a room air conditioner as a result of the winter heating energy penalty. This study has provided a framework for better understanding this penalty and for evaluating potential solutions. By applying this framework to field results from real buildings, we have demonstrated that the heating energy penalty of room air conditioners is significant both at the level of an entire building and citywide. This large problem, however, is very diffuse in nature and requires customized approaches for particular buildings and owners.

At the end of the day, owners and managers of buildings are the experts at getting things done in their buildings. If an owner wants to make this issue a priority and is armed with a tool kit of off-the-shelf approaches to draw from and customize, minimizing the impact of room air conditioners on envelope performance is a manageable problem. For early adopting owners and property managers, a metric for evaluating the success of a particular room air conditioner treatment strategy could be used to further refine and optimize particular approaches. Synthesizing and disseminating the outcomes of these early efforts in case-study form (with owner permission) could provide other owners with actionable information informed by the work of their peers and the realities of real, occupied buildings.

Solutions that do not exist today are also required to adequately address the challenge. While the technical challenges associated with alternative systems are significant, the greatest hurdle to the development and delivery of alternative systems is a lack of consumer demand. In the case of the improved window AC installation kit, organizing a small group of owners and industry trade organizations to define specification and price-point requirements may represent one concrete next step to tap into NYC area entrepreneurs and guide a market response.

ENDNOTES

[1] Table Credit: http://friedrich.com/products/commercial/thru-the-wall/uni-fit

[2] Personal communication, Jim Fitzgerald, Conservation Services Group, Sep. 12, 2010

[3] "The Path toward Net-Zero High-Rise Residential Buildings: Lessons Learned from Current Practice", Graham Finch, Dave Ricketts, and Warren Knowles, ASHRAE 2010, available at www.rdhbe.com/building_science_technology/publications.php as "High Rise Study."

[4] www.healthyhomestraining.org/GHMSMFP/Improving_Ventilation_Central_Roof_Exhaust.pdf

[5] www.healthyhomestraining.org/GHMSMFP/Improving_Ventilation_Multi-family_Buildings_Fan_Powered.pdf

[6] www.urbangreencouncil.org/greencodes/

[7] www.chillstopr.com

[8] www.sleevesentry.com

[9] "Bigger is Not Better: Sizing Air Conditioners Properly", John Proctor, Zinoviy Katsnelson, and Brad Wilson, Home Energy May/June 1995, available at www.homeenergy.org/archive/hem.dis.anl.gov/eehem/95/950509.html

[10] Photo credit: Henry Gifford

RECOMMENDATIONS OF

THE RESEARCH ADVISORY COMMITTEE

The members of the Research Advisory Committee listed below have endorsed the following statement for policy makers and manufacturers:

Leo Baez
Director of Construction,
Enterprise Community Partners

Greg Bauso
co-Principal,
Monadnock Construction

Scott Frank
Partner,
Jaros, Baum & Bolles

Richard Leigh
Director of Research,
Urban Green Council

Mo Siegel
President / Co-CEO,
Ice Air, LLC

Russell Unger
Executive Director,
Urban Green Council

The authors of the report, **Marc Zuluaga, Sean Maxwell, Jason Block,** and **Liz Eisenberg,** all of Steven Winter Associates, also endorse the following statement.

POLICY RECOMMENDATIONS

There Are Holes in Our Walls shows that envelope penetrations from room air conditioning equipment are a significant cause of air leakage, cooling inefficiency, and winter heat loss. We believe that this study, based on field testing of 16 different room air conditioner configurations in 11 NYC buildings represents a crucial initial exploration of the nature and order of magnitude of both a critical problem and a readily addressable opportunity. While the sample size is limited and the study has not been subject to peer review, we believe that the potential opportunities identified for realizing large scale energy and carbon reductions merit further evaluation and action from policymakers, manufacturers and above all, building owners.

We recommend the following:

1. To Building Owners, Operators, and Training Organizations

1.1 Whenever possible, establish a building-wide program to remove and store window ACs during the heating season.

1.2 Inspect all window ACs, sleeve ACs and PTACs on a regular basis and air-seal openings in the installation to the extent possible.

1.3 Discourage or forbid the installation of window ACs in sleeves; spend extra effort air-sealing them if it cannot be avoided.

1.4 Incorporate an introduction to air sealing into any courses for building operators; as the "best practice" guides recommended in Section 5.3 become available, include these in the course material.

2. To Manufacturers and Equipment Suppliers

2.1 This work indicates that there may be very substantial air leakage if sleeve air conditioners are installed in sleeves designed for larger units. All sleeve air conditioners should include installation kits to ensure a tight fit in older or larger sleeves.

2.2 The plastic louvers supplied with typical window air conditioners allow significant air leakage and thermal transfer, especially as they age. We recommend the development of affordable, high performance installation kits for window air conditioners. These kits should be tested in accordance with the protocols developed in this study and included as standard equipment with all new window air conditioners. Such kits should also be manufactured as retrofit applications for existing room air conditioners.

2.3 Gaskets for PTACs and PTHPs are typically effective when a unit is first installed. However, these gaskets may fail after the units have been removed multiple times for servicing. We recommend designing and testing gaskets for PTACs and PTHPs that are able to withstand the repeated removal and reinstallation of the units, or that can be replaced with the unit. Gasket integrity should be tested using procedures based on the protocols developed as part of this study.

2.4 Optional outside air intake dampers are not typically provided with gaskets and robust closure mechanisms to prevent air infiltration when dampers are in the closed position. This should be corrected.

2.5 Even with good gasketing, this study shows that sleeve air conditioners and PTACs conduct significant heat and often pass significant amounts of air, whether on or off. Advanced design sleeve units should be developed that will offer both thermal and infiltration isolation between interior and exterior environments, employing thermal breaks and separate motors, so that only refrigerant tubes and wires connect the interior and exterior components thermally.

2.6 Split AC systems minimize penetrations through building envelopes because the only necessary connections between inside and outside are wires and tubing. We recommend the development of new mass-market split AC systems or the marketing of existing split systems in the United States. Split systems are widely used overseas, but would need substantial aesthetic improvement before they could be used on building exteriors in the U.S. Also see also 4.2 and 4.3.

3. To the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, the International Code Council, and the U.S. EPA:

3.1 We recommend updating energy modeling and analysis protocols governed by ASHRAE 90.1, including Appendix G, to better capture the impact of room air conditioners on envelope performance.

3.1.1 When room air conditioners are modeled in whole building energy simulations, we recommend that infiltration rates for rooms served be adjusted to account for leakage around the envelope penetration associated with these units.

3.1.2 Guidelines for leakage area and infiltration rates in spaces served by room air conditioner should be developed based on further field-testing. Field-testing with tracer gasses should also be pursued to assess the relationship between leakage area and infiltration rate in high-rise buildings.

3.1.3 Leakage area and infiltration guidelines for energy modeling should be developed for each type of room air conditioner (PTAC, sleeve, window air conditioner) to correlate with “typical” and “best practice” installations. All baseline energy models with room air conditioners should then be modeled using “typical” leakage area per room air conditioner assumptions. Only projects that explicitly include a best practice room air conditioner installation specification should be modeled using the assumptions for best practice leakage area.

3.1.4 In all climates where some form of mechanical cooling is common, models of buildings that do not include designed cooling such as central cooling, sleeve ACs or PTACs, should assume leakage associated with window ACs in some number of rooms to be determined.

3.2 We recognize that in many cases, energy modeling software must be improved to implement the changes described above. We recommend that ASHRAE encourage software developers and the U.S. DOE to improve the capabilities of energy modeling software to evaluate different rates of infiltration in baseline versus proposed energy models.

3.3 The U.S. EPA should incorporate the recommendations above into its energy modeling protocols for the Multi-family High Rise (MFHR) Program.

4. To the City of New York and New York City Council:

4.1 New York City codes should be amended in accordance with the recommendations in Section 3.1.

4.2 Revise the requirements of the New York City Electrical Code for an exterior disconnect switch on the external component of split air conditioning systems to allow a single disconnect location on the inside portion to serve both halves of the unit, while maintaining otherwise appropriate safeguards.

4.3 Revise zoning law and building code as needed to permit installation of components of split ACs and heat pumps on building exteriors, where safe and appropriate.

5. To Energy Efficiency Program Developers

5.1 Federal minimum standards for Room ACs only address direct energy consumption by the equipment. We recommend that these standards be revised to minimize air leakage and to require sleeve and window ACs to include more effective installation kits.

5.2 Energy Star standards for Room ACs only address direct energy consumption by the equipment. We recommend that these standards be revised to exceed the minimum standards on leakage and conductivity proposed in Section 5.1.

5.3 We recommend the development of a succinct best practice guide to problems and potential solutions for minimizing air leakage due to room air conditioners. This guide should be geared to building owners and maintenance staff and be based on both the results of this paper and further case study evaluations. This fact sheet should be disseminated to owners, energy auditors and other key stakeholders in the real estate community.

5.4 These best practices for room air conditioner retrofits should be incorporated into existing energy conservation incentive programs.

5.5 We recommend actively engaging and educating key stakeholders in order to stimulate demand for improved solutions.