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Investigation of Airtightness Interactions in New Multifamily Buildings – Phase II

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Table of Contents

Table of Tables

Table of Figures

Executive Summary

This study examines the effects of increased envelope airtightness driven by recent Energy Code changes in Washington State on the performance of multifamily buildings. The project sought to determine what level of airtightness should be specified in code for these buildings and proposes the types and designs of ventilation and exhaust systems that are appropriate at different levels of airtightness. This study is a continuation of a preliminary investigation spurred by tenant complaints in new multifamily buildings of nuisance noise and cold drafts related to ventilation systems. Twelve buildings were visited in this study. Of the 12, 10 were mid-rise (seven stories or fewer) and two were high-rise buildings. Nine were designed around exhaust-based ventilation systems and the remaining three had balanced flow ventilation schemes with energy recovery ventilation (ERV).

All seven of the mid-rise exhaust-based buildings, in which each residential unit is ventilated by a dedicated bathroom fan running continuously with makeup air sourced through trickle vents and other envelope penetrations, were completely depressurized at base-level ventilation flows (2012 IMC compliant). The whole building airtightness test results for these buildings ranged from 0.21 to 0.47 cfm/ft^2 at 75 Pascals testing pressure. Even buildings that failed to meet the 2015 Washington State Energy Code (WSEC) target of 0.4 cfm/ft^2 were observed to be depressurized at their base ventilation levels. In other words, all air leaving the buildings is intentionally being drawn through mechanical fans and reducing air leakage further will not change the infiltration/ventilation rate in these buildings. This suggests that the current 2015 WSEC airtightness target of 0.4 cfm/ft^2 is appropriate for exhaust-based multifamily systems and that increasing the envelope tightness target will not result in added energy savings in these building types.

When examining the two high-rise buildings, full depressurization at base-level ventilation flows (i.e., without added exhaust from kitchen hoods or dryers) was not apparent. The high-rises, unlike any of the mid-rise buildings, were dominated by stack effect – with cold air infiltrating at the bottom floors, warming within the building, and exfiltrating at the top floors. In the case of these high-rise buildings, increased levels of airtightness may result in additional energy savings by reducing uncontrolled infiltration on the higher and lower floors.

As expected, the three balanced flow buildings, which rely on unit-by-unit ERVs to exhaust and supply each unit, were not depressurized at the base ventilation flows. When kitchen hoods and dryers were switched on, the ERVs were unable to provide any significant amount of additional makeup air to the apartment, and the units behaved similarly to their exhaust-based counterparts. Nevertheless, since the units are not mechanically depressurized during standard operation (without appliances running), the envelope airtightness is a factor in the energy consumption of the building since air is now able to more freely flow through the envelope, causing added load to the heating and cooling systems. As codes progress toward requiring balanced flow systems in all multifamily construction, explicit envelope tightness targets must be set to ensure energy savings are realized.

Throughout all 12 buildings in the study, the ventilation airflows were not observed to be hindered by the overall envelope tightness levels of the building. Ventilation systems were running within the bounds of the intended design, but building depressurization varied based on ventilation system type and the envelope tightness. Kitchen hood airflows were relatively unaffected by testing conditions (while sometimes reversing bathroom fan flows), indicating that these typical appliances had no difficulty overcoming the additional differential pressure caused by airtight construction. Clothes dryers, on the other hand, indicated reduced airflow in a few test conditions when subjected to increased differential pressures related to tight envelope construction.

Energy codes in Washington State are progressing with the commonly accepted belief that tighter buildings save energy, without specific focus on the interaction of airtightness with the ventilation system design. This study shows that in mid-rise apartments with exhaust-only ventilation systems, airtightness beyond about 0.4 cfm/ft^2 at 75 Pascals does not result in energy savings and may cause some adverse impacts related to increased drying times for clothes dryers, nuisance drafts, and whistling under doors.

On the other hand, high-rise buildings and buildings with balanced flow ventilation systems will continue to see additional energy savings from higher levels of airtightness. Research to date is insufficient to determine the optimal levels of airtightness achievable by the building industry that would result in worthwhile energy savings not adversely impact other systems or aspects of the building. This research should be completed before extending the code requirements concerning airtightness and ventilation system design in this building type. A current proposal before the Washington State Building Code Council from the Energy Technical Advisory Group seeks to require balanced flow ventilation systems in all multifamily buildings with minimally efficient heat recovery ventilators and airtightness levels of 0.25 cfm/ft^2 at 75 Pascals. This type of code change proposal should be supported with additional research targeted to answer the following questions:

1. What is the optimal airtightness level for multifamily buildings with balanced flow ventilation systems?
2. What is the optimal minimum thermal effectiveness specification for heat recovery ventilators in multifamily buildings?
3. What is the optimal specification for fan performance in heat recovery ventilators for multifamily buildings?
4. What products are currently available that meet these optimized specifications? What work with manufacturers or distributors may need to be done to develop or import more products that are targeted to this market segment?
5. Are there design or product solutions for makeup air to improve performance of kitchen hoods and dryers in airtight multifamily buildings? What products may need to be developed or imported?
6. What barriers may exist to implementation of whole building or floor-by-floor solutions that reduce the architectural and maintenance impact of heat recovery ventilation (HRV) systems in each apartment?

1. Introduction

This Investigation of Airtightness and Ventilation Interactions in New Multifamily Buildings study is the continuation from a Phase I study entitled Multifamily Unit Depressurization Study (MUDS). Phase I investigated depressurization and ventilation system characteristics within residential units, which had had recent tenant complaints of exhaust-based ventilation systems negatively affecting comfort (drafts and noise). Phase II expands on the work from Phase I to study the effects of high levels of mandated airtightness in a larger sample of multifamily buildings. Phase II endeavors to determine, for exhaust-based ventilation systems, what level of building tightness leads to diminished energy savings from infiltration reduction. For units with balanced heat recovery or energy recovery ventilation systems (HRVs/ERVs), investigations are performed to determine whether these systems provide adequate makeup air pathways to improve performance of intermittent exhaust appliances (e.g., clothes dryer, kitchen hood).

Some theoretical degree of airtightness exists that would make current exhaust-only ventilation strategies problematic and would interfere with the operation of traditional dryers and kitchen hood fans. The assumption has been that, with existing construction techniques, over-tight multifamily buildings were unlikely to occur in reality – that there would always be enough air leakage in real-world building envelopes to provide sufficient makeup air to exhausting appliances. However, given builders' commendable improvements in creating tight building envelopes, it is now important to reevaluate whether traditional ventilation strategies still make sense in new construction and whether any additional tightening of the building envelope is advisable and enforceable by code.

Energy codes will continue to become more stringent as energy savings become more elusive. Awareness of where savings can be realized, and avoidance of the wrong measures, will be crucial. This research project will aim to steer future code development in the right direction with regard to building envelope tightness.

1.1. Research Objectives

This study aims to document and understand what level of airtightness results in the depressurization of the building due to the operation of ventilation and other exhaust fans, quantify the impact of this level of airtightness and operation of ventilation fans on the operation of appliance exhaust fans (clothes dryers and kitchen hood fans), and to determine the degree to which a balanced ventilation system is able to contribute to solving the problems observed. If these systems can be relied upon to temporarily provide some degree of unbalanced ventilation, they may be an effective measure in reducing depressurization issues and thus provide builders with an ideal envelope tightness target rather than sealing buildings to the point where it becomes counterproductive. Determining air tightness criteria will require whole-building air barrier test results in combination with field measurements of baseline and induced pressures in individual units.

2. Methodology

A total of 12 multifamily buildings were visited in this study, with a minimum of four units tested per building. The only requirement in recruiting buildings was that a whole-building air-barrier test had been completed and was available. In Washington state, the airtightness testing requirement was added to the 2009 edition of the Washington State Energy Code; therefore, all recruited buildings had to have been constructed within the last 10 years. All buildings included in the study were built after 2014 and all but one were built in accordance with the 2012 energy code (the other based on the 2009 energy code). Ten of the 12 buildings were within Seattle city limits, and therefore complied with the Seattle Energy Code amendments; the remaining two were within King County and thus adhered to the Washington State Energy Code.

Within each building, the selection of units was primarily driven by vacancies with an emphasis on bottom- and top-floor units whenever possible. Bottom-floor units allowed measurement of airflow from the exterior, and comparing those measurements with top-floor units facilitated accounting for any influence of the stack effect on unit (de)pressurization.

Table 1 summarizes the site characteristics of each building visited in the study. Site 11 has been split into two distinct project sites for analysis as two separate buildings were tested in accordance with this study.

Table 1. Site Characteristics

Site No.	Building Area (ft^2)	Floors	Units	Blower Door (cfm/ft^2 @ 75 Pa)	Vent System	Makeup Path
S1	49,560	6	71	0.233	Exhaust only	Slot vents
S2	175,153	7	384	0.208	Exhaust only	Slot vents
S3	101,042	6	130	0.330	Exhaust only	Slot vents
S4	219,560	41	393	0.354	Exhaust with supply air for upper floors	Slot vents (floors 2-13); supply air (floors 14-41)
S5	305,321	7	304	0.470	Exhaust only	Slot vents
S6	342,080	5	231	0.425	Exhaust only	Slot vents
S7	93,195	7	83	0.175	Balanced (ERV)	n/a
S8	82,129	6	103	0.246	Balanced (ERV)	n/a
S9	193,218	7	111	0.258	Balanced (ERV)	n/a
S10	567,403	39	339	0.237	Exhaust only	Operable windows
S11_A	216,814	7	308	0.287	Exhaust only	Slot vents
S11_B	209,357	7	300	0.270	Exhaust only	Slot vents

2.1. Data Collection

Airflow and pressurization measurements were recorded across a host of fan, appliance, and makeup air pathway scenarios. Residential units were simulated to run in five different scenarios: base-level ventilation (continuous, design flow), boost-level ventilation (either occupant sensor or manual timers to increase the flow of ventilation air), ventilation system with the kitchen hood on, ventilation system with the dryer on, and ventilation system with all appliances on. Relative pressures with respect to the building exterior as well as to the corridor were taken at each operating point and ventilation system airflows were directly measured by a calibrated flow hood. When possible, flow rates were taken from exterior vent caps – this allowed for direct measurement of exhaust base appliances but was not possible at most locations.

Differential pressure values were measured using an Energy Conservatory DG-700 Pressure Flow Gauge. The reference pressure was within the unit and pressure tubes were routed under the entrance door, into the hallway, and another out through a window to the exterior. The window was taped off to simulate the standard operating point for the pressure readings. Slot vents in exhaust-based units remained open during all standard tests. In a couple of cases, simulated makeup air paths, mimicking an abandoned dryer duct, were created to analyze the effect a permanent makeup path may have on the apartment pressurization.

Ventilation flow rates within each apartment unit were measured by placing a flow hood (LoFlow Balometer Model 6200) over diffusers and fans to measure volumetric flow. Where possible, flow rates were measured at exterior vent caps to capture appliance flows at different operating points.

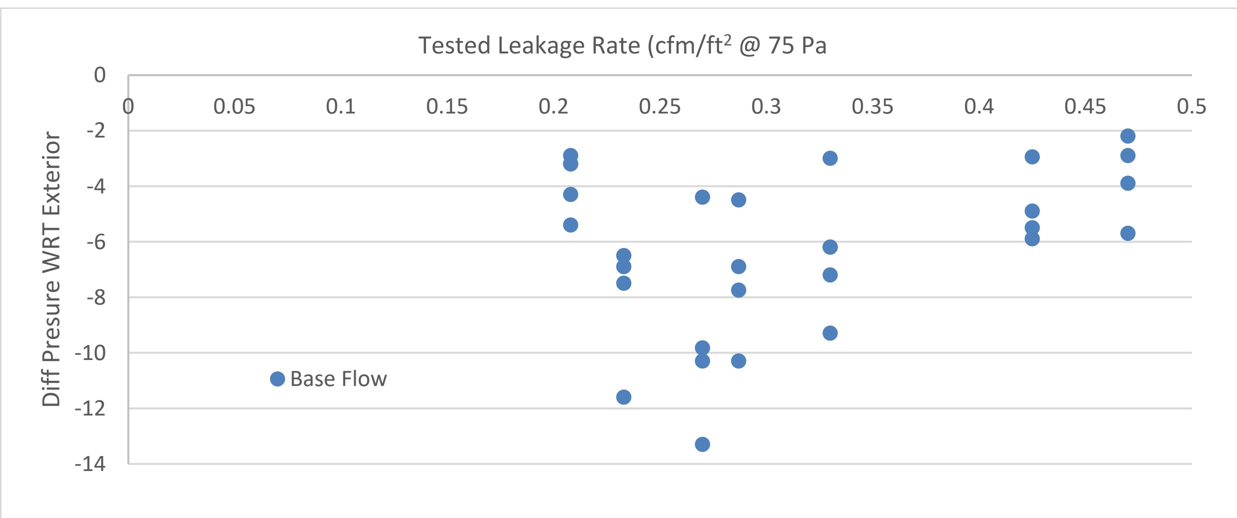
3. Results and Findings

Ten of the 12 buildings were mid-rise buildings (seven stories or fewer) and the remaining two were high-rise construction (39 and 41 stories). Three buildings, all mid-rise, used a balanced ventilation flow scheme in which unit-by-unit Energy Recovery Ventilators (ERVs) exhausted bathrooms and laundry rooms and supplied air directly to all living spaces. The remaining nine buildings were designed with exhaust-based ventilation systems, with ductwork routing horizontally to exterior vent caps. All exhaust-based buildings used a bathroom exhaust fan (also called a whole house fan, WHF) set to run continuously at a base-level flow and ramp to high speed from an occupancy sensor. Aside from the high-rise apartments, all exhaust-based units sourced air through trickle vents built into the windows. The high-rise apartments relied on operable windows, trickle vents, or had makeup air supplied directly to the unit.

3.1. Exhaust-Based Buildings

For the exhaust-based, mid-rise buildings, all units tested were completely depressurized with respect to the exterior at their base (ASHRAE 62.2) ventilation levels. **Error! Reference source not found.** Figure 1 shows the depressurization measurements of the 30 units across seven buildings, plotted against the whole-building air barrier test results. The tested leakage rate (cfm/ft^2 @ 75 Pa) is the average leakage rate obtained from the positive and negative pressurization tests required by the Washington State Energy Code and in compliance with ASTM E779-10. Whole-building air barrier tests were not conducted as part of this study; the test results were provided by building owners and/or the third-party testing agencies.

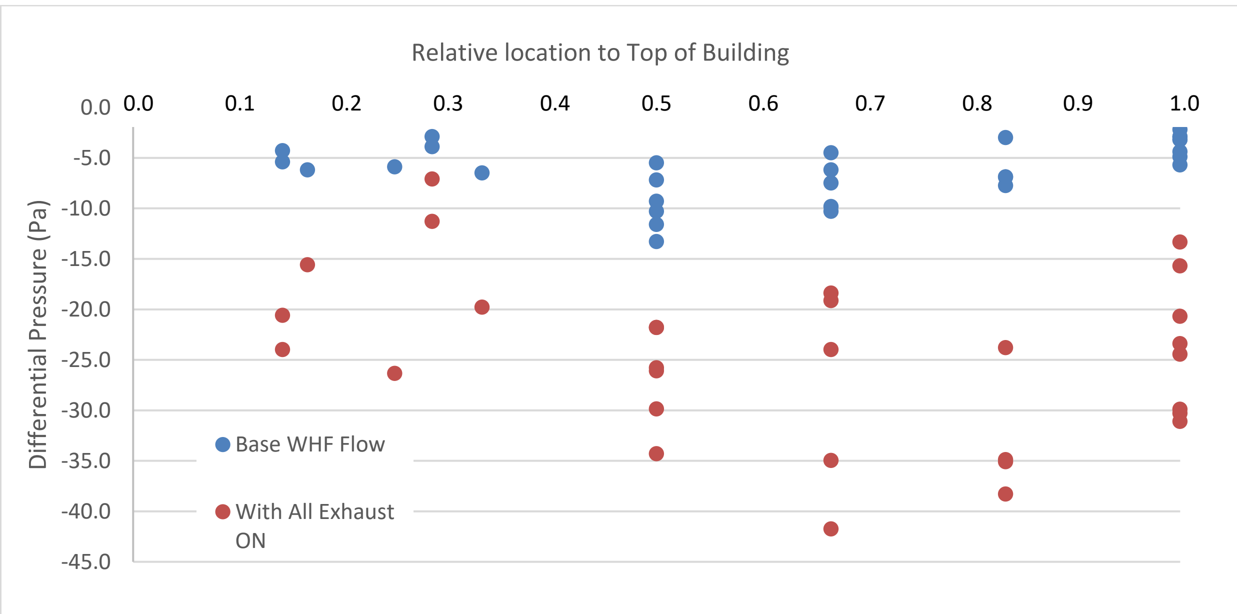
Figure 1. Differential Pressure *wrt* Exterior – Building Envelope Tightness (Mid-Rise)



The main takeaway from **Error! Reference source not found.** is that all the units were completely depressurized to the exterior at their design ventilation flow. Even the two buildings that failed to meet the whole-building airtightness test of 0.4 cfm/ft^2 maintained a negative pressure differential to the exterior at the base-level ventilation flow. Multifamily buildings that rely on exhaust-based ventilation strategies behave in a unique manner in that they are constantly pulling air through the envelope, either through intended openings (trickle vents) or through unsealed portions of the exterior envelope construction. When considering exhaust-based multifamily buildings, a theoretical whole-building airtightness level exists that would keep the building just slightly negative with respect to the exterior. This point is beneficial because it eliminates any extra outdoor air load on the heating/cooling systems via infiltration and it does not create a situation in which exhaust fans and exhaust-based appliances "struggle" to source air for the fans, which increase fan energy consumption. It is recommended that the mandatory (code required) airtightness target for exhaust-based multifamily buildings not be lowered any further than 0.4 cfm/ft^2 at 75 Pa.

A supplemental condition tested in various units was to turn the exhaust fans off entirely and measure the differential pressures. All mid-rise units tested under this condition remained depressurized with respect to the exterior. Although this study did not investigate compartmentalization of residential units, this finding is interesting in that it shows that even with tighter envelope construction, measurable crossover effects between units still exist.

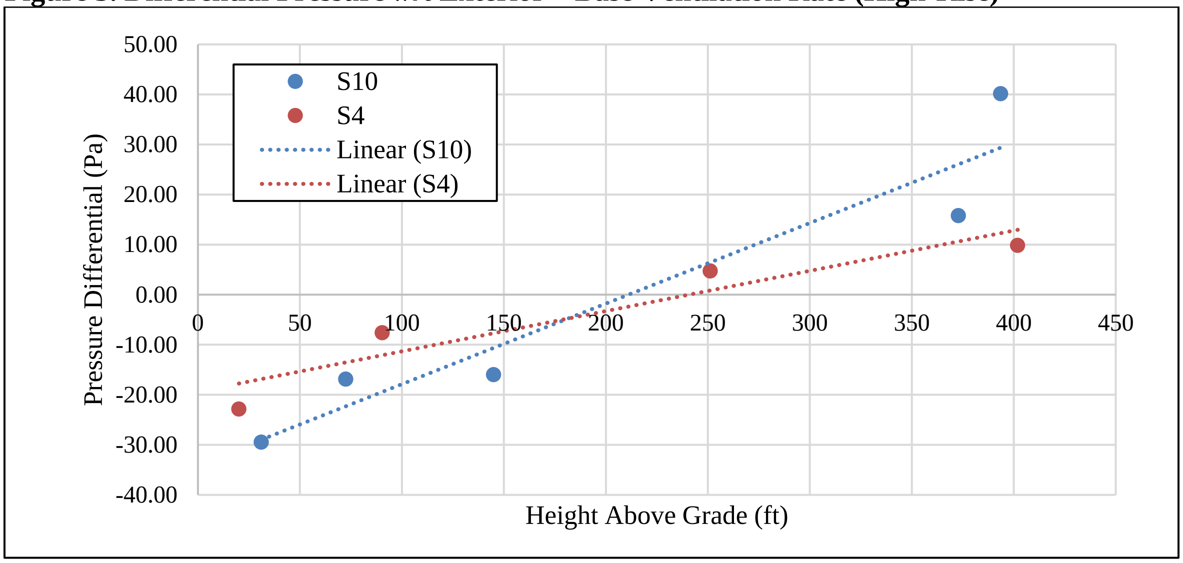
Figure 2. Differential Pressure *wrt* Exterior – Relative Height (Mid-Rise)



All seven of the mid-rise, exhaust-based buildings were completely depressurized at all flow conditions tested. Figure 2 shows the differential pressure readings taken at both the base-level flow from the whole house fan (WHF) as well as with all exhaust-based appliances running (kitchen hood, dryer, and any bathroom fans present). The horizontal axis normalizes each unit's relative height to the overall building height. For instance, a unit on the 3rd floor of a 6-story building would be halfway to the top of the building and placed at "0.5" in the figure above. The average differential pressure with respect to the exterior, at the unit's base ventilation flow, was -5.8 Pa and was -23.9 Pa with all exhaust appliances running. The units shown in the figure have whole building airtightness results that vary from 0.208 to 0.47 cfm/ft^2 at 75 Pa.

Figure 2 also indicates no observable correlation between the unit's relative height in the building and the extent of depressurization with respect to the exterior. This implies that stack effect in mid-rise multifamily is not a significant driver of differential pressure in residential units when compared against the effects of exhaust fans and appliances. However, this was not the case in high-rise buildings. The impact of the stack effect was evident in each of the high-rise buildings visited in this study; both buildings were completely depressurized in the bottom-most units and positively pressurized on the top floors. The research team visited each of these buildings in December, with outdoor temperatures below 50°F, so it is expected that cold air infiltrates at the bottom floors, heats up in the building, rises and exfiltrates at the top-most floors. This principle is distinctly shown in Figure 3 below. Both buildings show their respective neutral plane (zero pressure differential to the exterior) slightly above their middle floor; this is expected given that all units' exhaust fans were running, thus depressurizing more of the building and pushing the neutral plane higher.

Figure 3. Differential Pressure *wrt* Exterior – Base Ventilation Rate (High-Rise)



3.2. High-Rise Buildings

Airtightness and ventilation system design have different implications for high-rise buildings than they do for mid-rise.[1] High-rise buildings experience much more significant impacts of stack pressures, as well as wind-driven pressures, which can lead to draftiness, air noise, high differential pressures, and poor ventilation system performance. In cold weather, air will be leaking into the building in the lower floors, rising as it warms, and escaping out of the building at the upper floors. Airtight construction will limit the amount of this airflow.

Stack pressures are directly related to the height of the building and the temperature difference between the inside and outside. This study's field data were mostly collected during relatively

[1] For this discussion, mid-rise covers buildings of 3-7 stories (up to 75 feet above grade to the highest occupiable level).

mild outdoor temperatures (around 45°F). At these temperatures, stack pressure differences were not apparent in the data collected from the mid-rise buildings, but were obvious in the data from the high-rise buildings, as shown in Figure 3. For very tall buildings, care must be taken to separate the stair and elevator shafts in the core from the apartment units to reduce stack effects in the units. If no effort is made to separate the central shafts from the residential units, the building operates as a single chimney with differential pressures greater than 65Pa in 40-story buildings, when measured in the lower and upper floors. If each floor and apartment were to be perfectly sealed off from the rest of the building, then each apartment would operate as its own 10-foot-high stack, with minimal stack pressures. Real buildings operate somewhere in between these two extremes. The tightness of the exterior envelope and interior walls between the units and the core will govern the pressure differential across the envelope. If the external envelope is very tight compared to the walls between the units and the core, then this will result in high differential pressures between the units and outside. To achieve best results, designers and builders must strive to reduce external leaks, as well as internal leaks between floors, the shafts, and the apartments.

The high-rise buildings included in the study were both remarkably airtight with whole-building pressure test results of 0.24 and 0.35 cfm/ft^2 at 75 Pa. Test conditions of 45°F outside air temperature yielded maximum unit-to-exterior differential pressures of -23 and -30 Pa on the lower floors. These pressures would suggest much higher (38–58Pa) differential pressures during design heating days of 26°F outside air temperatures. These levels of differential pressures are in the range that will impact the performance of a clothes dryer and could lead to whistling of air through cracks or under doors. This indicates that as designers and builders endeavor to achieve higher levels of exterior airtightness, they should likewise pay attention to “compartmentalization” in high-rise buildings.

3.3. Balanced Flow Buildings

Three of the 12 buildings visited had a balanced ventilation design within the residential units that utilized unit-by-unit energy recovery ventilators (ERVs) to exhaust bathrooms and laundry rooms (when present) and to supply the main living area and bedroom(s). All units were set to run continuously, with two buildings giving the residents a manual control to boost the flow of the unit for 20 minutes. Similar test procedures were run in the balanced flow buildings as in the exhaust-based buildings. Differential pressures and ventilation system airflows were measured at the base-level continuous setting, then appliances were turned on to measure the effects on differential pressure readings and airflows of the ventilation system. The study team expected that balanced ventilation systems would not induce a negative pressure differential relative to the exterior at standard operation; field-measured pressure readings confirmed this theory with readings within a range of ±5 Pa for each unit.

When kitchen hoods and dryers were switched on, however, the units became depressurized with readings consistent with those from the exhaust-only ventilation systems. This implies that makeup air for the kitchen hood and dryer was sourced through the same means as the other buildings – through envelope penetrations, neighboring units, and the adjacent corridor. This was surprising since a permanent makeup air path, via the 5” or 6” round supply duct (and associated supply fan) tied to the ERV, would not help to supply makeup air to the apartment unit.

Figure 4. Differential Pressure *wrt* Exterior – All Mid-Rise Buildings

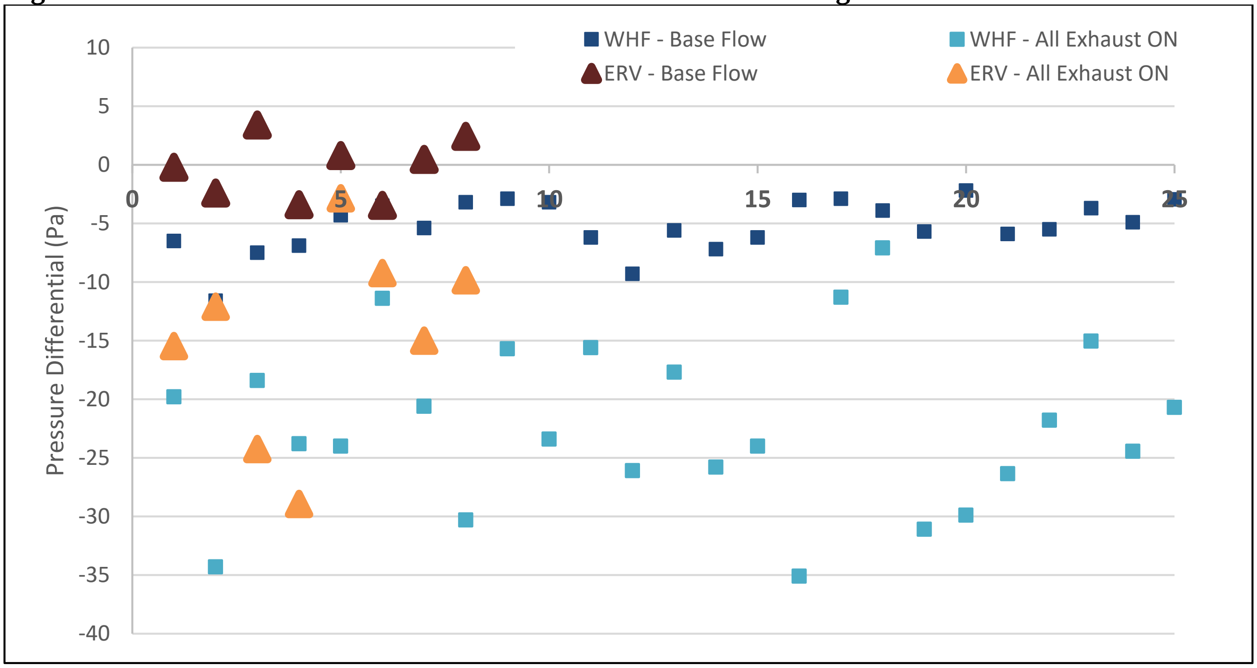


Figure 4 summarizes the pressure differential relative to the exterior at the base (continuous) ventilation flow as well as when the unit's kitchen hood and dryer (if present) were running for all nine mid-rise buildings in the study. As shown, the units with an ERV reacted similarly to those with exhaust fans when all exhaust was on (kitchen hood and dryer) – meaning the ERV did not provide additional makeup air to the apartment. This was confirmed from flow hood readings on all the interior terminals (diffusers and grilles) associated with the ventilation system, with results shown below in Table 2.

Table 2. Flow Measurements of ERV Systems

• Site ID	Unit	Floor	Base Ventilation Flow		Ventilation Flow with All Exhaust ON		Pressure Differential *wrt* Exterior with All Exhaust ON
			Return	Supply	Return	Supply	
S7	204	2 of 8	47	53	33	52	-15.5
S7	207	2 of 8	38	54	30	56	-12.1
S7	804	8 of 8	47	52	37	59	-24.3
S7	807	8 of 8	32	51	25	61	-28.9
S8	121	1 of 6	51	54	51	51	-2.9
S8	124	1 of 6	61	67	60	66	-9.2
S8	611	6 of 6	57	55	52	56	-15
S8	616	6 of 6	62	65	57	73	-9.9
S9	221	2 of 7	32	53	31	62	N/A*
S9	316	3 of 7	59	76	53	80	N/A*
S9	621	6 of 7	55	69	53	70	N/A*

* Windy conditions prevented accurate measurement of exterior pressure

Kitchen hoods and dryers, combined exhaust is roughly 180 cfm.[2] For units with balanced ventilation flow, the average depressurization level was -14.7 Pa, or -0.06" w.g. With this level of depressurization, and an induced exhaust flow of 180 cfm from the apartment, the study team theorized that the ERV and associated supply ductwork would be capable of delivering a portion of the makeup air needed. Measurements contradicted the theory and showed that makeup air is sourced in the same manner as in exhaust-based apartments.

In closer examination of building S7, static pressure calculations of the existing ERV supply ducts showed that an extra 60 cfm could be supplied through the system with a pressure increase of only -0.08" w.g. (equal to the unit's depressurization level when all exhaust appliances are turned on). However, an average increase of only 5 cfm was measured in the units. When examining the external static pressure chart for the ERV (Lifebreath 120), it became obvious that adding even just the 5 cfm through the ERV core equated to an increase of nearly 0.1" w.g. in static pressure in the system – effectively counteracting any loss in pressure caused by the exhaust-based appliances. The installed ductwork, louvers, and diffusers would be able to make up roughly 1/3 of the exhausted air; however, the ERV core is not designed to deliver that extra air, therefore the makeup air for the apartment is sourced through the envelope (interior and exterior), similar to the condition for exhaust-based apartments.

[2] The minimum airflow for a kitchen range hood is only 100 cfm per Table 403.3.2.3 of 2018 IMC at the link. Dryer exhaust airflow is estimated at 60-80 cfm from the test results at Site S2.

4. Next Steps

4.1. Code Implications

The current momentum for codes and standards across the United States has been increasing levels of mandated or targeted airtightness and movement toward balanced flow ventilation – away from exhaust-only ventilation systems. The current (2015) Washington State Energy Code (WSEC) requires whole-building airtightness testing for all commercial buildings. The code has set a target leakage rate of 0.4 cfm/ft^2 at 75 Pascal test pressure (all references will assume 75 Pa unless noted), with an optional credit under Section C406 for reaching 0.25 cfm/ft^2. The Seattle amendments to the state code currently mandate a target of 0.3 cfm/ft^2. These targets are set with the theory that achieving savings from higher levels of airtightness eliminates most of the "uncontrolled" leakage from stack and wind effects and reduces the airflow through the building to only the intentional airflow associated with the ventilation system. These targets are without regard to ventilation system design.

The tightness target of 0.4 cfm/ft^2, in combination with an exhaust-only ventilation system, appears sufficient to achieve full building depressurization in mid-rise multifamily buildings and is an achievable target with no demonstrable adverse effects on building occupants. Increasing airtightness beyond this level (to 0.25 or tighter) without changing the ventilation system design does not save energy, may introduce comfort and noise complaints, and may begin to impact the performance of appliances such as the dryer. Therefore, switching to a balanced flow ventilation system design when going to higher levels of airtightness should be considered.

The 2018 Washington State Energy Code, commercial provisions, requires all commercial buildings in Washington State (including mid- and high-rise residential) to achieve a tested envelope tightness level of 0.25 cfm/ft^2. All multifamily buildings would be required to provide a balanced flow ventilation system with a heat recovery ventilator.[3] Approximately half of the buildings tested in the sample for this study achieved a 0.25 cfm/ft^2 or better level of airtightness.

4.2. Future Work

If balanced flow heat recovery ventilation systems become mandatory, several design aspects should be emphasized to assist the market in the transition and to achieve true energy efficiency without creating unintended negative consequences,

1. Air tightness targets

When using continuous exhaust-only ventilation systems in multifamily construction, no energy savings accrue from tightening multifamily buildings beyond roughly 0.4 cfm/ft^2. However, the introduction of a balanced flow ventilation system to a leaky building will lead to uncontrolled infiltration from wind and stack effects. Tighter buildings will result in additional energy savings in the case of balanced flow, which raises the following questions: How much energy is saved from tighter targets, how achievable are those tighter targets in the marketplace, and how much (if any) does it cost to achieve those tighter targets?

[3] See https://sbcc.wa.gov/sites/default/files/2020-04/2018%20WSEC_C%202nd%20print.pdf

AirflowNetwork in EnergyPlus can be used to assess prototype buildings in various Northwest climate zones to determine the amount of energy savings potentially available from various levels of airtightness in multifamily buildings with balanced flow ventilation systems. Surveys of contractors and envelope consultants can be used to assess the feasibility of market-wide achievement of higher airtightness levels and the potential costs to achieve those higher levels.

2. Makeup air

With tighter envelope construction, data show that the ability of appliances (such as the dryer) to draw makeup air begins to be impacted at levels below about 0.4 cfm/ft^2. Balanced flow ventilation systems provide makeup air for the base level of ventilation air but are not designed to provide makeup air for other appliances. The study showed that adequate makeup air for the dryer or kitchen hood cannot be drawn through a heat recovery ventilation system designed to supply base levels of ventilation. Based on these findings, airtight construction with a balanced flow ventilation system may be the most energy efficient option for providing the base level of ventilation; however, it does not help source the makeup air for the dryer or kitchen hood. In typical construction, the majority of makeup air for the kitchen hood and dryer are being pulled from the corridor and from neighboring apartments.

A ventless heat pump dryer could be a good solution as it does not require exhausted air from the unit to function and will not be affected by reduced leakage area as buildings get tighter. In contrast, many questions remain about whether a ventless kitchen hood can provide adequate indoor air quality. At higher levels of airtightness, a different solution for providing makeup air for the kitchen hood is required, such as a makeup air fan controlled in conjunction with the exhaust fan. These products are not currently on the market to any significant degree in the US.

Additional research could include investigating how other parts of the world that have adopted the Passive House approach have addressed the issues of makeup air, including whether they have design techniques and/or products designed to solve this issue.

3. Fan energy and thermal effectiveness

The energy savings of a balanced flow ventilation system is affected by the envelope tightness and the performance of the ventilation system. A complete specification for codes or programs should therefore include targets for the minimum airtightness level, minimum thermal effectiveness of the heat recovery mechanism, and minimum fan efficiency. Without targets for these measures, a balanced flow heat recovery ventilation system will not always lead to energy savings.

- With a balanced flow ventilation system, the building is no longer fully depressurized, so the wind and stack effects will drive additional uncontrolled infiltration through the cracks in the building. Without an adequately airtight envelope, the uncontrolled leakage will continue to impact the heating load from ventilation and infiltration.
- Heat recovery ventilators use fans to push air through a filter, heat exchanger, and ductwork to exhaust and supply air to the space. Relative to a simple exhaust fan, this system requires added fan energy. A heat recovery ventilator with poor fan efficiency

will use more fan energy than it recovers in heating energy. Fan performance for this type of equipment can typically vary from 0.5 to 2 cfm/W.
- The thermal effectiveness of heat recovery equipment typically varies from 50%–80%. A heat/energy recovery ventilator with low thermal effectiveness will not recapture enough heat from the exhaust air to make up for the increased fan energy required to power the heat recovery ventilator. Note that the value of the heat recovered also varies a great deal depending on the balance point of the apartment (small well-insulated apartments do not need very much heat) and depending on the efficiency of the heating system (heat recovery in an electric resistance apartment is worth much more than heat recovery in an apartment heated by a ductless heat pump).

Given these variables, research should be conducted to arrive at an optimal specification for heat recovery ventilation equipment that includes thermal effectiveness and fan performance.

The market for heat recovery ventilation in multifamily buildings is underdeveloped in this region. Very few successful examples exist of highly functional, low maintenance, quiet, and highly energy efficient balanced flow ventilation systems in multifamily buildings in this region. The design issues for this type of system are much different from those of an exhaust-only system based on bath fans. Whole building, floor-by-floor, and unit-by-unit solutions each present different design challenges. Equipment location, maintenance access, and noise control are important. Some efforts to assess and support this market may be necessary for a successful rapid transition of the industry to these products. Such efforts could include outreach to product reps and manufacturers to speed development and/or importation of highly energy efficient products, and development of design guidelines and training for designers to advance whole building and floor-by-floor design solutions.

Questions for further research

1. What is the optimal airtightness level for multifamily buildings with balanced flow ventilation systems?
2. What is the optimal minimum thermal effectiveness specification for heat recovery ventilators?
3. What is the optimal specification for fan performance in heat recovery ventilators for multifamily buildings?
4. What products are currently available that meet higher optimized specifications? What work with manufacturers or distributors may be necessary to develop or import more products targeted to this market segment?
5. Are there design or product solutions for makeup air to improve performance of kitchen hoods and dryers in airtight multifamily buildings? What products may need to be developed or imported?
6. What barriers may exist to implementation of whole building or floor-by-floor solutions that reduce the architectural and maintenance impacts of HRVs in each apartment?