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Investigation of Airtightness Interactions in New Multifamily Buildings – Phase III

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Executive Summary

The following report summarizes the continued investigation from NEEA's multifamily depressurization (MUDS) field studies (Phase I and Phase II) to determine the levels of compartmentalization that may have a negative impact on exhaust appliances. It also addresses code changes introduced in the 2018 Washington State Energy Code (WSEC) that affect multifamily buildings. Additionally, this project seeks to identify current limits to typical multifamily exhaust fan and dryer technologies and to propose design solutions to mitigate issues.

- Previous studies found that standard practice for ventilating dwelling units in new mid-rise multifamily buildings in Washington State consisted of continuously exhausting each dwelling unit. Even though these buildings achieved the code level for whole building tightness of 0.4 cfm/ft^2 at 75 Pascals (75 Pa), all of the exhaust fans operating together led to full depressurization of the buildings. This meant that increased levels of airtightness contributed no energy savings in typical buildings.
- However, the 2018 Washington State Energy Code (WSEC) and Washington State Mechanical Code, effective by February 1, 2021, will require balanced flow ventilation systems in mid- and high-rise multifamily buildings. This means that these buildings will no longer be fully depressurized by the ventilation system and that energy savings are available from increased levels of airtightness.
- Commercial codes for the other states in the Pacific Northwest region (Oregon, Idaho, Montana) do not require balanced flow ventilation within apartments, and standard practice ventilation system design in those states does not always include continuous operation of exhaust fans. In the absence of standard practice ventilation design trends in those states, determining the potential impacts of increasing the code-mandated (and tested) envelope tightness levels is difficult.
- The 2018 WSEC lowers the airtightness limits to a maximum of 0.25 cfm/ft^2 @ 75 Pa for all commercial buildings (including multifamily buildings of more than three stories). Optional points are available from Section R406 for achieving a tighter level of 0.17 cfm/ft^2.
- Field data from different sources indicate that current typical construction techniques can achieve the 2018 WSEC target of 0.25 cfm/ft^2 @ 75 Pa. Data also indicate that the Section R406 target of 0.17 cfm/ft^2 is also achievable.
- Since the 2018 WSEC ventilation systems will require balanced supply and exhaust air delivered at each apartment unit, a tight building envelope will not impact the ventilation system performance. However, to the extent that exhaust appliances such as clothes dryers and kitchen range hoods exist in the apartments, they must still source their makeup air by depressurizing the apartments and pulling air through cracks in the construction.
- A recent relevant data set of low-rise apartments indicates that about 25% of the leakage area of a typical apartment is associated with leaks to the outside. This proportion is likely even lower for mid- and high-rise apartments given the lower ratio of exterior wall area. Furthermore, the energy code focuses on limiting leakage through the exterior skin

of the building – meaning the majority of makeup air for intermittent exhaust appliances will likely be drawn from neighboring apartments and common spaces.

- Whole-building tightness tests measure the tightness of the external envelope and govern the leakage and energy impact of the envelope airtightness. Compartmentalization tests measure the total envelope of an individual apartment, including the interior and exterior walls. This governs interior air quality and the source from which makeup air will be drawn for exhaust appliances. A recent DOE low-rise study found no correlation between compartmentalization tests and whole building tightness tests, so one type of test cannot be used as a predictive surrogate for the other in any individual building.
- Whole building airtightness therefore has little direct impact on the performance of exhaust appliances since they will source most of their makeup air from interior building leakage.
- The fans of exhaust appliances must be powerful enough to drive adequate air against the pressure drop created by the exhaust ducting, elbows, backdraft dampers, and wall termination on the exhaust side, added to the pressure drop through the cracks in the building envelope for makeup air on the supply side.
- Typical installations for dryers and kitchen range hoods result in about 0.4–0.6 inches of water (in. w.g.) of pressure drop on the exhaust side of the fan for minimum acceptable airflow (about 100 cfm). Typical range hood fans and "long vent" dryer fans have the capability to move their minimum flow against about 1.0 to 1.4" w.g. of total static pressure. So, on average, these installations have about 0.65" w.g. of static available to overcome envelope airtightness to source their minimum makeup air.
- A compartmentalization tightness level of 0.065 cfm/ft^2 at 50 Pa leads to a pressure differential across the envelope of a typical 600 ft^2 apartment of 0.34" w.g. with typical exhaust-based appliances (dryers and kitchen range hoods). This study proposes that this is a reasonable upper limit for compartmentalization in apartments with typical exhaust appliances installed.
- For airtightness exceeding 1 ACH50, the team recommends use of ventless dryers and kitchen range hoods with an integrated makeup air pathway.

1. Introduction

This report summarizes the continued investigation from NEEA's multifamily depressurization (MUDS) field studies (Phase I and Phase II) to determine the levels of compartmentalization that may have a negative impact on exhaust appliances. It also addresses code changes introduced in the 2018 Washington State Energy Code (WSEC) that affect multifamily buildings. This project also seeks to identify current limits to typical multifamily exhaust fan and dryer technologies and to propose design solutions to mitigate issues.

The 2018 Washington State Energy Code and Washington State Mechanical Code will come into effect by February 1, 2021 and will require balanced flow ventilation systems in all R-2 dwelling units.[1] This changes the impact of airtightness regulations in multifamily buildings. With exhaust-only systems, airtightness greater than 0.4 cfm/ft^2 @ 75 Pa would be expected to have no impact on energy savings and would be potentially counterproductive for comfort. With balanced flow ventilation systems, any increase in airtightness will theoretically yield a beneficial decrease in heating energy requirements and an increase in occupant comfort. This study examines the question in light of the new balanced flow ventilation requirements: Is there a point at which buildings could be considered "too tight"?

[1] 2018 Washington State Energy Code and 2018 Washington State Mechanical Code

2. How Tight is Too Tight?

Airtightness is a measure of air infiltration through building components such as walls, windows, doors, ceilings, and floors. The two types of airtightness testing currently performed are whole building and compartmentalization. Both tests pressurize and/or depressurize a space, either the whole building or the individual unit, and measure the airflow in cubic feet per minute (cfm) required to maintain a standard test pressure of either 75 or 50 Pascals (Pa).

Whole building pressurization measures the airtightness of the exterior envelope and is the value regulated by the Washington State Energy Code (WSEC). Whole building tightness is focused on energy efficiency as it measures infiltration between the interior and exterior of a building. It can be difficult to measure in large buildings.

Compartmentalization pressurization testing measures the airtightness of all interior and exterior building components of a single unit. Testing individual units is generally much simpler than whole building testing. Leadership in Energy and Environmental Design (LEED) certification requires multifamily residential units to meet certain maximum levels of compartmentalized airtightness.

Increasing compartmentalization airtightness is driven by the desire to improve indoor air quality (IAQ) and to reduce stack effect (in tall buildings). The majority of wall, floor, and ceiling areas in a multifamily residential unit are interior. Improving the airtightness of interior building components prevents infiltration from neighboring units and the corridor, thus reducing unwanted smells and poor air quality from one unit into another. The stack effect suggests that buildings act like chimneys. Hot air rises to the top of the building, pulling cold outside air into lower levels. Reducing the stack effect can have a significant energy impact in large buildings. Occupants on lower levels are colder due to infiltrated air and as a result may increase the temperature setting of their space. That hot air rises and overly warms occupants on upper levels, who may open windows, thus pulling air through the building at a faster rate. Interior walls and floors that are built to a higher standard of airtightness greatly reduce the flow of air through the building.

In Washington state, multifamily ventilation air has traditionally been provided through exhaust-based design. A whole house fan, typically located in the main bathroom, runs continuously or intermittently at code-specified levels and exhausts directly to the exterior of the unit. Fresh air is provided through operable trickle vents integrated with the window frames. Trickle vent or makeup air is generally sized according to the whole house fan exhaust. When exhaust appliances such as the dryer and kitchen range hood are also in use, additional makeup air is pulled through the unit envelope.

Tightly constructed buildings with exhaust-only ventilation systems are negatively pressurized. All air entering the building is leaving through the exhaust appliances; therefore, further tightening of the envelope will not result in energy savings – it will only force the same amount of air through fewer and smaller cracks. This has led to unpleasant effects such as whistling and drafts in some instances in new buildings.

Previous mid-rise multifamily building field studies have indicated that whole building airtightness beyond 0.4 cfm/ft^2 @ 75 Pa may not yield significant energy savings and could potentially have adverse comfort and acoustical effects;[2] however, it is important not to conflate compartmentalization and whole building airtightness testing. No correlation between the two has been found, and each ultimately represents disparate characteristics. "How tight is too tight?" is a question about compartmentalization. It is asking how airtight units can be before the exhaust appliances may begin struggling to exhaust air from the unit.

2.1. Compartmentalization vs. Whole Building

As noted above, compartmentalization and whole building tightness testing are vastly different from each other. Whole building testing is related to energy efficiency whereas compartmentalization is related to indoor air quality and performance of exhaust appliances. While the two tests are related (theoretically buildings with tighter compartmentalization tests will have tighter exterior building envelopes), little data exist to compare the two. One recent source of relevant data was being analyzed in parallel to this study and was in draft at the time of this report.[3] This was a national sample of low-rise multifamily buildings for which compartmentalization testing and whole building testing were completed on the same sample of buildings. While this is a different building type than mid-rise or high-rise multifamily, a portion of the data examined buildings with common entries (typically double-loaded corridors) similar to the configuration of mid-rise and high-rise buildings.

Graphics showing the basic set-ups for the compartmentalization and whole building tightness tests are shown in Figure 1 and Figure 2 below:

[2] NEEA Investigation of Airtightness and Ventilation Interactions in New Multifamily Buildings – Phase II

[3] Commercial Buildings and Energy Code Field Studies: Low-Rise Multifamily Air Leakage Testing. Report in progress for the DOE by Ecotope and the Center for Energy and Environment.

Figure 1. Compartmentalization Test Configuration

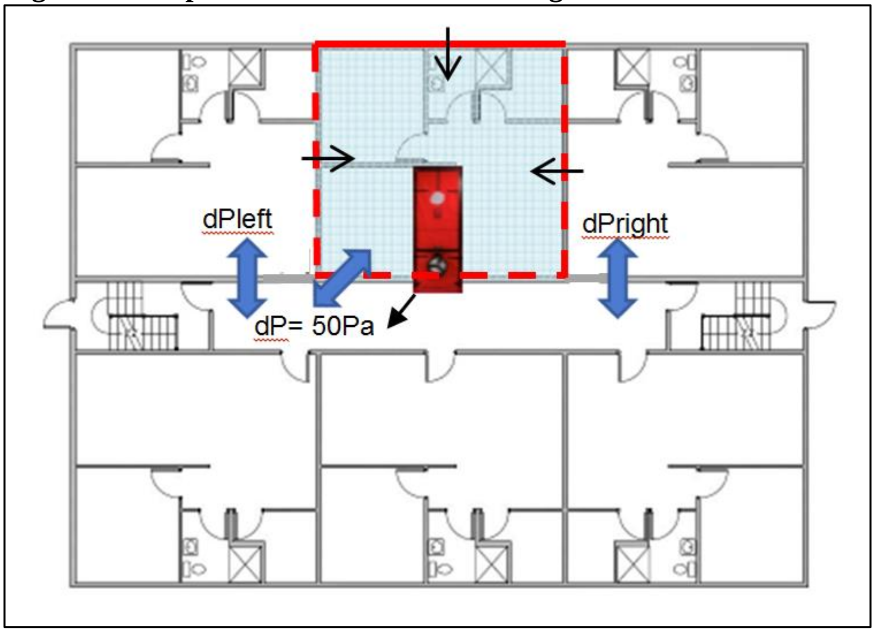
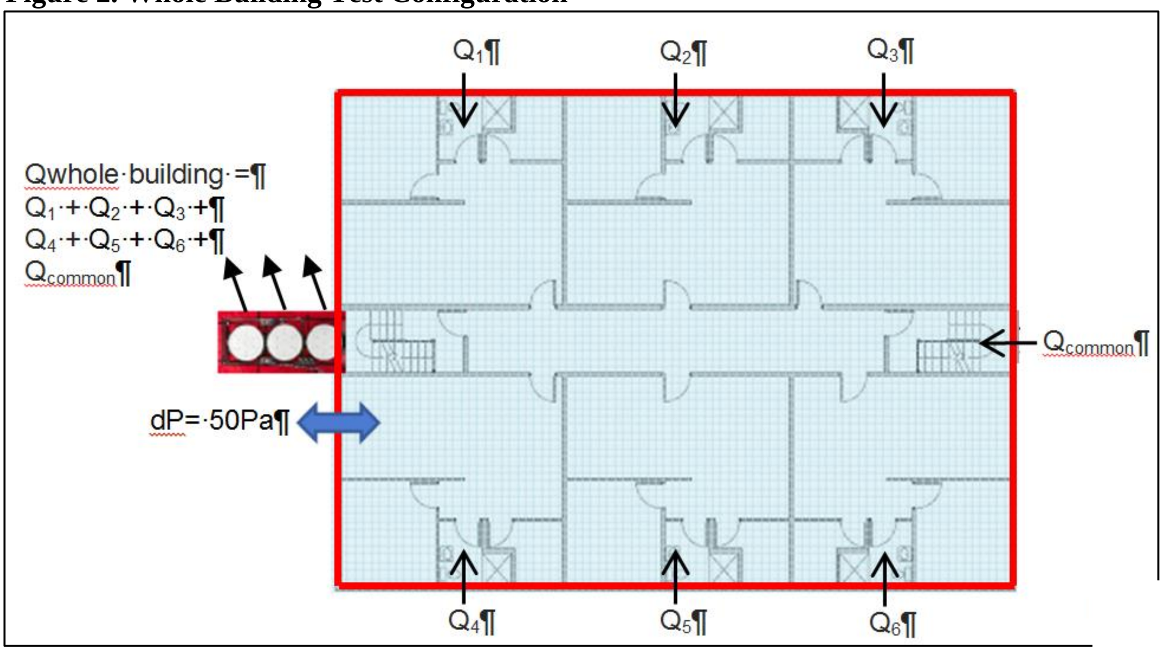


Figure 2. Whole Building Test Configuration



The Power Law Equation (1) is utilized to determine airflow and pressure difference across an opening:

$$Q = c(\Delta p)^n \qquad \textbf{(Equation 1)}$$

Q = airflow through opening, cfm
c = flow coefficient, cfm/Pa
Δp = pressure difference across opening, Pa
n = pressure exponent, dimensionless

When whole building or individual unit pressurization test data are fitted to Equation 1, the value of *n* typically falls within the 0.6-0.7 range.[4] The value of the flow exponent (*n*) is governed by the shape of the cracks. For this study, an assumed *n* = 0.65 was used which represents small sharp-edged cracks. In conjunction with building air leakage data, which measures airflow at a set pressure, the flow constant (*c*) can be determined for a specific apartment unit or building and is governed by the leakage area of the enclosure. The determined *c*-value can be used to calculate the expected pressure difference in a unit when certain exhaust appliances are in use.

The DOE study included 15 common entry buildings of 12 units or greater and provides some data supporting the lack of correlation between compartmentalization and whole building test numbers. Results of the relevant testing are shown in Table 1:

Table 1. Results of Compartmentalization and Whole Building Airtightness Testing

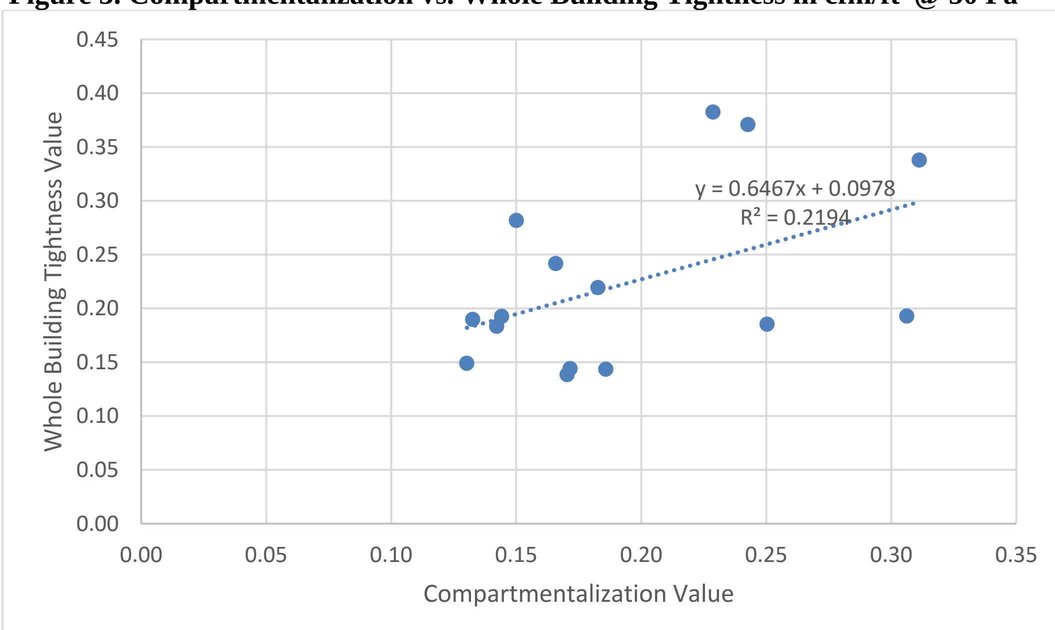
Building ID #	Average Dwelling Unit Compartmentalization Test Values (cfm/ft^2 @ 50 Pa)	Whole Building Tightness Values (cfm/ft^2 @ 50 Pa)
2	0.24	0.37
41	0.23	0.38
81	0.15	0.28
61	0.31	0.19
62	0.25	0.19
63	0.31	0.34
51	0.17	0.14
54	0.17	0.24
55	0.19	0.14
57	0.14	0.19
58	0.14	0.18
59	0.13	0.19
71	0.13	0.15
72	0.17	0.14
73	0.18	0.22
Median of Sample	**0.17**	**0.19**
cfm/ft^2 @ 75 Pa (equivalent)	**0.22**	**0.25**

[4] 2013 ASHRAE Handbook Fundamentals

Note that in the WSEC, the whole building test targets are in cfm/ft^2 @ 75 Pa (cfm75) to align with the Army Corps of Engineers commercial building test standards. The typical residential testing standards use 50 Pa (cfm50) of pressure difference. To approximately convert between the two, we can use Equation 1 above. With an assumed flow coefficient of 0.65, we can convert cfm50 to cfm75 by multiplying by 1.3. With this conversion we see that coincidentally the median test value from the DOE sample of 0.19 cfm/ft^2 @ 50 Pa lines up exactly with the 2018 Washington State Energy Code target of 0.25 cfm/ft^2 @ 75 Pa.

Interestingly, the converted equivalent median of the compartmentalization testing yields almost the same value (0.22 cfm/ft^2 @ 75 Pa). This might lead one to believe that the compartmentalization test could be used as a surrogate for the whole building tightness test. However, looking at the data from the individual projects shows that the compartmentalization tests are a poor predictor of the overall airtightness of the building. Figure 3 below graphs the median unit compartmentalization test versus the whole building test for the sample projects, with no statistical correlation between the two.

Figure 3. Compartmentalization vs. Whole Building Tightness in cfm/ft^2 @ 50 Pa



These test results illustrate that compartmentalization tests cannot be used a predictor of whole building tightness on any given building. However, it is interesting to consider whether the variations might balance out for a total population as they did with this limited data set, so that for the entire population a specific compartmentalization test target could yield the desired result of achieving a similar whole building tightness level.

The DOE Low-Rise Multifamily study yielded another interesting preliminary finding: In the common entry buildings (double-loaded corridor), about 25% of the effective leakage area in an individual apartment unit was related to leakage to the outside. This indicates that for intermittent exhaust appliances, such as dryers and kitchen range hoods, the majority of makeup air will likely be pulled through neighboring apartment units and the corridor, as opposed to the outside.

Based on these findings, apartment buildings would require two separate air sealing efforts and tests to achieve the goal of reducing infiltration through tightening the exterior envelope and reducing transfer of air between apartments through tightening at the “compartment” level. It is important to note that as long as exhaust-only appliances are used in apartments, there will always be occasional differential pressure and therefore air transfer between neighboring apartments (the makeup air for exhaust fans must come from somewhere).

2.2. Compartmentalization Pressurization Testing Targets

Another source of pressure test data for multifamily buildings is potentially available within the sample of buildings registered with the LEED for Homes program of the US Green Building Council. The LEED certification for Homes and Multifamily Midrise requires all relevant dwelling units to test under a maximum compartmentalized leakage rate. At the same time, these buildings are required to submit whole building test data in compliance with the Washington State Energy Code (WSEC). Consequently, a sample of mid-rise buildings is theoretically available with both compartmentalization and whole building test values. To the knowledge of the research team, this information has not been collected into a database. Potential sources for collection of these data are from the LEED Rating organization and the building department or general contractors for the projects.

LEED version 4 certification for Homes and Multifamily Midrise requires relevant projects to obtain an average compartmentalized maximum leakage of 0.23 cfm/ft^2 @ 50 Pa. Mid-rise buildings can obtain an additional 3 points out of 110 total (certification requires 40 or more points) for testing an average maximum leakage of 0.15 cfm/ft^2 @ 50 Pa. Note that these tests were influenced by the residential program, so they are using 50 Pa as the test pressure as opposed to the commercial standard of 75 Pa.[5]

The study team was able to obtain compartmentalization test data for a typical LEED mid-rise building in Seattle from the primary LEED for Homes rater in the area. The sample buildings included ground floor townhouses, studios, and 1- and 2-bedroom apartments. The minimum compartmentalization test was 0.1 cfm/ft^2 @ 50 Pa, the maximum was 0.3 cfm/ft^2 @ 50 Pa, and the median was 0.21 cfm/ft^2 @ 50 Pa. This is similar to the median compartmentalization results from the DOE Low-Rise Multifamily study of 0.18 cfm/ft^2 @ 50 Pa.

[5] This paper assumes a typical flow coefficient of 0.65 to allow for conversion between tests at 50 Pa and tests at 75 Pa.

2.3. Typical Exhaust Appliances

To investigate potential interaction between tight construction and typical exhaust appliances, the team collected fan performance data for common appliances in the Washington construction market, summarized in Table 2.

Table 2. Exhaust Appliance Airflow Rates

Exhaust Appliance	Airflow Range (cfm)
Dryer	105–230
Bath fan	45–85
Range hood	100–200

The dryer minimum and maximum airflow rates come from manufacturer literature. The whole house (bath) fan values come from the Washington State Energy Code minimum continuous exhaust rates based on number of bedrooms and unit conditioned floor area. The kitchen range hood value of 100 cfm is the code minimum and 200 cfm is the high setting on a typical range hood used in multifamily applications.

For residential dryers, the team examined five top manufacturers. This analysis is based on a single model dryer from Whirlpool. According to the manufacturer's documentation, any Whirlpool dryer should operate between 105 and 230 cfm. The airflow of a dryer depends on the designs of the exhaust vent, backdraft damper, wall register, and the level of maintenance of filters and ducts. The best fan curve data available was for a typical Whirlpool appliance, as shown in Table 3 below.

Table 3. Maximum Allowable Back Pressure for Dryer

Maximum Allowable Back Pressure for Dryer	
Maximum Rated Vent Length without 90° Elbows (determined from product literature)	Maximum Allowable Back pressure at connection to dryer (no clothes loaded and clean lint screen)
36-37 ft	0.40" Water Column
64 ft	0.60" Water Column
100 ft	0.80" Water Column
120 ft	1.00" Water Column
130 ft	1.10" Water Column

Typical dryer installations in multifamily buildings require three to four 90-degree elbows. Furthermore, dryers tend to be located toward the center of the building because the area near the perimeter windows is highly coveted for living space. Most major manufacturers offer "long vent" models for their dryers with more powerful fans. For typical Whirlpool products with four 90-degree bends, the maximum recommended duct length is only 27 feet; the "long vent" models increase that vent distance to 120 feet. Table 4 below shows maximum recommended vent lengths for installations using a typical sloped vent cap.

Table 4. Vent System Charts (Standard and Long Vent Models)

Standard Vent System Chart

Number of 90° elbows	Type of vent	Angled hoods
0	Rigid metal	64 ft. (20 m)
1	Rigid metal	54 ft. (16.5 m)
2	Rigid metal	44 ft. (13.4 m)
3	Rigid metal	35 ft. (10.7 m)
4	Rigid metal	27 ft. (8.2 m)

Long Vent System Chart

Number of 90° elbows	Type of vent	Angled hoods
0	Rigid metal	160 ft. (48.8 m)
1	Rigid metal	150 ft. (45.7 m)
2	Rigid metal	140 ft. (42.7 m)
3	Rigid metal	130 ft. (39.6 m)
4	Rigid metal	120 ft. (36.6 m)

Based on the above manufacturer's data, a "standard vent" Whirlpool dryer[6] can provide its minimum rated airflow with an external static pressure of about 0.6 inches of water gauge pressure (0.6" w.g.). A "long vent" model can produce its minimum rated flow with an external static pressure of about 1.4" w.g.

To determine typical existing conditions, the team measured dryer duct runs on three sample buildings, as shown in Table 5. These conditions were then compared to the maximum allowable duct pressure to stay within manufacturer's guidelines for minimum flow.

Table 5. Four Inch (4") Dryer Performance at Minimum Airflow (Standard and Long Vent Models)

Building	Length (ft)	# 90° bends	Allowable length for min. flow (std vent)	Extra pressure (in. w.g.) for min. flow (std vent)	Allowable length for min. flow (long vent)	Extra pressure (in. w.g.) for min. flow (long vent)
Edgewood	31	3	35	0.03	130	0.69
Revel Lacey	33	3	35	0.01	130	0.68
Holy Names	27.5	4	27	-0.004	120	0.65

6 https://www.whirlpool.com/content/dam/global/documents/202004/owners-manual-w11364660.pdf

Table 5 shows that the installations studied are right at the maximum allowable ducting for a standard vent model dryer. However, if a long vent model is selected, considerably more static pressure (~0.65” w.g.) could be added to the system before the dryer would be expected to fall below the minimum airflow rating. Note that the values in the table above assume clean filters and clean ducts; as ducts and filters become loaded with lint, static pressure will increase and airflow will decrease.

A similar exercise was completed for kitchen range hoods. Standard base-model Broan or Whirlpool range hoods are intended to provide about 200 cfm with a maximum of about 35 feet of 7” round ducting with three 90-degree bends and a typical wall cap with backdraft damper. This indicates a fan capable of providing about 1” w.g. of static pressure external to the hood. Typical multifamily installations require about 25–30 feet of ducting, so they are also right at the limits of manufacturers’ recommended installation. However, the minimum airflow for the International Mechanical Code for a kitchen range hood is only 100 cfm, so considerably more back pressure (~0.65” w.g.) could be added before the range would likely drop below code minimum performance.

So, for both the typical range hood and the typical long-vent dryer, the added pressure drop across the envelope could be as much as 0.65” w.g. (160 Pa) before we would expect degradation of exhaust appliance performance below code or minimum manufacturer’s recommendations.

2.4. Practical and Code Limitations on Airtightness

One practical and code limitation to airtightness levels in apartment buildings is that pressure differentials must stay within range to allow for easy and safe operation of doors. Pressure differentials will put pressure on doors, making them more difficult to open and/or close. Section 5-2.1.1 of the National Fire Protection Association (NFPA) 101, Life Safety Code requires the door opening force in the egress path to be limited to no more than 30 pounds. With industry standard 36” wide, in-swinging doors into apartments, this limits the pressure difference across the door to about 140 Pa. At this level of pressure the door will swing in strongly and be somewhat difficult to close. Cracks under the door will likely have the tendency to whistle.

NFPA 92 regulates minimum and maximum pressure differences across smoke barriers for smoke control systems to 25–88 Pa (0.1–0.35” w.g.). While this limit is only enforced across designated smoke control barriers, it perhaps provides a practical target for thinking about reasonable pressure differences within buildings. Ideally, a minimum of 200 cfm should be able to be exhausted from a typical apartment without exceeding about 0.35” w.g. of depressurization from within the unit to the corridor.

Table 6 below shows the pressure impacts of 100 and 200 cfm of exhaust on a typical 600 ft^2 apartment at varying levels of compartmentalization. The table examines compartmentalization levels identified by the LEED program, a proposed tightness level of 0.065 cfm/ft^2, aspirational tightness levels of 1 air change per hour at 50 Pascals (ACH50), and a level paralleling the

Passive House[7] whole building target of 0.6 ACH50. As can be seen in Table 6, a tightness level of 0.065 cfm/ft^2 at 50 Pa leads to a pressure across the envelope of a typical 600 ft^2 apartment of 0.34" w.g. with 200 cfm of exhaust. The team proposes that this is a reasonable upper limit for compartmentalization in apartments with typical exhaust appliances installed.

Table 6. Depressurization Impact of 100 and 200 cfm of Exhaust Flow on a 600 ft^2 Apartment at Varying Compartmentalization Levels

Compartmentalization Level	Tightness Target (cfm/ft^2 at 50 Pa)	cfm @ 50 Pa	Pressure at 100 cfm (inch w.g.)	Pressure at 200 cfm (inch w.g.)
LEED Prerequisite	0.23	504	0.02	0.05
LEED Points	0.15	329	0.03	0.09
Smoke Barrier Max (88 Pa)	0.065	142	0.12	0.34
1 ACH50	0.04	90	0.24	0.68
Passive House (0.6 ACH50)	0.025	54	0.52	1.5

Note that this only addresses the pressure created by the exhaust fans; it does not address potential comfort or acoustical issues that may arise from high levels of depressurization. More study may be needed to determine whether these levels of performance with exhaust fans are acceptable.

As noted in Table 6, if we limit peak exhaust flows to 100 cfm, then we can target tighter levels approaching Passive House levels of airtightness before exceeding 0.35" w.g. of induced pressure, so typical long-vent dryers and typical kitchen range hoods should be expected to deliver their minimum performance requirements under conceivable levels of airtightness achieved through code. However, the makeup air for these exhaust appliances will be largely pulled from neighboring apartments and the common areas which may lead to localized drafts and/or acoustical "whistling," depending on the location and shape of the cracks in the envelope.

[7] https://www.phius.org/phius-certification-for-buildings-products/project-certification/overview

3. Design Solutions

Increasingly tightened envelope construction has presented challenges for multifamily housing. A tight building envelope means less leakage area for makeup air into a unit, and thus forces more air through window trickle vents or other openings in the unit (such as under the entry door). Poorly-placed trickle vents located near sitting areas can lead to jets of cold air directed into the space. Uncomfortable occupants close the trickle vents, which further limits the available makeup air pathways and can lead to air “whistling” under doors. The 2018 WSEC will require balanced ventilation in multifamily dwelling units which will solve some of the issues exacerbated by traditional exhaust-based ventilation systems, but it does not fully solve potential issues associated with intermittent exhaust appliances such as the dryer and kitchen range hood. As such, potential design solutions to ensure occupant comfort and optimal operation of exhaust appliances merit consideration.

3.1. Ventless Solutions

An obvious and readily available approach to solving depressurization issues in multifamily housing is the use of ventless appliances. By eliminating the root cause of the problem (airflow through the building exterior), both the occupant comfort and appliance effectiveness issues can be resolved. The following sections outline various appliance-related solutions to solving pressurization issues.

3.1.1. Recirculating Range Hoods

The kitchen range hood penetration can be eliminated entirely by installing a recirculating range hood. These hoods pull vapors and grease from the cooking surface through filtration devices within the hood and then push the air back into the space. Since they do not exhaust to the exterior, they create no induced pressure differential across the envelope and makeup air is not an issue. However, code does require that the kitchen be exhausted in this scenario; however, the 2018 Washington State Energy code requirement of balanced ventilation in dwelling units will largely solve this problem.

While these types of hoods present an immediate solution, they are often linked to poor indoor air quality (IAQ) conditions – especially when installed over gas stoves, since the products of combustion are never directly exhausted out of the living space. Filtration systems in these hoods must be cleaned and/or changed on a routine schedule, but occupants do not necessarily have a habit of regularly checking these systems.

If depressurization issues were to outweigh IAQ issues, this design solution would be especially beneficial in small apartment units as they were found to be most prone to air starvation problems.

3.1.2. Condensing and Heat Pump Dryers

Ventless dryers (condensing and heat pump) offer an immediate and well-rounded solution to depressurization and airflow issues in multifamily buildings. They eliminate the issue of air starvation since they do not vent to the outside, but instead recirculate air within the living space. In addition to airflow solutions, ventless dryers provide numerous other benefits including lower annual energy use, allowing for tighter envelope construction by elimination of the dryer duct, and elimination of maintenance (lint cleaning) of the dryer hoods.

Condensing dryers pass ambient air through a condenser where it is heated and then pushed into the drum to heat up the wet laundry. The hot wet air loops back through the evaporator to cool down and remove moisture from the air, which drains into a pipe or tray. That air is then reheated, and the process repeats until no additional water can be removed and the clothes are dry. These units often still rely on partial electric resistance heating of the airstream.

Heat pump dryers use a similar process but are even more energy efficient as they use a heat pump only to exchange the hot and cold air, saving more than half the energy use of standard dryers.[8] Additionally, space heating and cooling energy is reduced as there is no exhausting of indoor air and no need to condition the makeup air. Their small, compact size can be beneficial for small apartment units where usable area is a premium. While these units tend to have increased drying times, increased airtightness of the exterior envelope induces more pressure on traditional exhaust-based dryers, starving them of airflow and thereby also increasing their drying times.

A cost benefit analysis of heat pump dryers by a regional general contractor for a recent multifamily project in Seattle showed hybrid heat pump dryers as marginally less expensive to purchase and install when compared to standard clothes dryers. Although the dryer unit price is more costly (roughly $270 incremental cost over a standard dryer), it is negated by not having to install a dryer vent. Dryer vents add nearly $300 per unit to construction costs. Not only does the removal of the laundry vent reduce first install costs, but it also eliminates annual duct cleaning maintenance costs.

3.1.2.1. Central Laundry

An alternate way to eliminate venting and dryer performance issues within dwelling units is to provide a central laundry facility within the building. This is also the most economical solution, as the number of washers and dryers needed is greatly reduced compared to one set per unit. The makeup air system could be an engineered system, designed to run in sync with the number of dryers in operation. However, this is not always an acceptable solution in a market where occupants expect in-unit washers/dryers.

3.2. Ducted Solutions

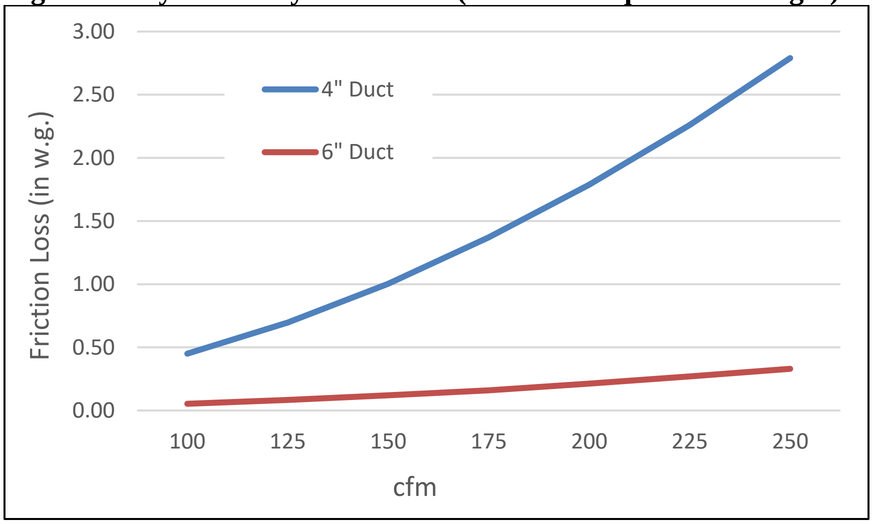
Since an immediate switch to ventless appliances is unlikely (and can lead to health issues in the case of recirculating hoods), alternate solutions based around traditional vented appliances should be considered.

[8] https://neea.org/img/documents/Heat-Pump-Clothes-Dryers-in-the-Pacific-Northwest.pdf

3.3. Upsize 4” to 6” Exhaust Duct (Dryers)

Although most clothes dryer manufacturers recommend a 4” diameter metal exhaust duct, upsizing to a 6” diameter duct would drastically decrease the static pressure experienced by the dryer exhaust fan. Figure 4 below illustrates calculated (average) friction loss of a dryer system as a function of airflow through 4” and 6” diameter ducts. As shown, a 6” duct at roughly 65 feet (equivalent) length will not introduce 0.5” w.g. of static pressure even at full flow of ~230 cfm.

Figure 4. Dryer Duct System Curve (at 65 Feet Equivalent Length)



Whirlpool dryer venting specifications clarify that the minimum duct air velocity during normal operating conditions should be 1,200 fpm to prevent lint buildup in the vent. That translates to 105 cfm of airflow in a 4” diameter duct; increasing to a 6” diameter duct would bump the airflow to a minimum of 230 cfm. Increased duct size would greatly reduce static pressure in the dryer duct, but airflow should remain sufficient to limit lint buildup. The dryer would vent more air through the drum which would reduce drying times, improve energy efficiency, and potentially increase the longevity of the dryer. With a 4” duct, Whirlpool recommends annual inspection and cleaning. A 6” duct system would likely require more frequent cleanings, which could lead to hazardous operating conditions if not performed regularly.

3.3.1. Passive Supply Duct

In theory, a passive makeup air duct could be routed to the laundry or kitchen to provide makeup air to these exhaust-based appliances. However, the duct would have to be quite large to supply adequate airflow and, due to space constraints, is likely not a viable solution.

3.4. Fan Solutions

Along with ducted solutions, a host of fan-based designs could be implemented to address depressurization issues. However, these solutions require another piece of mechanical equipment (namely a fan) that must be wired and provided with controls – which adds to the overall construction cost of multifamily development.

3.4.1. Booster Fan (Dryer)

Installing a dryer booster fan on long exhaust vent runs is already common practice; however, many modern manufacturers made a “long vent” dryer model that substantially increases the static pressure capabilities. This design solution enables the dryer to obtain enough airflow for proper operation; however, it does not solve the makeup air issue in a tight building. Booster fans are a costly addition and require an additional electrical connection, a filter that requires maintenance, and space in a soffit over the dryer.

3.4.2. Makeup Air Supply Fan

To ensure sufficient airflow to the dryer or range hood without starving the rest of the unit of air, a makeup air duct with supply fan could be installed. The fan could be balanced to match the exhaust airflow of the dryer and/or range hood in order to create a well-tuned makeup air path to these appliances. Though technically feasible, this solution leads to other design problems. For instance, this fan would require an additional electrical connection, controls, more ductwork, add another penetration in the building envelope, and create more air-terminal separation headaches for the designer to be in compliance with the mechanical code. While this added supply fan introduces several complications, none of them present an insurmountable challenge to design teams.

3.4.3. Integrated Range Hood

An integrated range hood would constitute a new product-based solution for development by manufacturers. The idea would be to mimic commercial style Type I hoods, which duct supply air directly to the range hood. As air is exhausted from the cook surface, supply grilles integrated into the hood would provide makeup air directly to the hood. An added benefit of this type of system is that the exhausted air is now primarily outside air as opposed to conditioned indoor air. This solution would also require an added fan and ductwork but if developed as a packaged product (similar to some European products), this may be more readily accepted by the industry.

4. Conclusions

Early results from a DOE-sponsored low-rise multifamily study found no statistical correlation between whole building tightness testing and compartmentalization tightness. The DOE study had coincidental agreement between the median results of whole building and compartmentalization testing for the entire sample, but a more statistically valid regional sample would be needed prior to making any claims that compartmentalization testing could be used as a predictive surrogate for whole building testing for the entire population of buildings.

Most of the surface area and leakage area drawn upon by individual exhaust fans in an apartment are associated with common walls between apartments and the common area. Therefore, absent significant efforts to increase compartmentalization tightness, it appears that typical range hood exhaust fans and “long vent” dryer models will have sufficient pressure capabilities to exhaust their minimum required airflows of about 100 cfm. This appears to be independent of the tightness levels of the exterior envelope.

The 2018 WSEC has added requirements for balanced flow ventilation in apartments. Once the code is effective, it will supersede the industry-standard practice of continuous exhaust-only ventilation within the dwelling units. Building tightness will no longer significantly impact ventilation system performance (balanced flow) but will become a potential source of increased energy efficiency since pressure differentials across the envelope will stay relatively neutral. Washington State codes are currently the only codes in the Pacific Northwest region to mandate balanced flow ventilation; other states should likewise consider requiring balanced flow systems along with increasing envelope airtightness levels.

Future codes could continue to drive down the whole building tightness target without fear of impacting the ventilation system performance if balanced flow systems are required. Increased whole building tightness is unlikely to cause typical exhaust appliances to fail to meet their minimum airflow since most of the makeup air for those appliances will be drawn from inside the building. Compartmentalization tightness would need to approach 1 ACH50 before traditional dryers or kitchen range hoods would likely fail to meet minimum exhaust flows.

However, as the focus on airtight construction persists, other adverse impacts such as localized drafts or air noise may become apparent. More study may be needed to track exhaust system performance in extremely airtight apartments.

Design solutions are available to reduce exhaust appliance interactions. The most promising technology is (to shift from vented to) unvented dryer appliances. These provide significant energy savings while eliminating interactions with the building envelope. The study team does not recommend unvented kitchen range hood technologies at this time due to potential indoor air pollution concerns. A focus on super-tight compartmentalization and elimination of cross-unit airflow would therefore require a balanced flow approach to kitchen range hoods, such as is required in commercial kitchen applications. A residential product incorporating makeup air is possible and would theoretically not be difficult to manufacture; however, no such appliances appear widely available in the US market.