Technical Report

Door gaps and natural ventilation with adjoining rooms

Date: 03.21.2022

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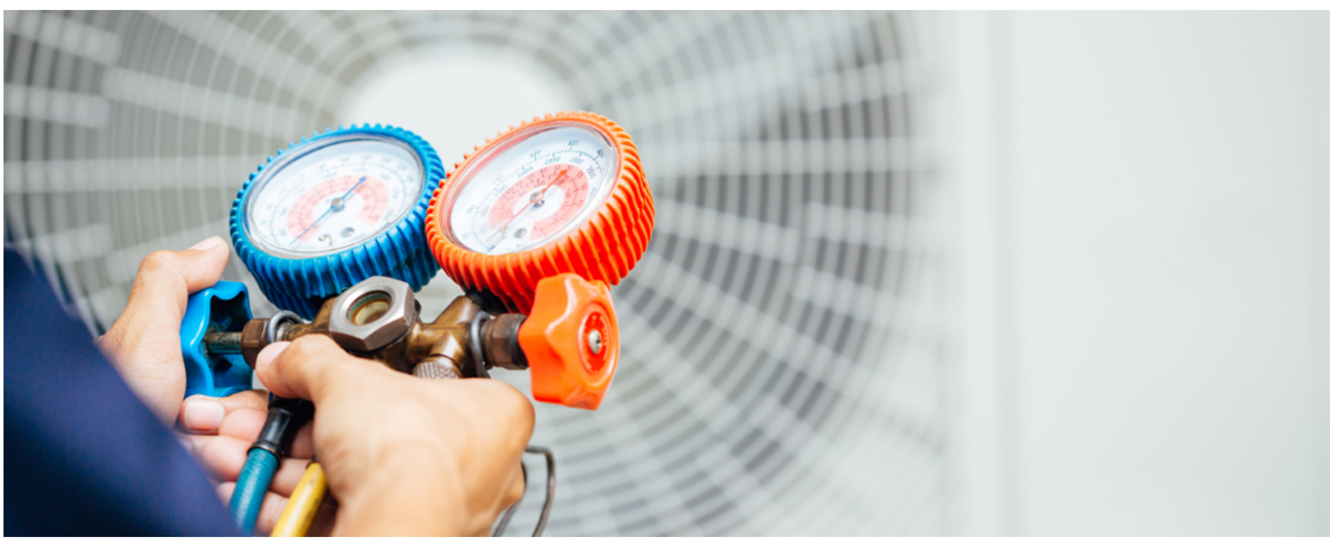
Table of contents

Background

Over the past few decades, evolving building codes for energy conservation have increased the air tightness of building construction. However, this tight construction is from the interior of the building to the exterior. Interior room spaces are not as tightly constructed. Interior walls typically are not insulated. As a result, gaps appear under doors. Clearances below doors are increased to permit operation with unlevel floors, and clearances can be larger to allow for airflow circulation in spaces that do not have dedicated return-air registers for each room. Building codes specify that a fire door's maximum clearance at the bottom is 19 mm (3/4 inch)[1] (NFPA, November 2021). Current requirements in both the international (IEC) (IEC, 2018) and North American (UL/CSA) (UL, 2019) versions of Standard 60335-2-40 permit room size as a mitigating factor for refrigerant concentration buildup in a space. In general, doorways are permitted to be used to increase the room volume, provided that certain natural ventilation criterion are met. One of these criteria (Clause GG.1.4 of UL60335-2-40) is that the opening must be at least 20 mm (0.79 in.) with a total area calculated in accordance with equation GG.7.

There is limited understanding of the leak-rate for failures of air-conditioning (AC) and heat pump (HP) products installed in the field. This was investigated for the worst-case scenario of an indoor refrigerant leak without an interior compressor. In Japan, Japanese Society for Refrigerating and Air Conditioning Engineers (JSRAE) investigated regarding AC leaks (Hihara, 2016), evaluating thousands of reported field leak cases. The investigation found that the maximum leakhole releases 5 kg/h at 65°C condensing temperature with liquid phase. Providing 2 times factor of safety was chosen to take unknown level leaks into account.

Therefore, the maximum leak rate from an indoor unit is assumed to be 10 kg/h (with no compressor or pressure vessel type component in the indoor unit). This study shows that a refrigerant leak from indoor AC units releases slowly. A door gap can have a significant impact on concentration of refrigerant in the room where the leak occurs.



[1] *4.8.4 Clearance*
4.8.4.1 Clearance under the bottom of a door shall be a maximum of 3/4 in. (19 mm).

Test set-up

After committing to a contract, UL Solutions conducted a project consisting of full-scale refrigerant release testing. This testing was conducted at UL Solutions laboratories in Northbrook, Illinois.

As a part of this study, rooms were constructed to simulate a 66.9 m^2 (720 ft^2) apartment in one of UL Solutions test chambers. The structure was built using standard construction materials and techniques that would be used in North America. The walls were framed using 2x4 inch dimensional lumber and two layers of drywall for durability and strength. A layer of foam sill gasket was placed between the footer and the cement floor of the test chamber. The seams of the drywall were sealed using standard joint compound and the rooms were given two coats of white paint. All interior doors were standard single pre-hung interior doors.

All of the refrigerant releases detailed in this report were conducted using R 32, a single component refrigerant. The refrigerant was introduced into the space by simulating a leak in the coil of a mini split that was located on the wall in Room A, as shown in Figure 1. The minisplit was installed on the wall with the bottom 2.1 m (83.5 in) off the floor. Leak rates were around 2.8 g/sec (5.9 oz/min) which corresponds to the Enhanced Tightness Refrigerating System (ETRS) leak rate of 10 kg/h. For each test the total amount of release was 3.84 kg (8.4 lbs). Sensors, which had been calibrated to determine the volume fraction of refrigerant, were placed at various points in the room where refrigerant was released as well as in the adjoining rooms.

The clearance between the bottom of the door and the floor were adjusted and the concentration profile during and after the release can be compared. Three different arrangements were conducted: a door sealed tight and seams taped; small clearance of 4 mm by 800 mm (0.16 in x 32 in) below the lower edge of the door; and a larger clearance opening of 25 mm by 800 mm (1 in x 32 in).

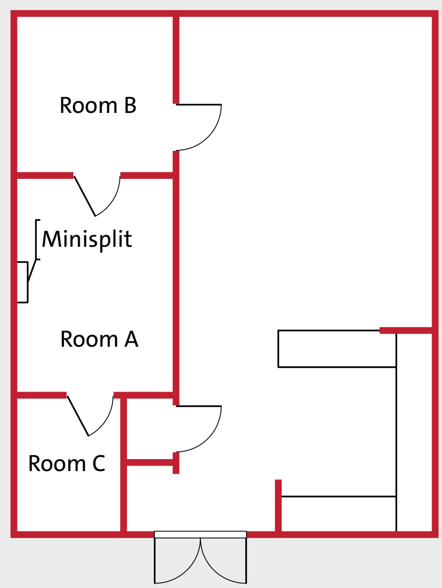


Figure 1 – Room layout

Test results and observations

Room tightness (sealed door gap)

For this test the doors to the adjacent rooms were sealed around the perimeter using aluminum tape (see Figure 3). Refrigeration sensors were placed in several locations in each room. The refrigerant concentration for sensors located at three corners of Room A are indicated in Figure 2. This shows small differences for horizontal locations when there is a difference between sensor heights. The other figures in this report will only detail concentration at one location. It is expected that any location in the room should have similar concentration.

The refrigerant concentrations in the rooms are identified in Figure 2.

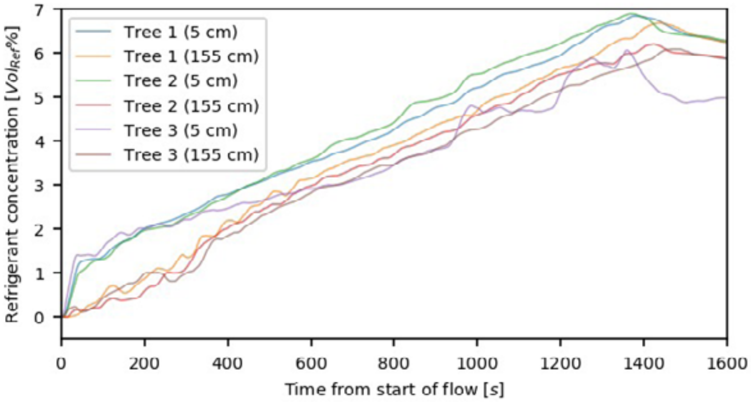


Figure 2 – Refrigerant concentration in Room A

Figure 3 – Door sealing

From this data we can see that the majority of the refrigerant released stays within the room where it was released. At the start of the release, the refrigerant sensor closest to the floor responds quickest, with the sensors at 80 cm and 155 cm responding to a significant refrigerant rise at 200 s and 600 s, respectively. At the end of the release the refrigerant concentration was approximately 6.5% for all sensors located up to 155 cm (61 in) height. The floor area of the room A is 15 m^2, so the volume of refrigerant remaining in the room was estimated at 15 x 1.55 x. 065=1.51 m^3 (53.33 ft3). This corresponds to 3.2 kg (7 lbs) of refrigerant.

There is a concentration rise at the lower sensor in Room C, which starts 600 s after the start of the release. We do not see this same concentration rise in Room B, so there must have been an opening that was not completely sealed.

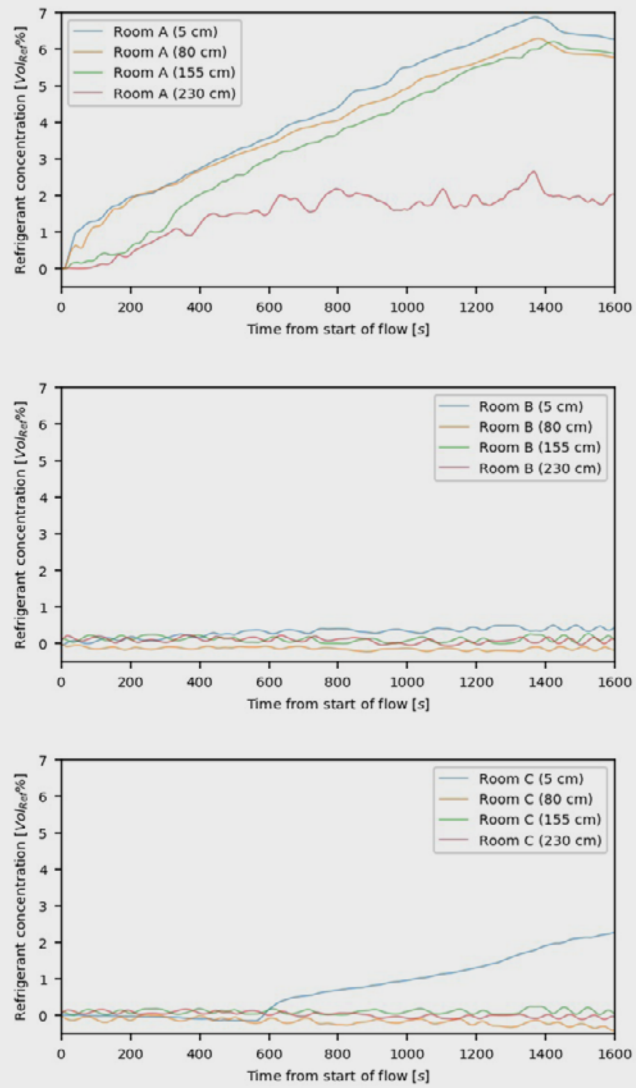


Figure 4 – Room tightness concentrations

Door clearance – small

A strip of wood was attached to the lower edge of the door allowing for the clearance between the bottom of the door and the floor to be controlled. Prior to this test, the clearance at the bottom of the door was set to 4 mm. We are seeing that the refrigerant concentrations are highest in the room with the refrigerant release. In addition, there is evidence that the refrigerant is flowing under the doors and into the two adjoining rooms.

The sensors located 5 cm above the floor both see a refrigerant rise after the start of the release. The sensor at the floor level (5 cm) in Room C responds faster and shows a higher concentration than the sensor in Room B. Refrigerant is also detected at the 80 cm sensor in Room C. These differences in the response and concentrations are due to two factors: room size and overall structure geometry. Room B has a floor area of approximately 173% of Room C. We can then expect higher concentrations in the smaller room, assuming equal refrigerant ingress rates. Room B is also connected to the larger room space by another door. Any refrigerant introduced to Room B will also progress and mix in the larger room space, which is why there is no refrigerant concentration indicated at the 80 cm height for this room.

The concentration in Room A was approximately 1% lower than the tight room test for sensors at a height of 155 cm (61 in) and lower. The remaining refrigerant in the space is estimated 2.7 kg (5.9 lbs), with 0.5 kg (1.1 lbs) of refrigerant flowing through the 4mm (0.16 in) door gap.

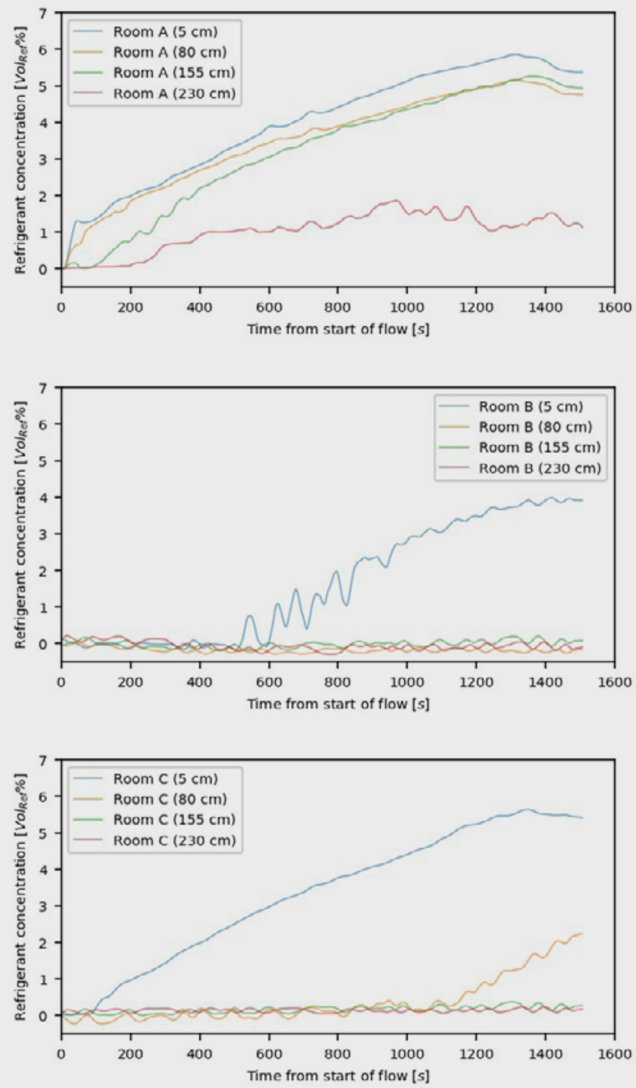


Figure 5 – Small clearance concentrations

Door clearance – large

Prior to the refrigerant release in this test, the clearance at the bottom of the interior doors was set to a 25 mm (1 in) clearance. We are seeing that the refrigerant concentrations are highest in the room with the refrigerant release. As with the smaller door clearance, there is evidence that refrigerant is flowing into the two adjoining rooms.

The concentration increases in Room B were similar to the smaller door clearance case but reached faster. The concentration increases in Room C were slightly lower than they were during the small clearance tests. However, the refrigerant is mixing faster within the room volume as the concentration increases were started earlier with these tests. This, along with the lower concentrations in Room A, indicates that the refrigerant mixture near the floor is passing beneath the doors and into the larger room space. The peak concentration of Room C was close to that of Room A. This shows that if a room is connected through an opening of 25 mm x 800 mm (1 in x 32 in), the concentration in the small room behaves similar to that of a larger connected space.

Other observations

To fully investigate leakage through the door gap, plastic sheets were applied to all the surfaces of the walls and the floor of the test room and all seams were taped. Although every effort was made to seal the room, minor leaks were still observed. These findings highlight that it is extremely difficult to construct a tightly sealed interior room. Interestingly, consensus standards assume all rooms to be reasonably tight when evaluating the risk of a refrigerant leak. For both the IEC and UL/CSA versions of the 60335-2-40 Standard, all rooms are considered to achieve the same tightness, except for restrictions placed on the lowest rooms below grade (which are only applied in certain situations).

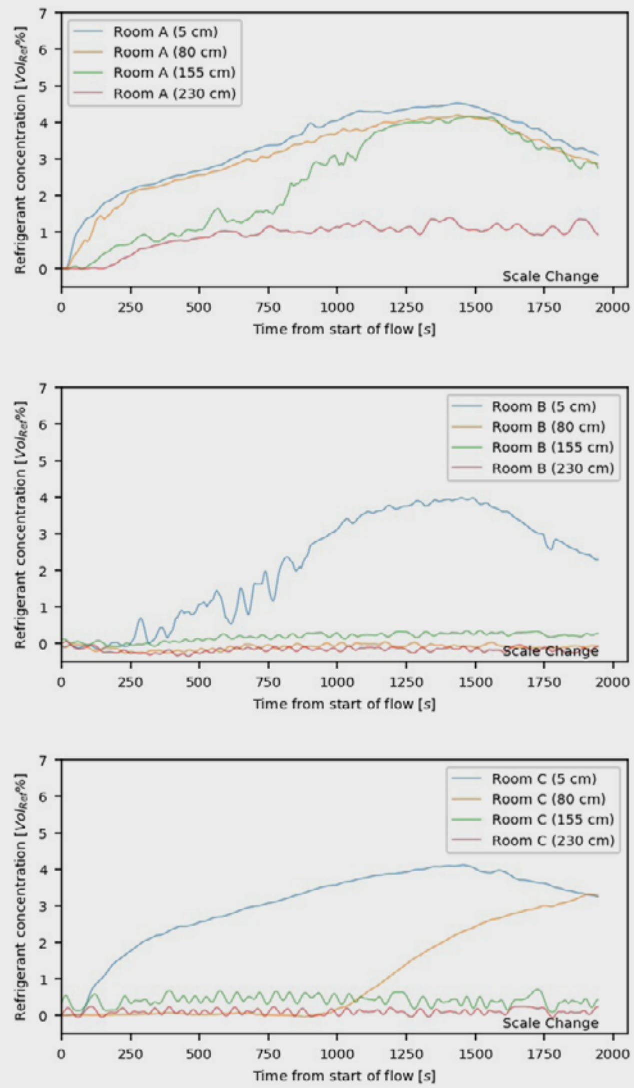


Figure 6 – Larger clearance concentrations

Summary

Interior rooms of buildings are not tightly constructed. A small opening — such as a 4 mm (0.16 in) gap at the bottom of the door — has a significant impact on maximum concentration of leaked refrigerant in the space. Gaps are always present at the bottom of an ordinary door to facilitate the easy opening and closing of the door. In addition, rooms having only one door and no other opening are very limited. Most rooms have multiple doors, window(s) and closets or similar connected spaces. As the safety standards cannot verify the arrangement and construction of the rooms that the products are installed in, it is important for the installation codes to clarify if door gap sizes can be used as a method to disperse refrigerant. The opening under the door has a significant effect on the amount of refrigerant flowing out of that room. Figure 6 details individual sensors for the test conditions in the previous sections.

There is a 1% absolute refrigerant concentration between the sealed room and small door gap. As the refrigerant concentration increases towards the lower flammability limit (LFL), the pressure differential between the rooms would increase, and the refrigerant velocity into the other rooms would increase. Fluid velocity at a hole is generally proportional to square root of pressure difference, so velocity is almost proportional to square root of the concentration. In addition, refrigerant concentration increases proportionally to the escaping mass of refrigerant. The tests in this study were conducted below half of LFL. If concentration in the room approaches LFL, it is expected that the refrigerant velocity from the room is expected to be increased by a factor of 2.8.

Floors are also not constructed tightly enough to prevent the refrigerant leakage. Evaluation of major water leaks has proven that water flows to lower floors. Water leaks are never contained to the upper floor having the leak. Cracks in the floor also provide a path for refrigerant to flow. Even when ducts are installed and sealed using industry best practices, previous research has shown that refrigerant will leak into spaces below the room (Skierkiewicz & Rogers, 2021).

The clearance below the door can be used to mitigate refrigerant release into the space. Clearances below the minimum value indicated in the standard can still be effective. It is understood that values in the standard already incorporate safety factors.

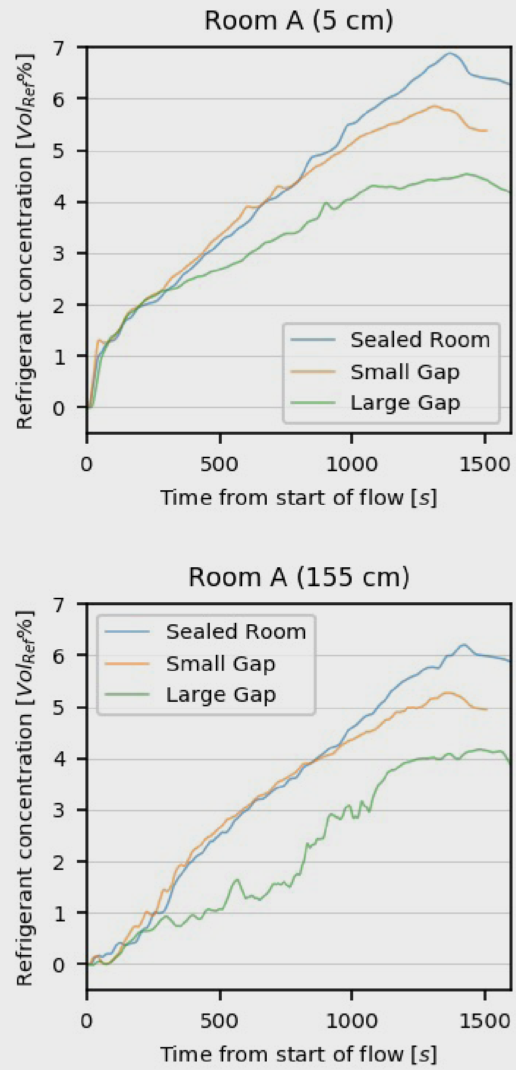


Figure 7 – Door gap summary

To learn more about how requirements impact specific products, visit Flammable Refrigerants Testing for Air Conditioning and Refrigeration on UL.com/Solutions.

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