Technical Report

Penetration of refrigerant leaks into furniture

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Introduction

Previous research on refrigerant releases investigated the refrigerant concentration in the room space. In the past, several research projects (Lewandowski, 2012), (Gandhi, Hunter, Haseman, & Rodgers, 2017), (Baxter, et al., 2018) took into account the effect that obstructions could have on the dispersal of refrigerant in the room space. These projects identified that obstructions could limit the refrigerant's ability to mix in the room space. However, in these projects, researchers constructed obstructions out of hollow boxes intended to displace room space by simulating furniture, clutter, etc.

Researchers leading the AHRTI 9007-1 project sealed the edges of the box and the seams at the floor to prevent refrigerant from infiltrating into the obstacle. No instrumentation was placed inside the obstruction to determine any change of refrigeration concentrations.

Researchers disagree on the significance of furniture volume in a space when determining the safe charge quantity of flammable refrigerants.

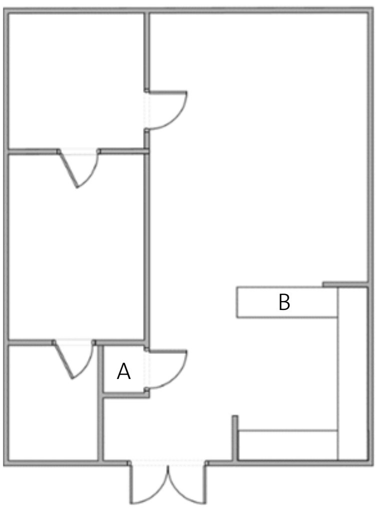

Figure 1: Overall layout of test arrangements for Part I

Some stakeholders claim that furniture occupies a significant volume, thereby increasing the refrigerant concentration by reducing the room volume available to dilute the refrigerant. Proponents of this model advocate reducing the refrigerant charge to account for the volume of the furniture. Others maintain that because refrigerant gasses — which have virtually no surface tension — flow into small gaps, furniture volume does little to prevent penetration. Most researchers agree that soft furnishings, such as cushions for chairs and sofas, allow refrigerants to penetrate.

This paper focuses on hard-surface furnishings, such as cabinets, drawers, wardrobes and armoires, that nominally have significant displacement volume relative to the room volume.

Method

UL Solutions conducted a full-scale refrigerant release testing project at UL Solutions laboratories in Northbrook, Illinois.

As part of this study, we constructed rooms to simulate a 66.9 m² (720 ft²) apartment in one of UL Solutions test chambers. UL Solutions conducted all the refrigerant releases detailed in this report using a single compound refrigerant, R32. We released refrigerant into the unit via a discharge tube located near the A-coil of an air handler unit installed in a closet at location A, as shown in Figure 1. We installed this unit to simulate the indoor section of a split-system air conditioner with a single floor level return and several discharge registers located at or near ceiling level. We placed sensors calibrated to determine the volume fraction of refrigerant at various points in the room. Part I of the results detail the concentration of refrigerant located inside the kitchen cabinets. A simulated kitchen space incorporated two standard kitchen cabinets (B30 size) in position B in Figure 1. The remainder of the kitchen employed a plywood form to simulate lower cabinets and countertops.

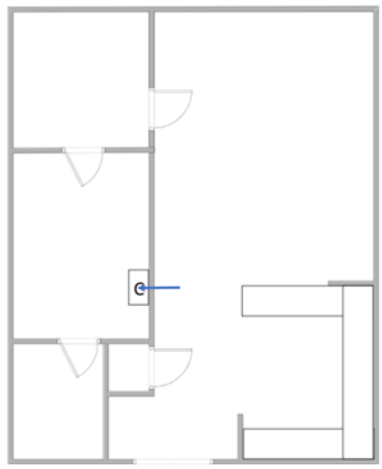

Figure 2: Room layout for Part II

Part II details the results of releasing refrigerants directly into one of the smaller rooms. For this series of tests, we placed a chest of four drawers in the space below the release location. The arrow in Figure 2 shows the approximate location of the refrigerant release; the chest of drawers is C in this figure. We introduced the refrigerant into the room through a supply grill located in part of a wall near the ceiling. We did not connect any ductwork outside the room, ensuring that all of the released refrigerant flowed into this smaller room. We directed the refrigerant discharge in such a way as to remove the flow's momentum so that gravity served as the main factor causing airflow, and there was no fast flow, which would introduce mixing in the room volume. We did not apply any mitigation methods for the results in this part of the proceedings.

We have deconvoluted all the data presented in this report to account for the sensor's response.

Results — Part I

We conducted testing to simulate refrigeration releases with and without indoor blower circulation. In this scenario, the refrigerant concentration inside the kitchen cabinet reached 70% to 80% of the external concentration in four minutes. Cabinet and furniture doors typically do not have finished gaskets around their perimeter to create a seal when closed. In addition, cabinets have bumpers or cushions for sound-dampening, creating greater gaps between closed doors and associated cabinets or furniture. The cabinet sensor in this test was located on the bottom of the cabinet, approximately 26 cm (10.5 in) from the front of the cabinet; see Figure 3. With the doors closed, there remained a 0.6 cm (0.25 in) gap between the doors.

Figure 3: Location of sensor in cabinet

Fast leak rate

We conducted testing with a refrigerant release of 50 grams per second, simulating the leak rate of AHRTI 9007-1 residential split A/C scenarios. For this testing, we activated airflow for five seconds (Figure 4) and 10 seconds (Figure 5) after the start of the release. In the testing, an indoor fan mixed the refrigerant in the space and, in both cases, after 100 seconds, there was only a minimal difference between the concentrations outside versus inside the cabinet.

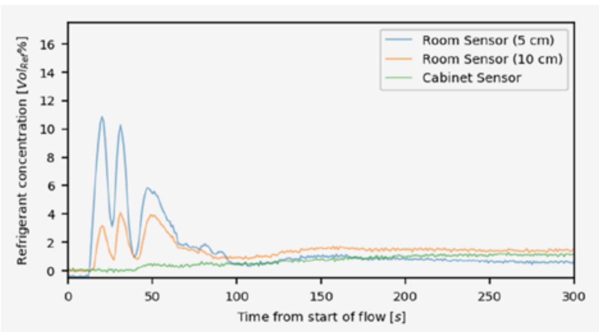

Figure 4: Fan activated five seconds after the start of release

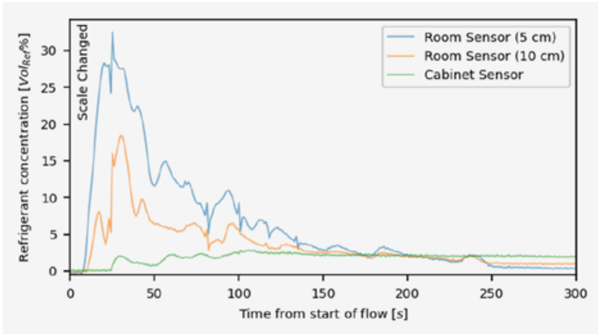

Figure 5: Fan activated 10 seconds after the start of release

IEC leak rate results

Both the IEC (IEC, 2018) and UL/CSA (UL, 2019) versions of 60335-2-40, the Standard for Household and Similar Electrical Appliances - Safety - Part 2-40: Particular Requirements for Electrical Heat Pumps, Air-Conditioners and Dehumidifiers, assume that a catastrophic leak will release the entire refrigerant charge in four minutes. Figure 6 shows the results for this four-minute leak rate. For the testing conducted with no mitigation, the concentration inside the cabinet was lower than what the sensors located in the room space at similar heights recorded. Current standards requirements do not permit the test conditions we used here to establish the charge criteria in this floor area.

For a fan-off condition, we introduced refrigerant into the space at a lower point in the system. The tests simulated here featured a return grill at the floor level, and almost all refrigerant flowed into the room through this grill.

Unlike in the previous tests where the sensor in the cabinet indicated similar levels to that of the outside sensors after 200 seconds, in this test, it indicated a lower concentration than those outside the cabinet at equivalent heights. This was because the high concentration in the cabinet generated flow toward the exterior that reduced the refrigerant concentration inside. The concentration inside the cabinet represented an average of the concentration measurements of external refrigerant layers. The concentration at the bottom was lower inside the cabinet, but the cabinet seemed to contain concentrations equivalent to the exterior average concentration. The concentration decreased starts just after the external concentration at 20 cm height decreased, demonstrating this principle. It means that the cabinet contained sufficient refrigerant to generate equivalent pressure to the external pressure. Once the external pressure decreased, the refrigerant flowed out of the cabinet, indicating a lower concentration value. When we used the fan for mitigation, the concentration inside and outside of the cabinet was equivalent after 150 seconds following the start of the release, as shown in Figure 7.

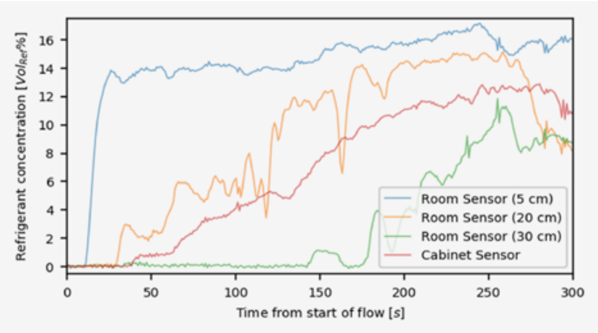

Figure 6: Refrigerant concentration, no unit airflow

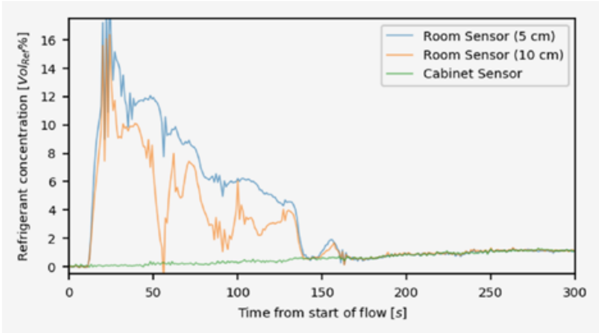

Figure 7: Fan activated 10 seconds after release

Enhanced tightness refrigerating system leak rate
To simulate a leak introduced by a system constructed with enhanced tightness refrigerating system (ETRS) requirements, we utilized a lower refrigerant release rate. We also conducted testing for this leak rate without mitigation, which neither the current requirements in the IEC version of 60335-2-40 nor the proposed requirements in the next edition of UL Solutions version (UL Solutions, estimated 2022) permit. Five minutes after the leak began, the concentration inside the cabinet was approximately 70% of the concentration outside the cabinet at the same height. When the leak concluded, the refrigerant concentration inside the cabinet was approximately 80% of that measured by the sensors outside.

The test results show that the concentrations near the floor are significantly higher than those located at a greater height. That indicates the occurrence of stratification. Similar to the IEC case, the interior concentration measurements were lower than those outside the cabinet at similar heights above the floor. In this case, the concentration measurement inside the cabinet was close to that of 20 cm outside.

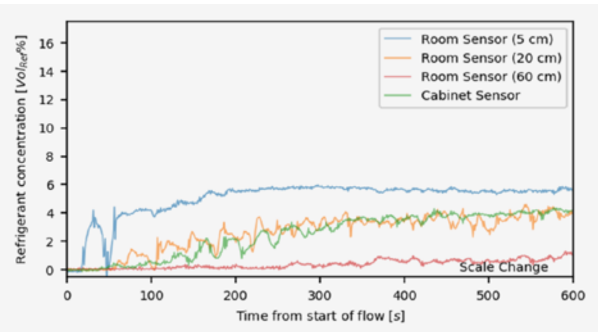

Figure 8: Refrigerant concertation, no unit airflow

The refrigerant was concentrated at a lower level when entering the room at the early stage of the release. The high concentration layer generated flow in the cabinet, resulting in lower refrigerant concentration inside. At the second stage, lower-concentration refrigerant flowed into the room and spread above the initial layer after flow from the duct (due to gravity) was established and moved into the cabinet. So, similar to the IEC scenario case, the refrigerant concentration inside the cabinet indicated a lower concentration at the bottom part of the cabinet, but the average concentration seems to be equivalent.

Results — Part II

We conducted testing presented in Part II without a fan operating for mitigation. The chest of drawers was a commercially available product which we purchased off the shelf from a big box store and assembled per the instructions. We placed sensors in two drawers: the bottom and third from the bottom. Each drawer was 14.2 cm (5.8 in) deep. The edge of the bottom drawer was 25 cm (9.8 in) off the ground, and that of the third from the bottom was 72 cm (28.3 in) off the ground. For these tests, we placed the sensors on either side of the chest of drawers at approximately the same heights.

The first test involved a fast release rate of refrigerant. After 100 seconds and 150 seconds, there was no difference between the sensors located in the bottom drawer, the third drawer and the outside space.

Figure 9: Chest of drawers

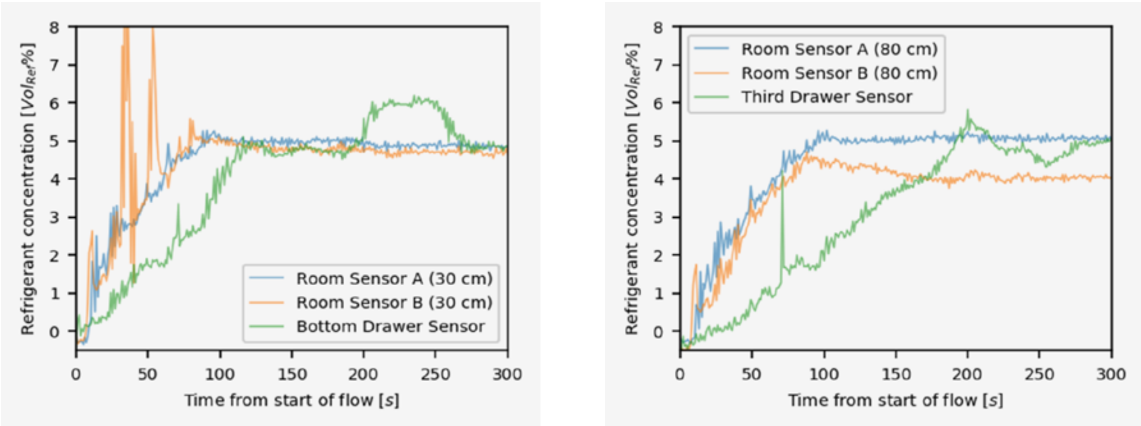

Figure 10: Refrigeration concentrations, fast release

The next test involved a release at an intermediate rate for four minutes. This served as the baseline flow referenced in both the IEC's and UL/CSA's versions of 60335-2-40. After 250 seconds, the concentration was the same inside the drawers and outside the test space.

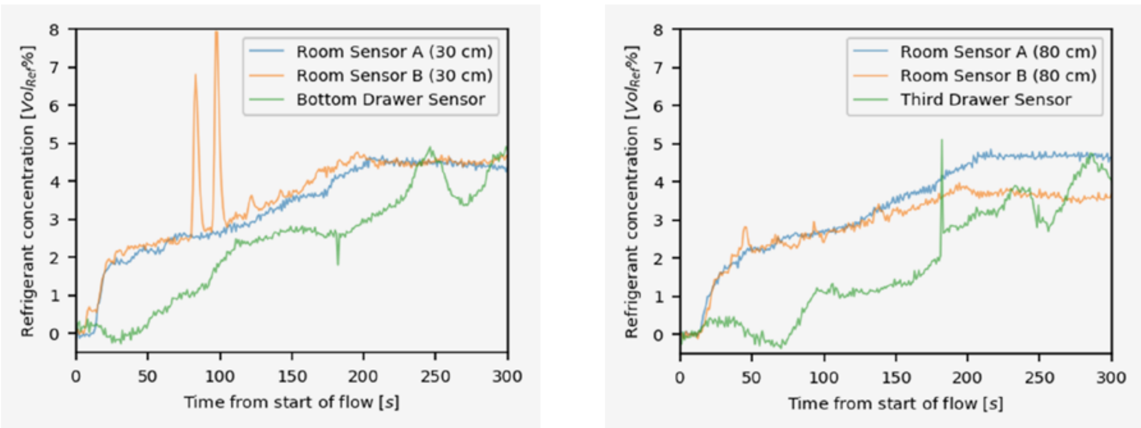

Figure 11: Refrigerant concentrations — intermediate release rate

The third test in this series was a slow-release rate of 3 grams per second, which corresponds to an ETRS leak rate (10 kg per hour). There was no significant difference between the refrigerant concentrations observed inside the drawers and in the room space during the release. During this test, the data for the drawer sensors oscillated due to noise present on the base signal and amplified by the applied deconvolution.

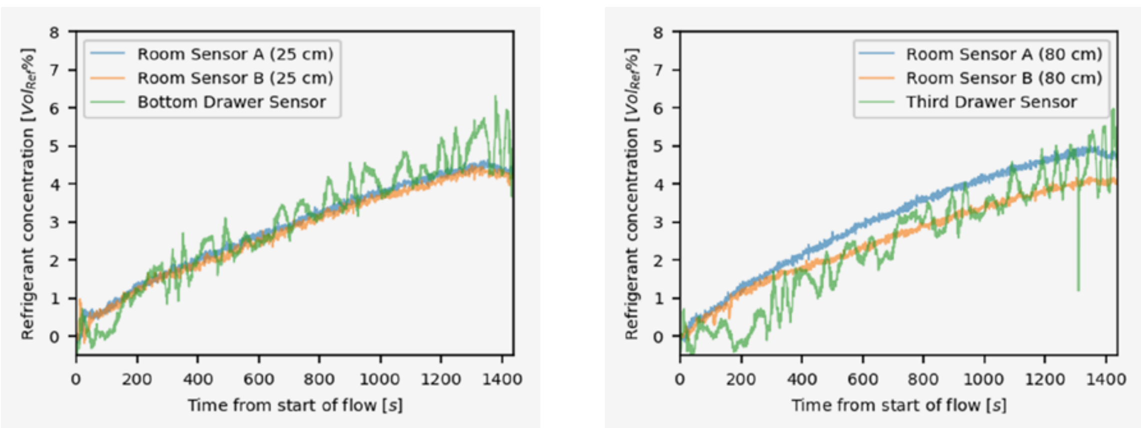

Figure 12: Refrigerant concentrations — ETRS release rate

Summary

The results from Part I showed concentration measurement results inside and outside the B30 kitchen cabinet with R32. Green curves represent the concentration inside the cabinet, while blue and orange curves represent the concentration outside the cabinet at equivalent heights. Almost all refrigerant flowed out from the return grill when the fan was not operating, resulting in a high concentration layer near the floor. When the fan was operating or turned on as part of a mitigation procedure, it distributed the refrigerant throughout the entire room space. In all release tests except for the one without fan mixing, the refrigerant concentration inside the cabinet approached the refrigerant concentration outside of the test space. The test exceptions were without mitigation, and the concentration values seem to reflect an averaged value of external concentration layers resulting from the refrigerant mixing in the cabinet.

The results from Part II showed concentration measurement results inside the drawer in green curves, with the concentration at the approximate height of the drawer in blue and orange. For these tests, the concentration values in the drawer had a slight delay, but soon after the end of the releases, the concentrations at the same heights inside and outside of the drawer had similar values.

These test results demonstrated that researchers should recognize that furniture and structures with hollow interiors have little impact on room volume calculations. Evidence confirmed the assumption that refrigerant behaves as all fluids and will flow fairly quickly as a function of a pressure differential.

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