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COMPLEX RADON MITIGATION OF A LARGE BUILDING

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ABSTRACT

"Home Plate", a combination bar, grill, and recreation center, is an 8000 ft^2 single-story slab-on-grade building with a partial basement. Radon testing of each ground-contact room found elevated radon levels in seven of eight rooms (5.6 pCi/L to 13.4 pCi/L). Mitigation diagnostics determined that the installation of three active soil depressurization (ASD) systems would reduce the levels to <4 pCi/L if the (-) 80 Pa shell differential pressure (DP) caused by the building's exhaust systems could be reduced to ≤ 8 Pa. In 2002, a phased approach to reduce the significant DP was implemented. This approach included installation of passive louvers and a prototype 5-ton supplemental air-makeup system. The approach was successful, with postmitigation results ranging from < 0.5 pCi/L to 2.0 pCi/L.

BACKGROUND

"Home Plate", located on the island of Guam, is a combination bar, grill, and recreation center (Figure 1). The 8000 ft^2 single-story concrete masonry building is slab-on-grade construction with a partial basement. The original part of the building, about 2000 ft^2, was constructed in 1959 and was used for office space. Between 1959 and 1983, the building was used for various purposes (e.g., as a machine shop, electronics repair and restaurant), and its size tripled to about 6000 ft^2. In 1984, the building was converted to its current size and use, with the addition of 2000 ft^2 (game room and dance floor). Because of these past renovations, the roofline of the building spans two levels, with one span covering the original and newest part of the building.

During 1997 to 1998, long-term radon testing using alpha-track detectors was performed within all routinely occupied rooms. Of the seven rooms tested, six were determined to have elevated radon levels, ranging from 5.6 pCi/L to 13.4 pCi/L (Figure 2). In 1999, short-term follow-up testing (electret) was repeated in the seven rooms, the basement, and both bathrooms. These follow-up tests confirmed the original long-term test data and identified three additional rooms for radon mitigation (Figure 3).

MITIGATION DIAGNOSTICS

During radon testing, it was noted that the main entrance door into the building was hard to open because of a large pressure imbalance (negative pressure). Therefore, before the initiation of radon mitigation, the building's mechanical systems were inspected.

The building is cooled by two separate forced-air mechanical systems, each with its own controls and ducting. System 1 is a 5-ton package unit compressor, servicing the Cyber Café, the lounge, Office 1, and the two bathrooms. The system is 100% recirculated air, and no allowances were made during initial installation for sufficient fresh-air makeup. System 2 is a split system with two 10-ton chillers and provides service to the remaining parts of the building, with the exception of the kitchen, which is not conditioned. System 2 has a 500-CFM-rated fresh-air makeup grill located on the central blower unit in the mechanical room, but the grill was not ducted to the outside.

With respect to other non-cooling mechanical systems, the building has five independently switched air-exhaust systems totaling 11,000 CFM. All of these systems are operational during normal business hours (1100 to 0200) with a capacity of:

- men's room (200 CFM),
- women's room (200 CFM),
- janitor's closet (100 CFM),
- dishwasher (500 CFM), and
- grill exhaust (10,000 CFM).

Relative to the outdoors and with all exhaust systems turned off, the game room (Figure 1) shell differential pressure (DP) was (-) 5 Pa and 0 Pa if both air conditioning mechanical systems were turned off as well. This 5-Pa loss of conditioned air was linked to leaks in the external ductwork of System 1 and the transition collar at the unit supply duct interface. Sealing around the transition collar was feasible. However because the supply duct was covered with a riveted, insulated metal wrap, finding the duct joints that were leaking would have required replacement of the entire duct. During normal mechanical operation, little variation in DP (± 2 Pa) was found in the lounge or in offices relative to the open areas of the building. This was an indication that the forced air systems were balanced. Overall, the ducting design for both air conditioning systems was found to be adequate, and both systems were found to be reasonably well balanced and maintained. The only problem noted was the absence in the design for any fresh-air makeup.

With respect to the other air exhaust systems, a systematic study was performed as a function of "on" versus "off" for each of the air exhaust systems. Individually, none of the non-kitchen exhaust systems created a significant negative pressure problem. However, when all were turned on, the combined DP relative to outdoors was (-) 14 Pa. If the 10,000-CFM kitchen exhaust fan was also activated, the building's DP increased significantly to (-) 80 Pa. For the bathrooms a DP of (-) 6 Pa to (-) 8 Pa was measured with the doors closed. However, the doors were typically left open during business hours. Therefore, the potential impact of the pressure imbalance in these rooms was minimal. Interviews with the building manager and workers confirmed that the typical configuration during normal business hours was to have all exhaust fans operating and there was no convenient way to change this practice. Therefore, it was concluded that the pressure imbalance would have to be worked around or negated before radon mitigation could be achieved.

Because the 10,000-CFM grill air-exhaust system was the largest single reason for the negative pressure in the building, it was examined first. The grill exhaust was installed in the late 1980s, and during installation, no allowances were provided for makeup air. The only source of makeup air for the kitchen was a wall/ceiling-mounted intake fan of about 500-CFM capacity. It is worth noting that the pressure differential in the room was so great that the small intake fan actually performed better when turned off and allowed to windmill (700 CFM). Because of code changes (fire and public health) since the kitchen was installed, modification of the grill exhaust system to incorporate fresh-air makeup would have required replacement of the entire fire suppression system, grill, exhaust hood, and exhaust blower and potentially a rework of the entire kitchen orientation (e.g., sink location and fire exits). Excluding the loss of revenue from food sales during down time for remodeling, the rework would have cost over $60,000. However, because the kitchen was unconditioned, the problem with providing makeup air for the room could potentially be solved by installing a larger makeup air fan or by installing screened louvered windows.

Assuming that the makeup air problem in the kitchen could be solved, diagnostics were then directed toward the two forced–air mechanical systems to determine if they could condition sufficient makeup air to equalize the pressure imbalance, pressurize the shell, or increase the building's air change significantly. To determine if vacuum reduction was an option, continuous radon measurements (CRM) using a FemtoTech Model 210F radon detector were performed in three rooms with all mechanical exhaust systems turned off. Although the radon levels were significantly lower at (-) 5 Pa, all three rooms were still >4 pCi/L (Figure 4). Shorter duration tests with the mechanical exhaust turned off, as well as with the two forced–air mechanical systems turned on (0 Pa), did not show any additional decrease in radon levels.

To estimate the volume of air needed to pressurize the building, a blower door test was performed while the building was in a neutral condition (all mechanical systems turned off) and while the kitchen was isolated from the rest of the building. Excluding the kitchen exhaust, the test estimated that 2500 CFM would be needed to pressurize the building shell to around 4 Pa. On the surface, this approach seemed feasible, but to isolate the kitchen, two 6-ft air locks (one for both interior entrances to the kitchen) would be needed. For the hallway entrance into the kitchen, an air lock would not have caused a significant problem. However, an air lock at the other kitchen entrance, to the right of the dance floor, would have reduced the dance floor area by 20% and would have required relocation of the disk jockey's booth. Therefore, mitigation solutions that required an air lock were dismissed.

With respect to increasing the air change, episodic air-change measurements performed in the lounge and game rooms found 0.5 and 0.75 air changes per hour (ACH) respectively (with the kitchen exhaust grill turned on). Using the lower ACH (0.5) and the highest radon level (13.4 pCi/L), an additional 4500 CFM of makeup air would be needed to provide sufficient ventilation for radon reduction. Although the building had a total of 25 tons of cooling, the air exhausted during normal operational hours was around 28 tons. To compensate for this cooling deficit, all AC systems were operated at 100%, 24 h/day to preload cool the building during the unoccupied times. This preloading cooling during the off hours resulted in condensation problems in areas of the building that contained exposed, uninsulated ductwork. In addition, besides the increased energy costs, operating any air conditioning mechanical system for more than 80% of the time results in increased wear on the machinery and higher operation and maintenance costs. Therefore, the conclusion was reached that under the current conditions the addition of any significant volume of outdoor air would overwhelm the existing cooling systems. Because of these problems and concerns, replacement of all mechanical systems (air conditioning and exhaust) in the building was then considered. However, the estimated cost for replacement at $200,000 was considered too high.

Because of the renovation history of the building, subslab diagnostics were performed on each of the three slab-on-grade subslabs and the basement slab to determine if active soil depressurization (ASD) was feasible (Figure 5). Field extension data collected with the air conditioning turned on and no exhaust systems operating [(-) 5 Pa] determined that a three-fan, three-suction point system (Figures 6, 7, 8, and 9) would cover 100% of the slab-on-grade subslabs. The diagnostics were then repeated at (-) 14 Pa (all exhaust systems except the grill), and the coverage dropped to about 60%. Coverage with all exhausts systems turned on [(-) 80 Pa] dropped subslab coverage to an average of <5%. With the marginal coverage at (-) 14 Pa for the slab-on-grade subslabs, it was estimated that three additional suction points would be needed. Two of these additional penetrations would be located on the exterior of the building and would not cause a problem. However, because of the usage of space and the mostly open floor plan, one of the suction points would need to be near the middle of the dance floor. Therefore, this option was discounted as well.

The partial basement, which was under only the kitchen, was not conditioned, had no external exhausts, and had a single exit to the outside. In addition, inspection of the basement ceiling found that all the pipe penetrations from the kitchen were well sealed. DP tests relative to the outdoors found that the basement was consistently (-) 2 Pa regardless of the DP in the kitchen above. In addition, subslab diagnostics in the basement found excellent communication under the entire subslab (Figure 5). With respect to system design, the basement suction point could be manifolded to the slab-on-grade ASD System 1 (Figure 7).

MITIGATION PLAN

At the conclusion of the diagnostics, it was realized that the obvious mitigation solutions were either too expensive (e.g., reworking the building's mechanical systems) or impractical (e.g., installing a suction pipe in the middle of the dance floor). Therefore, a combination approach using a multidiscipline team (radon mitigators and mechanical engineers) was adopted to address each of the problems. The first problem was how to neutralize the 10,000-CFM exhaust blower in the kitchen. Option 1 was to replace the currently inadequate 500-CFM intake fan with a suitable-size intake blower. The problem with this approach was where to deposit the 10,000 CFM of makeup air without creating a wind tunnel in the kitchen. Each proposed orientation of the ductwork would have resulted in air velocity problems for the workers in the room and may have caused problems with the kitchen exhaust. However, shell pressure diagnostics performed in the kitchen with the grill exhaust turned on found that about 30 ft^2 of outdoor leakage was needed to passively equalize the pressure in the room. Twelve feet above the kitchen floor and, most importantly, away from the direct line of the main work area were three windows with a combined 36 ft^2 of opening. Removal and replacement of these windows with screened, adjustable louvered windows lowered the building DP to (-) 14 Pa (Picture 1).

The three-fan (GP 501), four-suction-point ASD system was installed as originally proposed (Figure 6). As predicted by the subslab diagnostics, at (-) 14 Pa , with all exhausts turned on except for the grill, only 60% of the subslabs were covered. Postmitigation testing found that only conditions in the Cyber Café were mitigated. CRM measurements performed in three rooms identified as having elevated radon levels showed that room conditions were mitigated if the exhaust systems were turned off (Figure 10). Additional subslab diagnostics determined that mitigation could be achieved if the shell pressure could be reduced to (-) 8 Pa or less. After consulting the blower door curves generated during earlier diagnostics, it was estimated that only 800 CFM of additional fresh air would be needed to achieve this pressure.

Because the building's cooling deficit had been significantly reduced with the addition of passive louvers in the kitchen, the original idea was to use the existing chiller forced air system (System-2) to provide the conditioning needed for the additional 800 CFM. The assumption was that the preexisting 500-CFM intake in the mechanical room could be enlarged and hard ducted to the outside to provide the additional air. However, experimentation using the preexisting 500-CFM intake in the mechanical room found that the volume of condensation generated during conditioning of the outdoor air exceeded the capacity of the existing drain. Examination of the 1½-in.-diameter drainpipe found that it was already at capacity because of other discharges in the building. Replacement with a larger diameter pipe or installation of another drainpipe would require removal of all the machinery in the mechanical rooms and removal of the floor. Because this option would require the shutting down the business for at least one week, it was eliminated as well.

Analysis of the required cooling load of the building, based on maximum occupancy and customer activities, estimated that the building should have least 30-tons of cooling, compared to the existing 25 tons. Because at least 2-tons of cooling capacity would be needed to condition the estimated 800 CFM of fresh air needed, concern was expressed whether a 3-ton unit would have sufficient reserve capacity to condition additional air if the original projections were optimistic. Mindful of the fact that the building needed an additional cooling, a 5-ton compressor was selected. This choice provided additional cooling and a reasonable "cushion" if estimates were wrong. The system design included auto sensors that would shut the system down if a fire occurred or if the supply air stream exceeded 78°F or 50% humidity. Because of comfort factors, the location of the discharge point for the 2000 CFM of air (total system capacity for 5 tons) became an issue. Long, complex duct runs that would evenly distribute the conditioned air throughout the building would degrade system performance. Therefore, the shortest duct run possible to the point of highest load would be ideal. Examination of the building's activities identified the dance floor as the most likely location to meet these criteria. The location required only 20 ft of supply duct and was the place of highest physical activity in the building. Installation and activation of the 5-ton system (Figure 11 and 12) reduced the negative pressure within the building to (-) 7 Pa, which was within the desired range.

POSTMITIGATION TESTING

Postmitigation testing of the building with the passive kitchen louvers open, all three ASD systems operational, and the 5-ton supplemental makeup air system (800 CFM) operational found that radon levels within the building had dropped significantly (Figure 13). As an added benefit, the changes made to the building (e.g., passive louvers and the added cooling) significantly improved the overall comfort factor of the building. For one, these improvements eliminated the need to preload cool the building prior to opening. Second, condensation problems within various rooms of the building were eliminated. Third, for the first time, the two preexisting mechanical systems in the building actually achieved the desired thermostat setting and cycled off, meaning potentially lower energy and maintenance costs.

CONCLUSION

In general, the mitigation of commercial buildings is more complex than mitigation of residential buildings. Complex subslabs, larger more complex forced air systems, and space utilization all can have an impact on potential mitigation solutions. As seen in this example, competing problems, customer driven priorities, and the cost of potential solutions directed the course of radon mitigation. In addition, other problems observed in the building (e.g. condensation, preload cooling, humidity problems and mold) needed to be addressed and were. However, by taking a team approach that included working with the customer and teaming with mechanical engineers, the radon levels were mitigated, with improvements in the building's comfort and energy efficiency.

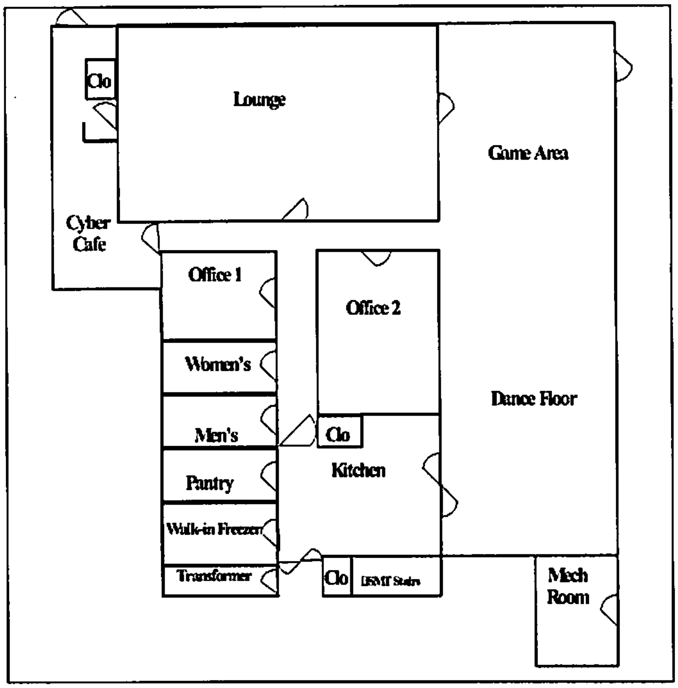


Figure 1. Home Plate floor plan

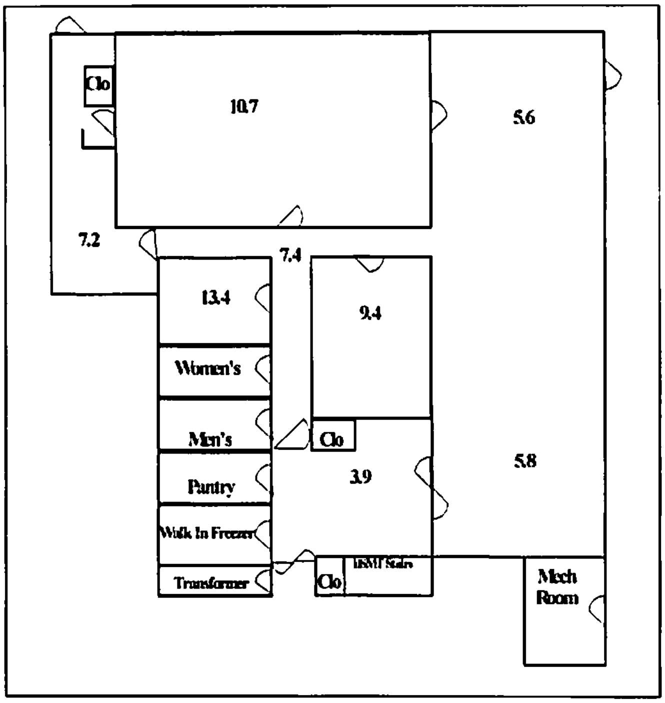


Figure 2. Long-term radon results in pCi/L

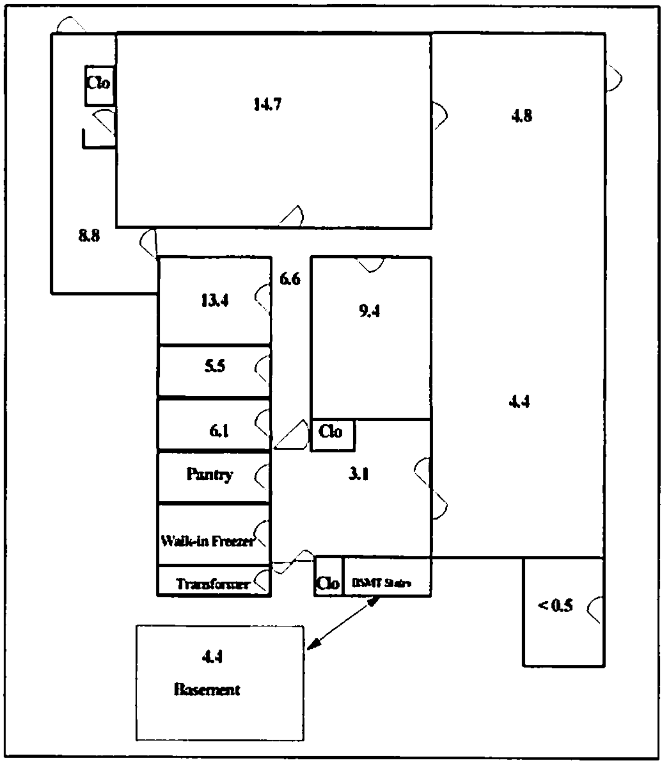


Figure 3. Short-term radon results in pCi/L

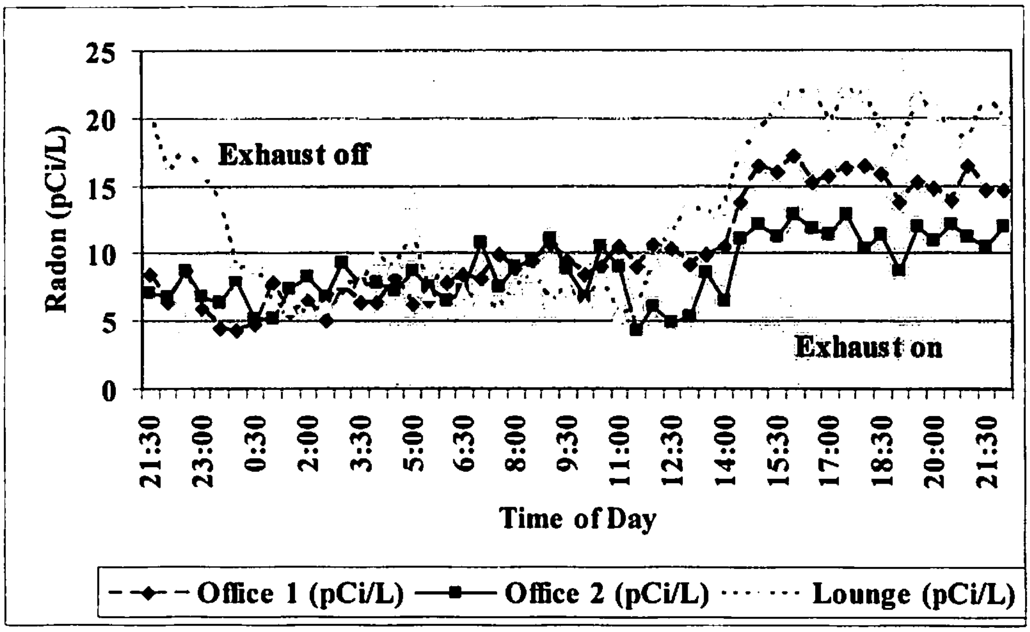


Figure 4. Continuous radon levels in three rooms as a function of exhaust

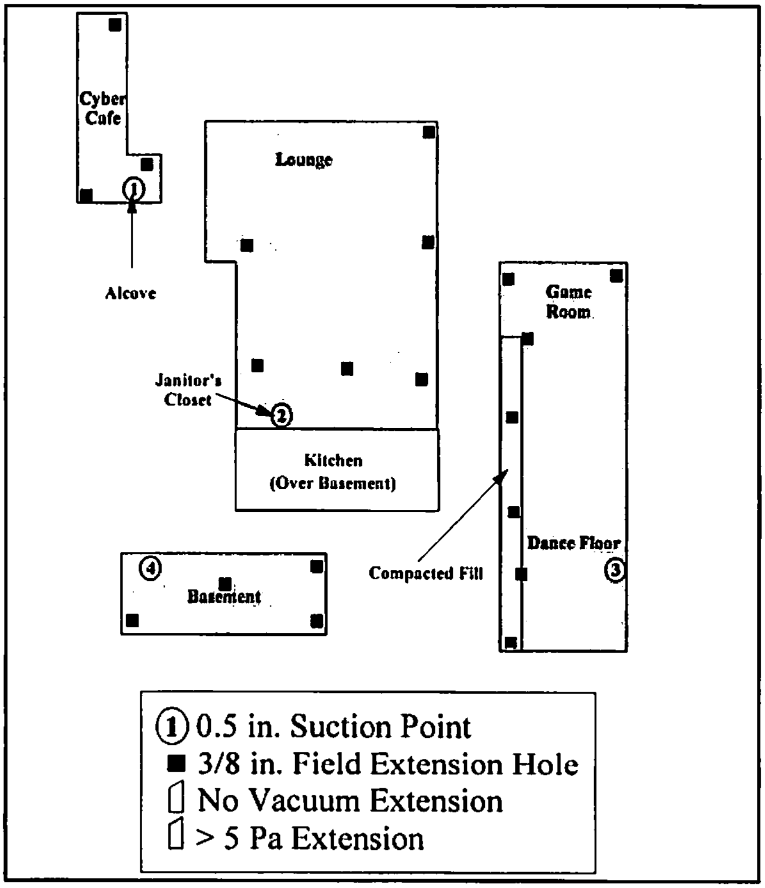


Figure 5. Subslab field extension

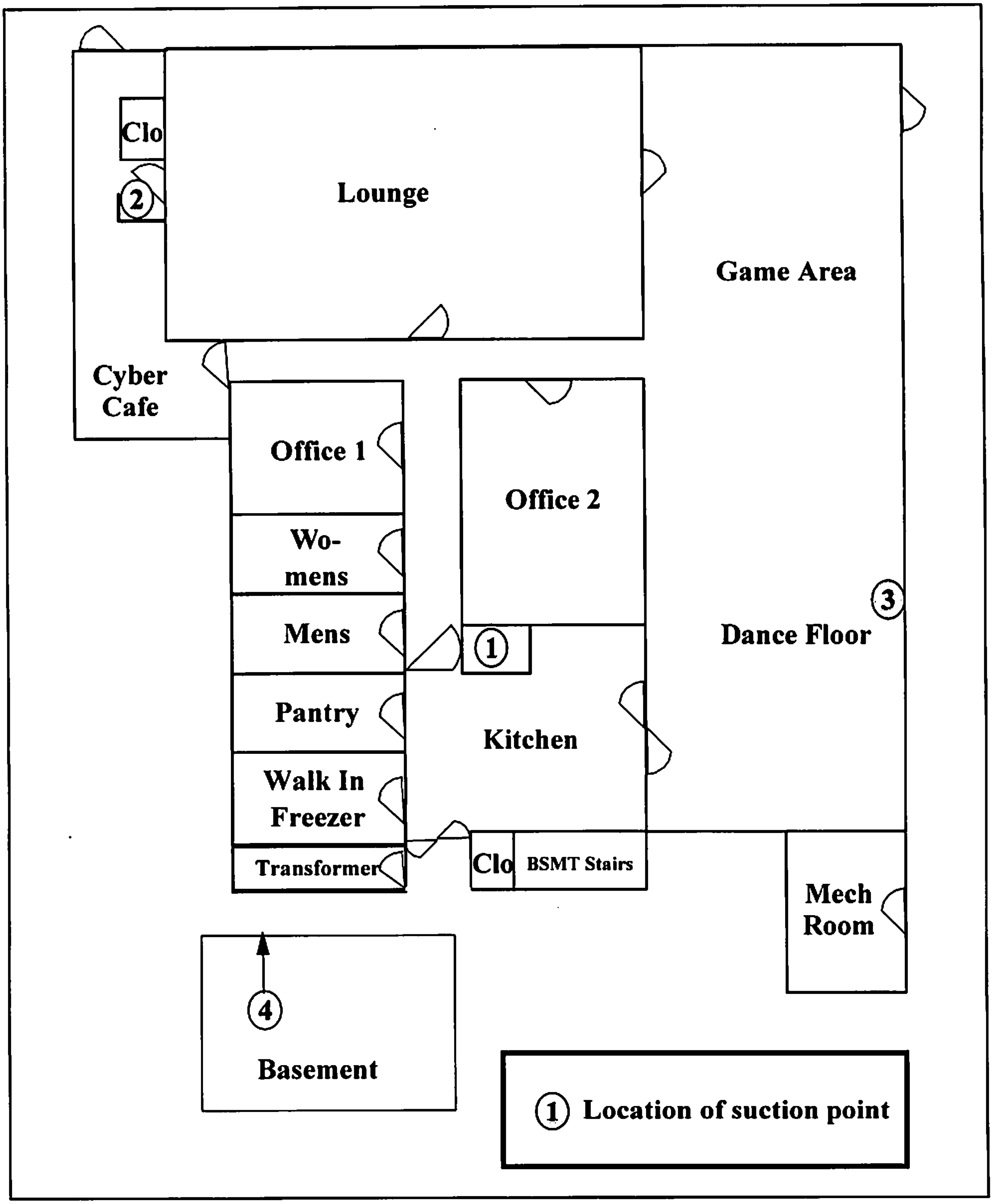


Figure 6. Suction point location

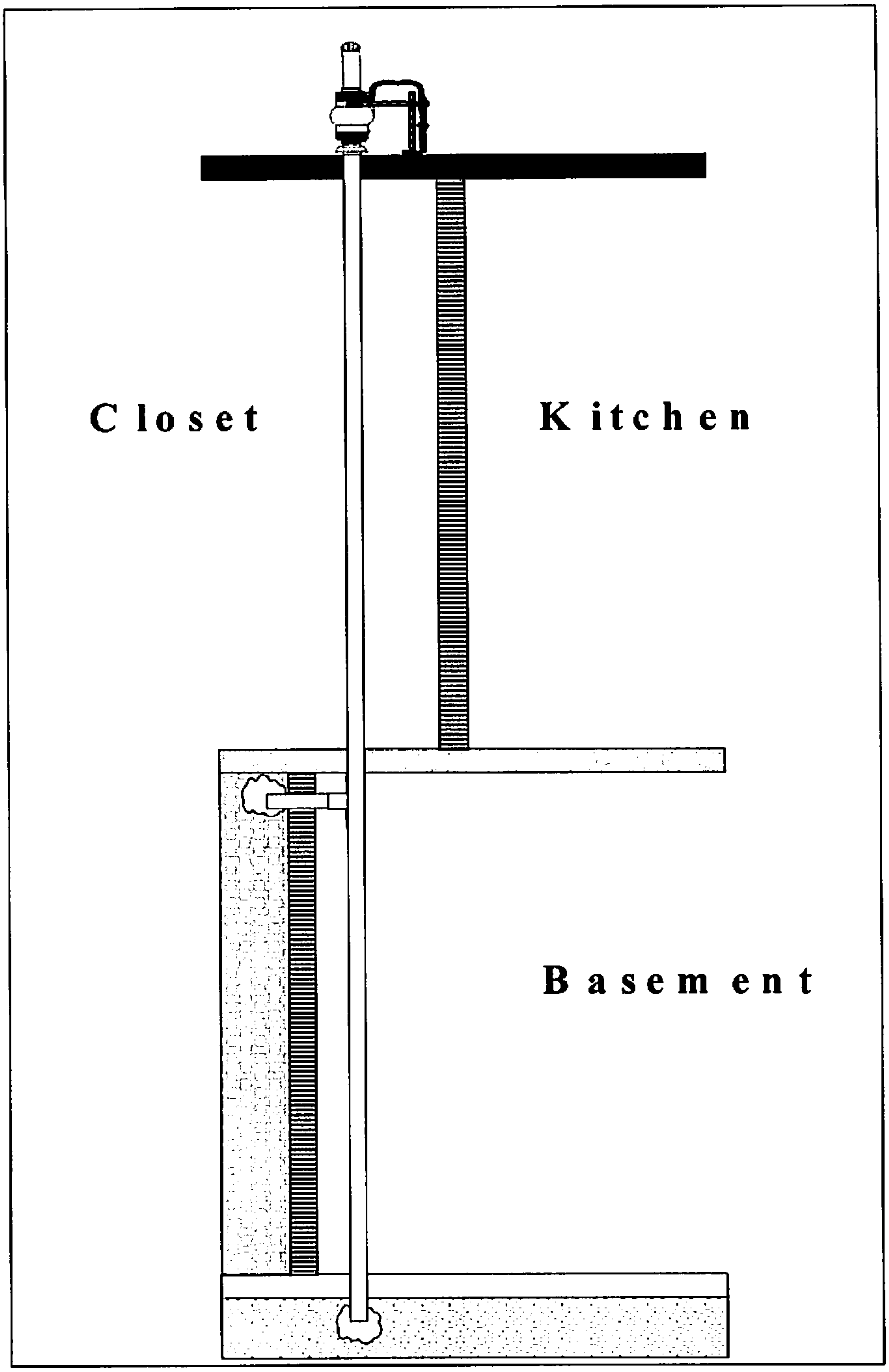


Figure 7. ASD System 1

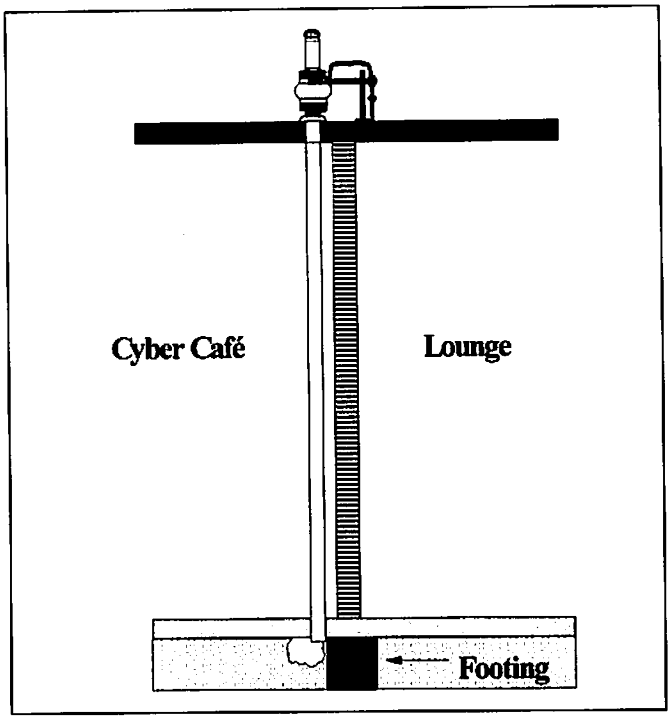


Figure 8. ASD System 2

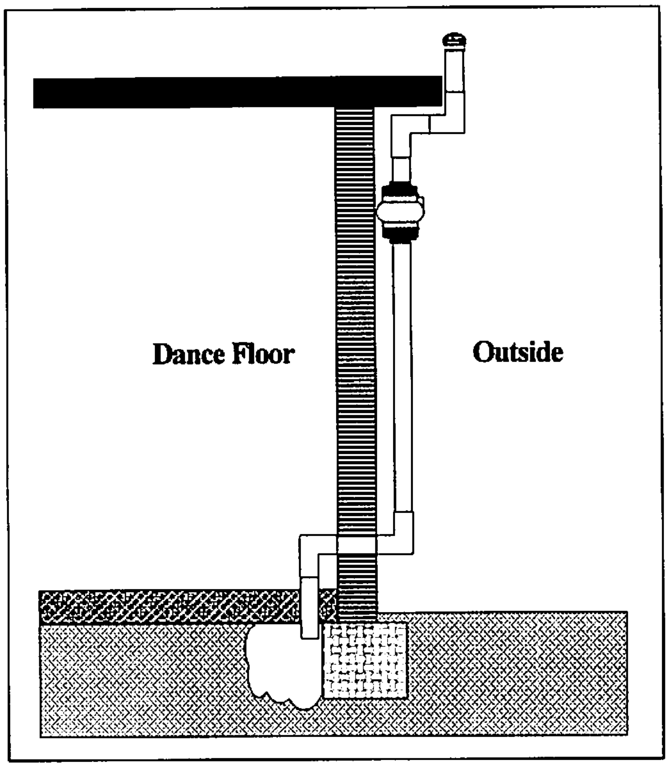


Figure 9. ASD System 3

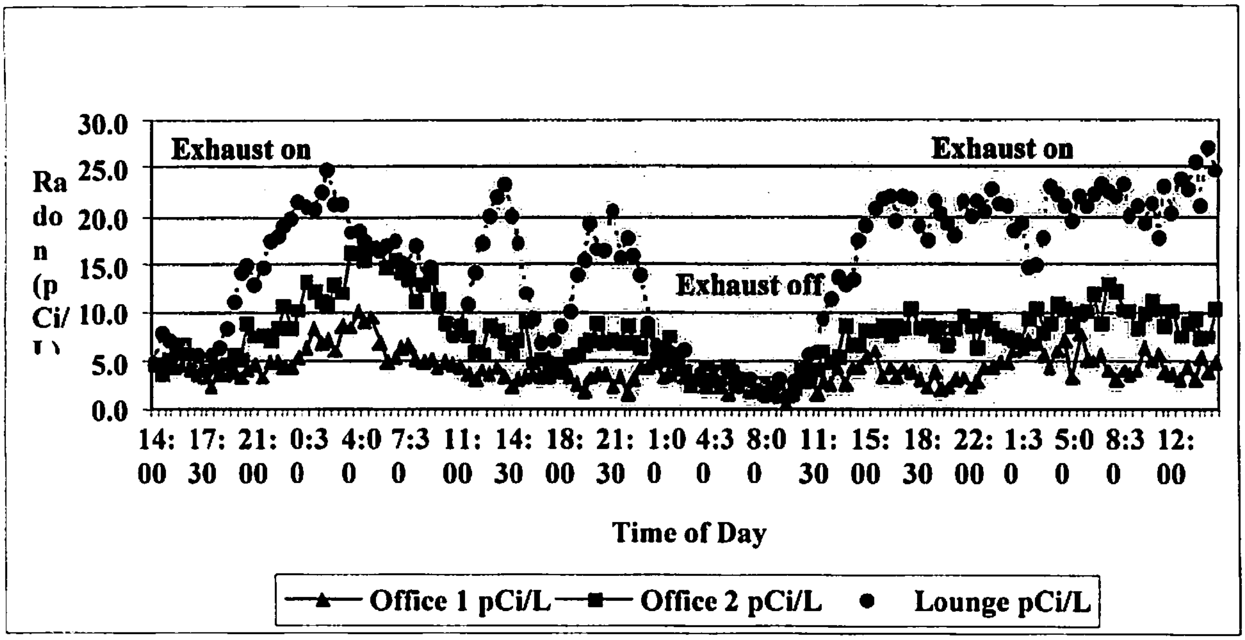


Figure 10. Radon levels in three rooms before supplemental air

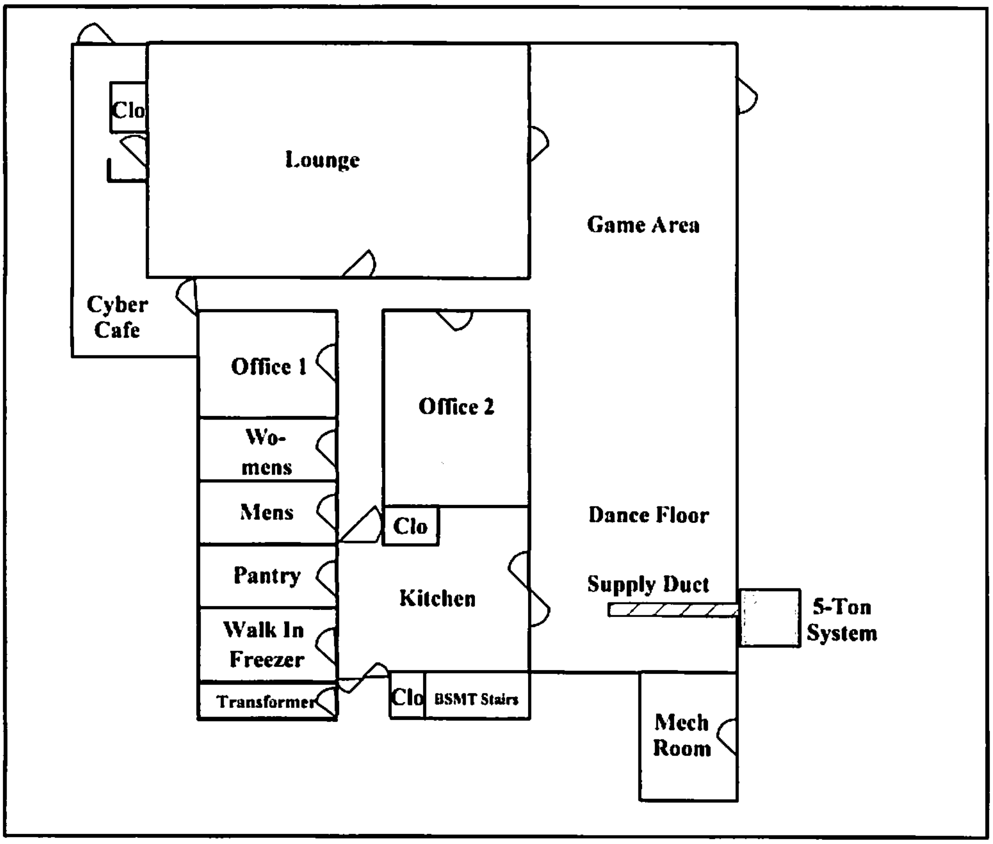


Figure 11. Location of the 5-ton supplemental air makeup system

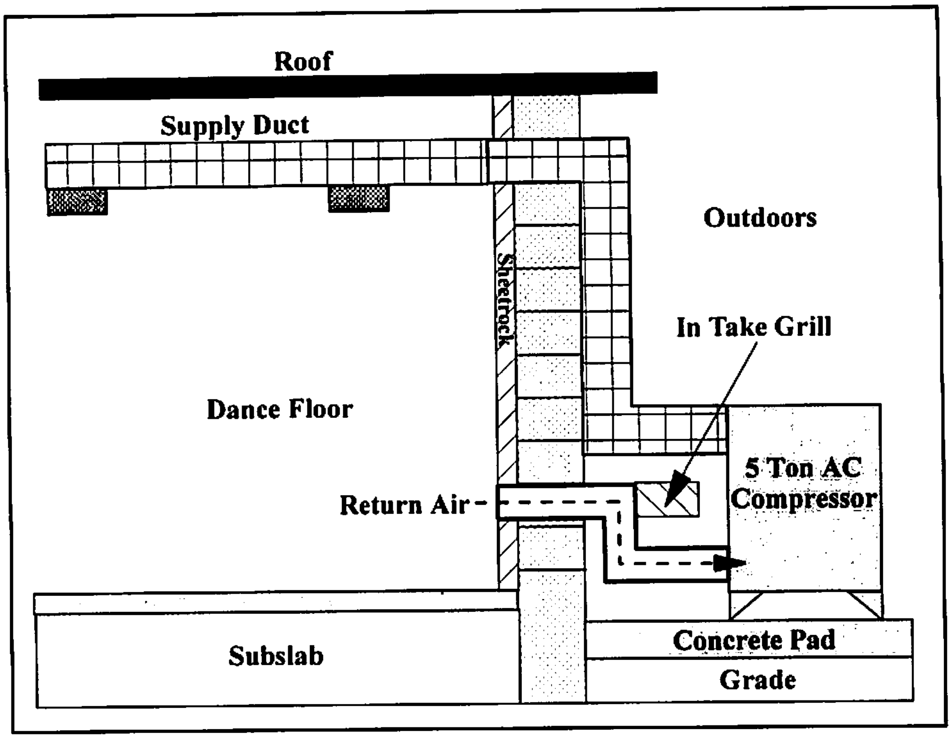


Figure 12. Supplemental air makeup

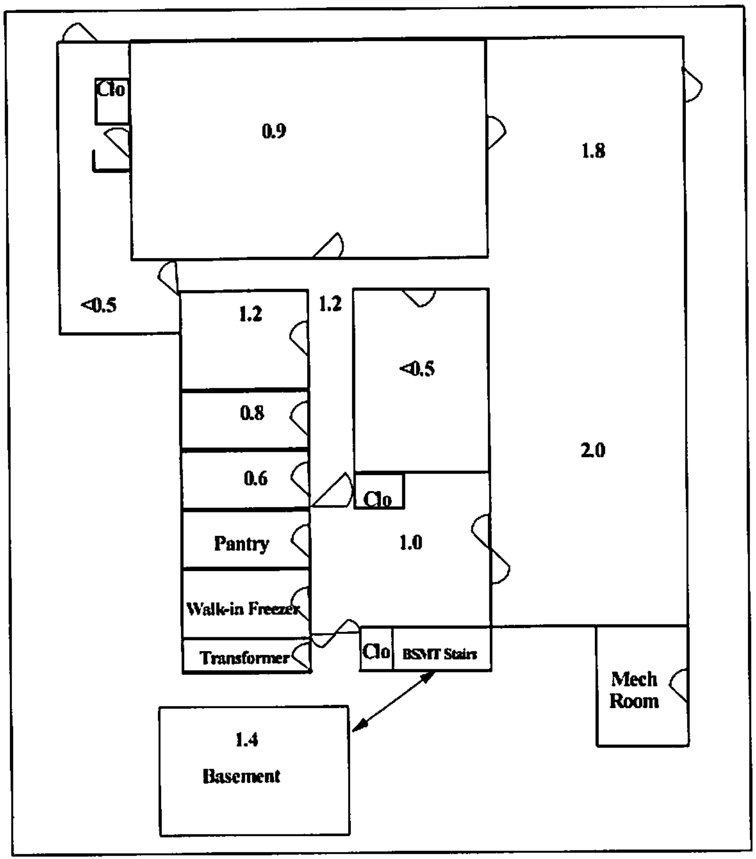
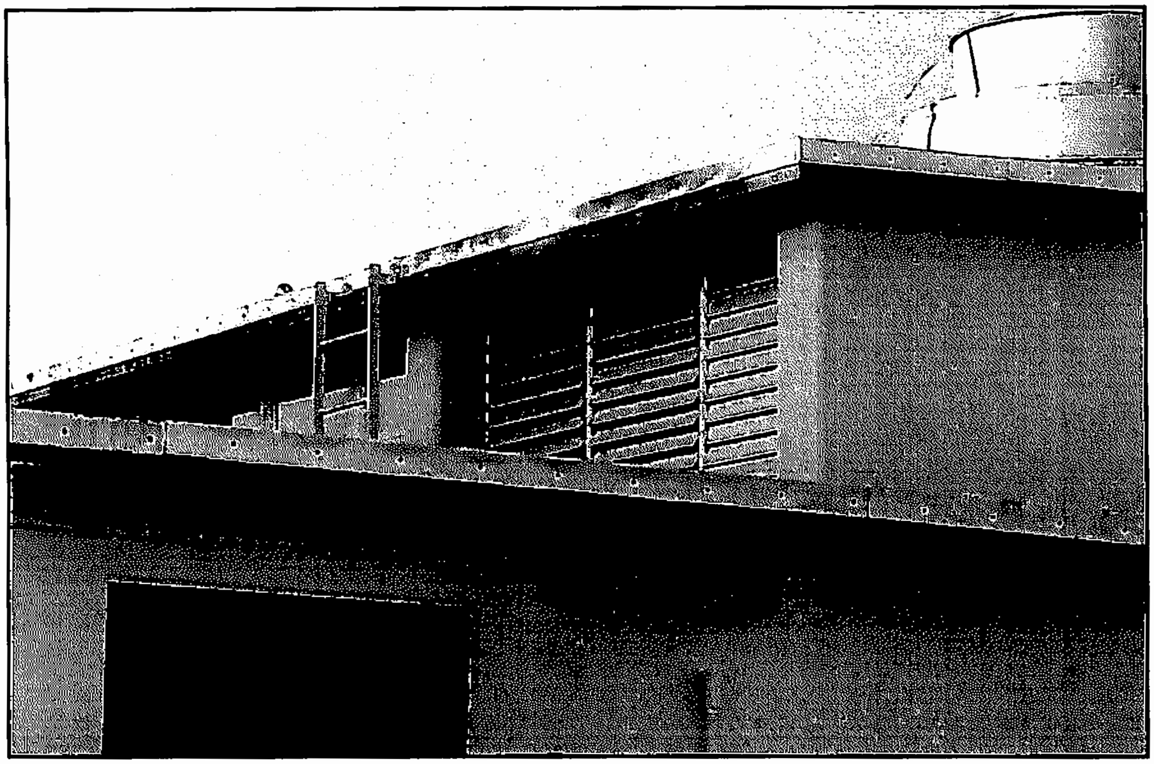


Figure 13. Postmitigation results in pCi/L



Picture 1. Installed louvers in the kitchen

DISCLAIMER