RADON IN CONCRETE PASSIVE VENTING MITIGATION

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Abstract

The radon and ventilation levels in four condo units in a six story concrete constructed residential building in Florida measured 8-16 pCi/l of radon and 0.02-0.06 air changes per hour (ACH) of ventilation. ASHRAE outdoor air ventilation recommendations for residential homes have been in the range of 0.35 ACH for decades. Once it is determined that concrete is the source the typical radon mitigation is to mechanically add outdoor air into the negative return HVAC closet. In this study the negative pressure inside the HVAC closet was evaluated to determine if a passive vent from the closet to the outside could reduce the radon levels to acceptable levels. The study included measurements of the natural ventilation rate and the changes in radon and humidity levels as outdoor air was introduced. The negative pressure in the HVAC closet was tested to determine how much outdoor air could be introduced into the unit when the HVAC was running.

1.0 STUDY SETUP

1.1 Building Construction

The study building was built around 2010 and hereafter will be referred to as the Condo. The building is six stories tall. The individual units are predominately two stories tall. The primary access to each unit is from the courtyard for the ground floor units and from an open balcony on each side of the open court yard on the third and fifth floor. The central courtyard is open to the outside air on both ends and has a translucent roof that arches above the six stories to keep rain out. There are 117 individually owned units in the Condo. The Condo is located in Southern Florida close to Miami. The building is constructed with concrete floors and ceilings. It could not be determined if the exterior walls of the each unit were constructed with poured concrete or concrete blocks. In the electrical closets on the balcony there are poured walls for the first nine feet and block walls on top of the poured walls for the next nine feet. The entire interior is finished in each individual unit with ceramic or marble tile used extensively for flooring. There are no windows in any of the units. There are two or three eight foot high sliding glass doors in each unit that opened onto an exterior balcony or exterior garden area if the unit is on the ground floor. Under the entire building except the office area is an underground garage with five large exhaust fans. There are openings around the plumbing pipes in the ceiling of the garage but it could not be determined if the piping was sealed air tight as it entered the individual units on the floor above. Each unit had an HVAC closet that had an air handling unit taking up almost the entire closet. The door to the HVAC closet has a large open grill that allowed return air to enter the HVAC unit. There is also an open duct run from the closet to the first floor bedroom/office room. All the supply ducts were routed in the walls and ceiling to individual rooms. There are duct runs to the outside for the dryer and bathroom fans. The exterior vent cap for these vents included a flapper damper.

The following units in the Condo were tested over two days for radon levels in March and April of 2022 with the following results.

Main Office	0.7 pCi/l	
Unit-A	10.2 pCi/l	
Unit-B	8.8 pCi/l	
Unit-C	3.3 pCi/l	Note: levels climbing to 7.0 at the end of the test
Unit-D	8.1 pCi/l	
Unit-E	4.8 pCi/l	Note: levels climbing to 7.0 at the end of the test
Unit-F	5.9 pCi/l	
Unit-G	4.1 pCi/l	Note: levels climbing to 6.0 at the end of the test
Unit-H	6.1 pCi/l	
Unit-I	7.7 pCi/l	
Unit-J	0.2 pCi/l	

Table (1): Initial radon results

Figure (1): Entrance to each unit is from
an open air interior courtyard

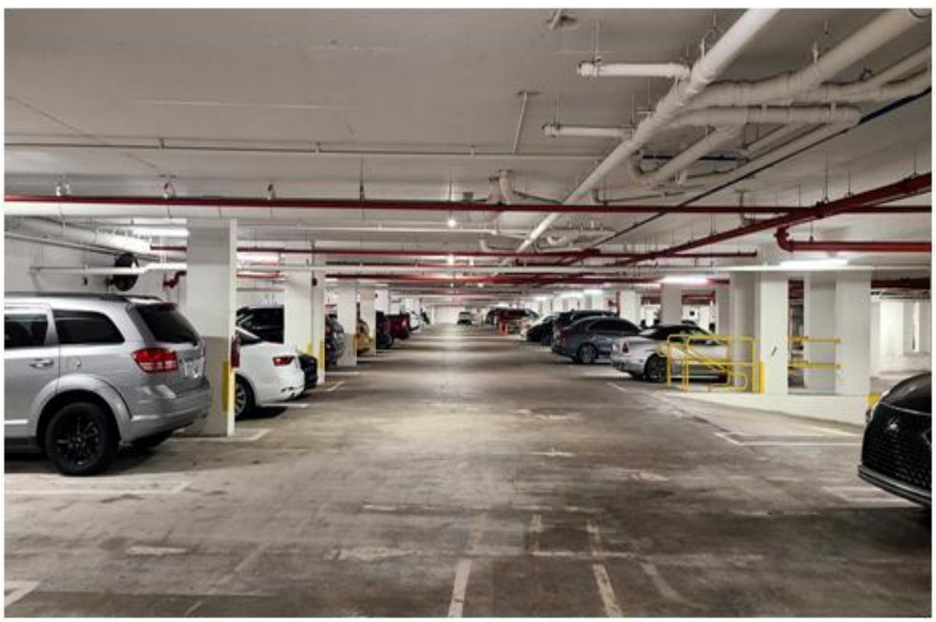

Figure (2): Condo parking garage below entire building

Figure (3): Exterior view of the Condo

1.2 Reasons to Perform Diagnostic Testing

The purpose of doing initial diagnostics and system design at the Condo was to accomplish the following goals.

a) Design an effective radon mitigation system
b) Reduce system installation cost
c) Minimizes occupant disruption during construction
d) Minimizes disturbing system operating noise
e) Minimize loss of storage space
f) Minimize yearly maintenance & operating cost
g) Minimize increased humidity and possible mold growth

1.3 Diagnostic Procedures

Radon and ventilation diagnostics were performed at the Condo from June 3 until June 11th of 2022. Radon monitors were placed in four available units four days before the additional ventilation was started. The test was done in two, two bedroom units and in two, three bedroom units. RadonEye Pro continuous radon monitors that report each average hourly radon concentration and EcoTrackers that can report radon variations every 5 minutes or hourly were used for the entire diagnostic project including the flux measurements. The radon monitors also reported the temperature and humidity level. The measurement of humidity was important to determine the increase in indoor humidity from adding additional outdoor air to the unit. Mitigation systems that increase the introduction of outdoor air in Florida and other humid climates must take into consideration the possibility of mold growth, air conditioning humidity removal and occupant comfort in their design.

Additional radon testing was done at two locations in the underground garage. The main office was also tested for a brief period and found to have very low radon levels. The low radon levels in the office are likely due to the heating venting and air conditioning (HVAC) outdoor air supply that is typically required by code.

During a period of about 24 to 48 hours a measured amount of outdoor air was introduced into each of the units while the radon monitors were tracking the radon levels and humidity. These measurements allowed determination of the quantity of additional ventilation necessary to reduce the radon levels and an approximation of the natural outdoor air ventilation happening in each unit.

Direct flux measurements of the radon emanating from the concrete was attempted however all the tested units had tile covering all the exposed floors. Flux measurements were made in the center of each tile and at the junction of the grout joints. The radon emanation from the bare slab in the electrical closets was also tested. The flux testing of the center of the tiles produced no measureable radon emanation. The testing of the grout joints and the slab floor in the electrical closets did however reveal a significant radon emanation rate. Because the tile interfered with making a uniform flux measurement and because the wall surfaces and concrete ceiling could not be tested, a direct assessment of the radon contribution from these three surfaces could not be determined. The measurement of the radon reduction from the introduction of a known quantity of outdoor air however did provide a method to determine the natural ventilation happening in each unit and the amount of additional ventilation required to maintain radon levels below the EPA guideline level.

2.0 Results of the Diagnostic Testing

2.1 General ventilation and radon in concrete information

Elevated radon levels in residential dwellings have been considered to be almost exclusively caused by infiltration of radon laden soil gas through cracks and openings in parts of the foundation that have soil contact. In most residential dwellings the building ventilation rate has generally not been considered a significant factor in determining if a building will have elevated radon levels. This is because in typical residential buildings as ventilation increases from stack effect there is also generated a compensating greater negative pressure in the ground contact areas introducing more radon. When concrete is the primary source of radon entering a building, the emanation rate from the concrete is considered to be steady state. Any changes in the radon levels with concrete as the sole source are therefore due to changes in the ventilation rate of the unit.

There have been a number of cases of elevated indoor radon in high rise buildings in Florida and in North Carolina that are constructed with concrete that are similar in construction style to the units at the Condo. The typical method to remediate radon emanating from concrete in Florida is to either install a continuously running Energy Recovery Ventilator (ERV) or a low wattage radon fan bringing outdoor air into the HVAC closet (powered vent) that is set to run four hours on and four hours off or some other timing variation. There have been problems in Florida with increased moisture and mold growth in the HVAC closet from the powered vent method. Mold growth and comfort problems are caused by either introducing too much outdoor air or having the outdoor air introduced when the HVAC is not operating. Over-sized powered vent systems create a risk of occupant discomfort, increased energy costs, increased system noise and large swings in humidity levels as the air handlers cycle on and off separately from the radon mitigation system. The issue with mold growth is also more likely when the unit is not occupied and the thermostat is turned up or when the HVAC system is over sized and operates for too short of a cycle to remove the humidity. The variation in HVAC run time in winter months versus summer months was not evaluated in this study but should be done in future studies.

2.2 Radon Variation in Different Units

If one assumes the radon is coming from the concrete then the radon level in each unit will vary depending upon the concentration of radium in the concrete, the thickness of the concrete, the type of coatings or finishing's that have been applied to the concrete surface, the surface area of the concrete that is exposed in the unit, the volume of space the radon is emanating into and the ventilation of that unit. Thus the radon levels could vary significantly from unit to unit.

Radon levels in the four units tested were measured for four days prior to the start of adding any ventilation. The following graph displays the results of that testing. All four units had radon levels above the EPA action level of 4.0 pCi/l.

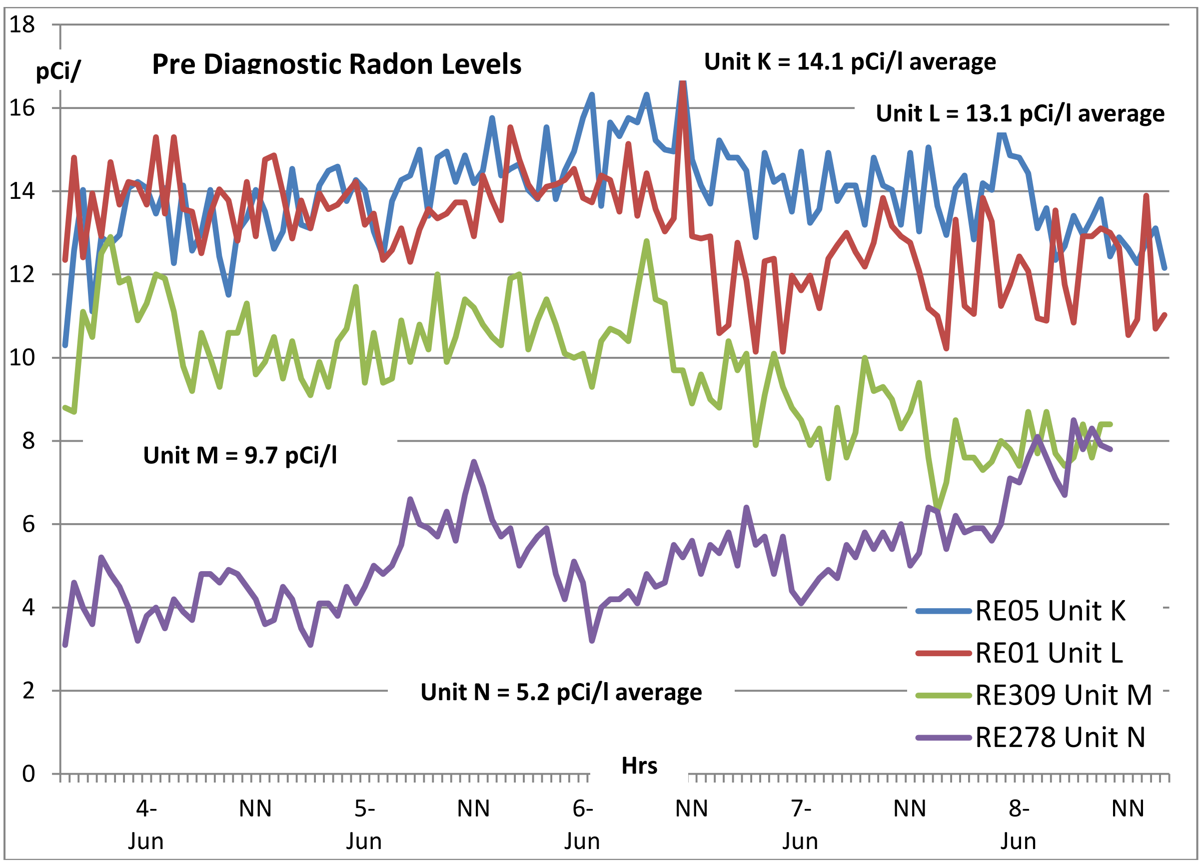

Figure (4): Pre-diagnostic unit radon levels

2.3 Garage Radon Levels

The garage was located directly below the entire first floor units and courtyard. The plumbing pipes passing through the ceiling of the garage into the first floor units typically had large spaces around the pipes that could not be determined if they were adequately sealed. In order to determine if the garage could be a source of radon for these first floor units a measurement of the radon levels in the garage was performed for two days in two different locations.

Figure (5): Plumbing openings in ceiling of garage

Figure (6): Garage exhaust fans

The garage had five exhaust fans that ran continually to remove carbon monoxide introduced by vehicle exhaust. These fans induce a negative pressure which in general prevents air in the garage from moving up into the first floor units.

Figure (7) depicts the radon results measured in the garage as less than 0.5 pC/l. This indicates the garage radon levels are close to outdoor radon levels. This in combination with the negative pressure in the garage shows that the garage is not contributing any significant radon to the first floor units. It would be logical to assume that any openings between the garage and a first floor unit would remove air from the unit and increase the ventilation, thus reducing the radon levels induced by the concrete. Unit L which was a ground based unit however had the second highest radon levels.

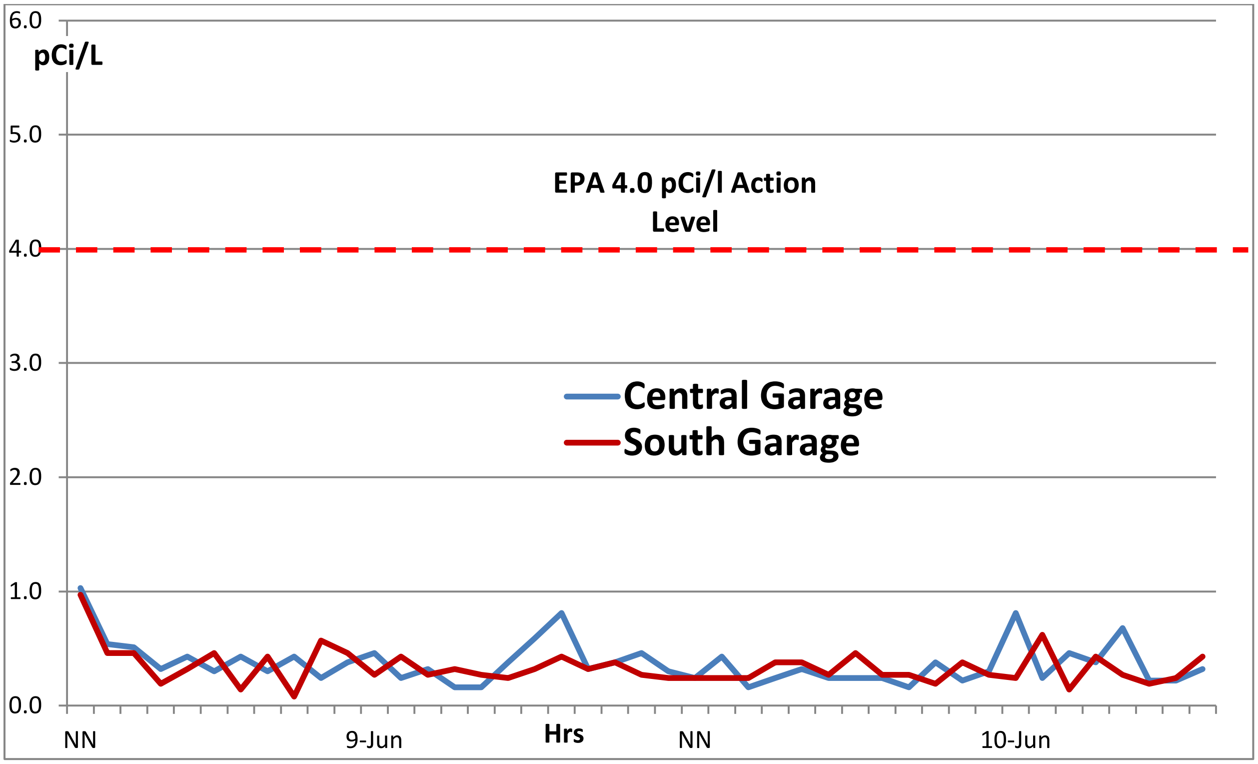

Figure (7): Garage exhaust fans

2.3 Radon Flux Measurements

Radon flux measurements were made by placing a continuous radon monitor and battery inside a metal three liter bowl that was inverted on a slab or tile floor. A gallon water jug was used as a weight to compress the rubber gasket attached to the bottom edge of the bowl.

Figure (8): Radon monitor inside flux bowl

The flux measurements were made in the center of the tile squares and over the intersecting grout joints. The center tile flux measurements showed no significant increase in radon levels. See

Figure (10). The intersecting grout lines did have significant radon ingrowth into the inverted metal bowls.

Figure (9): Flux measurement over intersecting grout lines

Flux measurements were also made in the outside hallway electrical closet and on the concrete walkway outside the recreation room to determine if direct concrete flux measurements would produce significant radon ingrowth into the inverted bowls. See Figure (11).

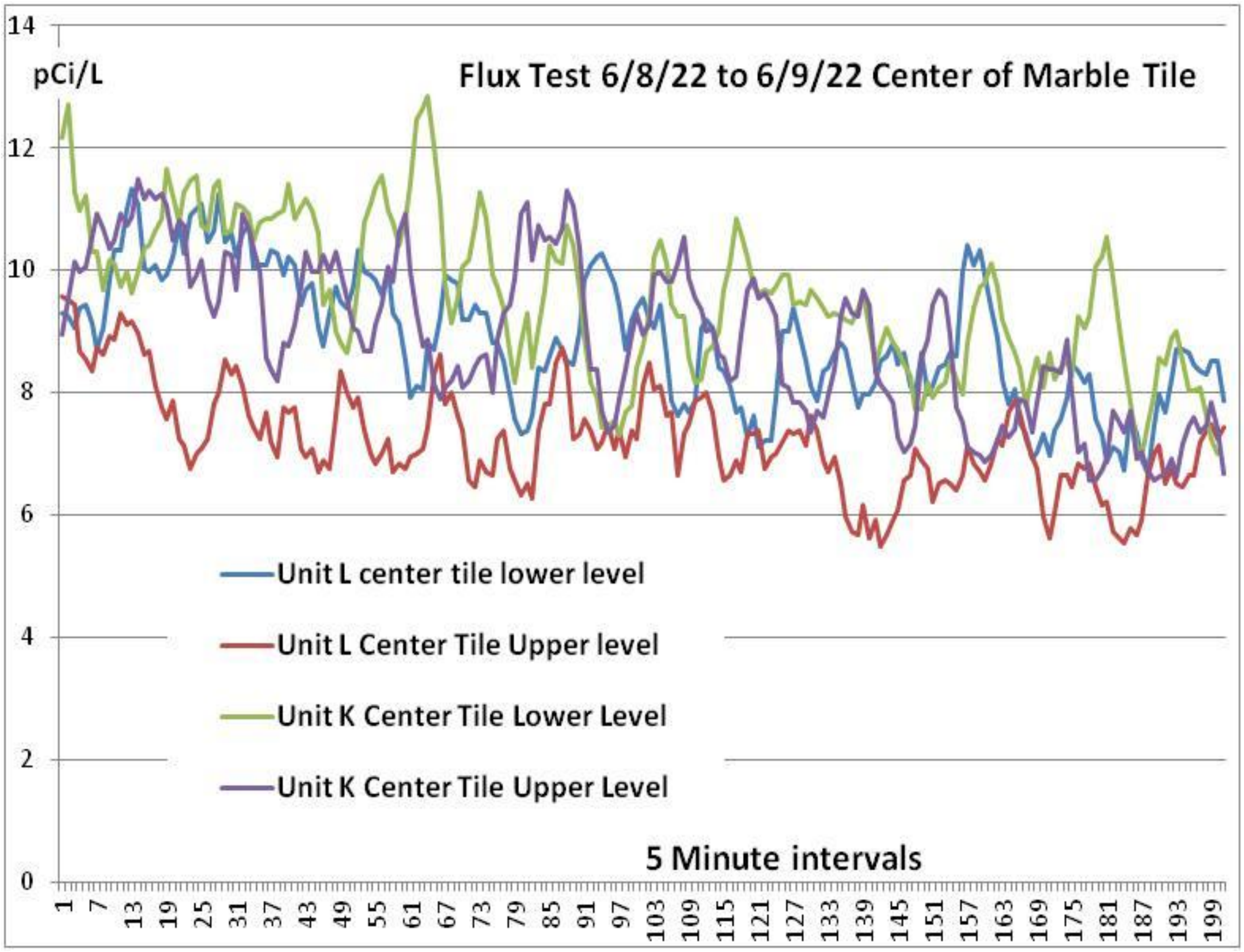

Figure (10): Flux measurements in center of tile square with no ingrowth

Figure (10) of four separate flux measurements made in the center of the tile squares shows there is no increasing radon into the bowls. The radon levels which start off as the radon levels inside Unit L and Unit K are actually decreasing because of the gradual decay of radon.

In contrast to Figure (10), the measurements of the radon ingrowth in Figure (11) are when the bowls are placed over the intersecting grout lines of the tile. The radon ingrowth is converted into pCi/square foot/hour (pCi/sf/hr) emanation rate. In previous work at an apartment complex in Doral Florida the average concrete flux rate varied from 20 to 35 pCi/sf/hr. In this case the flux measured between 14 and 58 pCi/sf/hr. Because the flux is assumed to only be from the grout lines, it cannot be consider as representing the actual square foot emanation of the slab below the tile without testing the slab without tile. Flux measurements of bare concrete outside the living space however had a similar range of flux. It appears that the tile floor did not significantly reduce the radon flux.

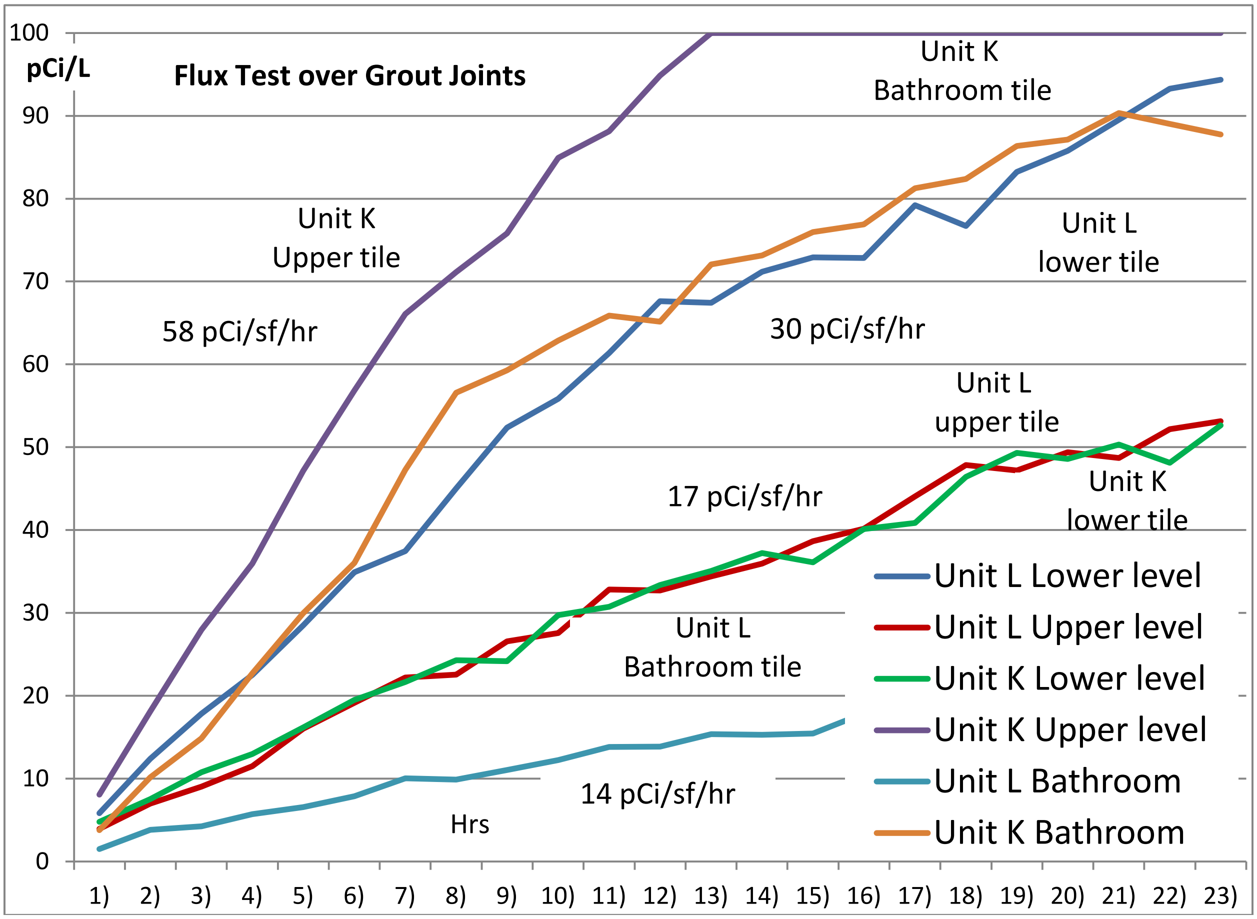

Figure (11): Flux measurements over grout lines

In order to get a better idea of the emanation from the concrete itself, each of the electrical closets on the third and fifth floor were measured as well as the open walk way outside the recreation room entrance door. Figure (13) depicts the results of these flux tests. The emanation rate varies again from 14 to 58 pCi/sf/hr. The variation in radon in each of the units would likewise have a similar or greater variation when combined with variation in ventilation rates. Although there is a significant variation, the emanation rate does approximate the average 20 to 35 pCi/sf/hr emanation rate that was measured at an apartment complex in Doral Florida that had similar indoor radon levels with no tile floor before additional outdoor air was added to each rental unit.

Figure (12): Flux measurements over bare concrete

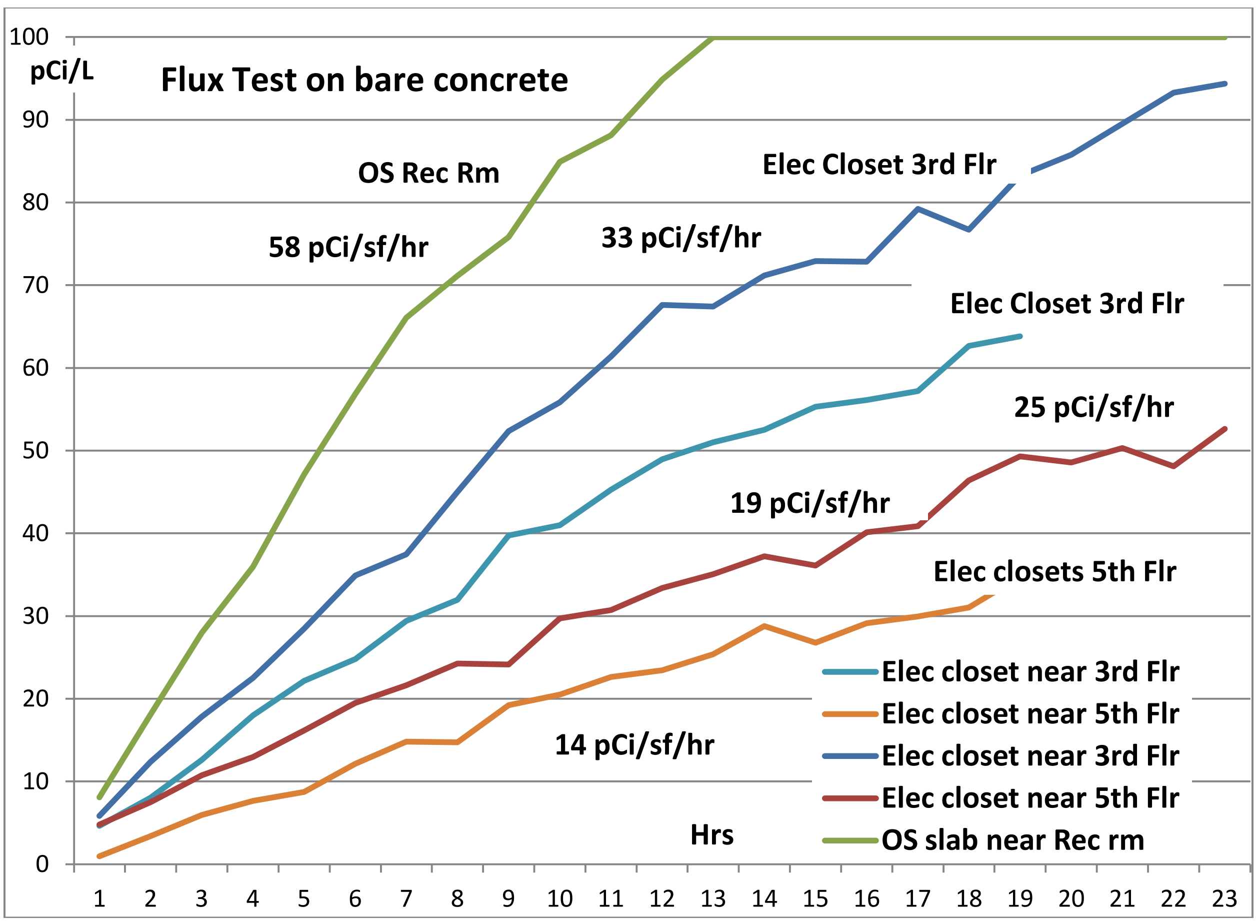

Figure (13): Flux measurements results over bare concrete

2.4 Ventilation test

All four units had 30 to 40 cubic feet per minute (CFM) of outdoor air introduced into the unit for up to 48 hours. The airflow rate was checked in the morning and the afternoon to maintain an airflow around 35 CFM during the ventilation test. Radon and humidity levels were continuously measured during the ventilation test. The radon and humidity was also measured in Unit L and Unit K after the ventilation system was removed.

The ventilation equipment was installed by opening the sliding door in the bedroom and inserting a 1x6 cedar board that had a four-inch round hole cut in the bottom. The openings around the door and wood board were sealed with painters tape. A 4-inch duct was routed to a common low wattage radon fan. The exhaust from the fan was routed with PVC pipe to a flow grid that was used to measure the airflow being induced from outdoors into the unit. A speed control was used to tune the airflow down to around 35 CFM. Note that at full speed the small 20 watt radon fans introduced about 100 CFM which was considered unnecessarily too high for this test.

Figure (14): Ventilation equipment and flow grid equipment

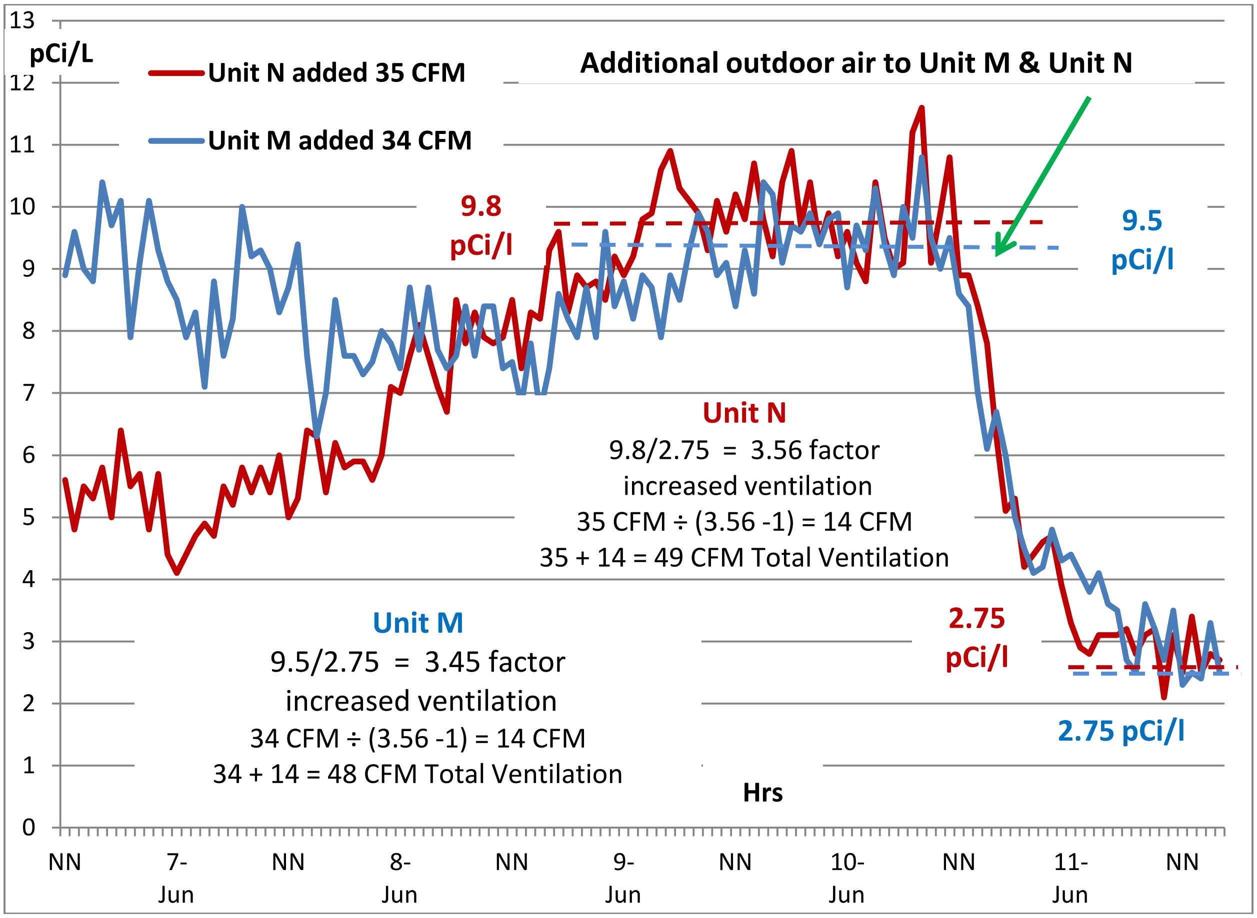

Figure (15): Ventilation increase to Unit 112 & Unit 526

The natural ventilation rate is determined by the formula of additional air divided by the reduction factor in radon minus 1.

Additional CFM ÷ ((Initial Radon ÷ Final Radon) – 1)

The ventilation increase is plotted in Figure (15) and Figure (16). In Figure (16) the radon levels in Unit M and Unit N varied from 6 pCi/l to 9.5 pCi/l while the radon levels in Unit K and Unit L were more consistently around 12 to 14 pCi/l. Because the radon coming from concrete is considered a steady source the primary difference between these units is variation in emanation rate from the concrete and the variation in ventilation. The multiple flux measurements done in the electrical closets and hallway indicate that there can be large differences in emanation rate in different units as well as ventilation rate.

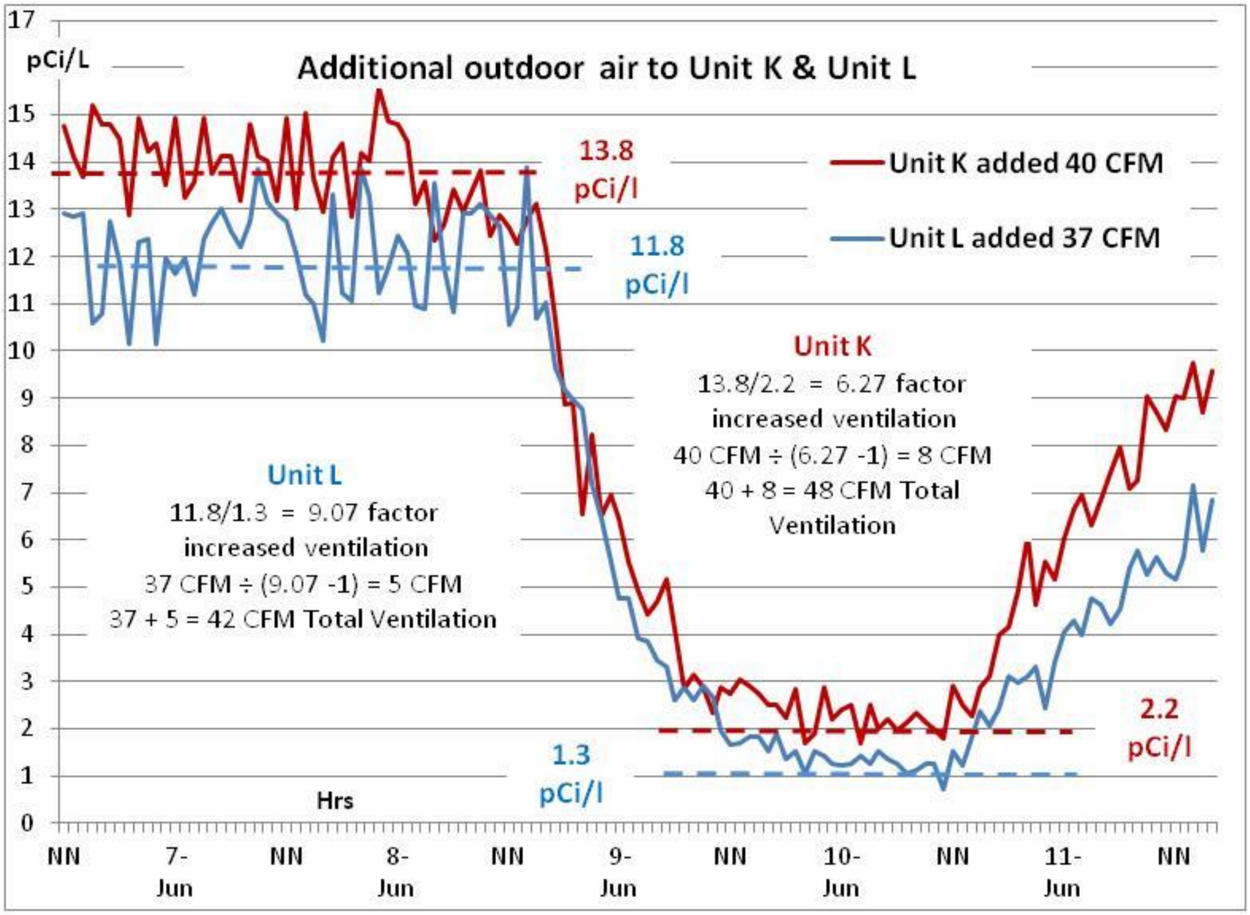

Figure (16) Ventilation increase to Unit K & Unit L

Unit M and Unit N are three bedroom units with about 1800 square feet of floor space and about 17,000 cubic feet of volume. Unit L and Unit M are two bedroom units with about 1500 square feet of floor space and about 15,000 cubic feet of volume. ASHRAE 62.2 recommends that homes receive 0.35 ACH (air changes per hour) but not less than 15 cfm per person as the minimum ventilation rates in order to provide acceptable indoor air quality. To meet this 0.35 ACH outdoor ventilation standard would require a total ventilation rate of 100 CFM for the three bedroom units and about 87 CFM for the two bedroom units.

Unit K had a total of 48 CFM of outdoor air with the additional 40 CFM of outdoor air. If the air was increased to 100 CFM the achieved radon level of 2.2 pCi/l would be additionally reduced to 1.1 pC/l.

Unit L had a total of 42 CFM of outdoor air with the additional 37 CFM of outdoor air. If the total ventilation air was increased to 87 CFM the achieved radon level of 1.3 pCi/l would be additionally reduced to 0.6 pC/l.

Unit M had a total of 48 CFM of outdoor air. If the ventilation was increased to 87 CFM the radon levels would be reduced to about 1.5 pCi/l.

Unit N had a total of 49 CFM with the additional 35 CFM of outdoor air. If the air was increased to 100 CFM the achieved radon level of 2.75 pCi/l would be additionally reduced to 1.4 pC/l.

Unit #	Natural CFM	Natural ACH	Initial Radon	Added CFM	Total CFM	New Radon	0.35 ACH	Required CFM	Final Radon
K	8	0.03	13.8	40	48	2.2	100	92	1.1
L	5	0.02	11.8	37	42	1.3	87	82	0.6
M	14	0.06	9.5	34	48	2.75	87	73	1.2
N	14	0.05	9.8	35	49	2.75	100	86	1.4

Table (2): Ventilation increase and radon levels

Table (2) depicts the results of the ventilation testing and the necessary additional air to reach 0.35 ACH as well as the predicted radon levels if this amount of outdoor air was added. The addition of 34 to 40 CFM of outdoor air reduced all the units to less than 3.0 pCi/l.

2.5 Humidity Increase from Adding Outdoor Air

The introduction of continuous 35 to 40 CFM of outdoor air in June in Southern Florida did cause the relative humidity level to rise from 45 and 50 percent to 55 to 65 percent in two of the units. See Figure (17). In Unit K the increase was about 5 percentage points of RH. In Unit L the increase was about 10 percentage points of RH. Increasing the amount of outdoor air entering a building will likely require the HVAC system to operate additional time not only to maintain the occupants chosen temperature but also the occupant may want to have a lower temperature if the humidity is higher and provides less physical cooling. Any increase in the total run time of the HVAC will provide additional humidity reduction.

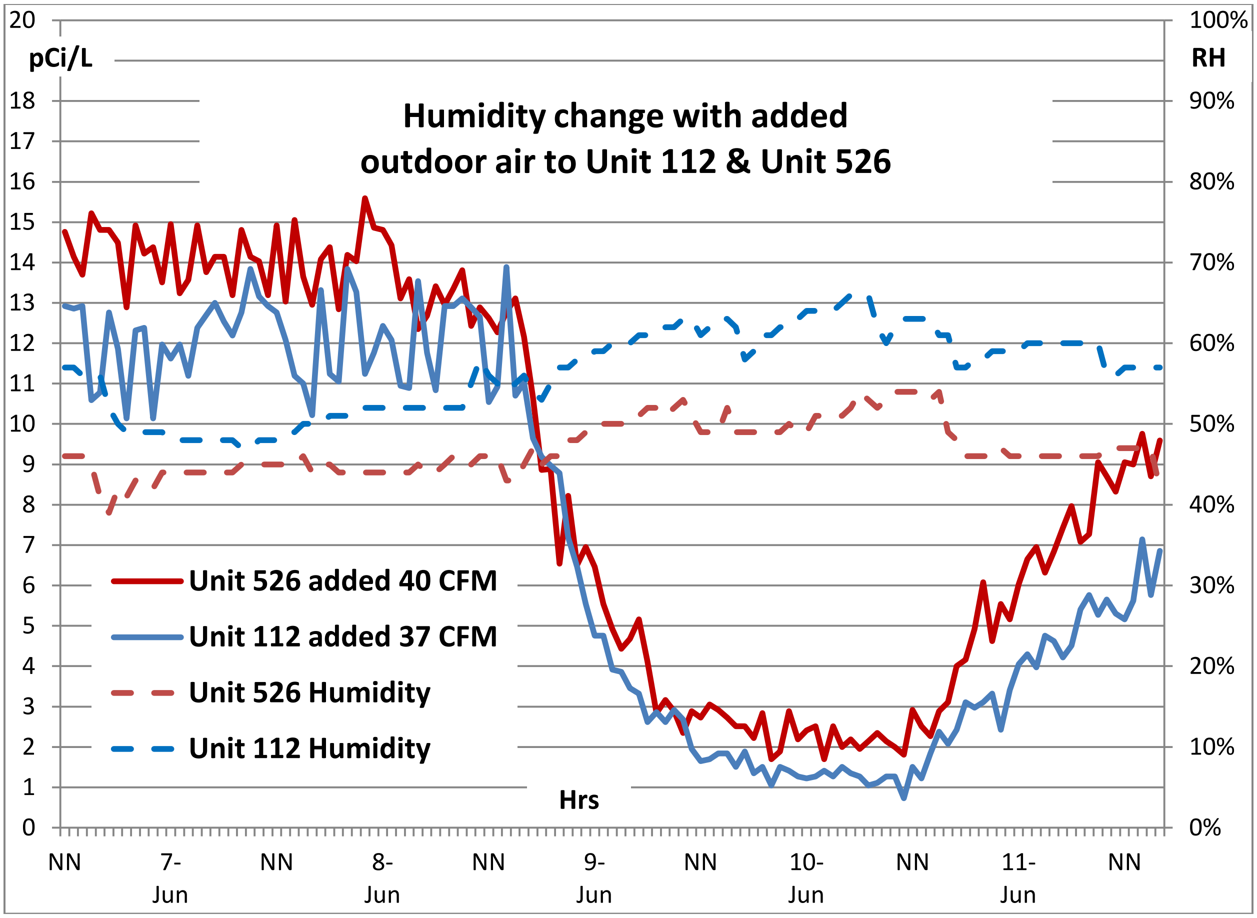

Figure (17): Measurement of humidity

2.6 Fan Induced Outdoor Air Mitigation

Multi-family buildings in Florida with elevated radon levels caused by radon emanation from the concrete have traditionally been remediated by one of following three methods.

1) Air to Air Exchanger
   An air to air energy recover ventilator is installed in every unit. The ERV brings in outdoor air while exhausting a similar amount of air. The two air streams are routed through an exchanger that moves some of the outdoor humidity and heat into the air stream from the indoors that is being exhausted. The ERV reduces the cooling and dehumidification required from the introduction of hot humid air typical of Florida. The ERV requires regular filter changes and occasional maintenance. The reasons this method is not typically installed is the space required for the unit, the routing of multiple ducts, the operating noise, the yearly or bi-yearly maintenance and the cost to install all the required components. The ERV unit is typically installed in a closet in a manner that allows access to the unit's filters. If an ERV system is installed at this Condo it would require loss of about half of the hallway storage closet or part of the bedroom/office

closet and significant ducting and drywall finishing. The HVAC closet in this Condo building has no available space for an ERV. See Figure (17) and Figure (18).

2) Whole Building Ventilation

   This method provides 100% conditioned air to every unit in the building by installing a commercial roof top unit (RTU) for each three unit wide section of the study Condo. The RTU would be installed on the roof. The building roof would have to handle the weight of each RTU. The building would also have to be able to power each RTU which would be conditioning about 750 CFM of outdoor air for nine units. A main air duct would need to be routed from the RTU down the inside or outside face of the building with individual air ducts routed to each unit. This design is the most expensive however it does provide 100% conditioned air for each unit. This method would be the least disruptive to the occupants space as only a supply grill in an exterior wall would need to be installed. Typically the fresh air supply enters above the entrance door or into the main living area.

3) Individual Vent Fan Installation

   This is the most common radon remediation system installed in Florida for concrete radon sources. A 20 watt radon fan similar to the ventilation fan used in this study is installed in the hallway closet or possibly in the HVAC closet if a small fan can be located. A single duct is routed from this fan to the outside. The fan requires a 120 volt power source which is not presently in the HVAC or hallway closet. The amount of air introduced into the building is controlled by having a simple water heater timer adjusted to on and off times. The timer is typically set to have the fan run four hours on and four hours off. The amount of on versus off time can be changed to provide more or less ventilation. The air introduced in the building is routed directly into the HVAC closet. The main concern with this setup is the radon vent fan will be operating when the air handler is not operating. Blowing hot humid air into a small conditioned space will quickly raise the humidity and the potential for mold growth. At the Condo the HVAC closet does not appear to have enough room to install a small radon fan. An alternate method is to install the fan in the adjacent closet with duct work to the outside and supply duct routed to the HVAC closet. At the Condo there is no 120 volt power source in the HVAC or hallway closet. A duct could be routed from the hall closet to the outside with an inlet grill installed above the entrance door on the outside of the unit. Any duct work would need to be dry walled and painted.

2.7 Passive Outdoor Air Venting

An alternative to the three methods listed above is to use the negative pressure induced by the air handler in the HVAC closet to bring outdoor air into the unit. The HVAC unit presently draws return air from the hallway via a grill in the door and a separate return duct routed from the bedroom/office. The HVAC at the three units were inducing a strong negative pressure inside the closet compared with the hallway or the outdoors. The primary benefit from this setup would be the outdoor air entering from the outside would be immediately conditioned by the running HVAC unit and thus minimizing excess humidity buildup in the closet and potential mold. The secondary benefit would be the reduction in installation cost from the elimination of the required closet radon fan and necessary electrical wiring. In the Condo a single duct would still need to be installed and finished from the AC closet, through the storage closet and hallway to the outside.

Figure (18)   HVAC closet with limited space and return grill.

Figure (19):   HVAC closet with ceiling return duct to bedroom/office

Figure (20): Testing airflow induced by negative AC closet

Figure (21): Non restricting return grill

Unit #	AC to Room	Box to Room	CFM
K	-53 pascals	-33 pascals	100
L	-42 pascals	-18 pascals	75
M	-25 pascals	-16 pascals	68
N	-9.8 pascals	-7.5 pascals	46

Table (3): HVAC closet negative pressure

A simple test was set up to measure how much air would be drawn through a four inch PVC pipe if one end of the pipe was installed into the HVAC closet. The open end of a card board box was pressed against the return grill to create negative pressure in the box when the HVAC was running. Note that Unit N had significantly less negative pressure in the AC closet than the other units. The reason for the low negative pressure was the return grill had been replaced with a simple straight through grill that reduced the back pressure as compared to the other units that had double louvered grills that created more restriction for the returning airflow. See Figure (21).

The results indicate that 33 pascals of negative pressure can induce 100 CFM of airflow which is the equivalent of the radon fan operated at full capacity. This is however with a two foot section of four inch PVC piping. The duct routed to the outside would be about twelve feet in length with several turns. A four inch PVC pipe is equal to about 12.5 square inches. A more traditional four by six inch duct routed to the outside would have almost double the four inch pipe opening at 24 square inches of cross sectional area.

Figure (22): Storage closet

Figure (23): Smoke detector

In the study Condo the 4x6 passive duct would need to be routed across the backside ceiling of the storage closet. See Figure (22). The duct would be routed into the entrance hallway just below the drop ceiling level. See Figure (23). In some of the units it will be necessary to move the smoke detector. The duct would be routed up to the ceiling of the hallway and then routed to the outside. The metal duct would be covered by drywall that would be spackled and painted to match the existing wall and ceiling.

To be able to modify the amount of air drawn into the HVAC closet an adjustable grill would need to be installed inside the HVAC closet at the 4X6 duct closet inlet. This grill would be adjusted as needed to modify the amount of incoming air. Ideally the grill adjustment would be made while using a bolometer air flow measuring tool on the outside grill to set the amount of incoming air. The airflow could also be adjusted by changing the inlet grill on the HVAC closet door to an adjustable grill that would be adjusted to induce a pre determined optimal HVAC closet negative pressure when the HVAC is running.

The success of the passive air duct will be determined by the settings of the dampers and the run time of the HVAC unit.

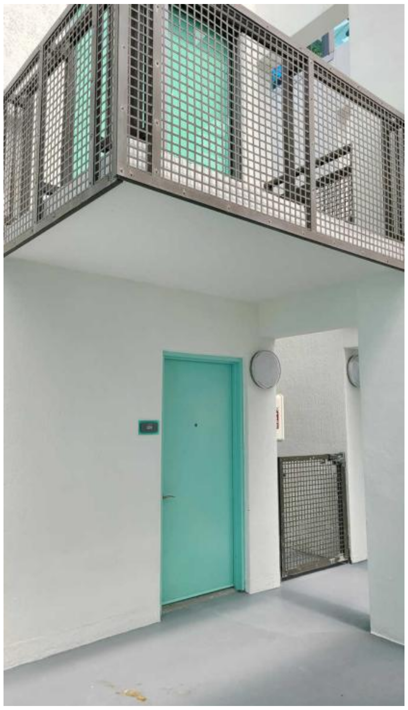

Figure (24): Proposed inlet grill location above and to the left of the entrance door

Figure (25): 4X6 duct installed in wall of HVAC closet with adjustable grill

The return grill in the guest bedroom appears to be over-sized for the size of the bedroom. This grill could be modified if it is necessary to induce more negative pressure in the HVAC closet.

Figure (27) is a drawing of a possible passive 4x6 duct run from the HVAC closet to the outside.

Figure (26): Bedroom/office return grill

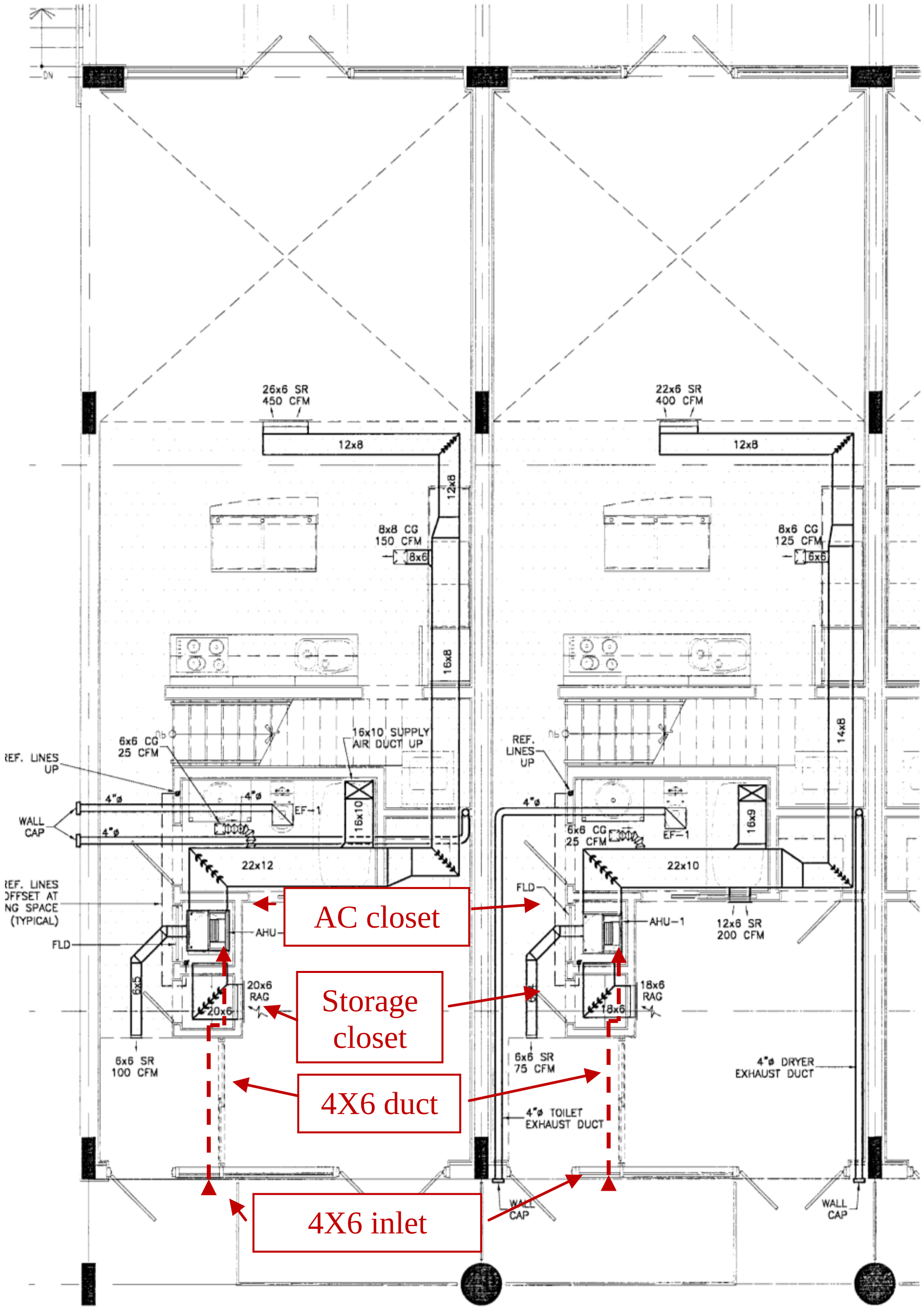

Figure (27): Possible passive vent pipe route

3.0 Final Conclusions and Recommendations

The radon emanating from the concrete is similar to the radon emanation compared to another concrete constructed building in Florida that had elevated radon levels that the author worked on. The radon levels in the units measured were double to triple the EPA radon action level. The amount of outdoor air entering the tested units at this studied condo was one 6th to one 16^{th} the 0.35 ACH amount recommended by ASHRAE 62.2. The addition of about 30 to 40 CFM of outdoor air was able to maintain radon levels in the range of 2.0 to 3.0 pCi/l in the units tested. Adding additional outdoor air provides many benefits for the occupants including reduction of pollutants from cooking or out gassing from materials or cleaning agents inside the unit. Outdoor air added without being conditioned into the unit in Florida as well as other Southern states does pose a risk of increased indoor humidity and possible mold growth. The author recommended to the clients that outdoor air be supplied when the air handler is operating to provide conditioning of the outdoor air to minimize the possibility of mold growth. To accomplish this goal, the author recommended a passive outdoor air source be installed into the HVAC closet with an adjustable damper set to provide adequate ventilation. This approach which uses the negative pressure of the air handler closet when the HVAC is running offers numerous benefits including simplified and less expensive installation. If in the future the passive system needs to be enhanced with a fan, the passive duct can be used for a fan powered system that is sequenced to run with the HVAC system. Further research to test this approach should be considered.

8.0 Reference Papers

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