

## **WHOLE BUILDING VENTILATION OF HIGH RISE CONDOMINIUM WITH ELEVATED RADON FROM CONCRETE**

Bill Brodhead

WPB Enterprises, Inc., 2844 Slifer Valley Rd., Riegelsville, PA USA

[bill@wpb-radon.com](mailto:bill@wpb-radon.com) [www.wpb-radon.com](http://www.wpb-radon.com)

Tom Hatton

Clean Vapor, LLC, 3 Maple Street, Andover, NJ 07821

[thatton@cleanvapor.com](mailto:thatton@cleanvapor.com) [www.cleanvapor.com](http://www.cleanvapor.com)

### **ABSTRACT**

The authors designed and installed a whole building ventilation system for a 100 unit five story high rise condominium building that had elevated radon levels on every floor. The building had two levels of ventilated garages under part of the building. Each floor was constructed with post stressed concrete floors and ceilings. Previous diagnostics revealed the low ventilation rate and high radon emanation rate from the concrete was the primary reason for the elevated radon. The radon reduction in the bedrooms of one unit was pre-tested with the bedroom doors closed, the HVAC air handler off and outdoor air introduced into only the main living area of the unit to determine if single point ventilation would treat an entire condominium. The installed whole building ventilation system routed conditioned air from the roof to a single location in each unit of the building. Post mitigation radon measurements indicated that the system is successfully reducing the radon levels below the guideline.

## 1.0 GENERAL BUILDING INFORMATION

The building described in this paper is five stories tall with 100 condominium units. Most of the building has ground contact. A portion of the building has a two story garage that is connected below grade to an adjoining eight story 110 condominium unit building that is not part of this project. The building was constructed between 2001 and 2002. In a previously published paper in 2008 Brodhead described elevated radon levels in different units on every floor of both buildings that was caused by the low ventilation rate of the condominium units and radon emanation coming from the concrete. The building was initially having condensation problems on the windows caused by low ventilation rates. The units were all constructed with concrete floors and ceilings. All of the units have exterior and interior metal stud framed walls that are covered with drywall. There are drywall covered suspending ceilings in most of the units. Units that are adjacent to stairwells and utility rooms have additional concrete exposure from the concrete walls that surround these rooms. There are multiple concrete beams throughout the building supporting the concrete slabs. The flooring material is a combination of carpet, wood, vinyl and tile floors. Eleven different units were measured with closed house conditions in 2007. The radon levels varied from 5.9 pCi/L to 13.2 pCi/l (218 to 481 Bq/m<sup>3</sup>).

In the Fall of 2007 WPB made a diagnostic study of the radon emanation rate coming from the concrete and the air change per hour (ACH) ventilation rate.<sup>1</sup> The ventilation rates were determined to be as low as 0.05 air changes per hour (ACH). The radon emanation from the concrete of both buildings was measured using a direct flux test of the concrete by sealing E-Perms in an accumulator. This method determined the radon emanation rate to range from about 30 to 50 pCi/ft<sup>2</sup>/hour (200 to 332 Bq/m<sup>2</sup>/min). This emanation and ventilation rate was determined to be the cause of the elevated radon levels.

The building was not designed with any common mechanical exhaust or ventilation fans since there are no common bathrooms or laundry rooms that would require this type of ventilation. Each individual condo unit has bathroom exhaust fans and a dryer exhaust. The range hoods are re-circulating. All units have operable windows and most units have one or more glass doors leading to an outside patio. Heating and air conditioning in each unit is provided by a heat pump with the compressor on the roof. The air handling components of these units are located totally inside the condo unit. No condo unit shares an HVAC system. The hallways are also conditioned by their own heat pumps with no introduction of outside air.

## 2.0 VENTILATION DISTRIBUTION TEST

The HVAC operation in the condo units is predominately for cooling and humidity control. The location of the building in a mid-Atlantic state, air tight construction and size of the condo units

minimizes the need for supplemental heat. There are significant periods during the heating season when the air handler does not need to operate. The Condo Association and engineering company hired by the association questioned whether introduction of outdoor air in a single location in the building when the air handler was not operating would provide adequate radon reduction throughout the condo unit since the source was in each room.

WPB was hired by the condo association to perform a ventilation test in order to determine both if single location outdoor ventilation would reduce the radon levels in the adjoining bedrooms when the bedroom doors are closed and the air handler is off and to confirm the amount of ventilation needed. Note that when the air handler is operating there will likely be no differentiation in radon levels when the bedroom doors are closed.

The ventilation test was performed in a single unit on the fifth floor. See floor plan below in Figure 1. In 2007 this unit had measured 7.5 pCi/l (278 Bq/m<sup>3</sup>). This unit has about 1763 square feet of floor space with 10 foot high ceilings. The ceilings, walls and floors expose 3500 square feet of concrete to the inside of the unit. The unit is next to a stairwell that has concrete walls. The stairwell walls and concrete support columns add about 650 additional square feet of concrete exposure for a total of 4150 square feet. The unit has two exterior balconies. One balcony is off the master bedroom and the other one is off the main living area. The only windows in the unit are in the two bedrooms. There are three French doors that open onto the outdoor balconies.

The existing outside dryer vent was used to provide the inlet for the fan ventilation test by propping open the outside dryer vent louvers located on the outside patio and hooking a 4" flexible duct into the laundry room dryer vent piping. The flexible duct was then routed to a radon ventilation fan. Four inch duct was then routed from the fan to a flow grid to measure the airflow and then the duct outlet was positioned so that the discharge was into the main entrance foyer. A digital micro-monometer was hooked up to the flow grid that had previously been calibrated to measure the airflow. See floor plan drawing below.

Three continuous radon monitors (Radalink AirCats )were used during the test. A monitor was placed in each of the two bedrooms. A third monitor was placed in the kitchen great room. The air handler was turned off and all windows and interior doors were closed. The radon monitors were operated during the entire test with the following sequence.

- 1) No outdoor air was introduced for about 12 hours with bedroom doors closed.
- 2) 47 CFM (22 l/s) of outdoor air with bedroom doors closed for 24 hours
- 3) 47 CFM (22 l/s) of outdoor air with bedroom doors open for 24 hours
- 4) 47 CFM (22 l/s) of outdoor air with bedroom doors closed for 24 hours
- 5) No outdoor air with bedroom doors closed for 48 hours

Note that during the test there was unusually cold weather with temperatures below freezing and strong winds. This increased the natural ventilation to the unit and caused the radon levels with the outdoor air off to be around 4.5 pCi/l (167 Bq/m<sup>3</sup>) compared

with a previous measurement of 7.5 pCi/l (278 Bq/m<sup>3</sup>). See the average radon results listed in Table 1 and the graphs of the actual radon changes in Figures 2, 3, 4, 5, and 6 below.

Set up	Kitchen pCi/L	Kitchen reduction	Master pCi/L	Master reduction	Guest pCi/L	Guest reduction
Fan off - doors closed	3.4		5.1		4.8	
Fan on - doors closed	1.0	- 75%	2.7	- 45%	3.1	
Fan on - doors open	1.8	- 54%	1.9	- 61%	2.1	
Fan on - doors closed	1.0	- 75%	2.4	- 51%	3.0	
Fan off - doors closed	4.5		4.7		4.7	

Table 1 Radon levels during each testing phase

Note that the radon levels in the bedrooms and the kitchen are almost the same when the bedroom doors are left open. This indicates the ventilation system discharge into the main living area does not need any additional forced circulation when these doors are open.

When the bedroom doors are closed the kitchen radon levels decrease from 1.8 pCi/L to 1.0 pCi/L (67 to 37 Bq/m<sup>3</sup>) while the bedroom radon levels increase from an average of 2.0 pCi/L to an average of 2.8 pCi/L (74 to 104 Bq/m<sup>3</sup>). The radon levels in the bedroom are still below the EPA guideline at this ventilation rate into the building (0.26 ACH). The master bedroom door had a larger gap under the door than the guest bedroom. This is the likely cause of the guest bedroom having a higher radon level when the doors were closed than the master bedroom.

If the induced mechanical ventilation rate is 0.3 ACH and the natural ventilation rate is only 0.03 ACH during mild weather conditions, the total ventilation will be 97 CFM (46 l/s) which will likely reduce the average radon in the bedrooms down to 2.2 pCi/L (81 Bq/m<sup>3</sup>) when the bedroom doors are closed and 1.5 pCi/L (56 Bq/m<sup>3</sup>) when the bedroom doors are open.

See Figure 2 through 6 below for actual recorded data.

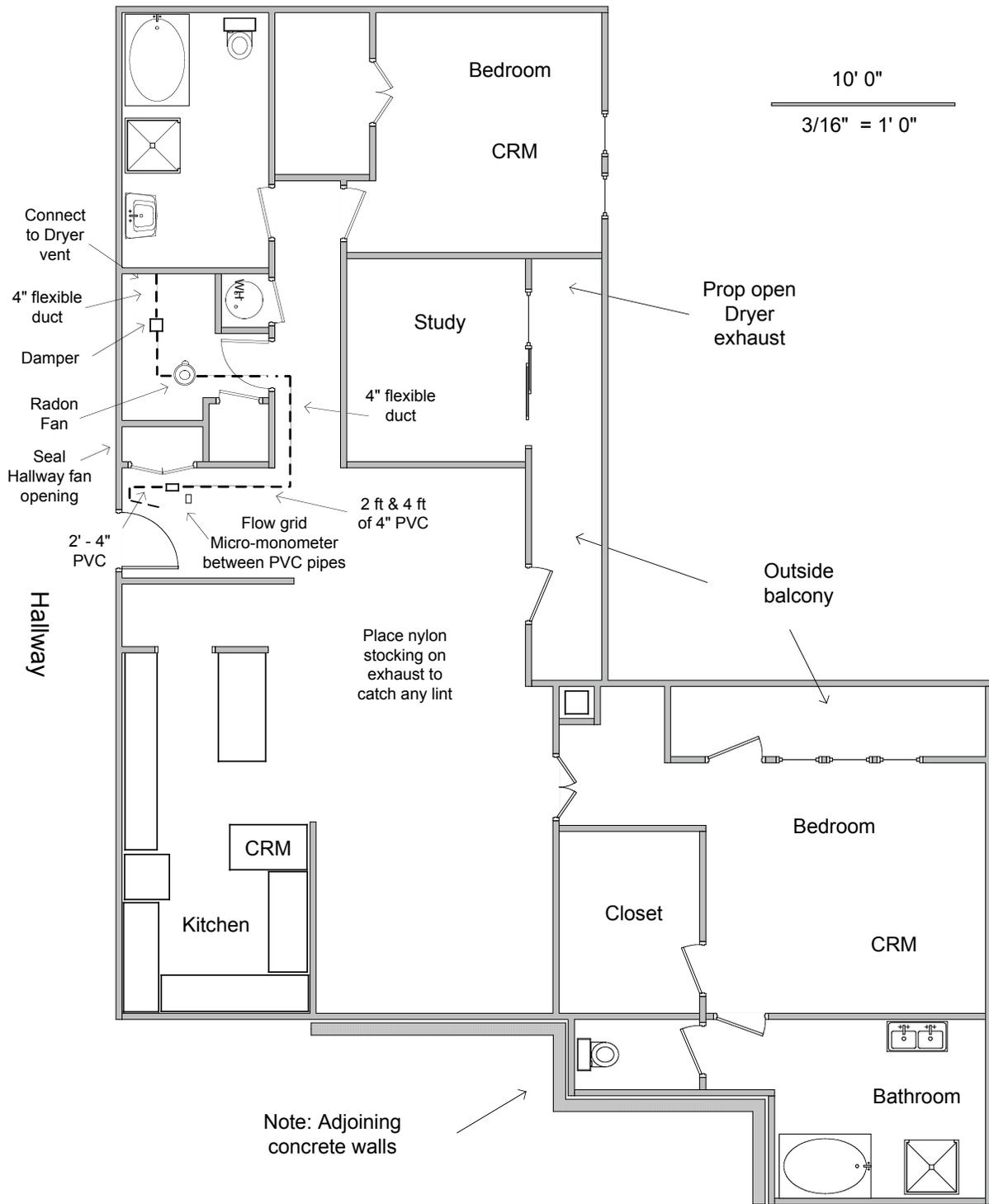


Figure 1 Unit 504 Floor Plan & Ventilation Test

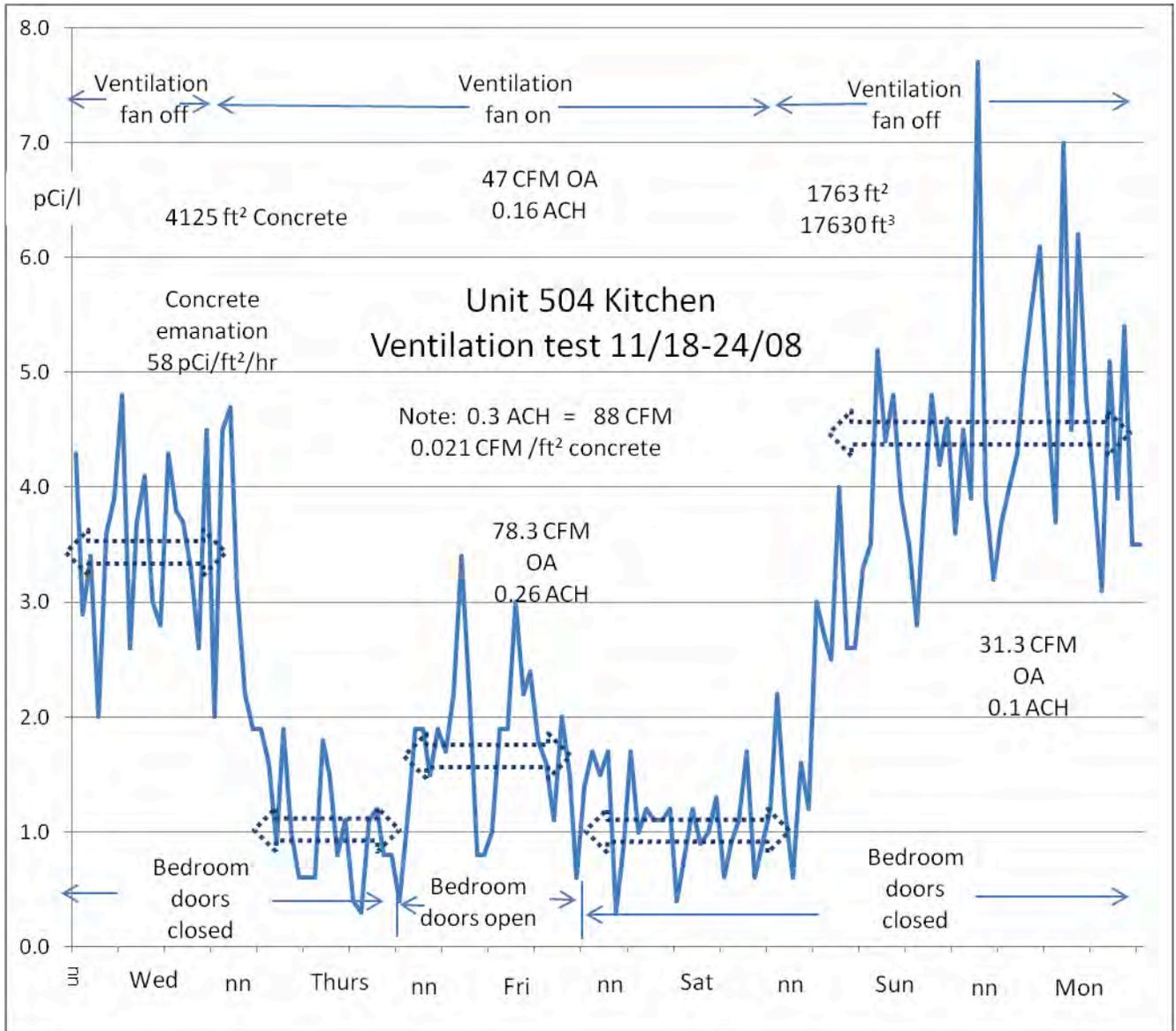


Figure 2 Kitchen results

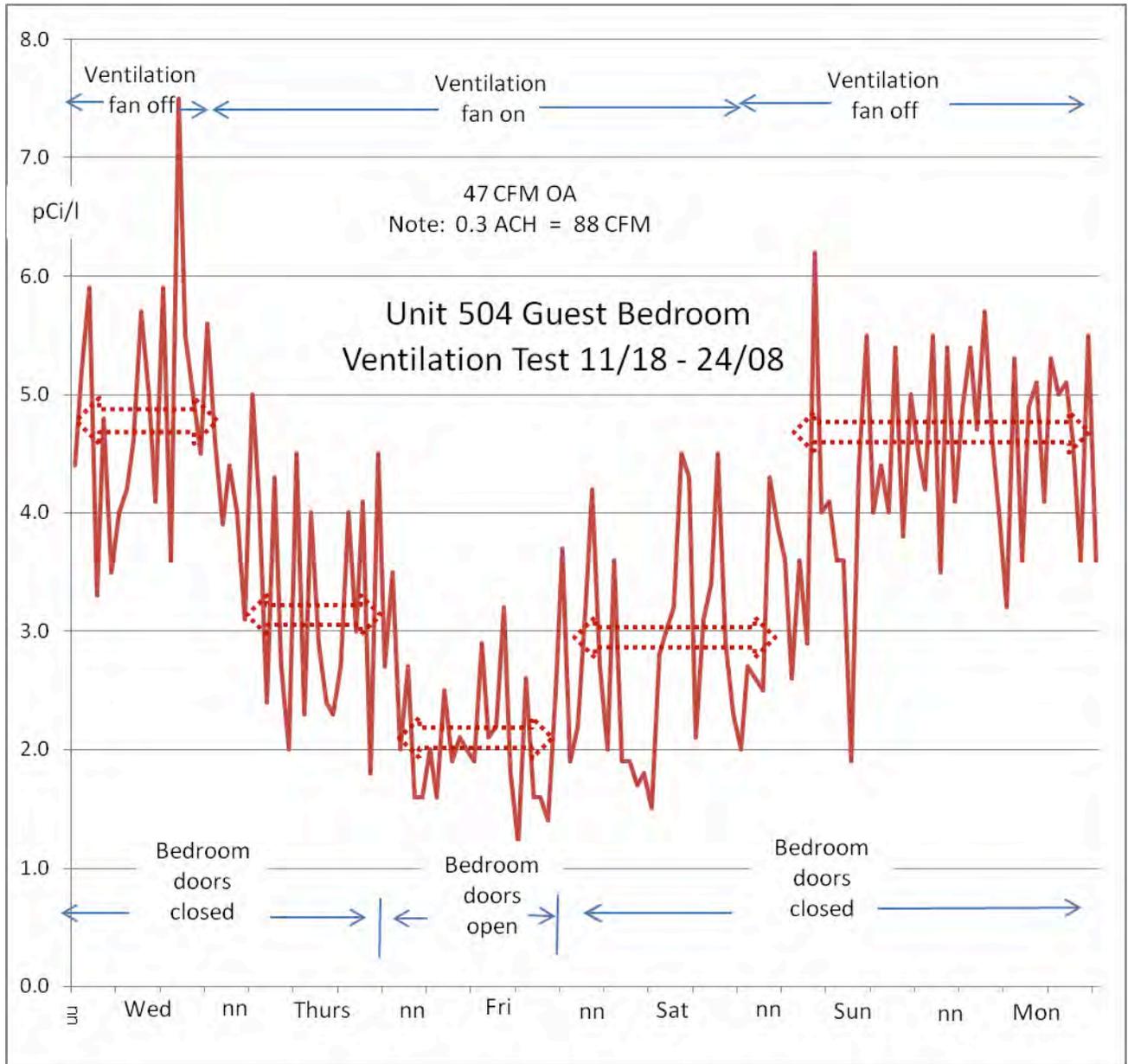


Figure 3 Guest Bedroom results

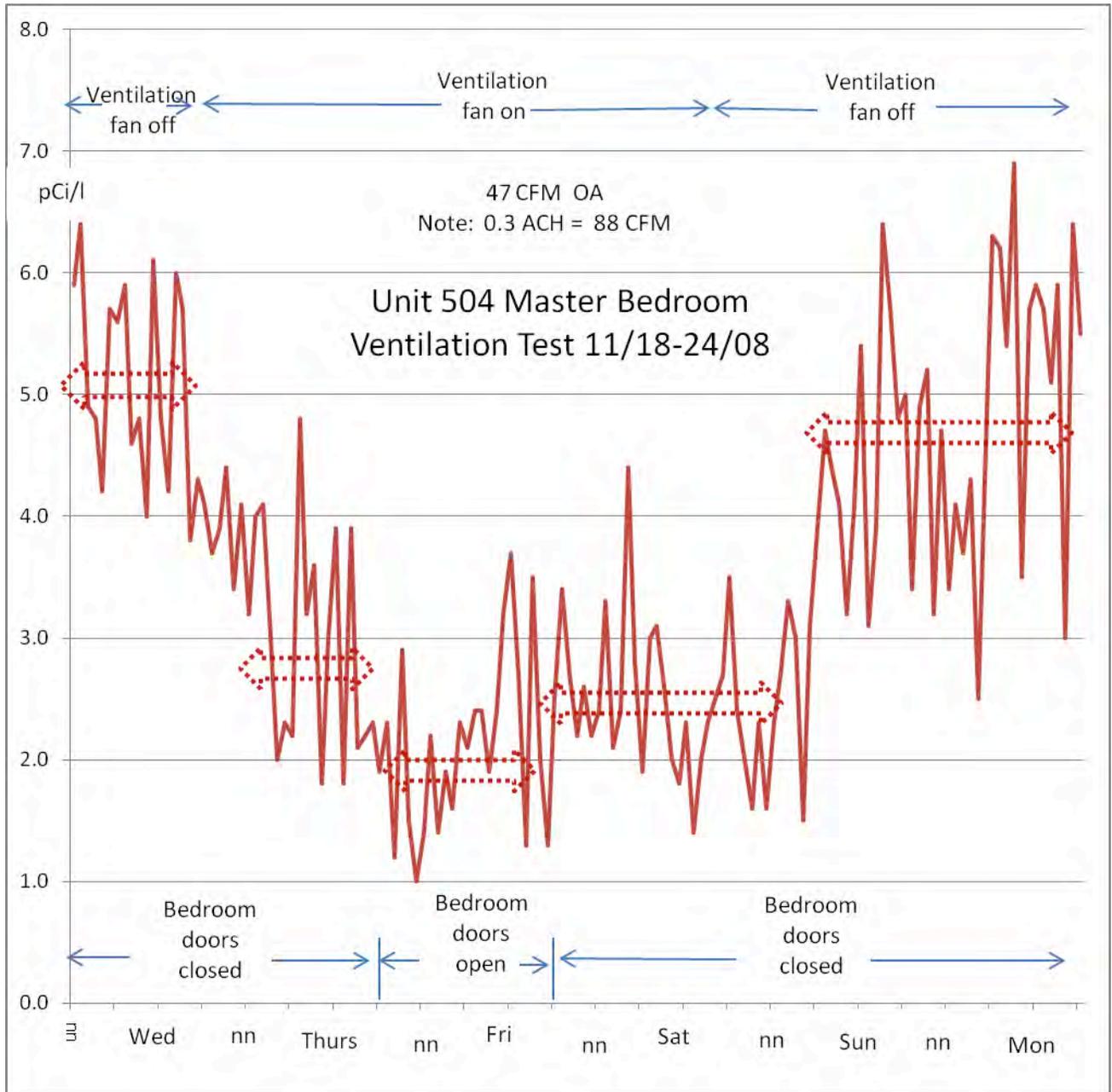


Figure 4 Master Bedroom results

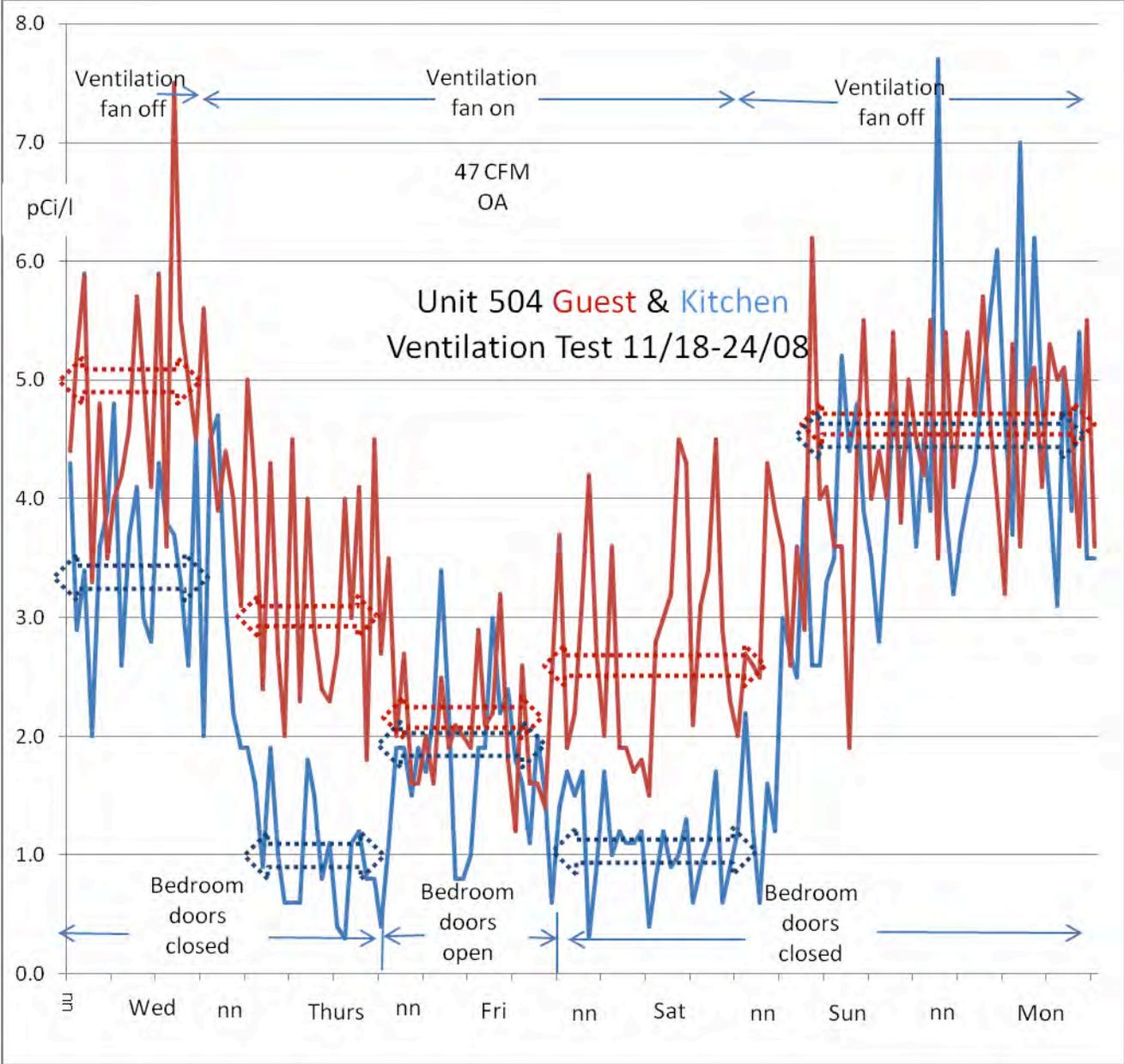


Figure 5 Guest Bedroom & Kitchen results

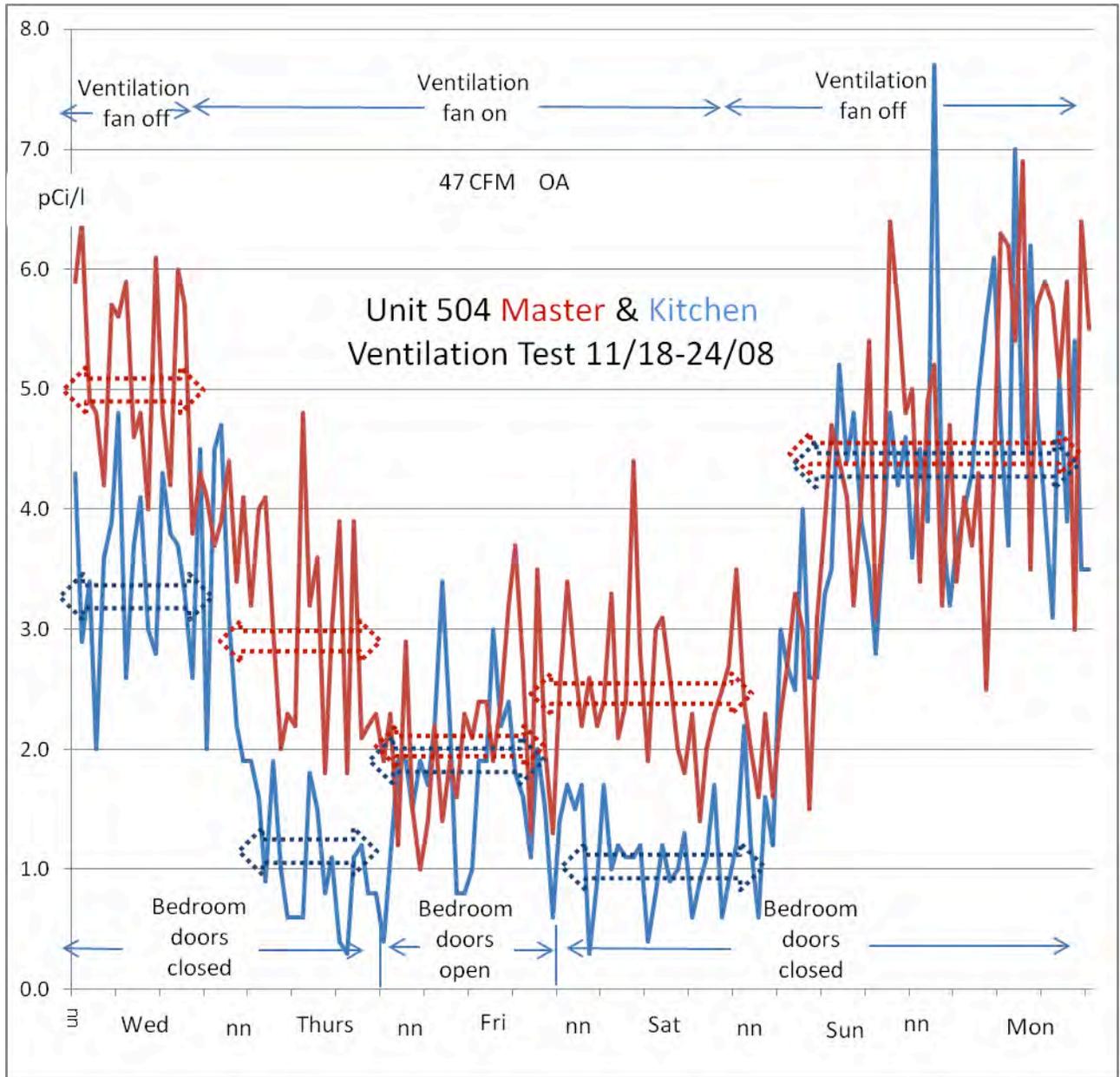


Figure 6 Master Bedroom & Kitchen results

#### 4.0 DETERMINING THE EFFECT OF INTRODUCING OUTDOOR AIR

If one assumes the radon emanation rate is consistent and uniform throughout each condo unit then the variation in radon levels will be directly related to the amount of outdoor ventilation taking place. The amount of ventilation added by the test fan can be carefully measured. The radon reduction in effect is the inverse of the ventilation increase.

- I-Rn = Initial radon
- N-Rn = New radon level with added ventilation
- I-Vn = Initial natural ventilation in CFM
- F-Vn = Fan Forced Ventilation
- N-Vn = New ventilation rate (Initial + Fan forced ventilation)

$$N-Rn = I-Rn \times (I-Vn \div N-Vn)$$

##### Formula 1 Calculating New Radon level based on ventilation change

The one variable that is not measured in the above calculation is the initial natural ventilation. Previous radon measurements made in main living area of the test unit measured 7.5 pCi/l (278 Bq/m<sup>3</sup>). The initial radon measurements made during this ventilation test measured 3.5 pCi/l (130 Bq/m<sup>3</sup>). This means the natural ventilation rate was about 2 times higher during the ventilation test. This is likely due to the cold windy weather happening during the ventilation test. See table 5 below that lists the outdoor high and low temperature swing during the ventilation test. The reduction in radon that can be achieved with outdoor air requires determining the natural ventilation rate by modifying the above formula.

$$I-Vn = F-Vn \times N-Rn \div (I-Rn - N-Rn)$$

##### Formula 2 Calculating Initial Natural Ventilation Rate

In the graph of the kitchen radon variation in Figure 2 above, the average of the final radon levels was used because of a longer measurement period. The radon levels averaged about 4.5 pCi/l (167 Bq/m<sup>3</sup>) without the fan operating. When the fan was supplying 47 CFM (22 l/s) of outdoor air and all the bedroom doors were open the radon levels dropped to 1.8 pCi/l (67 Bq/m<sup>3</sup>). Using the above Formula 2 the following initial natural ventilation rate is determined.

$$31.3 \text{ CFM} = 47 \times 1.8 \div (4.5 - 1.8)$$

Once we have determined the ventilation rate necessary to produce a radon level in the building we can use the following formula to determine natural ventilation rate that was occurring when a previously higher or lower radon concentration was happening in the

unit. It is important to determine this ventilation rate because it indicates the minimum natural ventilation rate of the unit and this ventilation rate is added to the fan forced introduction of outdoor air to predict the final radon levels within the dwelling during mild or windy cold weather.

$$I-V_n = N-V_n \times (N-R_n \div I-R_n)$$

**Formula 3 Determining the ventilation rate when other radon levels were measured**

Formula 3 can be used to determine that the ventilation rate when the radon levels were at 7.5 pCi/l (278 Bq/m<sup>3</sup>) was about 18.8 CFM.

$$18.8 \text{ CFM} = 78.3 \times (1.8 \div 7.5)$$

Or the ventilation rate without the fan running can also be used to determine the ventilation rate when the radon levels were at 7.5 pCi/L (278 Bq/m<sup>3</sup>).

$$18.8 \text{ CFM} = 31.33 \times (4.5 \div 7.5)$$

Note to obtain a more representative radon measurement of the effects of induced ventilation into a single room for this type of building it is important to have the air handler operating or to leave all the bedroom doors open. See the radon level variation that happens when the bedroom doors are closed in the figures and graphs above. The bedroom doors do not have to be left open when no additional outdoor air is being introduced.

**5.0 CALCULATING THE CONCRETE RADON EMANATION RATE**

If the ventilation rate of the unit is known and the radon is coming from the concrete the emanation rate of the concrete can be determined if the square footage of concrete is known. Unit 504 has 1763 square feet of floor area. Since there is concrete floors and ceilings this equals 3,526 ft<sup>2</sup>. The unit however is adjacent to the stair well. The concrete columns and stairwell concrete walls is assumed to equal about 600 ft<sup>2</sup> for a total exposure of 4126 ft<sup>2</sup>. If we use the 78.3 CFM air exchange rate that was maintaining 1.8 pCi/l (67 Bq/m<sup>3</sup>) we can determine the emanation rate from the concrete is 58.0 pCi/ft<sup>2</sup>/hour by the following formula.

$$\text{pCi/ft}^2/\text{hr} = (N-V_n \times 28.3 \times 60 \times N-R_n) \div \text{ft}^2 \text{ of concrete}$$

$$58.0 \text{ pCi/ft}^2/\text{hr} = (78.3 \times 28.3 \times 60 \times 1.8) \div 4126$$

**Formula 4 Calculating the Concrete Emanation Rate**

Previous radon flux measurements of bare concrete on the 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> floor of the building in the Fall of 2007 found a range of 32 pCi/ft<sup>2</sup>/hr to 49 pCi/ft<sup>2</sup>/hr (212 to 325 Bq/m<sup>2</sup>/minute). This calculated radon emanation rate of 58 pCi/ft<sup>2</sup>/hour (385 Bq/m<sup>2</sup>/minute) is 30% to 50% higher. In a paper presented by the author (see second reference at end of paper) the author found the E-PERM accumulator method against concrete used by the author had a 33% lower emanation rate compared to exposing a CRM under an accumulator. The concrete emanation rate for three other units in the building and the adjoining building also had emanation rates around 60 pCi/ft<sup>2</sup>/hour (398 Bq/m<sup>2</sup>/minute) using the ventilation measurements to determine the emanation. Unit 408 had emanation rates that were a third less at 39 pCi/ft<sup>2</sup>/hour (258 Bq/m<sup>2</sup>/minute). See the results in Table 3 below.

## 6.0 DETERMINING THE NECESSARY VENTILATION RATE

Necessary ventilation is typically determined using units of air changes per hour (ACH). Some of the condos in the building had additional exposure to concrete walls that adjoined the stairwells. There were also a number of condo units on the first floor that had living space on the two floors. The following formulas were used for determining the necessary ventilation for each unit.

$$\text{ACH} = \text{Ventilation rate in CFM} \times 60 \div \text{Volume}$$

Formula 5 Determining the ACH rate based on CFM ventilation

Therefore when the radon levels were 7.5 pCi/l (278 Bq/m<sup>3</sup>) in the kitchen and the air handler was likely operating, the ACH was around 0.06 ACH based on the calculated outdoor air ventilation of 18.8 CFM (8.5 l/s) .

$$0.06 \text{ ACH} = 18.8 \times 60 \div 17630$$

When the radon levels were 4.5 pCi/l (167 Bq/m<sup>3</sup>) in the kitchen and bedrooms, the natural ACH was around 0.1 ACH based on the calculated natural outdoor ventilation of 31.3 CFM (15 l/s).

$$0.1 \text{ ACH} = 31.3 \times 60 \div 17,630$$

When the ventilation fan was adding 47 CFM (22 l/s) and the bedroom doors were open, the radon levels in the kitchen dropped to around 1.8 pCi/l (67 Bq/m<sup>3</sup>) and the bedrooms dropped to about 2.1 pCi/l (163 Bq/m<sup>3</sup>). The ACH rate with the ventilation fan was 0.26 ACH..

$$0.26 \text{ ACH} = 78.3 \times 60 \div 17630$$

If the new additional outdoor air ventilation is sized for 0.3 ACH the fan forced outdoor

air ventilation rate would be 88 CFM (42 l/s).

$$0.3 \times 17630 \div 60 = 88 \text{ CFM}$$

In addition to the fan forced ventilation one can assume a natural ventilation rate during mild weather of at least 0.05 ACH or 15 CFM (7 l/s). This will give a new total ventilation rate in unit 504 of 103 CFM (49 l/s) during mild weather. Using the Formula 1 above, the radon levels in Unit 504 would be expected to be 1.4 pCi/L (52 Bq/m<sup>3</sup>) with the bedroom doors open or the air handler operating. The radon levels would be lower during any weather patterns or occupant activity that increased this minimal natural ventilation rate.

$$1.4 \text{ pCi/L} = 4.5 \times (31.3 \div 103)$$

If units of CFM per ft<sup>2</sup> of concrete is used the 88 CFM (42 l/s) in the above calculation is divided by the square footage of concrete that is adjacent to the unit ( 4126 ft<sup>2</sup> )

$$88 \div 4126 = 0.021 \text{ CFM per ft}^2 \text{ of concrete}$$

In the previous study done on this building it was recommended to provide at least 0.015 CFM per ft<sup>2</sup> of concrete to obtain a radon level concentration of 2.0 pCi/l (74 Bq/m<sup>3</sup>) or less depending upon the weather. Using 0.3 ACH ventilation rate raises the original ventilation rate to 0.02 CFM per ft<sup>2</sup> of concrete.

## 7.0 VENTILATION RECOMMENDATIONS

Table 2 below gives the projected radon levels based on a set emanation rate from the concrete with different fan forced ACH rates and weather patterns. The radon emanation rate from the concrete was based on the reduction in radon from introduced ventilation and the calculated ft<sup>2</sup> of concrete exposure. The radon levels are based on this emanation rate and the total ventilation from the fan forced air and the natural ventilation rate. The last column radon levels are based on the bedroom doors being closed and no air handler operation is taking place.

Note that both unit 318 and unit 504 are adjoining stairwells which causes these units to have less radon reduction if raises the final radon levels

The bold radon levels in Table 2 below are the projected radon concentrations based on using 0.3 ACH. All of the units are below 2.0 pCi/L (74 Bq/m<sup>3</sup>) during mild weather. The bedroom radon levels even when the doors are closed and the air handler is not operating are below 3.0 pCi/L (2.2 pCi/L to 2.7 pCi/L). Reducing the ventilation rate from 0.3 ACH to 0.2 ACH would likely reduce the energy costs by 25% and still maintain radon levels below 2.7 pCi/L (100 Bq/m<sup>3</sup>) and the bedroom levels below 4.0 pCi/L (150 Bq/m<sup>3</sup>) even when the bedroom doors are closed.

It was decided to introduce the equivalent of 0.3 ACH to each of the units. Most of the first floor units were actually two story units. Although the stairwells were open to each floor and the location of the air inlets was attempted to be located near the stairwells it was not possible in most cases to introduce the outdoor air on both floors. In order to assure adequate radon reduction on both floors the outdoor air was increased to 0.4 ACH in all two story units. Note that the distribution of outdoor air throughout the unit is only a concern when the unit's air handler is not operating.

Unit #	pCi/ft <sup>2</sup> /hr concrete	Fan Induced ACH	0.03 ACH Mild Weather pCi/L	0.10 ACH Cold Windy pCi/L	Mild weather Bedroom closed doors No HVAC
L-504		0.20	2.1	1.6	3.1
L-504	58.0	0.25	1.7	1.4	2.6
L-504		<b>0.30</b>	<b>1.5</b>	<b>1.2</b>	<b>2.2</b>
E-619		0.20	2.4	1.8	3.6
E-619	59.0	0.25	2.0	1.6	3.0
E-619		<b>0.30</b>	<b>1.7</b>	<b>1.4</b>	<b>2.5</b>
E-511		0.20	2.6	2.0	3.8
E-511	60.0	0.25	2.1	1.6	3.0
E-511		<b>0.30</b>	<b>1.8</b>	<b>1.5</b>	<b>2.7</b>
L-408		0.20	1.4	1.1	2.1
L-408	39.0	0.25	1.2	0.9	1.7
L-408		<b>0.30</b>	<b>1.0</b>	<b>0.8</b>	<b>1.5</b>
L-318		0.20	2.6	2.0	3.8
L-318	61.0	0.25	2.1	1.7	3.1
L-318		<b>0.30</b>	<b>1.8</b>	<b>1.5</b>	<b>2.7</b>

Table 2 Radon levels depending on ACH

## 8.0 WHOLE BUILDING VENTILATION VERSUS INDIVIDUAL ERV'S

A number of options were explored to deliver conditioned air to all 100 resident units and the hallways. First consideration was installing individual Energy Recovery Ventilator (ERV) units. This option had been chosen on an adjacent similar building. The ERV's installed in the adjacent building were effective in reducing radon concentrations to below 4.0 pCi/l, however, there were several negative issues including increased interior humidity and odor transfer from outdoors. The Condo association had concerns with individual ERV's about protecting the exterior styrofoam/stucco layer from water damage from the 200 necessary exterior penetrations necessary for ERV installation. The pros and cons of installing individual ERV's versus a central conditioned ventilation system (CCVS) are listed below.

After considering the pros and cons of both approaches the building condo association decided to have a central conditioned ventilation system (CCVS) installed. This required installing one or more air handlers on the roof that would condition 100% outdoor air. Two deliver systems were considered. The first option was to deliver the necessary air directly to each unit using a ducted system. A less costly second option was to supply all of the necessary conditioned air to the hallways. This air would be distributed to the hallways in multiple locations on each floor at timed intervals. Bathroom blowers in each unit would simultaneously be activated in the exhaust mode. Passive transfer grills would be installed between each unit and the hallway to allow the hallway conditioned air to pass into each unit from the depressurization created by the bathroom exhaust fans. This concept was rejected for several reasons.

- 1) There was concern that there would be large variation in the hallway ventilation to the units because of greater or lesser negative pressure in the units.
- 2) Maintaining consistent exhaust airflow from bathroom fans would be difficult
- 3) Bathroom fan noise would be too great and occupants would request turning them off
- 4) There would be a large ongoing expense to maintain the bathroom fan motors
- 5) Noise transfer from the hallways through the passive vents would not be acceptable.

After considering the pros and cons of both approaches the building condo association decided to have a central conditioned ventilation system (CCVS) installed. The cost to have a central conditioned system with ducted air to each unit was similar to the cost of having individual HRV/ERV's installed.

Concerns and Advantages for individual HRV/ERV versus whole building CCVS

- 1) 0.3 ACH for the units in this building requires airflow from 50 CFM to 110 CFM depending on the unit size. CCVS allows easier individual adjustment of the necessary ventilation. Obtaining the necessary airflow to achieve 0.3 ACH would require some units to have oversized HRV/ERV's that would then be damped down to obtain the necessary airflow. This increases the electrical cost, system noise and system intrusion in the unit.

- 2) HRV/ERV's do not typically transfer humidity. HRV/ERV's will contribute humidity to the unit while a C CVS will reduce indoor humidity. This became a factor in the decision process since the building had experienced interior condensation problems.
- 3) HRV/ERV's require penetrations of the exterior shell of the building at inaccessible locations that could create a potential for water leakage and building warrantee issues.
- 4) Maintaining adequate distance between intakes and exhaust vents for HRV/ERV's would be difficult.
- 5) Each of the units has an outdoor patio deck that is often used for smoking. These fumes could be brought back into an adjoining unit whose intake is too close to the adjoining patio.
- 6) HRV/ERV's located on lower floors could draw in dumpster orders, vehicle exhaust, and street level restaurant exhaust.
- 7) HRV/ERV's recover heat better than they recover cooling. In this climate and with this type of air tight construction there is mostly a cooling/ dehumidification requirement and very little heating requirement
- 8) Individual HRV/ERV units must be installed inside the unit in a location where it can be serviced. This may take up closet space within the unit. The HRV/ERV requires ductwork to the outside that is drywalled and finished to match the interior décor. C CVS only requires a grill adjacent to the hallway to be installed.
- 9) Each HRV/ERV installation requires an electrical inspection.
- 10) Higher maintenance cost to change HRV/ERV filters twice a year in each unit which requires visiting all 100 units versus servicing two roof top C CVS units.
- 11) The occupants of the building could interfere with ERV/HRV operation.
- 12) C CVS installation would be quieter operation for the occupants than the ERV/HRV.
- 13) If individual HRV/ERV dual motors fail it requires 100 replacements which may be difficult to access and replace any finish covering.

## 9.0 IS SUPPLEMENTAL HEAT REQUIRED?

During the study the temperature in the kitchen of unit 504 did not drop below 71 degrees (21.7 c) while 47 CFM (22 l/s) of outdoor air was being introduced when the outdoor temperatures were below freezing each night setting record lows for the area. See Table 3 and Figure 7. Note that there was no supplemental heat or occupancy induced heat or lighting that would add additional source of heat during the test. Note that the total CFM of outdoor air during the test was 47 CFM (22 l/s) induced and 31 CFM (15 l/s) natural for a total of 78 CFM (37 l/s) of outdoor air. The proposed airflow of 88 CFM (22 l/s) plus a natural ventilation of 31CFM (15 l/s) would give a total of 119 CFM (56 l/s) which is about 50% greater.

Date	Tues	Wed	Thurs	Fri	Sat	Sun	Mon
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High	43°	45°	61°	44°	45°	53°	47°
Low	24°	18°	26°	21°	13°	29°	30°

Table 3 Outdoor temperatures in F during the ventilation test

Note that the indoor kitchen temperature on Wednesday only dropped to 71 degrees (21.6 c) even though the outdoor temperatures had dropped to a low of 18 degrees (-7.7 c). Note that there was no supplemental heat, or lights left on or occupancy during this period to contribute additional heat from occupancy or from cooking or cleaning. The rise in temperature each day was from the solar gain into the unit. The guest bedroom climbed to 80 degrees during 5 of the 6 afternoons from solar gain. The master bedroom climbed to 91 degrees (32.7 c) during 2 of the afternoons and was above 80 degrees (26.7 c) every day.

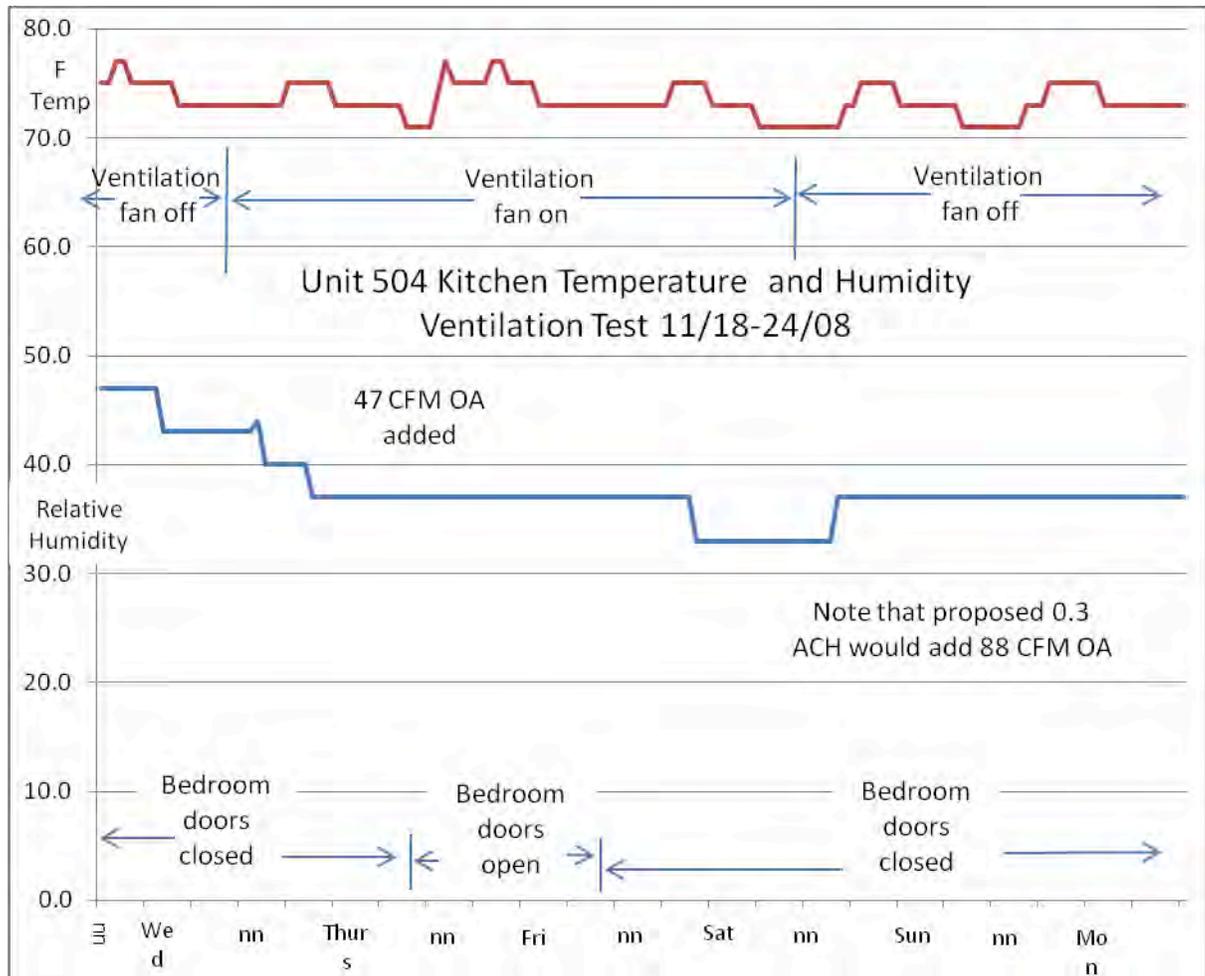


Figure 7 Kitchen temperature & relative humidity

Providing outdoor air that is not conditioned when the outdoor temperature is below 68 degrees would actually lower the occupancy cooling cost assuming the outdoor air did not significantly raise the humidity.

It was recommended to install supplemental heat in the air handler that is set to activate only when the outdoor temperatures reaches a pre-determined level and to have the capacity to adjust this activation temperature and the temperature of the air that is provided during cold weather. It may in fact not be necessary to add any supplemental heat.

## 10.0 BUILDING VENTILATION STANDARDS

ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers has been updating ventilation guidelines for commercial buildings for 100 years. The society however has not directed much attention to residential dwellings. Residential ventilation was traditionally not a major concern because it was felt that between operable windows and envelope leakage, occupants were getting adequate air. The latest standard developed by ASHRAE for ventilation of residential buildings is Standard 62.2-2003. This standard makes the target ventilation rate comprise a sum of the ventilation necessary to dilute background sources and sources attributable to occupancy. To find the total amount of outside air needed add 3 cfm/100 ft<sup>2</sup> (15 l/s/100 sq.m.) to 7.5 cfm/person (3.5 l/s/person). Thus the air change rate requirement varies by the size of the house and the occupancy. If one assumes two persons for a single bedroom unit and four persons for a two bedroom unit then the total ventilation rate might be the following listed in Table 4 below.

	Single bedroom	Two bedroom
1000 ft2	45 CFM / 0.3 ACH	60 CFM / 0.4 ACH
1500 ft2		75 CFM / 0.33 ACH
2000 ft2		90 CFM / 0.3 ACH

Table 4 ASHRAE current total ventilation recommendations

## 12.0 CONSTRUCTING A DESIGN AND INSTALLATION TEAM

A team was establishing early in the process that consisted of the following groups.

- 1) Building Association and point of contact person
- 2) Radon and ventilation consultant
- 3) HVAC Engineering company and point of contact person
- 4) General Contractor consultant
- 5) HVAC sub-contractor consultant
- 6) Electrical sub-contractor consultant

## 7) Building Association attorney

There were competing objectives among this group. On one side of the project is the group responsible for putting the project together. On the other side is the occupants who will be enduring the installation and performance of the system. Along with all of this are the issues of installation cost, and ongoing system energy and maintenance costs.

As-built building plans were not available for this project and caused extra design work. Legal issues prevented obtaining plans from the normal sources: builder, architect, sub-contractor, or office where the permits were filed.

A Request for Proposal (RFP) was distributed to HVAC engineering companies that had experience designing systems for similar buildings located in the same climate. The HVAC company was requested to consider all the issues of temperature, humidity, noise, installation issues, maintenance expense, and time table objectives of the project. The initial engineering company selected for this project had to withdraw because their insurance company would not cover the liability of the project.

This project required extensive on-site review of duct sizing and routing because of the limited availability of duct runs down through the building and in particular the allowable duct runs above the drop ceiling down the hallways. The hallway duct runs were difficult because the building association requested that the drop ceiling not be lowered in the hallways. There were biweekly meetings throughout the design and installation process to discuss concerns and share preliminary information.

The building owner selected Clean Vapor LLC as the commercial mitigation contractor based on cost, their previous experience with similar commercial building ventilation installations, their availability to complete the project on time, their references, and their willingness to work towards all the installation objectives.

A project management schedule listing all the functions and task times through completion of the project was used. The site manager was onsite every day work took place in the building. Extra effort was provided by the selected mitigation contractor to minimize system installation dust and debris and minimize installation impact on the building occupants. The Building Association POC informed residents by email weekly of all project time tables and potential impacts. Residents were given advanced notifications of X-rays, utility shut off's and items that require residents to evacuate their units. A project Health and Safety Plan (HASP) was developed and implemented by the Site Safety Officer.

## **13.0 INSTALLATION OF SUPPLEMENTAL VENTILATION SYSTEM**

The central conditioned ventilation system (CCVS) for the building was designed by a professional engineering company. On each floor of the building there were two storage rooms near the center of the building and a storage room on each of the outer wings of the building that

lined up with each other from floor to floor. In addition there was a drop ceiling on each floor above the hallway with about 8 inches of space.

Two roof top ventilating units were installed on the roof. Two 20 Ton AAON package units, rated at 3500 cfm were installed on the roof and lined up over the outer wing storage rooms below. Each unit weighed 2900 pounds (1311 Kg) and provided 100% conditioned outside air. During the cooling season the unit is delivering 65 degree (18 c) air at 50% relative humidity (rh). During the heating season the unit will deliver 70 to 75 degree (21 to 24 c) air at approximately 20% rh. On humid days during the cooling season each unit is producing condensation at a rate of ½ gallon per minute. An additional drain to the storm sewer was installed to accommodate the condensate discharge.

A fully ducted system was installed. The two main vertical ducts extended from the roof top units down to the first floor. The main trunks, that runs down through the building, required cutting through the concrete floors that had post tension stressed steel reinforcing cables. In order to avoid cutting any of these cables an X-ray scan of each slab penetration was performed.

On each floor horizontal duct runs were routed from the main trunk above the drop ceiling-along the entire hallway. In most cases an individual duct run from the hallway trunk was routed through the common wall of each resident's unit, to a supply louvered grill installed in the foyer of the unit. Fire dampers were installed in the main trunk at each floor and in the duct that passed through the resident's common wall to the hallway as per fire code requirements. An airflow damper was also installed in each duct to the unit to allow manual system balancing.

Each of the floors had four equally spaced ceiling mounted supply diffusers installed in the hallways and an additional diffuser installed in the central elevator area to maintain necessary hallway ventilation. The original hallway air conditioning and heating units were removed and donated to Habitat for Humanity.

As part of start up, an independent test and balance company conducted the testing and balancing to meet the design airflow specifications.

#### **14.0 RADON REDUCTION FROM VENTILATION SYSTEM INSTALLATION**

After the central ventilation system was installed and balanced all of the units were tested with individual radon charcoal detectors. It appeared that the necessary closed house conditions were maintained by almost all of the occupants.

Units Tested	Average Post Mitigation Radon Level
1 <sup>st</sup> Floor Quad units	2.1
1 <sup>st</sup> Floor units	1.2
1 <sup>st</sup> Floor without Quad units	0.8

3 <sup>rd</sup> Floor units	0.8
4 <sup>th</sup> Floor units	0.8
5 <sup>th</sup> Floor units	0.7
Hallways	0.6

Table 5 Post mitigation average per area

unit	Pre-Mitg	Post Mitg
118	9.0	0.8
145 Quad	5.9	2.7
312	16.3	1.3
318	13.2	0.8
322	10.6	0.5
410	10.0	0.3
428	9.5	0.8
500	5.1	1.3
504	7.5	0.8
Hallway 112	9.3	0.8
Hallway 313	5.5	0.3
Hallway 413	4.9	0.5
Hallway 506	6.6	0.7

Table 6 Post mitigation versus Pre-Mitigation levels

After the CCV was completed 91 of the 100 units tested below 1.5 pCi/l (56 Bq/m<sup>3</sup>). The average radon levels for each floor of the building are displayed in table 5 above. There are 12 two story units that are grouped into four units that are referred to as “Quad” units. See the first floor building layout in Figure 7 below. These units had the greatest distance from the roof top central ventilation air handlers. Four of the twelve Quad units had radon reductions between 2.0 pCi/l. and 3.0 pCi/l (74 to 111 Bq/m<sup>3</sup>). The average of the Quad units and the average of the first floor without the Quad units is displayed in Table 5 above. Note that the average radon levels for all the floors including the hallway measurements and excluding the Quad units is between 0.6 and 0.8 pCi/l (22 to 30 Bq/m<sup>3</sup>). Table 6 above compares the radon measurements that were obtained before the ventilation system was installed with the post mitigation radon results for these same units.

Overall the radon levels were dramatically reduced below the guideline, the indoor air quality was significantly improved, window condensation problems were eliminated, disruption to the occupants during construction and with operation of the system was minimized.

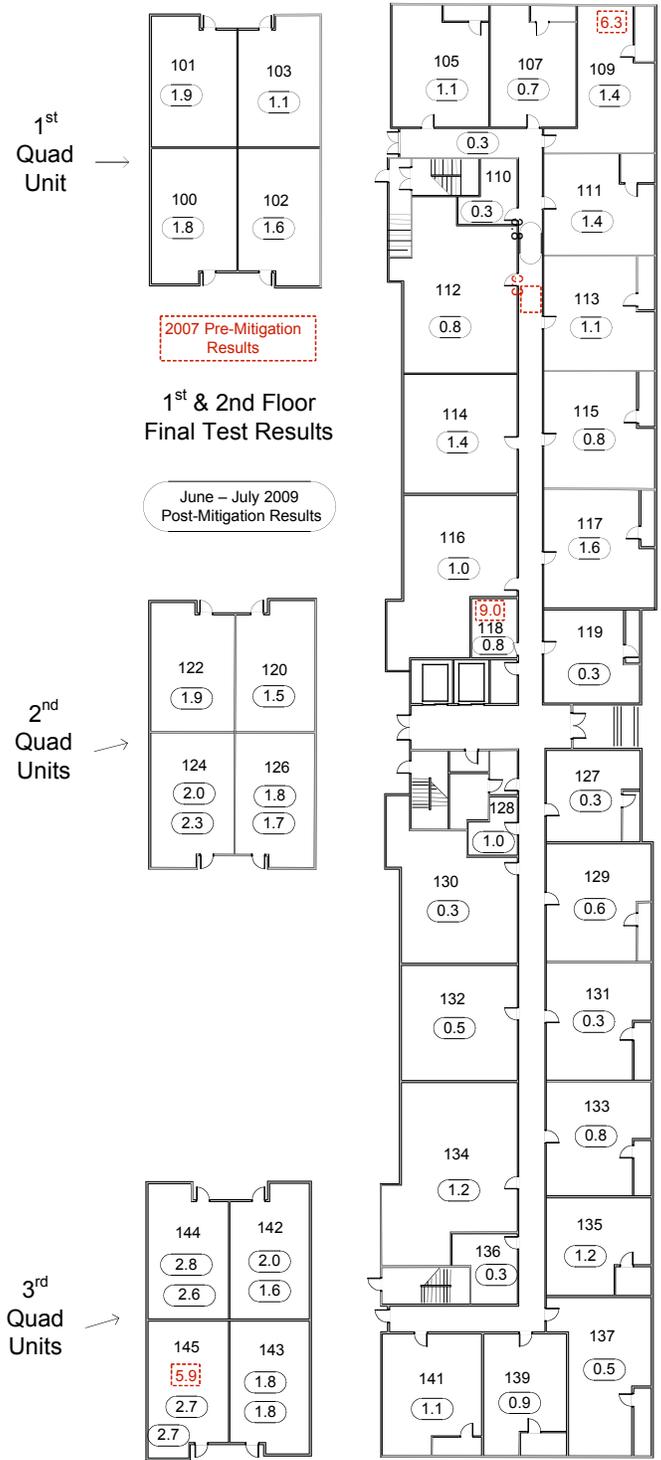


Figure 8 First Floor Final Radon Measurements

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