

## Appendix B: SenTech Room Volume Considerations (English)

Normal industry practice is to think about refrigerant leaks in terms of pounds of refrigerant per unit time such as lbs/hr or ozs/yr. This is a natural and logical way of looking at it. The system monitors the amount of refrigerant present in the air in Parts Per Million (ppm) by volume of refrigerant molecules as compared to air molecules. In order to develop a relationship between the leak rate in weight per unit time and ppm reading of the monitor, there are a number of items that need to be considered and accounted for. These are:

1. Room Volume.
2. The relationship between refrigerant amount in weight compared to refrigerant volume at the temperature and pressure of the room.
3. The amount of time the refrigerant has been leaking.
4. The rate at which fresh air enters the room (stale air is exhausted).
5. The location of the monitor inlet relative to the leak, the air patterns of the room, and the rate at which the leaking refrigerant expands to fill the room.

For a given specific situation items 1 through 4 are either known, can be calculated, or can be estimated. Item 5 is virtually unknowable, therefore in all the formulas and sample calculations it is assumed that leaking refrigerant expands immediately to fill the room. This is a reasonable and conservative assumption on the basis that you have located the monitor following the recommendations outlined in the installation section. If you have followed those recommendations, the monitor should see a higher concentration sooner than the idealized formulas.

The equations have been developed for two cases. **Case I** is for a sealed room, no air turnover. **Case II** is for a room with a known turnover of air.

To be able to convert between a leak rate in cubic feet per hour to a leak rate in pounds per hour the molecular weight of the refrigerant needs to be known. If you know the molecular weight of the refrigerant, you can calculate the necessary conversion factors at normal atmospheric pressure and room temperature.

$$\frac{\text{Mol Wt(gms)}}{1(\text{mole})} \times \frac{1(\text{mole})}{22.4(\text{ltrs})} \times \frac{1(\text{pound})}{454(\text{gms})} \times \frac{28.32(\text{ltrs})}{1(\text{cuft})} \times \frac{273}{293} = \frac{\#}{\text{cuft}}$$

Substituting for R-22 which is 86.48 grams/mole, you get  $0.22 \frac{\#}{\text{cuft}}$ .

### Conversion Factors for Common Refrigerants

R-22	.22 #/cuft	4.46 cuft/#
R-12	.31 #/cuft	3.18 cuft/#
R-11	.36 #/cuft	2.80 cuft/#
R-502	.29 #/cuft	3.45 cuft/#
R-123	.41 #/cuft	2.41 cuft/#

### PPM READINGS AND LEAK RATE RELATIONSHIP DEFINITIONS:

- PPM = Monitor PPM reading or trip point PPM setting
- LR = Leak Rate of refrigerant in cubic feet per hour
- FA = Fresh Air into the room in cubic feet per hour
- VOL = Volume of the room in cubic feet
- t = Time in hours (There are 8760 hours in one year)
- R = Amount of refrigerant in the room in cubic feet
- LR<sub>min</sub> = Minimum leak rate that will reach a given PPM

#### Case I: Sealed Room

$$\text{PPM} = \frac{\text{LR} \times t \times 10^6}{\text{VOL}} \quad t = \frac{\text{PPM} \times \text{VOL} \times 10^{-6}}{\text{LR}}$$

$$R = \text{PPM} \times \text{VOL} \times 10^{-6}$$

#### Case II: Room with Air Changing

$$\text{PPM} = \frac{\text{LR}}{\text{FA}} \left(1 - e^{-\frac{\text{FA}}{\text{VOL}}t}\right) 10^6$$

$$t = \frac{\text{VOL}}{\text{FA}} \times \ln \left(\frac{\text{LR}}{\text{LR} - \text{PPM} \times \text{FA} \times 10^{-6}}\right)$$

$$\text{LR}_{\text{min}} = \text{PPM} \times \text{FA} \times 10^{-6}$$

### Sample Calculations (Assuming The room is 40 feet by 30 BY 10 feet = 12,000 cuft)

#### Case I: Sealed Room

1. How much refrigerant is necessary to cause a 25 ppm reading ?  
 $R = 25 \times 12000 \times 10^{-6} = .3 \text{ cuft}$   
 If it is R-22:  $.3 \text{ cuft} \times .22 \text{ lb/cuft} = .066 \text{ lbs}$
2. If the leak rate is 300 lbs./year of R-22, how long will it take to reach 25 ppm ?  

$$\frac{300 \text{ lbs}}{\text{yr}} \times \frac{1 \text{ yr}}{8760 \text{ hr}} \times \frac{4.46 \text{ cuft}}{\text{lbs}} = .153 \text{ cuft/hr}$$

$$t = \frac{25 \times 12000 \times 10^{-6}}{.153} = 1.96 \text{ hrs}$$

#### Case II: Room with Air Changing

- Assume the same room 12,000 cuft.  
 Assume fresh air at 100 cfm or 6000 cuft/hr (1 air changes in 2 hour).
1. What is the minimum leak that will reach 25 ppm ?  
 $\text{LR}_{\text{min}} = 25 \times 6000 \times 10^{-6} = .15 \text{ cuft/hr}$   
 for R-22:  $.15 \text{ cuft/hr} \times .22 \text{ lb./cuft} = .033 \text{ lbs/hr}$  or 289 lbs/yr
  2. How long will it take to detect a leak of 500 lbs/yr of R-22?  
 $500 \text{ lbs/yr} = .26 \text{ cuft/hr}$   

$$t = \frac{12000}{6000} \times \ln \left(\frac{.26}{.26 - 25 \times 6000 \times 10^{-6}}\right) = 1.72 \text{ hrs}$$
  3. If the trip point is set at 10 ppm, what is the minimum leak rate of R-123 that will trigger the alarm ?  
 $\text{LR}_{\text{min}} = 10 \times 6000 \times 10^{-6} = .06 \text{ cuft/hr}$   
 for R-123:  $.06 \times .41 \text{ lbs/ft} = .0246 \text{ lbs/hr}$  or 215 lbs/yr
  4. How long will it take to detect a leak of 300 lbs/yr of R-123 ?  
 $300 \text{ lbs/yr of R-123} = .0825 \text{ cuft/hr}$   

$$t = \frac{12000}{6000} \times \ln \left(\frac{.0825}{.0825 - 10 \times 6000 \times 10^{-6}}\right) = 2.6 \text{ hrs}$$

These numbers represent worst case conditions. With the monitor placed close to the potential leak points and on the "downwind" side of the air flow, the trip points are likely to be activated sooner.

## Appendix B: SenTech Room Volume Considerations (Metric)

Normal industry practice is to think about refrigerant leaks in terms of weight of refrigerant per unit time such as kg/hr or kg/yr. This is a natural and logical way of looking at it. The system monitors the amount of refrigerant present in the air in Parts Per Million (ppm) by volume of refrigerant per volume of air. In order to develop a relationship between the leak rate in weight per unit time and ppm reading of the monitor, there are a number of items that need to be considered and accounted for. These are:

1. Molecular weight of the refrigerant.
2. Density of the refrigerant at the temperature of the room.
3. Room volume.
4. The rate at which fresh air enters the room.
5. The location of the monitor inlet relative to the leak, the air patterns of the room, and the rate at which the leaking refrigerant expands to fill the room.

For a given specific situation items 1 through 4 are either known, or can be calculated. Item 5 is virtually unknowable, therefore in all the formulas and sample calculations it is assumed that leaking refrigerant expands immediately to fill the room. This is a reasonable and conservative assumption on the basis that you have located the monitor following the recommendations outlined in the installation section. If you have followed those recommendations, the monitor should see a higher concentration sooner than the idealized formulas.

The equations have been developed for two cases. **Case I** is for a sealed room, no air turnover. **Case II** is for a room with a known turnover of air.

To be able to convert between a leak rate in cubic meters per hour to a leak rate in kilograms per hour the density of the refrigerant must be known. At normal atmospheric pressure and room temperature.

$$\text{DENSITY (kg/m}^3\text{)} = \frac{\text{Mol Wt(gms)}}{22.4(\text{ltrs})} \times \frac{273}{293} \times \frac{1(\text{kg})}{1000(\text{gms})} \times \frac{1000(\text{ltrs})}{1(\text{m}^3)}$$

As an example for R-22, Mol Wt = 86.48 gm/mole.  
Therefore density = 3.59 kg/m<sup>3</sup>, or 0.28 m<sup>3</sup>/kg

### Conversion Factors for Common Refrigerants

R-22	3.59 kg/m <sup>3</sup>	0.28 m <sup>3</sup> /kg
R-12	4.96 kg/m <sup>3</sup>	0.20 m <sup>3</sup> /kg
R-11	5.76 kg/m <sup>3</sup>	0.17 m <sup>3</sup> /kg
R-502	4.64 kg/m <sup>3</sup>	0.21 m <sup>3</sup> /kg
R-123	6.56 kg/m <sup>3</sup>	0.15 m <sup>3</sup> /kg

### PPM READINGS AND LEAK RATE RELATIONSHIP DEFINITIONS:

- PPM = Monitor PPM reading or trip point PPM setting
- LR = Leak Rate of refrigerant in cubic meter per hour
- FA = Fresh Air into the room in cubic meter per hour
- VOL = Volume of the room in cubic meter
- t = Time in hours (There are 8760 hours in one year)
- R = Amount of refrigerant in the room in cubic meters
- LR<sub>min</sub> = Minimum leak rate that will reach a given PPM

#### Case I: Sealed Room

$$\text{PPM} = \frac{\text{LR} \times t \times 10^6}{\text{VOL}} \quad t = \frac{\text{PPM} \times \text{VOL} \times 10^{-6}}{\text{LR}}$$

$$R = \text{PPM} \times \text{VOL} \times 10^{-6}$$

#### Case II: Room with Air Changing

$$\text{PPM} = \frac{\text{LR}}{\text{FA}} (1 - e^{-\frac{\text{FA}}{\text{VOL} \cdot t}}) 10^6$$

$$t = \frac{\text{VOL}}{\text{FA}} \times \ln \left( \frac{\text{LR}}{\text{LR} - \text{PPM} \times \text{FA} \times 10^{-6}} \right)$$

$$\text{LR}_{\min} = \text{PPM} \times \text{FA} \times 10^{-6}$$

### SAMPLE CALCULATIONS (ASSUMING THE ROOM IS 15 METERS BY 10 METERS BY 3 METERS = 450 CUBIC METERS)

#### Case I: Sealed Room

1. How much refrigerant is necessary to cause a 25 ppm reading ?  
R = 25 x 450 x 10 = .0011 cubic meter  
If it is R-22:  
Amount of refrigerant = .0011 m<sup>3</sup> x 3.59 kg/m<sup>3</sup> = .004 kg
2. If the leak rate is 150 kg/year of R-22, how long will it take to reach 25 ppm ?  
$$\frac{150 \text{ kg}}{\text{yr}} \times \frac{1 \text{ yr}}{8760 \text{ hr}} \times \frac{.28 \text{ m}^3}{\text{kg}} = 0.0048 \text{ m}^3/\text{hr}$$
  
$$t = \frac{25 \times 450 \times 10}{0.0048} = 2.35 \text{ hrs}$$

#### Case II: Room with Air Changing

- Assume the same room (450 m<sup>3</sup>).  
Assume fresh air at 225 m<sup>3</sup>/hr (1 air changes in 2 hour).
1. What is the minimum leak that will reach 25 ppm ?  
LR<sub>min</sub> = 25 x 225 x 10 = 0.0056 m<sup>3</sup>/hr  
for R-22:  
0.0056 m<sup>3</sup>/hr x 3.59 kg/m<sup>3</sup> = 0.02 kg/hr OR 175 kg/yr
  2. How long will it take to detect a leak of 200 kg/yr of R-22?  
200 kg/yr = 0.023 kg/hr  
$$t = \frac{450}{225} \times \ln \left( \frac{.023}{.023 - 25 \times 225 \times 10^6} \right) = 4.0 \text{ hrs}$$
  3. If the trip point is set at 10 ppm, what is the minimum leak rate of R-123 that will trigger the alarm ?  
LR<sub>min</sub> = 10 x 225 x 10 = .00225 m<sup>3</sup>/hr  
for R-123: .00225 x 6.56 kg/m<sup>3</sup> = .0148 kg/hr OR 130 kg/yr
  4. How long will it take to detect a leak of 150 kg/yr of R-123 ?  
150 kg/yr of R-123 = .0026 m<sup>3</sup>/hr  
$$t = \frac{450}{225} \times \ln \left( \frac{.0026}{.0026 - 10 \times 225 \times 10^{-6}} \right) = 4.0 \text{ hrs}$$

These numbers represent worst case conditions. With the monitor placed close to the potential leak points and on the "downwind" side of the air flow, the trip points are likely to be activated sooner.