SECTION IV

MODEL SET UP

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4. MODEL SET UP

4.1 CFD Model of the Isolation Room

Figure 4.1 shows the configuration of the isolation suite being studied. The suite consists of three rooms, being connected through the door gaps between them: the main isolation room, bathroom and vestibule. The main room is equipped with 4 slot diffusers near the window and a low induction diffuser on the ceiling.

Three extreme weather conditions that affect the supply temperature and thermal boundary condition at the external wall are considered:

- Peak Load: Maximum summer day solar loading for South facing isolation room: External temperature is 31.5°C (88.7°F).

- Peak T: Maximum summer day external temperature 35°C (95°F) without solar radiation in the room.

- Minimum T: Minimum winter night temperature of -11.7°C (10.9°F).

In the Peak Load scenarios, the transmitted portion of the solar flux through the window was included, and the absorbed fraction was added directly to the glazing. Radiation from the glazing was also included in the cases. As the room is considered to be surrounded by rooms of similar build and configuration, all the walls, the ceiling and the floor are considered adiabatic, except for the wall that is in contact with the external conditions, and so subject to heat loss/ gain. In all cases considered, the heat dissipated by the patient was included. Other heat gains in the room included lamps, a television, lighting, and miscellaneous items usually found in isolation rooms, for example, heating pads, equipment, etc.

The variation of the ventilation parameters involves:

- Supply flow rate (2 ACH- 16 ACH)
- Weather condition: summer or winter (supply temperature)
- Ventilation system:
    - Low exhausts
    - High exhausts
    - Low exhausts with baseboard heating for winter cases
    - High exhausts with baseboard heating for winter cases
    - Pressurization of the of rooms to corridor

The variation in UVGI includes:

- Two locations
- Three output power levels of the UVGI

20 cases with two low exhausts in the isolation room, as listed in Table 4.1, were studied to evaluate the influence of the supply flow rate and temperature on the particle tracking. In order to examine the effects of ventilation system change, another 20 cases were run with high exhaust locations; baseboard heating and pressurization of the isolation room were included (see Table 4.2). Figure 4.2 shows the locations of the diffusers, exhausts and the baseboard heating in the main room.

The baseboard heater used was 7.9’ (2.4 m) long and 18’’ (0.46 m) high, and accounted for 80% of the heating required in the extreme winter case. In particular, the heater dissipated 396W total, or 171.1 Btu/hr/ft (165 W/m).

Two locations of the wall mounting UV lamp fixture were studied. The output power of the UVGI was also changed, which results in 3 different UV intensity distributions, named as UV1, UV2 and UV3 as summarized below.

- UV1: Output power of 10W, located on the partition wall, 7.5’ (2.29m) from the floor.
- UV2: Output power of 20W, located on the wall near the bed, 7.5’ from the floor.
- UV3: Output power of 40W, located on the wall near the bed, 7.5’ from the floor.

Following the UV intensity pattern data from the manufacture and the data obtained by Dumyahn and First (1999), the UV field distribution can be determined for each given UV power output and Fixture location. The plan view of the UV field distribution for UV1 is shown in Figure 4.3. The UV intensity was assumed to be constant over the 5” (1.27e-2m) height of the lamp. The heat dissipated was not considered in the cases as it spread over a wide volume within the room, and represents only a small fraction of the heat budget in the room.

Great care was taken with regard to the correct representation of the diffusers in the room, as well as the numerical grid used. The numerical diffuser models were validated against available manufacturers data to ensure that throw characteristics were matched accurately. This was performed for all the diffuser types (linear slot, low induction and 4-way diffuser), and for an appropriate range of flow rates.

The number of grid cells used in these cases was on the order of 370,000 cells. Grid dependency tests were performed to ensure that the results were appropriate and would not vary on increasing the grid density. In particular, attention in the tests was directed at the areas containing the main flow or heat sources in the room, for example, the diffusers and the area close to the glazing, as well as areas of largest flow or temperature gradients, for example, the area close to the baseboard heating, and the flow through the door cracks. Grid was added appropriately in these regions and their surroundings until grid independence was achieved.

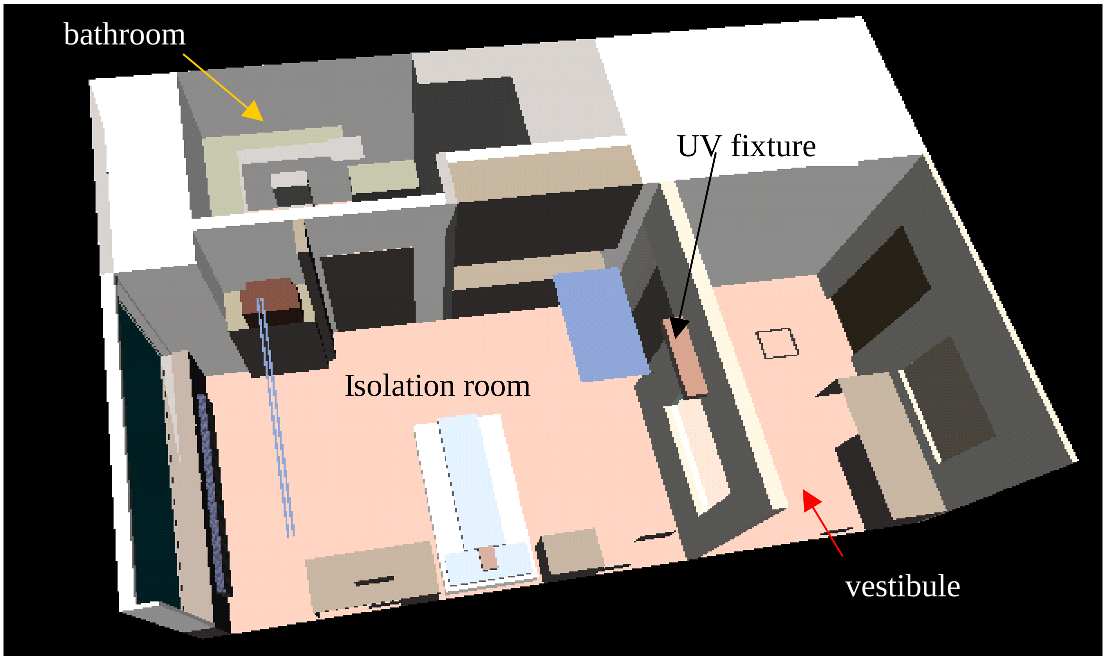

Figure 4.1. *Configuration of the isolation suite*

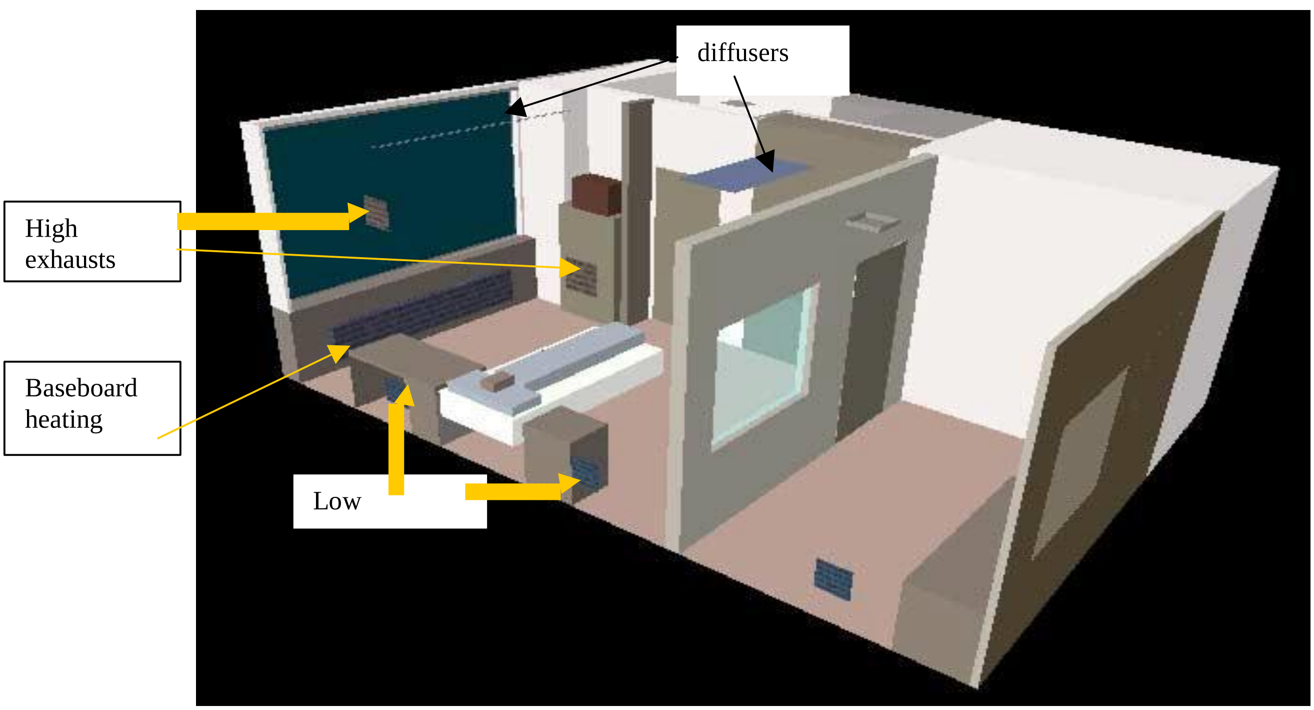

Figure 4.2. *Ventilation system in the isolation room*

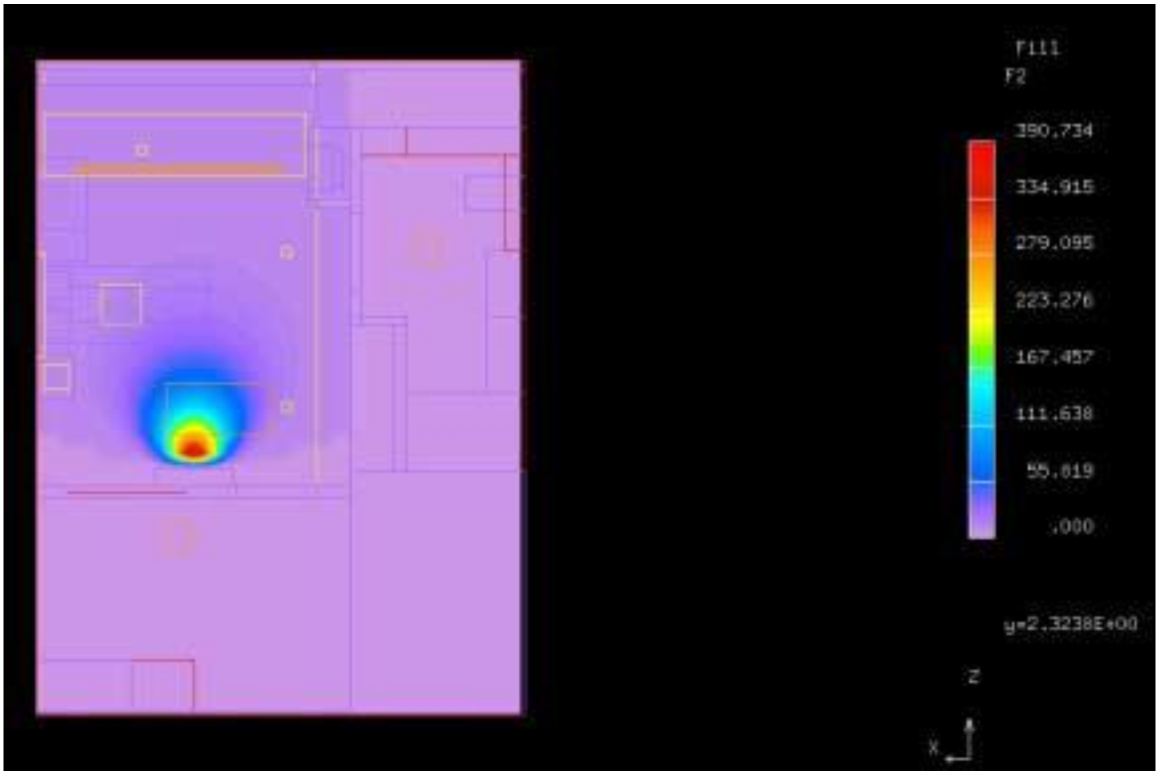

Figure 4.3. *Plan view of UV field with UV lamp located on partition wall and output power of 10W (Values in μW/ cm$^{2)}$.*

Table 4.1 20 low-level-exhaust cases with variation in supply flow rate and temperature

Case	Weather Condition	ACH	Main Isol. Room (cfm)		Bathroom (cfm)		Vestibule (cfm)		Supply T
			Sup.	Exh.	Sup.	Exh.	Sup.	Exh.	
Case1	Min. T	2	62	42	0	100	180	150	37.2
Case2	Peak T	4	125	105	“	“	“	“	9.2
Case3	Min. T	“	“	“	“	“	“	“	30
Case4	Peak T	6	187	167	“	“	“	“	13.8
Case5	Min. T	“	“	“	“	“	“	“	27.7
Case6	Peak load	8	250	230	0	“	“	“	9.6
Case7	Peak T	“	“	“	“	“	“	“	16.1
Case8	Min. T	“	“	“	“	“	“	“	26.5
Case9	Peak load	10	312	292	0	“	“	“	12.2
Case10	Peak T	“	“	“	“	“	“	“	17.5
Case11	Min. T	“	“	“	“	“	“	“	25.8
Case12	Peak load	12	375	355	0	“	“	“	14
Case13	Peak T	“	“	“	“	“	“	“	18.4
Case14	Min. T	“	“	“	“	“	“	“	25.3
Case15	Peak load	14	437	417	0	“	“	“	15.3
Case16	Peak T	“	“	“	“	“	“	“	19.1
Case17	Min. T	“	“	“	“	“	“	“	25
Case18	Peak load	16	499	479	0	“	“	“	16.3
Case19	Peak T	“	“	“	“	“	“	“	19.5
Case20	Min. T	“	“	“	“	“	“	“	24.8

Table 4.2. 20 cases with variation of ventilation system

Case	Weather Condition	ACH	Main Isol. Room (cfm)		Bathroom (cfm)		Vestibule (cfm)		Supply T (°C)	Change in Ventilation system
			Sup.	Exh.	Sup.	Exh.	Sup.	Exh.		
Case21	Min T	2	62	42	0	100	180	150	25.8	Baseboard Heating
Case22	"	6	187	167	"	"	"	"	23.9	"
Case23	"	12	375	355	"	"	"	"	23.5	"
Case24	"	16	499	479	"	"	"	"	23.3	"
Case25	Peak T	4	125	105	"	"	"	"	9.2	High exhausts in Main room
Case26	Min T	"	"	"	"	"	"	"	30	"
Case27	Peak T	10	312	292	"	"	"	"	17.5	"
Case28	Min T	"	"	"	"	"	"	"	25.8	"
Case29	Peak T	16	499	479	"	"	"	"	19.5	"
Case30	Min. T	"	"	"	"	"	"	"	24.8	"
Case31	Min T	2	62	42	"	"	"	"	25.8	Baseboard heating/high exhausts in Main room
Case32	Min T	6	187	167	"	"	"	"	23.9	
Case33	Min T	12	375	355	"	"	"	"	23.5	
Case34	Min T	16	499	479	"	"	"	"	23.3	
Case35	Peak T	4	125	75	0	150	180	130	9.2	Increased pressurization between suite to corridor
Case36	Min T	"	"	"	"	"	"	"	30	
Case37	Peak T	10	312	263	"	"	"	"	17.5	
Case38	Min T	"	"	"	"	"	"	"	25.8	
Case39	Peak T	16	499	449	"	"	"	"	19.5	
Case40	Min. T	"	"	"	"	"	"	"	24.8	

4.2 Model for Bacteria Killing

The bacteria are simulated as 100 particles released from each of 27 discrete source locations above the bed. The 2700 particles were tracked for 300s or until they were removed from the room by the ventilation system.

The percentage survival is dependent on exposure to UV dose, the relative humidity, and the susceptibility of the species of the bacteria. The UV dose is defined as:

$$\text{Dose} = \text{Exposed time} * \text{UV Irradiance} \quad (4.1)$$

In this report, the probability of survival was calculated using the experimental data shown in Figure 4.4.

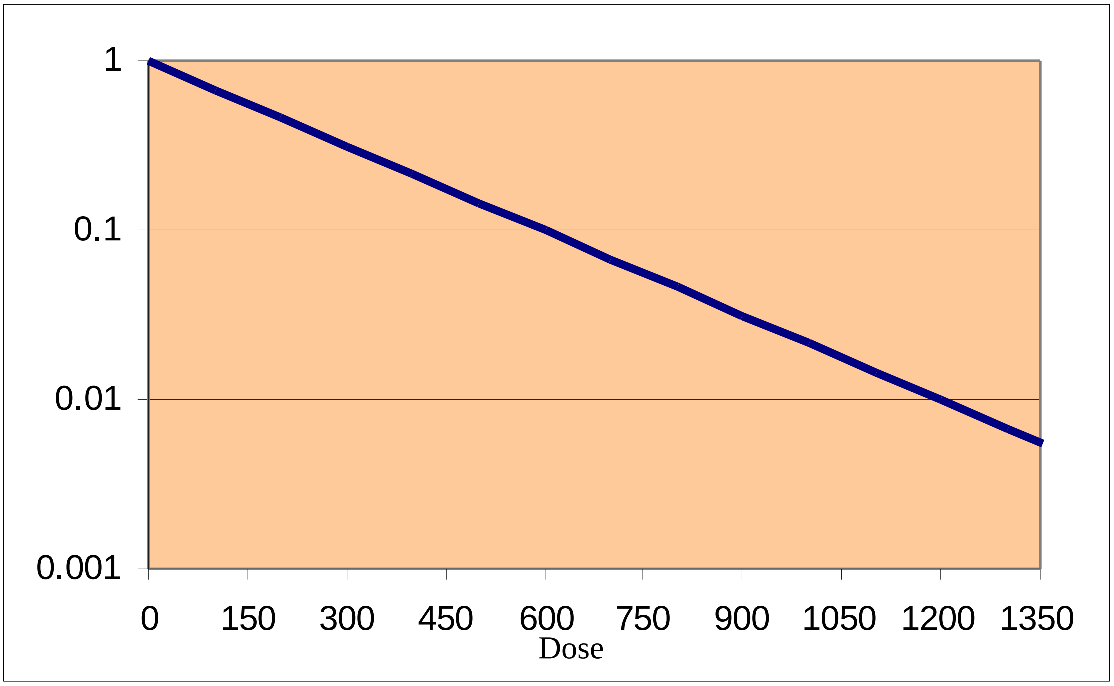

Figure 4.4. *Survival Fraction vs. Dosage for M. tuberculosis, First et al. Part I (1999)*

$$PS = a * \exp(-k\,x) \tag{4.2}$$

a=100
k=0.00384

Where
- a: coefficient from curve fitting
- PS: Survival probability
- x: UV Dose (= irradiance*time of exposure)
- k: susceptibility

In order to see the variation of the important parameters with tracking time, the survival probability needs to be calculated every minute, and killed particles need to be identified every minute as well. Two approaches, described as follows, were proposed for determination of particle killing.

Group counting:

In the group counting approach, the concept of "average dose" for all viable particles is used. At time t=0, 2,700 particles are released, and all are initially considered as viable. As the particles pass through the room, they are subject to, and accumulate UV dose. The dose is recorded at the end of each time interval at which results are considered. The UV dose experienced by each viable particle is used to calculate an average dose that is applied as the "x" value in Equation 4.2. This determines the survival fraction of the viable particles at the conclusion of the set interval. The particles receiving the highest doses will be eliminated in subsequent calculations. For example, based on the average dose of the remaining viable particles, if Equation 4.2 calculation shows 40% of the particles survive, the 60% of individuals with the highest UV doses will be eliminated from the program, and the remaining particles will be available for additional UV exposure during the next time interval.

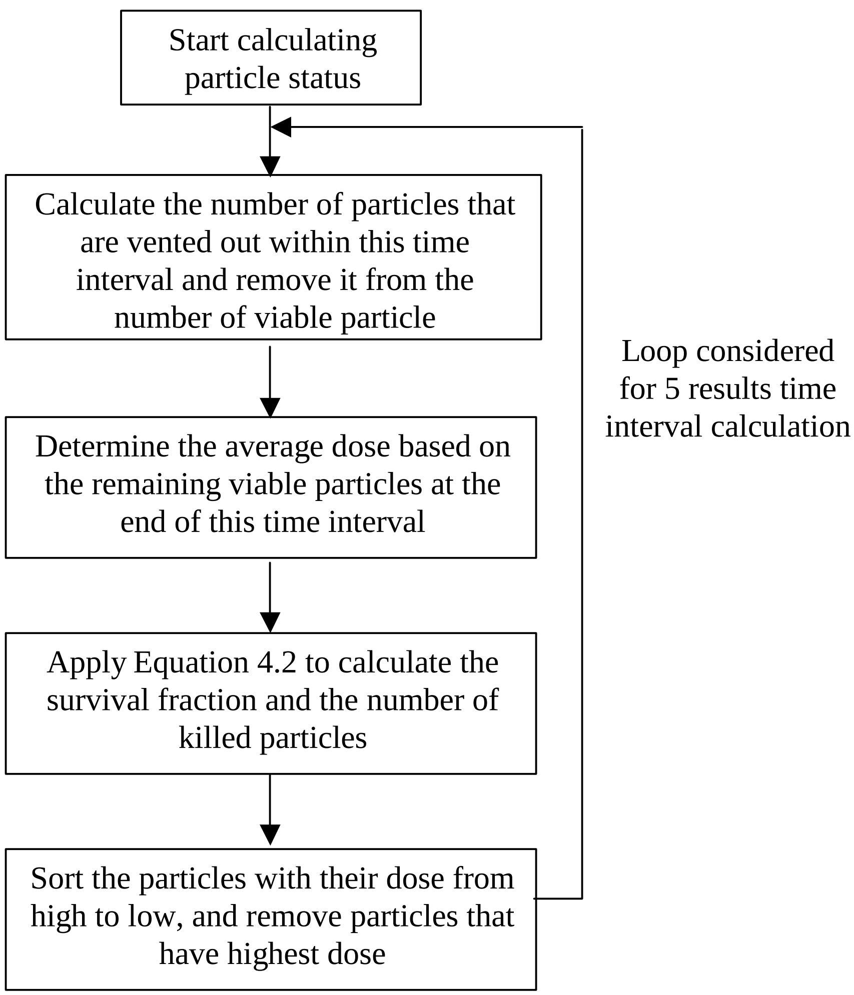

Figure 4.5. *Flow chart for particle status calculation in the group counting approach*

For the second minute calculation, the beginning conditions will be the same as the conditions at the end of the first minute, and so on for each interval of the five-minute run. In particular, dosages are accumulated, such that a dose a particle has after one minute is carried to the second minute calculation. The calculation procedure with the group counting method is shown in Figure 4.5.

Individual counting:

In the individual counting approach, the UV dose received by each particle is recorded at the end of each time interval at which results are considered, and is used as the "x" value in Equation 4.2 to derive the survival probability of the particle. The killing probability for each particle is equal to 1-"surviving probability". A random number between 0 and 1 is then used to determine whether a particle is actually killed. For example, if the killing probability of a particle is 0.002, there is a 2 out of 1000 chance that the particle is killed. The random number is compared with the killing probability of the particle; if the random number falls between 0-0.002, this particle is tagged as killed, otherwise, it will still be viable, and continuously receives dosage in the next time interval. This procedure is repeated for every time interval (one minute) in the particle trajectory until it either is killed, ventilated out, etc. as shown in Figure 4.6.

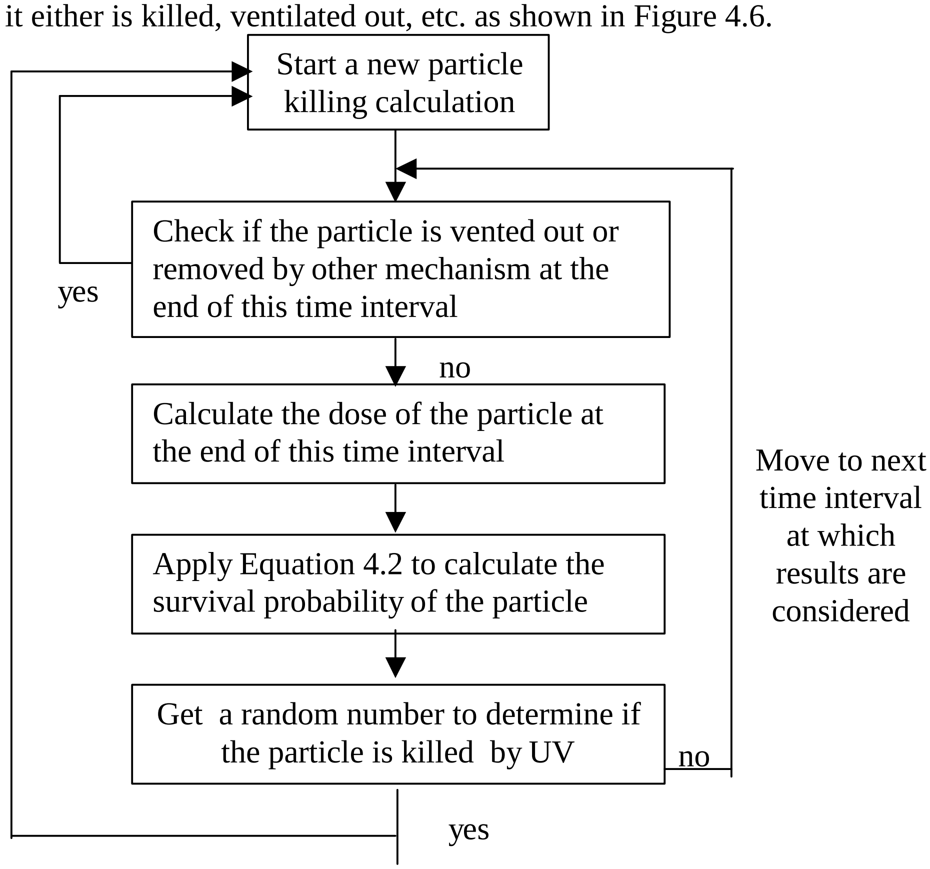

Figure 4.6. *Flow chart for particle status calculation in the individual counting approach*

The group counting method is considered as the primary particle-killing-calculation method in this study. As there is no solid consensus regarding which counting method better reflects the real killing process, the results based on the individual counting method are also presented for comparison.

4.3 Modeling Impingement of Particles on Solid Surfaces

In turbulent flow, the particles are transported not only by convection of the airflow, but also by the turbulent diffusion. Therefore, the particle trajectories are not identical to the streamlines of airflow. As we all know, particles can hit the wall surface when they are traveling close to the wall due to the turbulence effect.

Upon hitting a solid surface, the particle may be permanently deposited or 'bounced' away from the surface depending on electric forces, molecular forces, surface roughness, and temperature. The fact that the cough particles are essentially aerosol in nature is another influence. Theoretically, a depositing probability should be introduced to represent the various influences noted above. However, since there is no information available in the literature that is applicable to the particle conditions in this study, a depositing probability is not considered.

In this study a non-depositing model, in which particles are prevented from depositing on wall surfaces, is considered. It should be noted that the reason that a particle will hit a solid surface is because of the addition of the turbulent fluctuation velocity component to the particle trajectory.