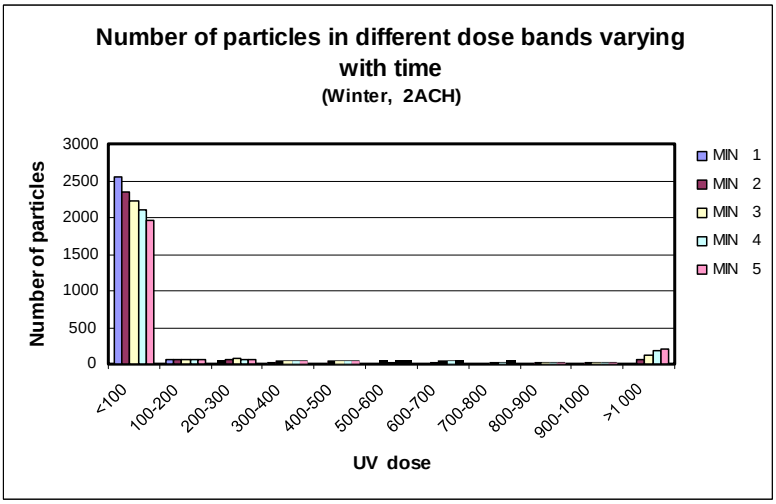
5.3.17 The Numbers of Particles in Different Dose Bands

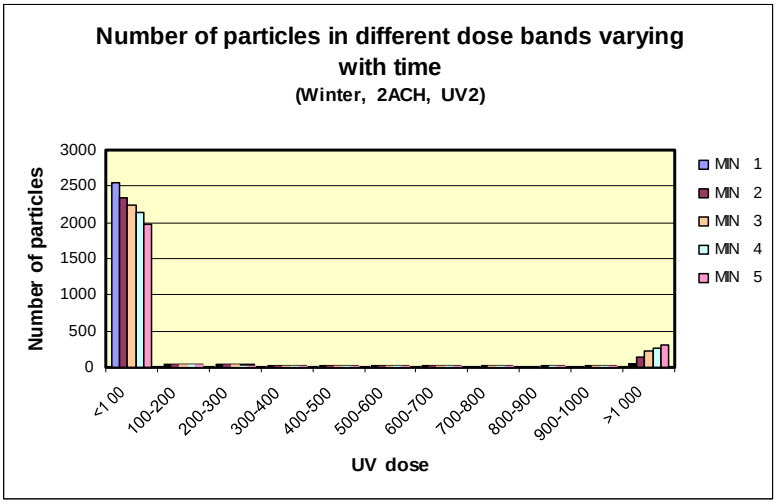
In this file, the numbers of particles in different dose bands varying with time for the non-stick model are presented.

There are 40 cases, or airflow conditions. Each case has 3 graphs of dose bands associated with 3 UV distributions presented in the same page. The UVGI output power and location are shown on the right hand side of each graph.

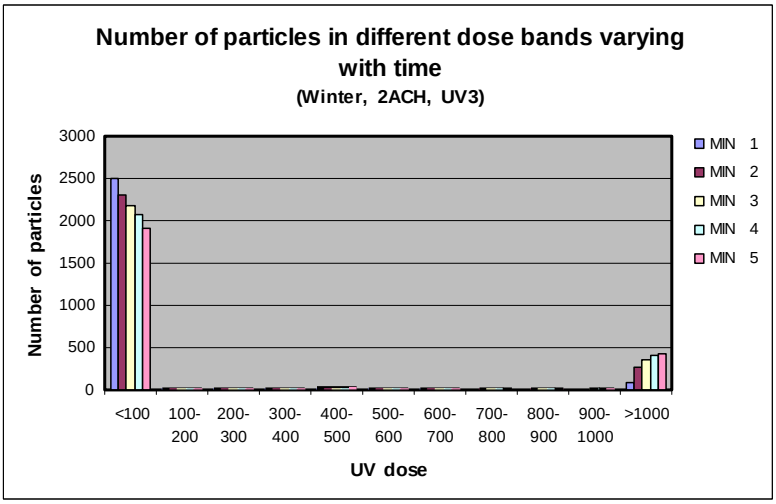
Case 1: Winter, 2 ACH, low exhausts



UV output of 10W, located at partition wall

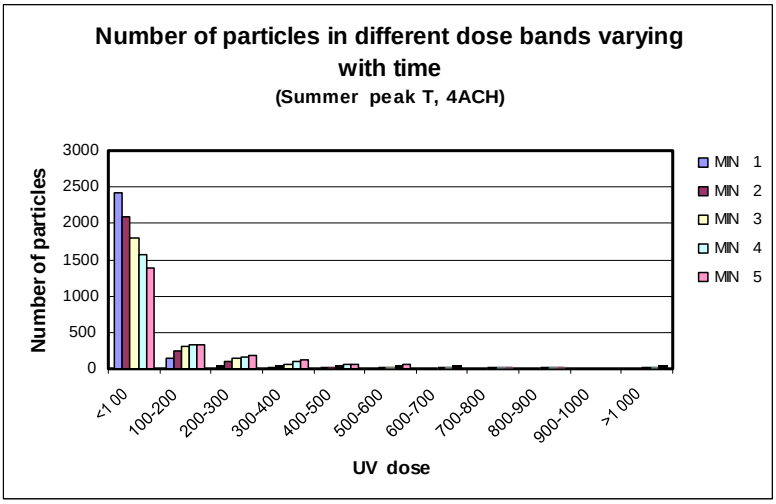


UV output of 20W, located at the wall near the bed

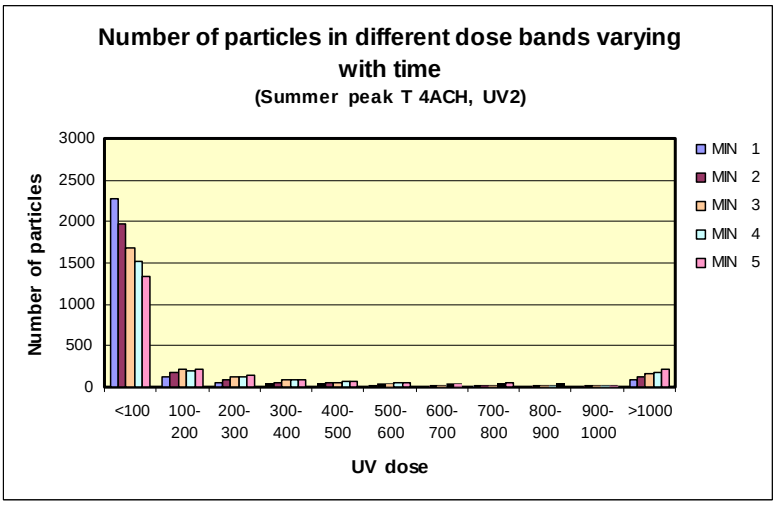


UV output of 40W, located at the wall near the bed

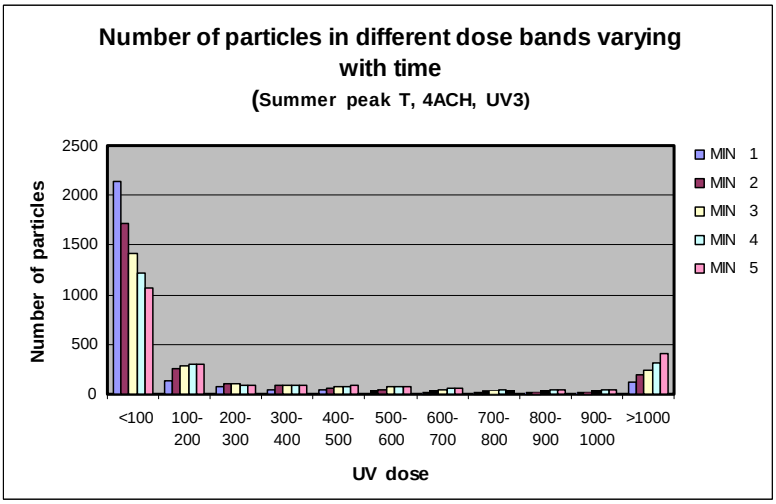
Case 2: Summer peak T, 4 ACH, low exhausts



UV output of 10W, located at partition wall

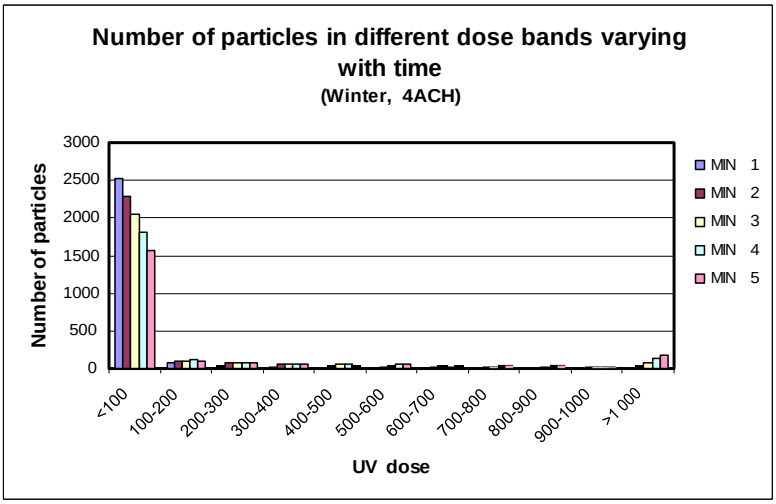


UV output of 20W, located at the wall near the bed

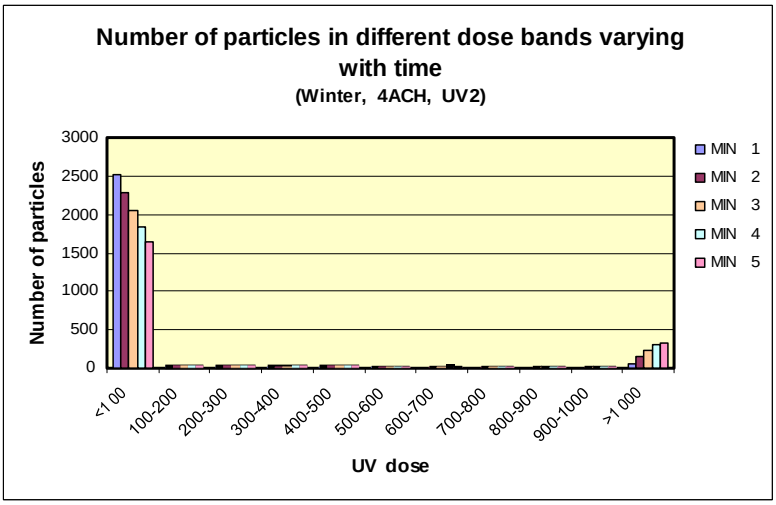


UV output of 40W, located at the wall near the bed

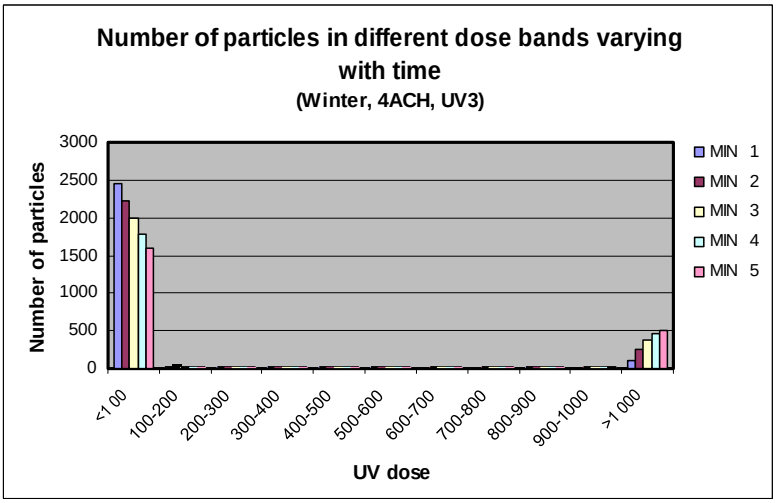
Case 3: Winter, 4 ACH, low exhausts



UV output of 10W, located at partition wall

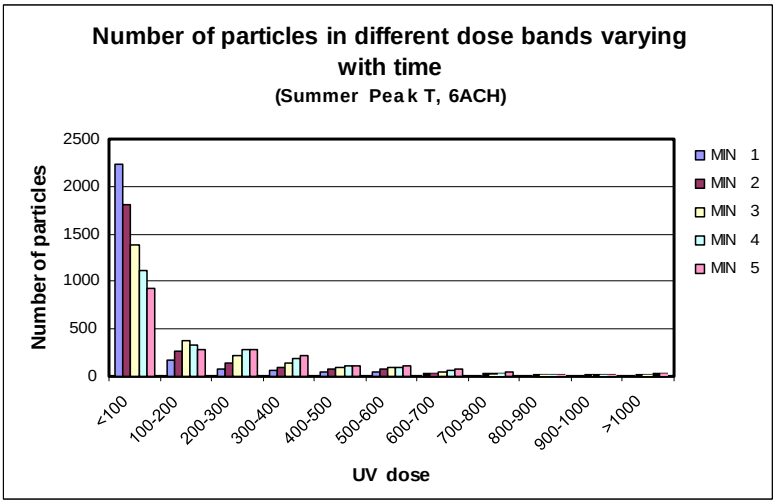


UV output of 20W, located at the wall near the bed

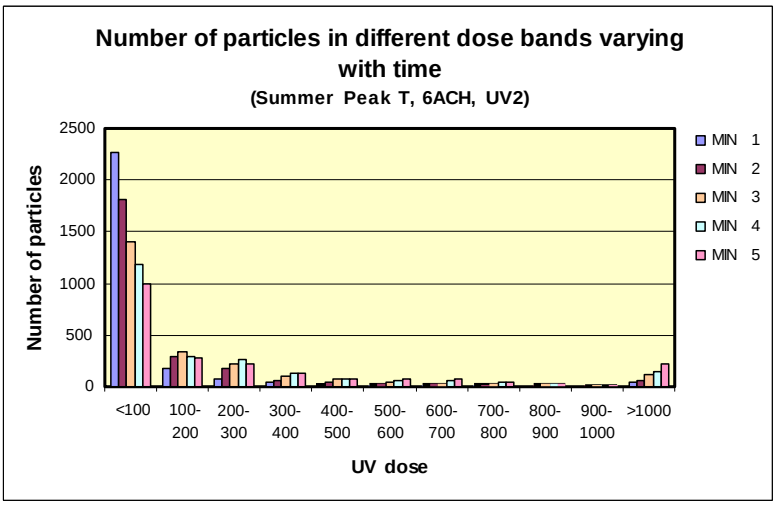


UV output of 40W, located at the wall near the bed

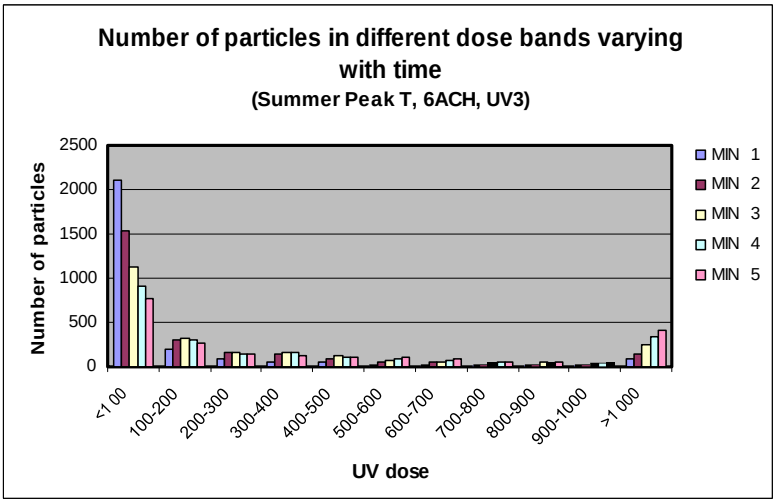
Case 4: Summer peak T, 6 ACH, low exhausts



UV output of 10W, located at partition wall

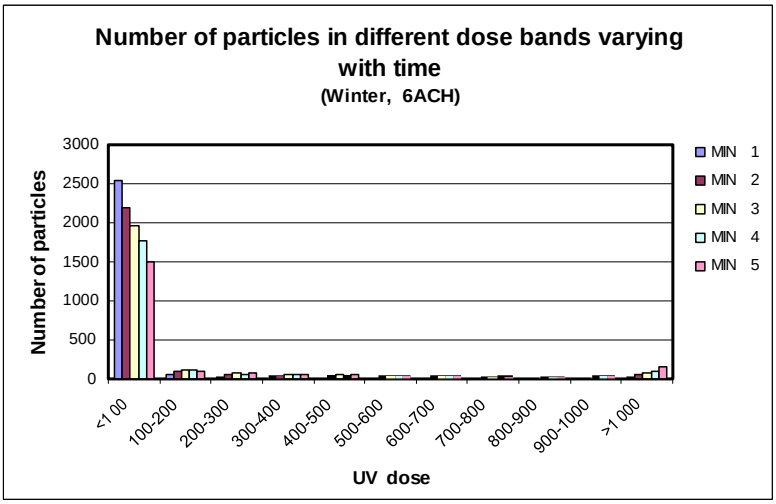


UV output of 20W, located at the wall near the bed

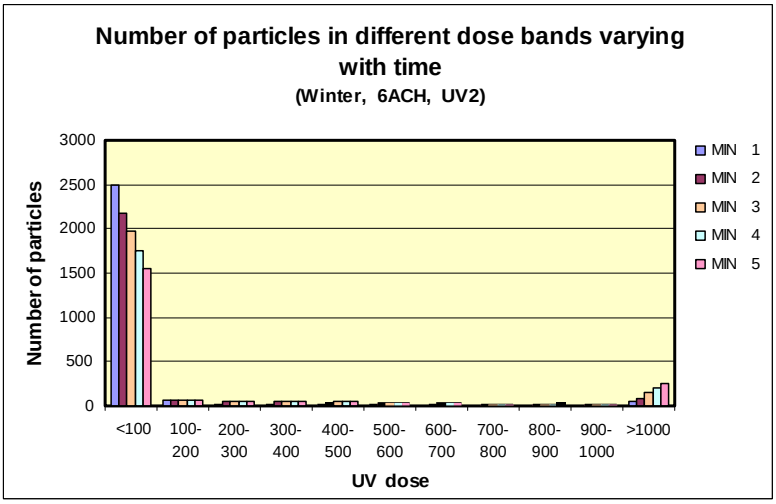


UV output of 40W, located at the wall near the bed

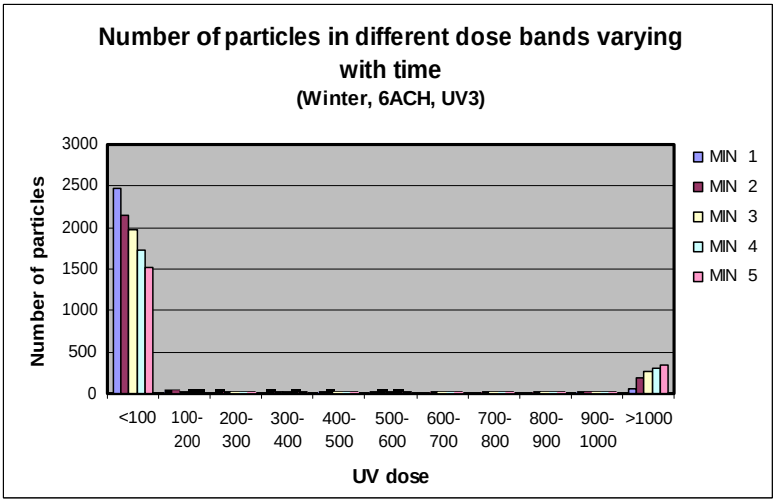
Case 5: Winter, 6 ACH, low exhausts



UV output of 10W, located at partition wall

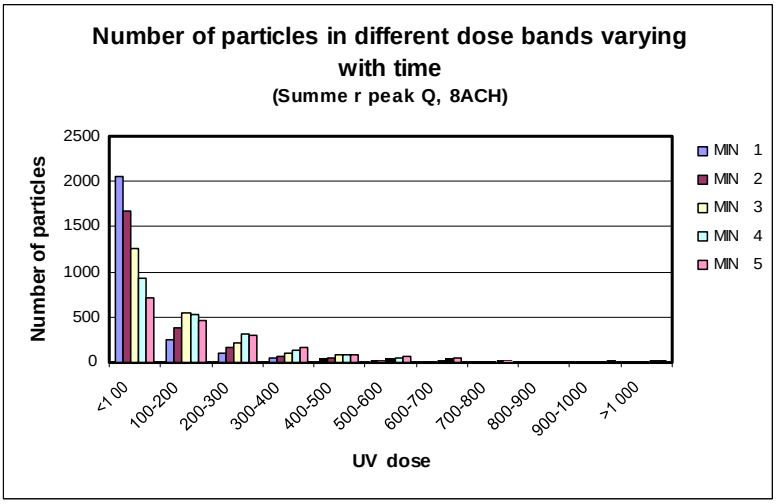


UV output of 20W, located at the wall near the bed

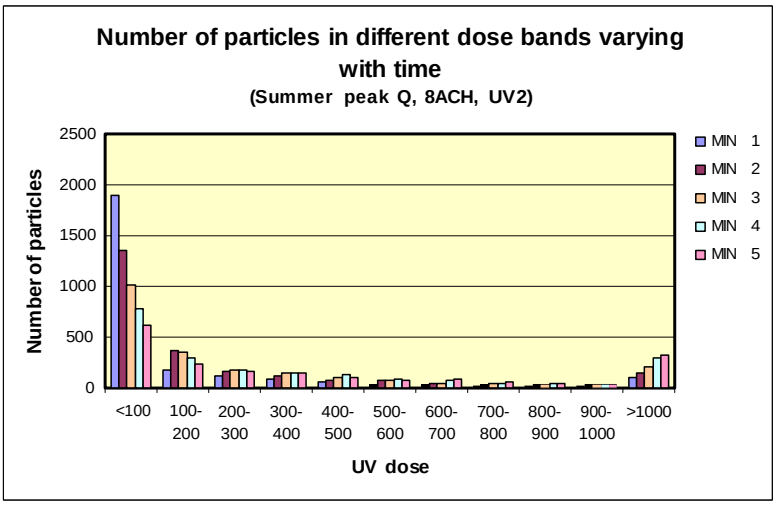


UV output of 40W, located at the wall near the bed

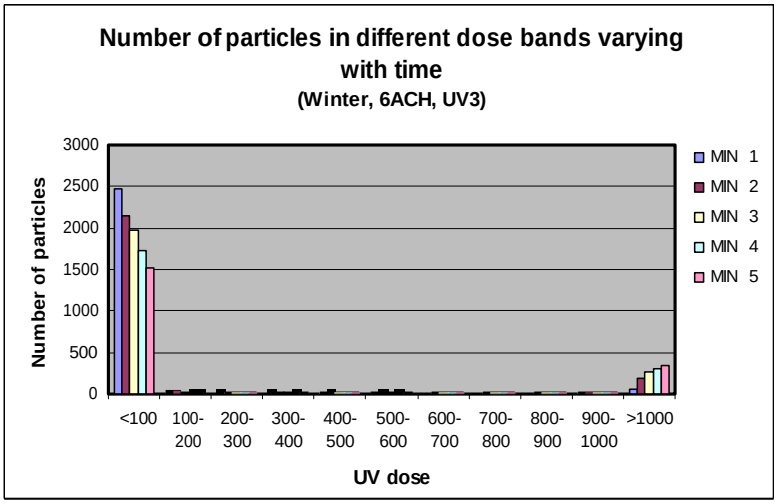
Case 6: Summer peak Q, 8 ACH, low exhausts



UV output of 10W, located at partition wall

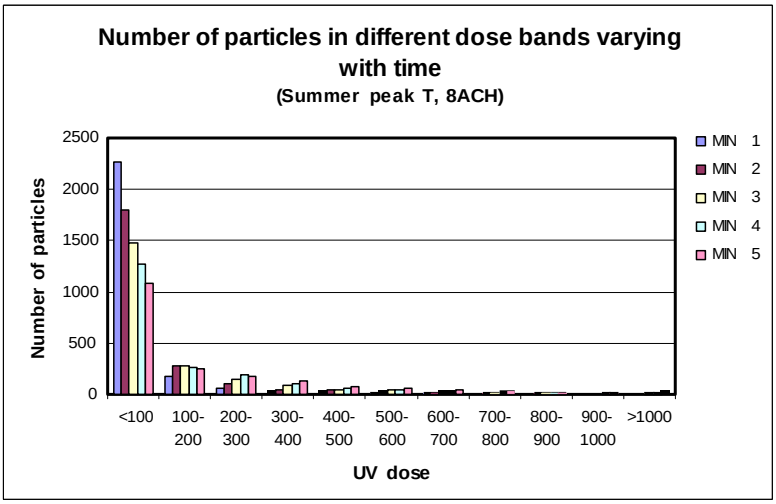


UV output of 20W, located at the wall near the bed

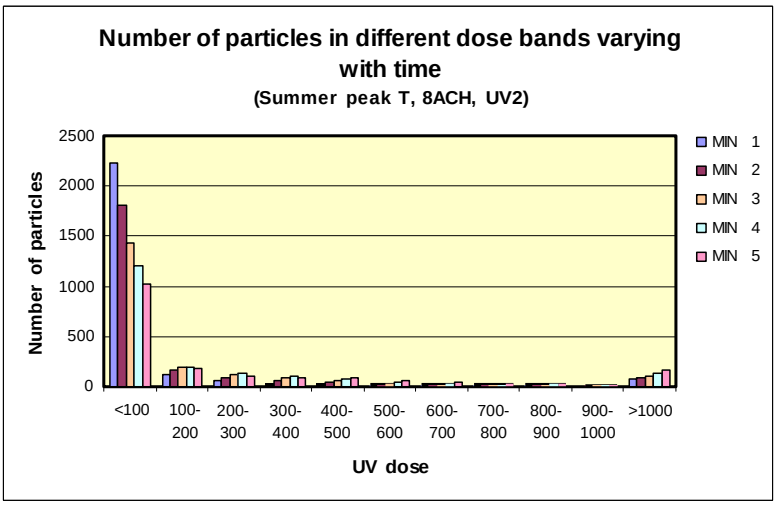


UV output of 40W, located at the wall near the bed

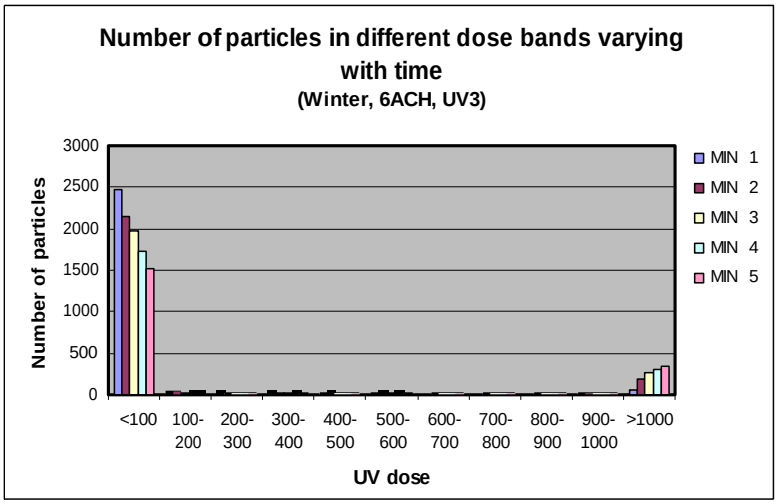
Case 7: Summer peak T, 8 ACH, low exhausts



UV output of 10W, located at partition wall

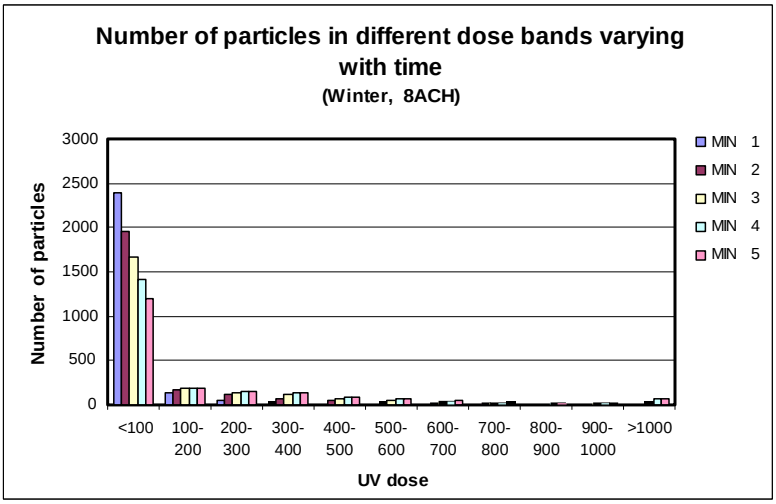


UV output of 20W, located at the wall near the bed

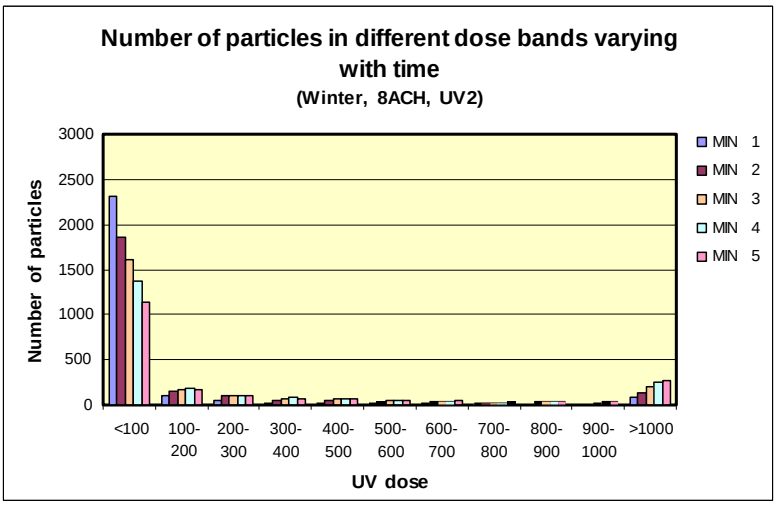


UV output of 40W, located at the wall near the bed

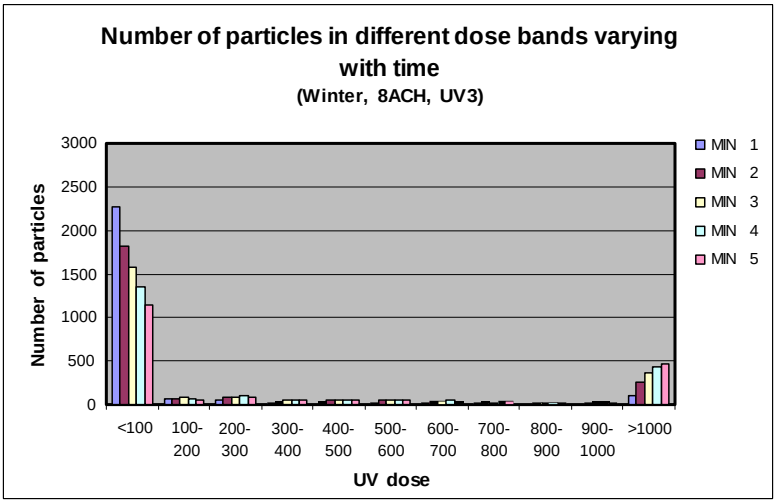
Case 8: Winter, 8 ACH, low exhausts



UV output of 10W, located at partition wall

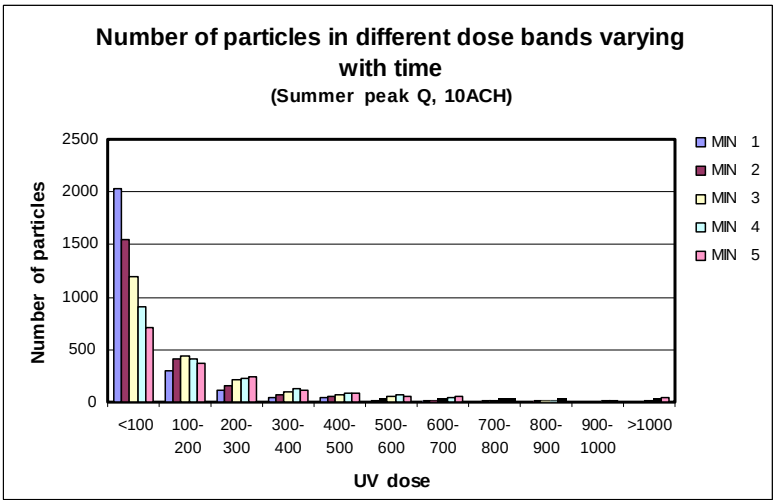


UV output of 20W, located at the wall near the bed

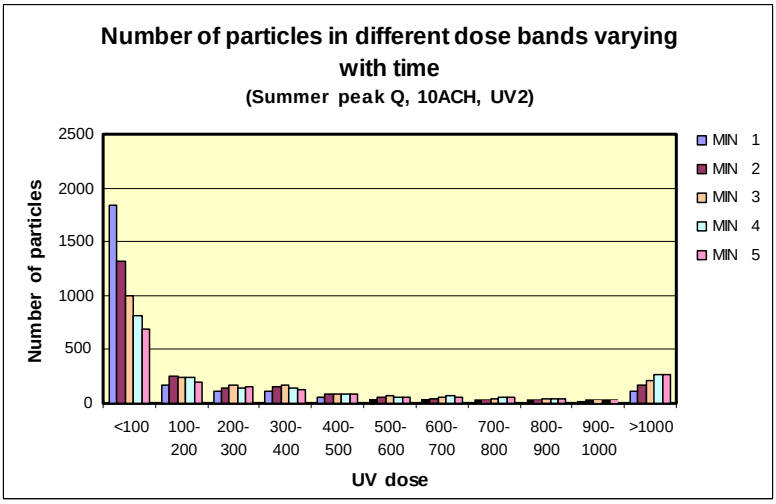


UV output of 40W, located at the wall near the bed

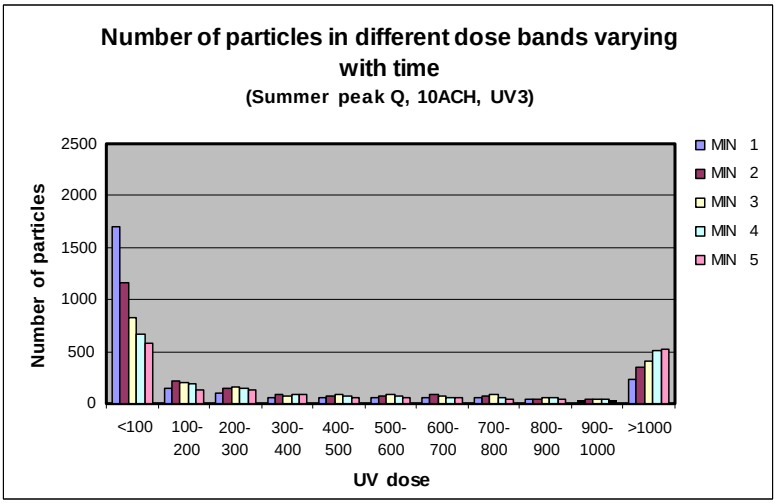
Case 9: Summer peak Q, 10 ACH, low exhausts



UV output of 10W, located at partition wall

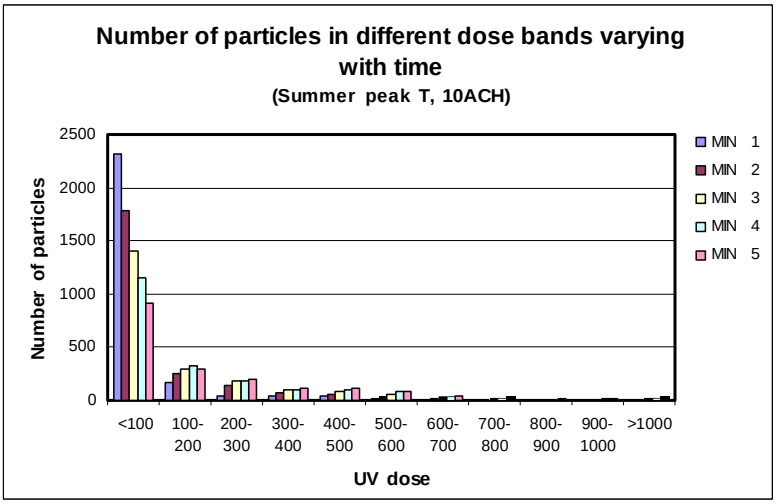


UV output of 20W, located at the wall near the bed

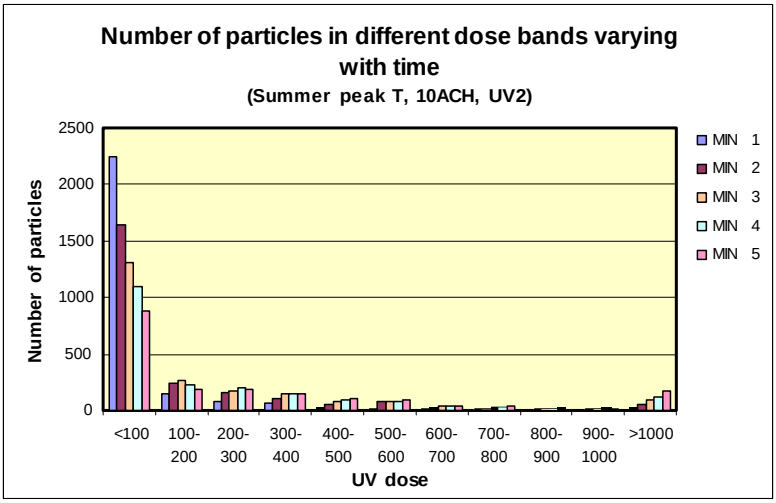


UV output of 40W, located at the wall near the bed

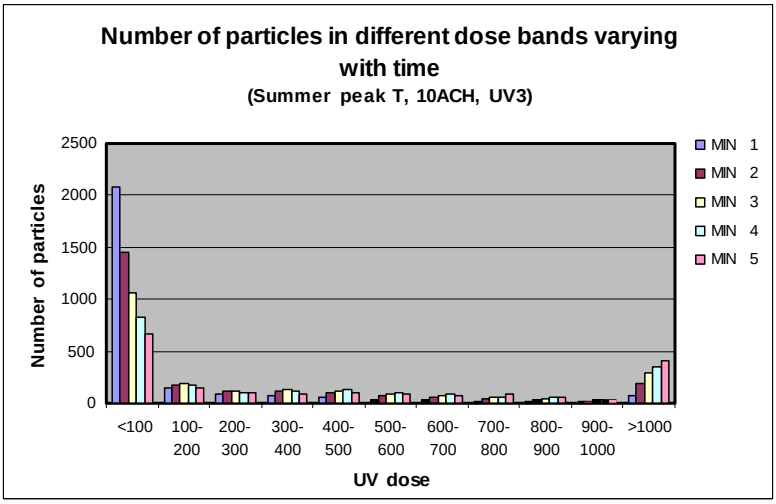
Case 10: Summer peak T, 10 ACH, low exhausts



UV output of 10W, located at partition wall

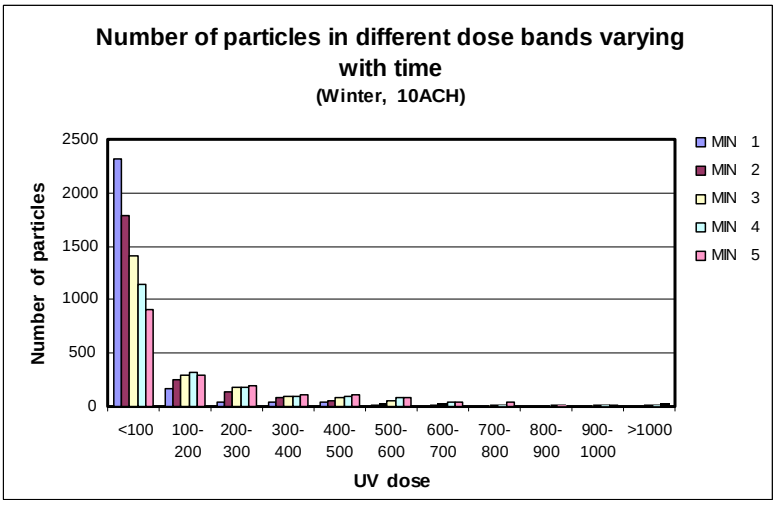


UV output of 20W, located at the wall near the bed

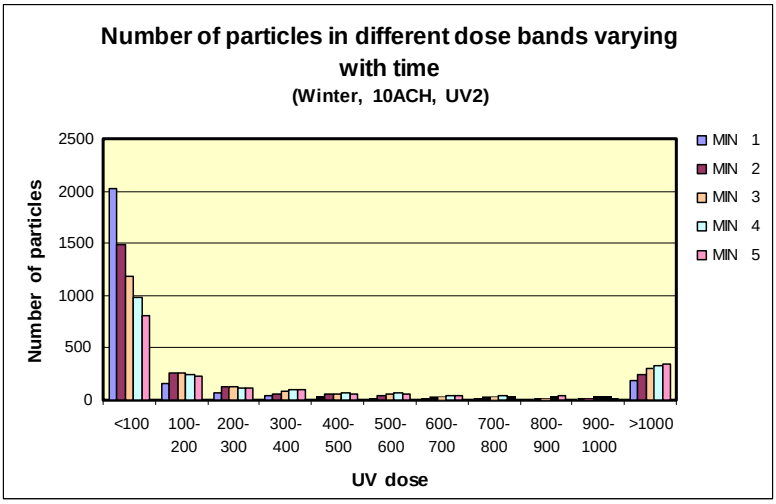


UV output of 40W, located at the wall near the bed

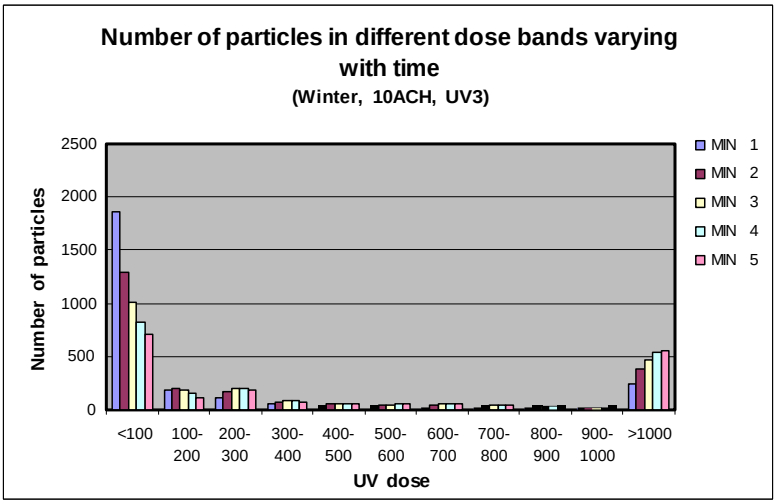
Case 11: Winter, 10 ACH, low exhausts



UV output of 10W, located at partition wall

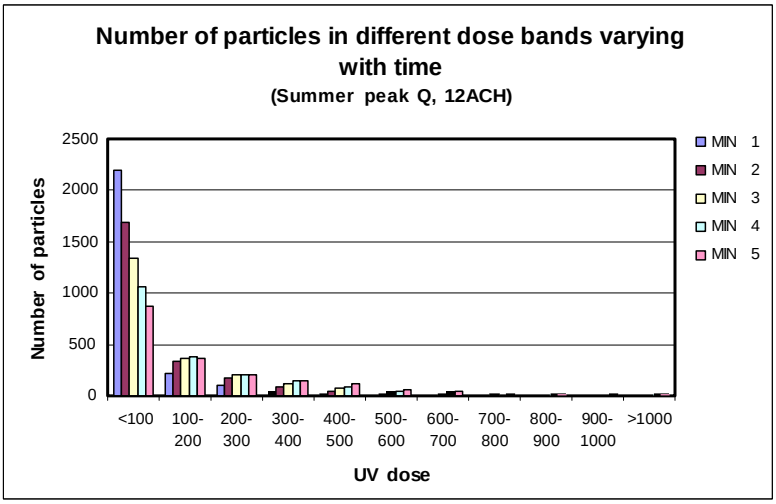


UV output of 20W, located at the wall near the bed

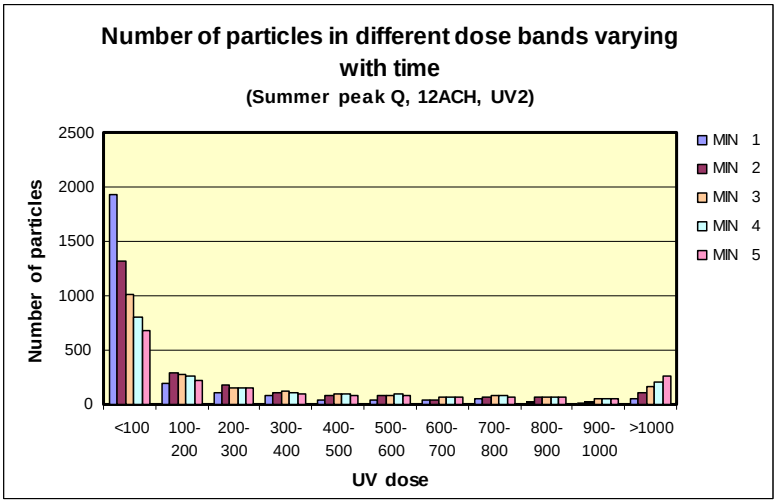


UV output of 40W, located at the wall near the bed

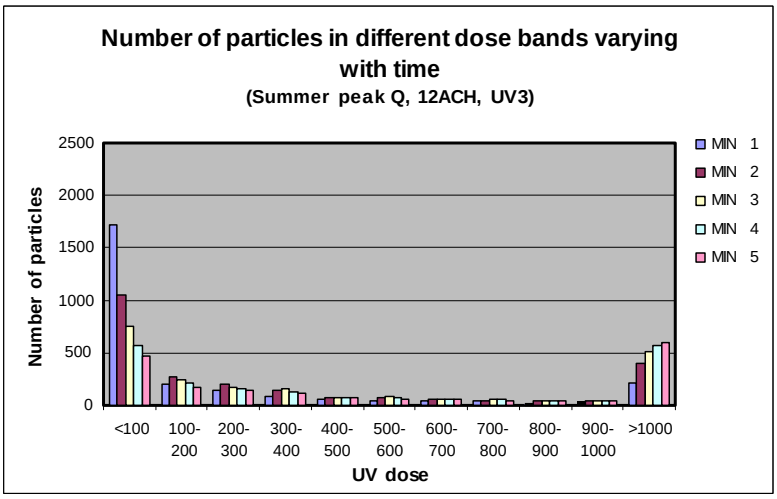
Case 12: Summer peak Q, 12 ACH, low exhausts



UV output of 10W, located at partition wall

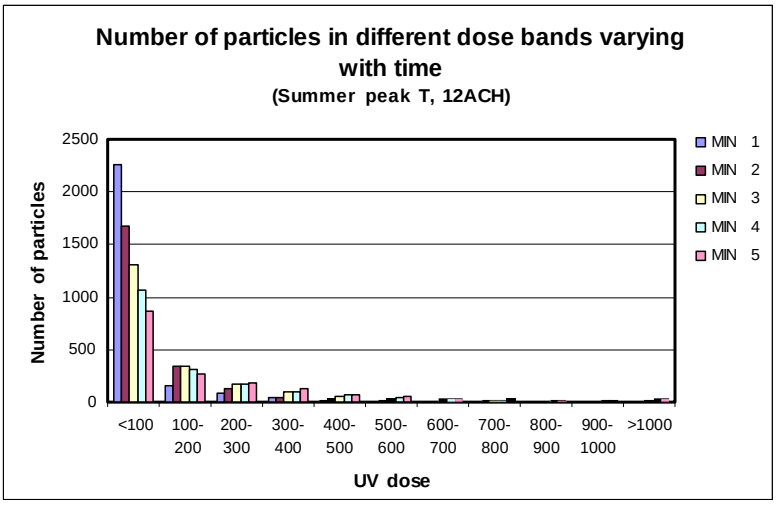


UV output of 20W, located at the wall near the bed

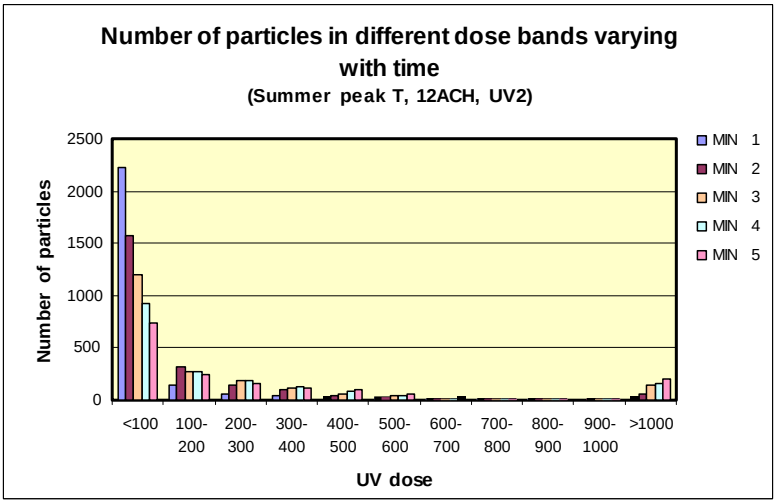


UV output of 40W, located at the wall near the bed

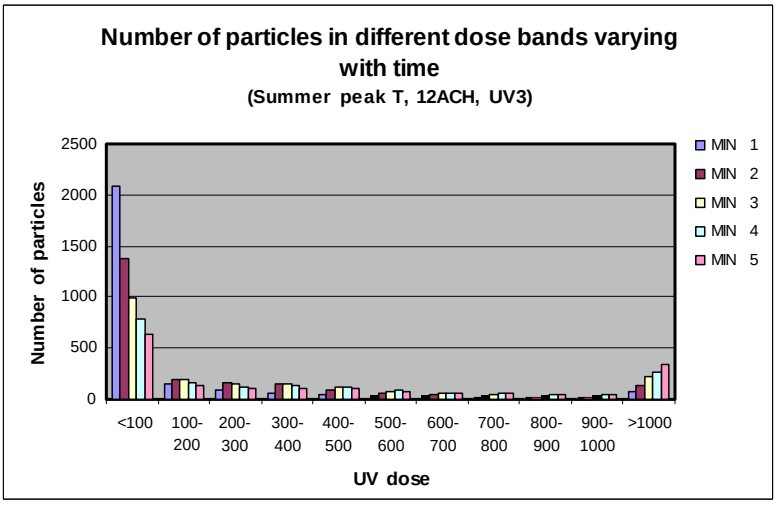
Case 13: Summer peak T, 12 ACH, low exhausts



UV output of 10W, located at partition wall

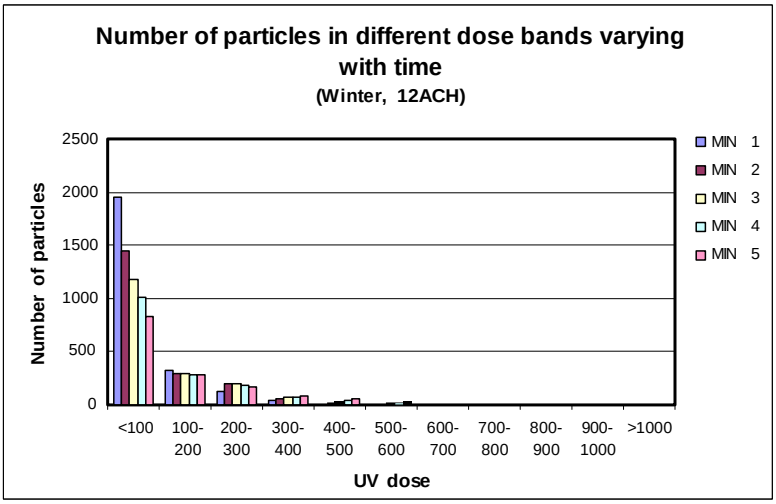


UV output of 20W, located at the wall near the bed

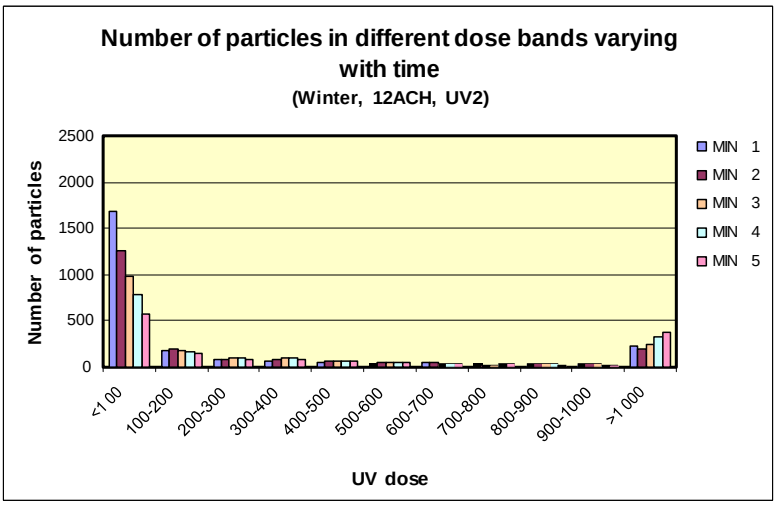


UV output of 40W, located at the wall near the bed

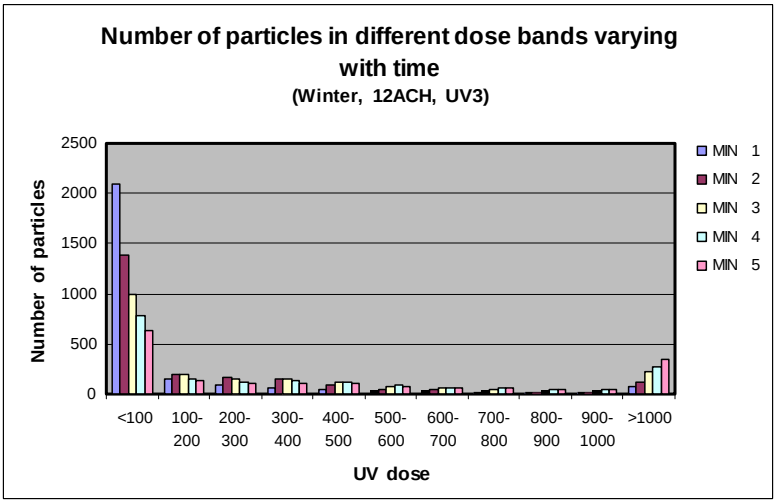
Case 14: Winter, 12 ACH, low exhausts



UV output of 10W, located at partition wall

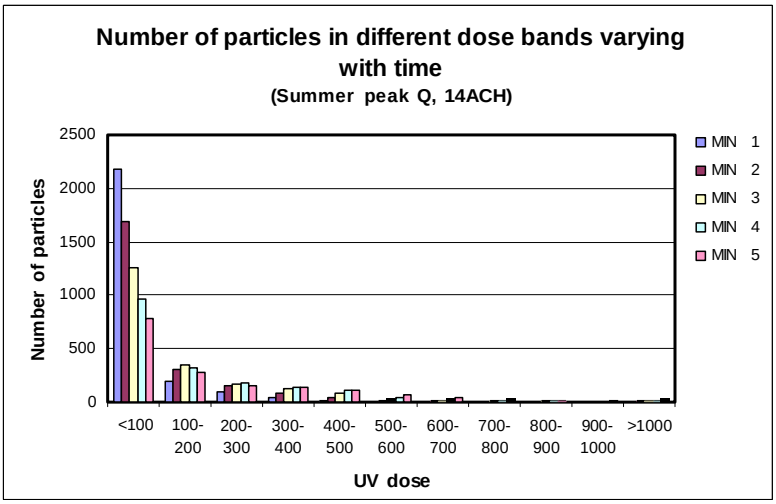


UV output of 20W, located at the wall near the bed

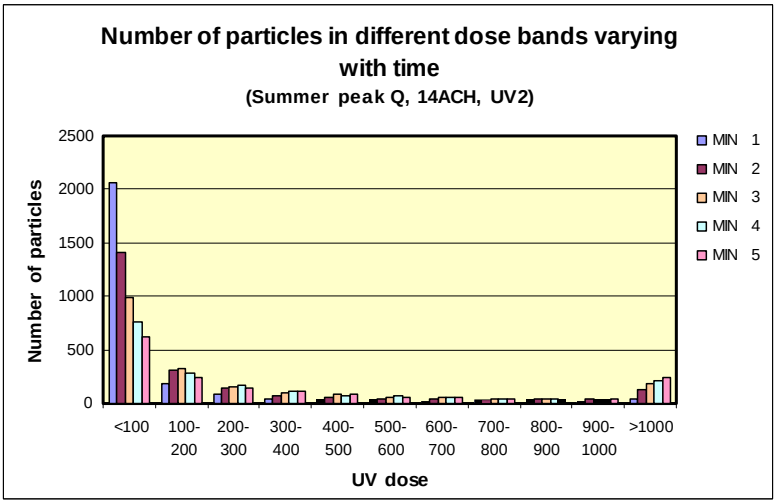


UV output of 40W, located at the wall near the bed

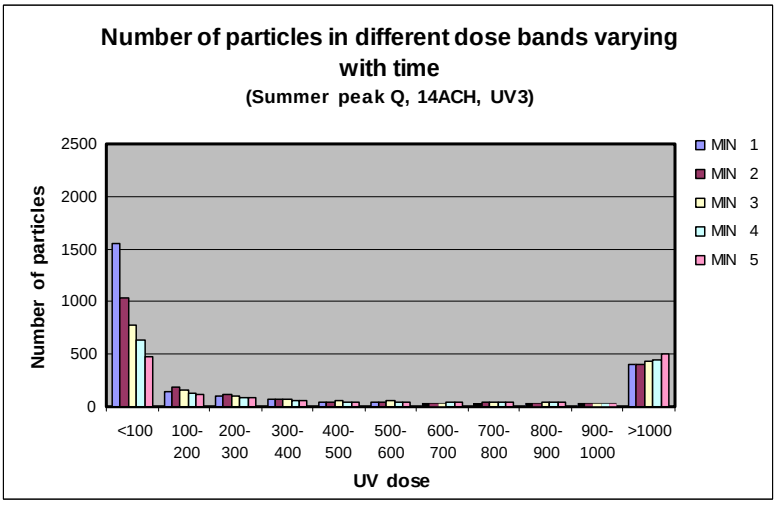
Case 15: Summer peak Q, 14 ACH, low exhausts



UV output of 10W, located at partition wall

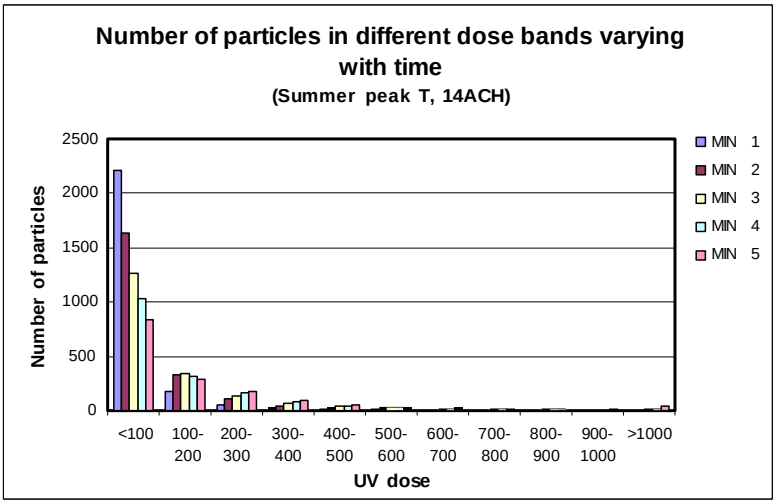


UV output of 20W, located at the wall near the bed

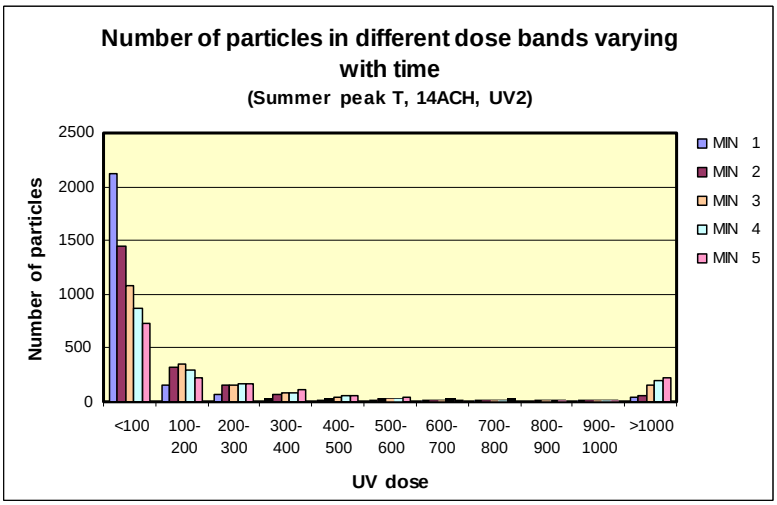


UV output of 40W, located at the wall near the bed

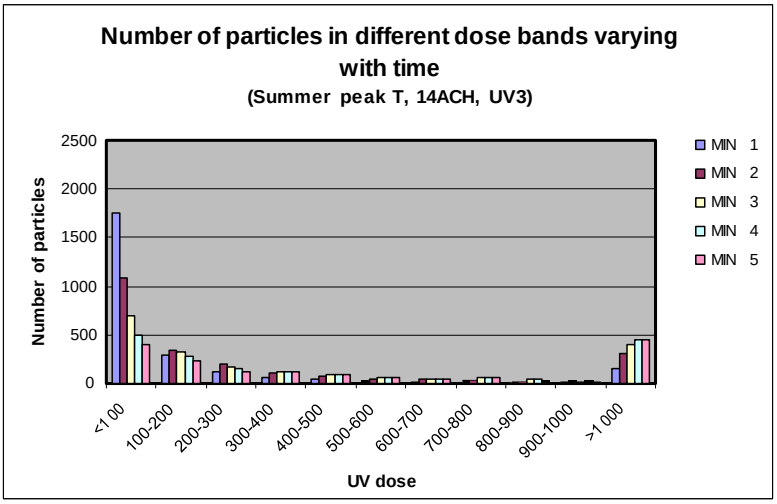
Case 16: Summer peak T, 14 ACH, low exhausts



UV output of 10W, located at partition wall

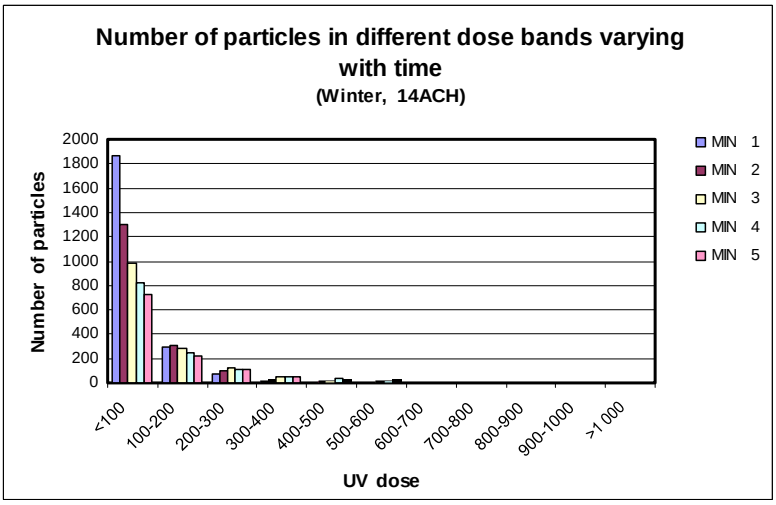


UV output of 20W, located at the wall near the bed

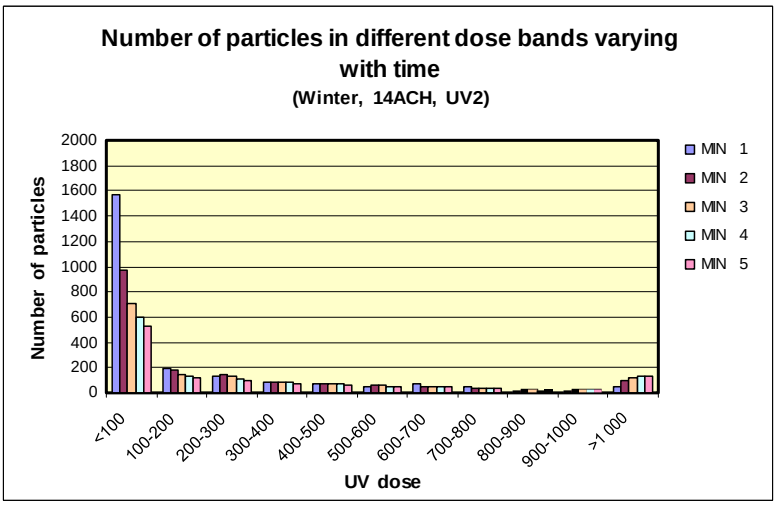


UV output of 40W, located at the wall near the bed

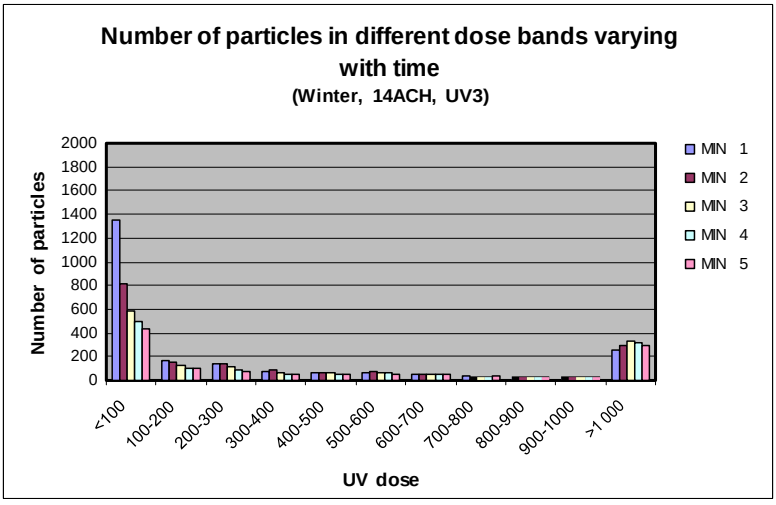
Case 17: Winter, 14 ACH, low exhausts



UV output of 10W, located at partition wall

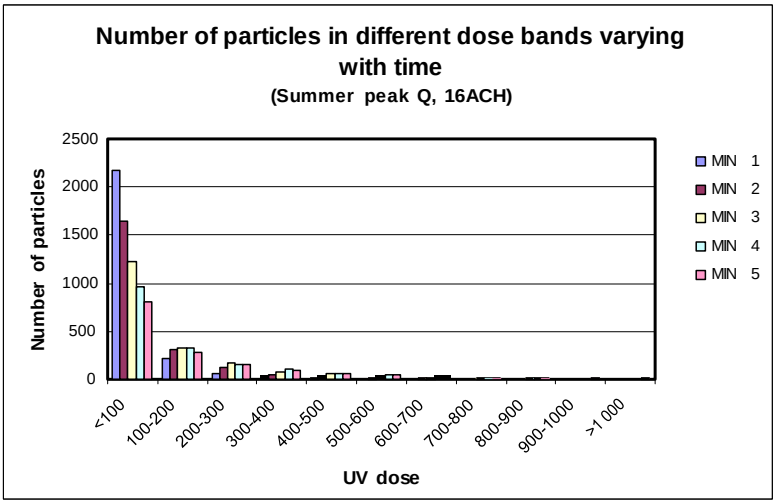


UV output of 20W, located at the wall near the bed

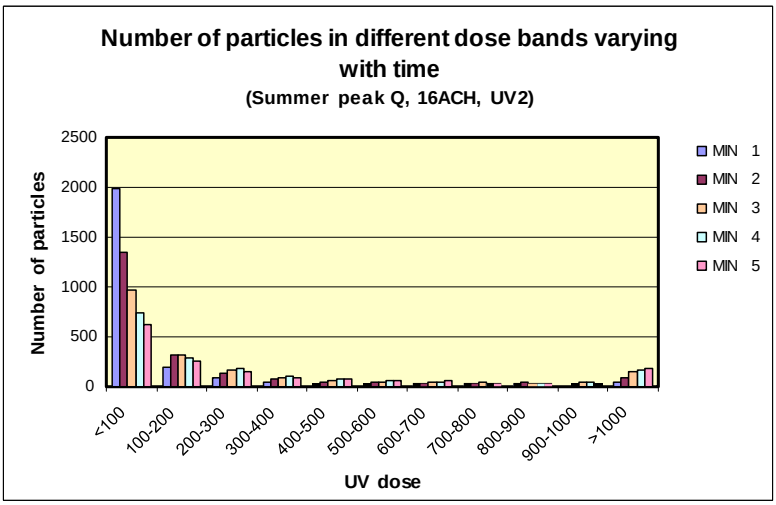


UV output of 40W, located at the wall near the bed

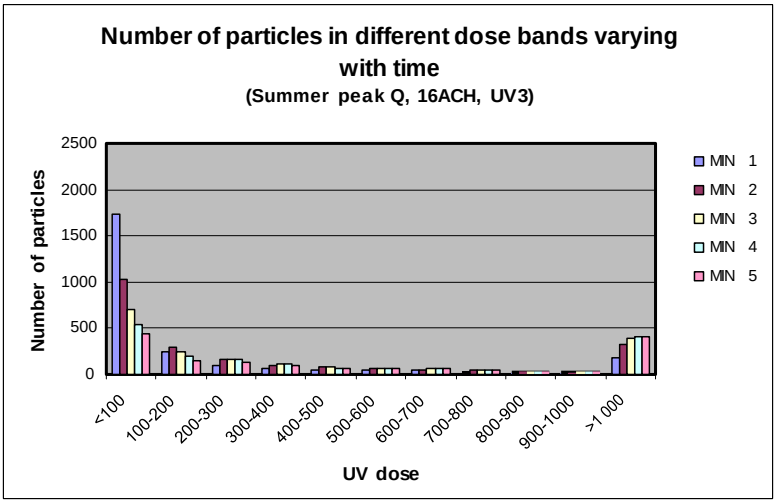
Case 18: Summer peak Q, 16 ACH, low exhausts



UV output of 10W, located at partition wall

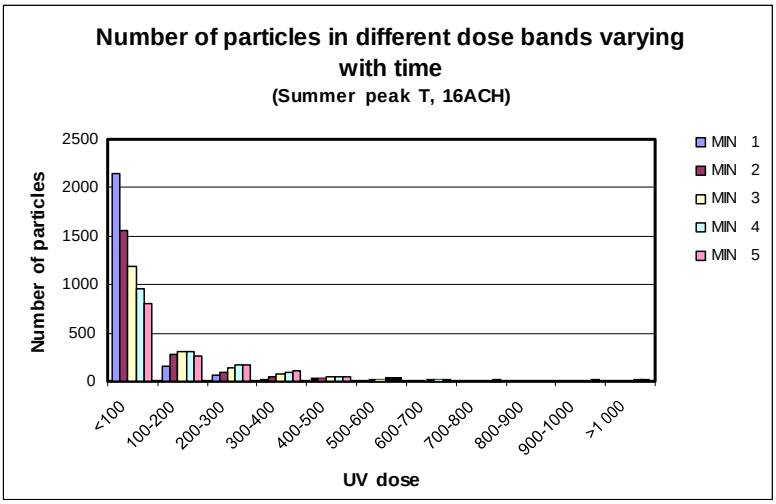


UV output of 20W, located at the wall near the bed

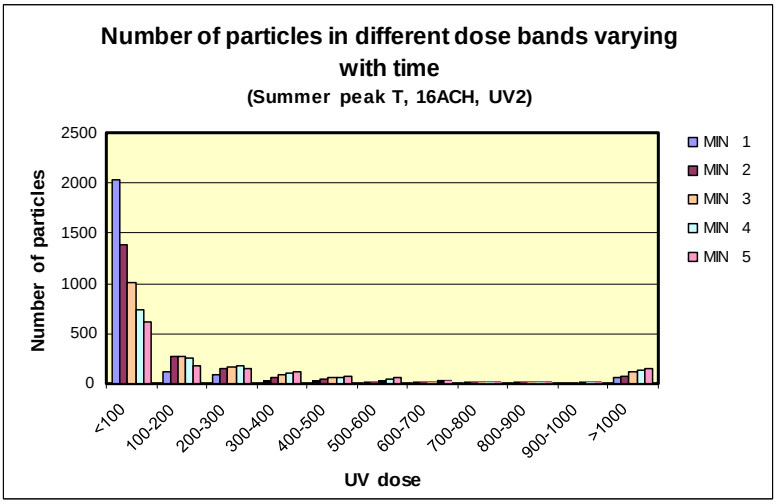


UV output of 40W, located at the wall near the bed

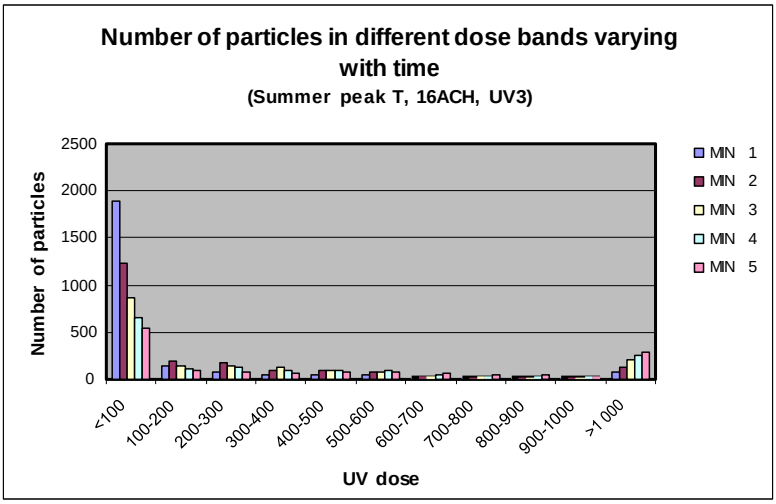
Case 19: Summer peak T, 16 ACH, low exhausts



UV output of 10W, located at partition wall

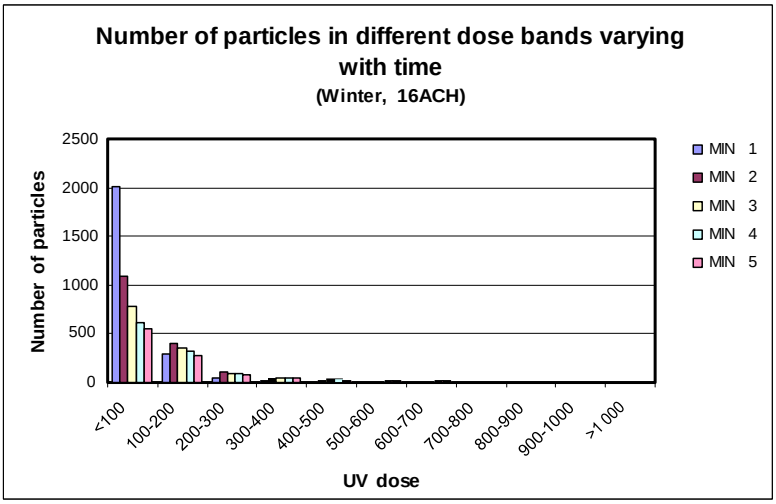


UV output of 20W, located at the wall near the bed

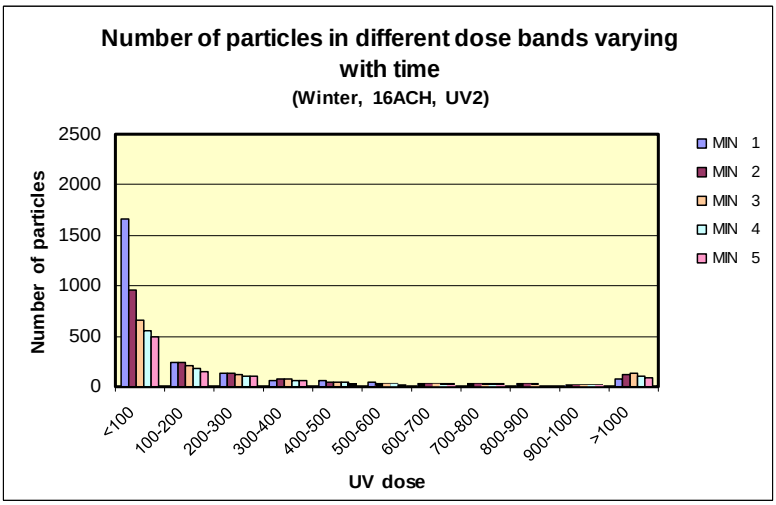


UV output of 40W, located at the wall near the bed

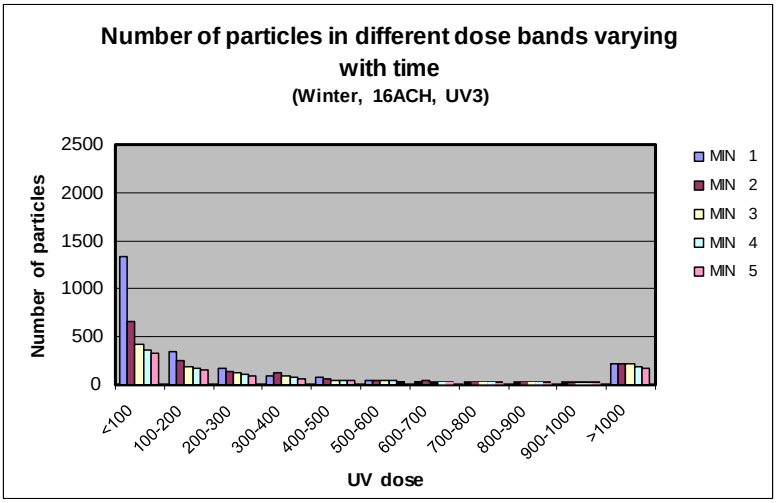
Case 20: Winter, 16 ACH, low exhausts



UV output of 10W, located at partition wall

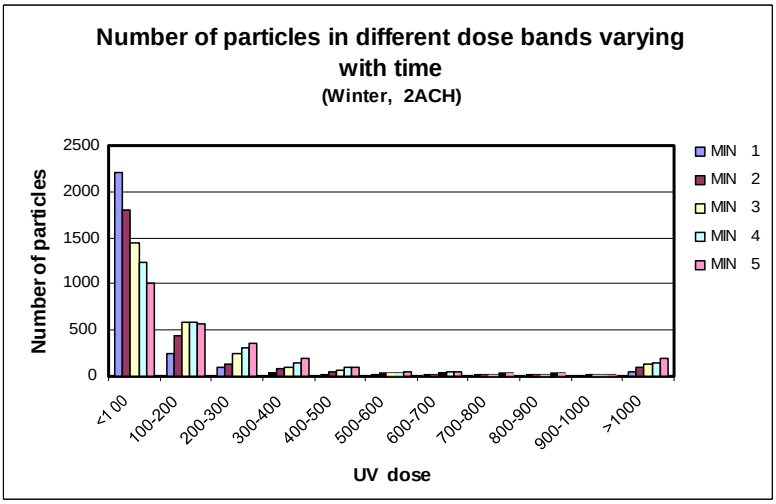


UV output of 20W, located at the wall near the bed

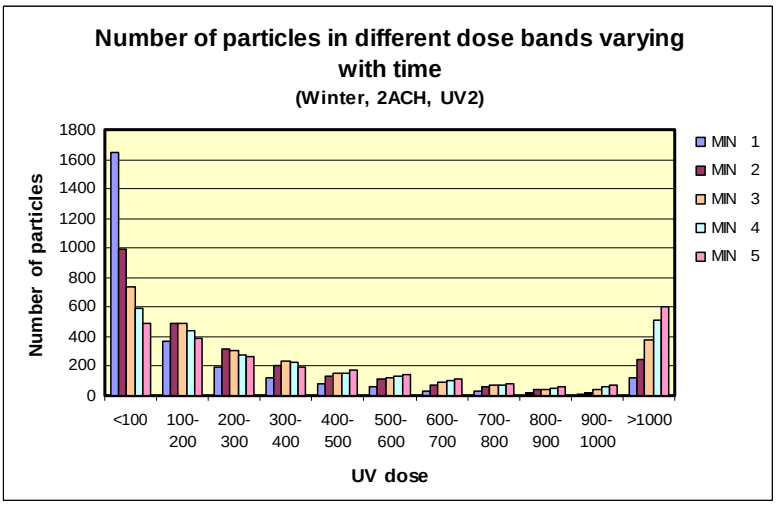


UV output of 40W, located at the wall near the bed

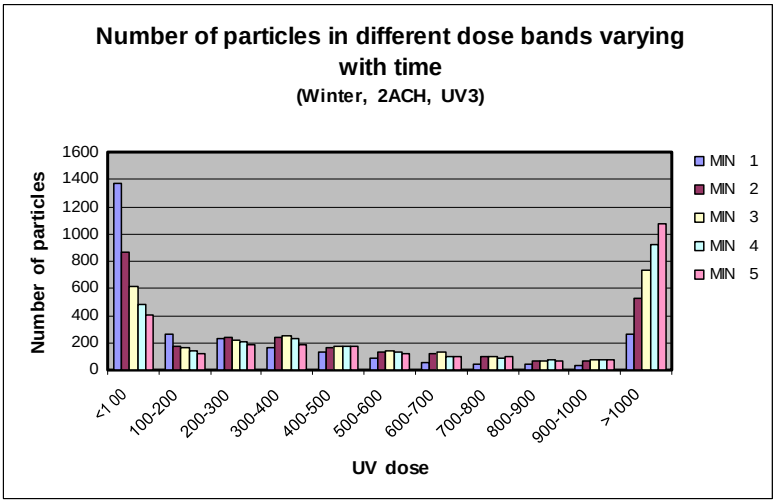
Case 21: Winter, 2 ACH, low exhausts with baseboard heating



UV output of 10W, located at partition wall

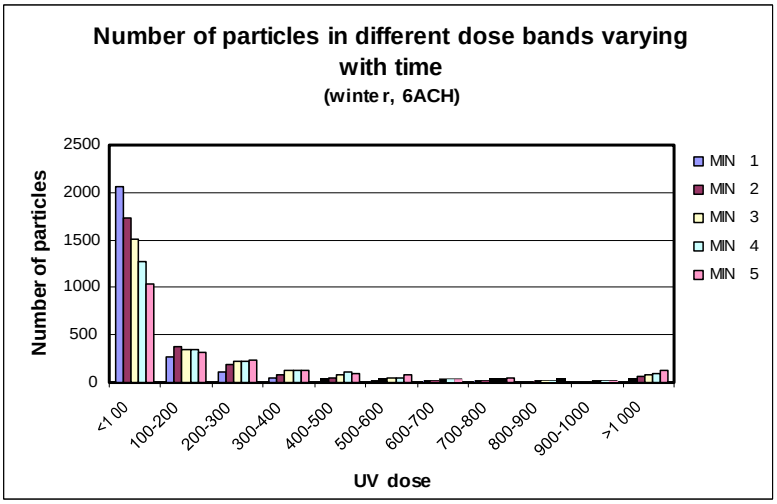


UV output of 20W, located at the wall near the bed

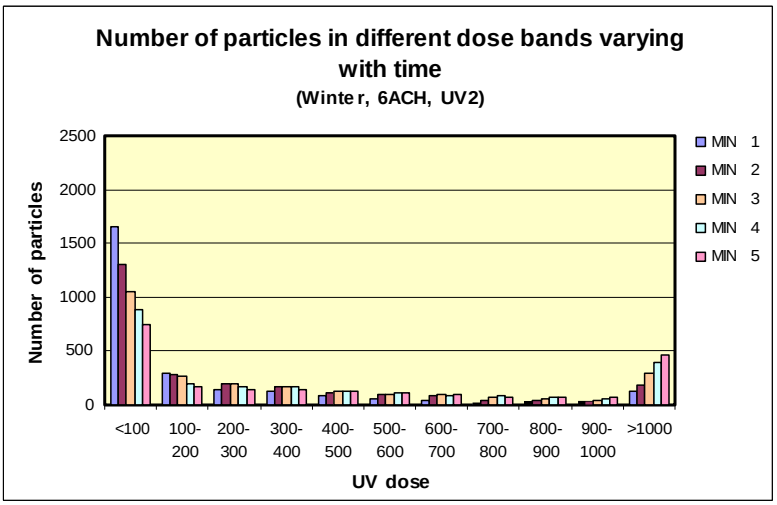


UV output of 40W, located at the wall near the bed

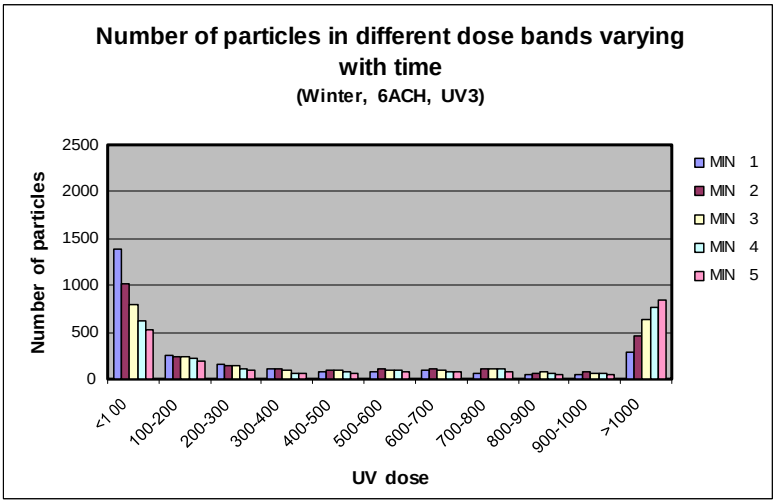
Case 22: Winter, 6 ACH, low exhausts with baseboard heating



UV output of 10W, located at partition wall

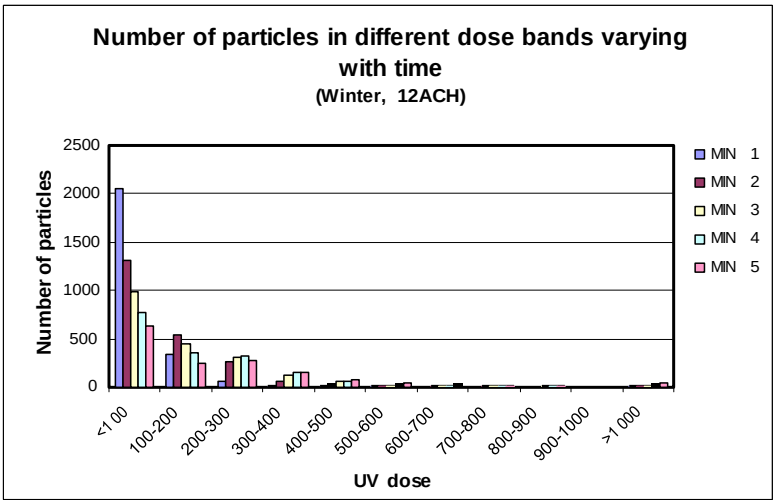


UV output of 20W, located at the wall near the bed

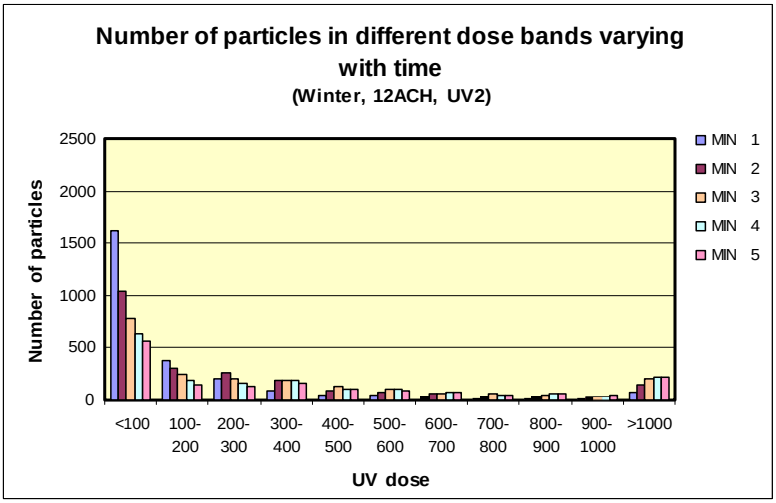


UV output of 40W, located at the wall near the bed

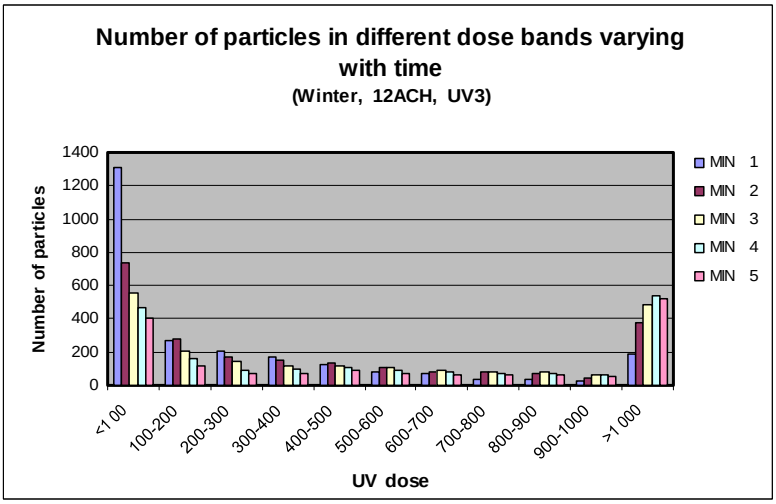
Case 23: Winter, 12 ACH, low exhausts with baseboard heating



UV output of 10W, located at partition wall

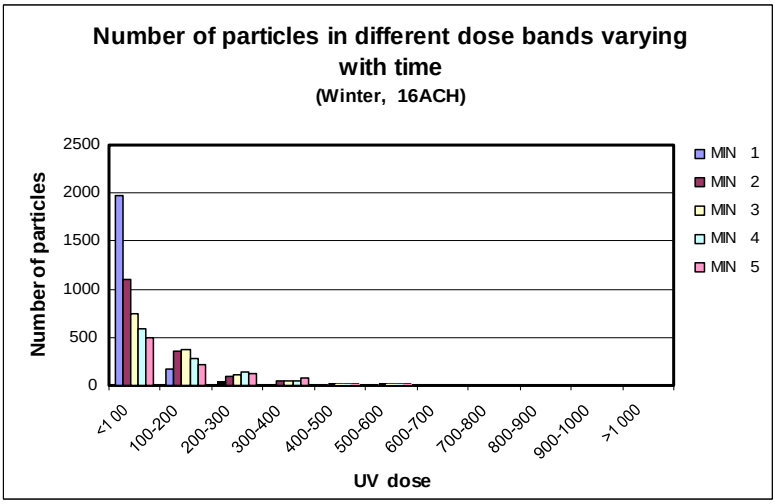


UV output of 20W, located at the wall near the bed

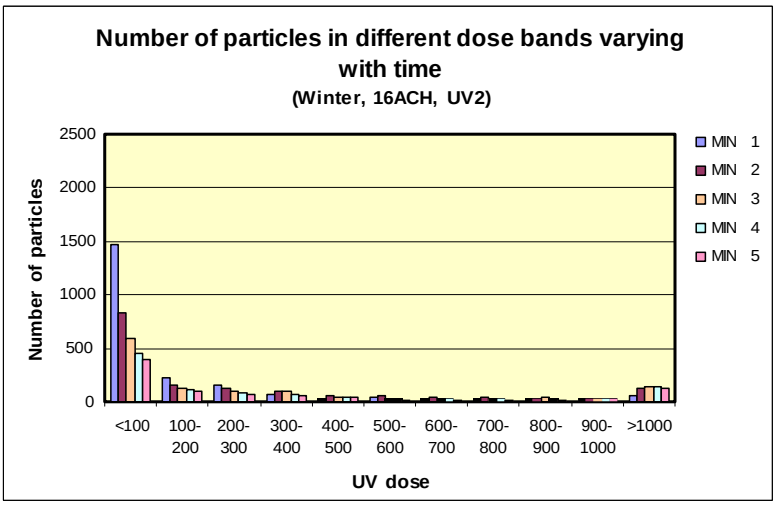


UV output of 40W, located at the wall near the bed

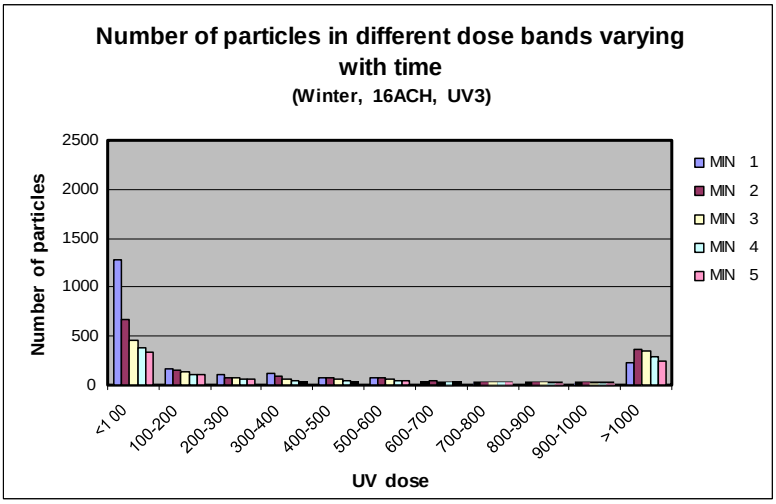
Case 24: Winter, 16 ACH, low exhausts with baseboard heating



UV output of 10W, located at partition wall

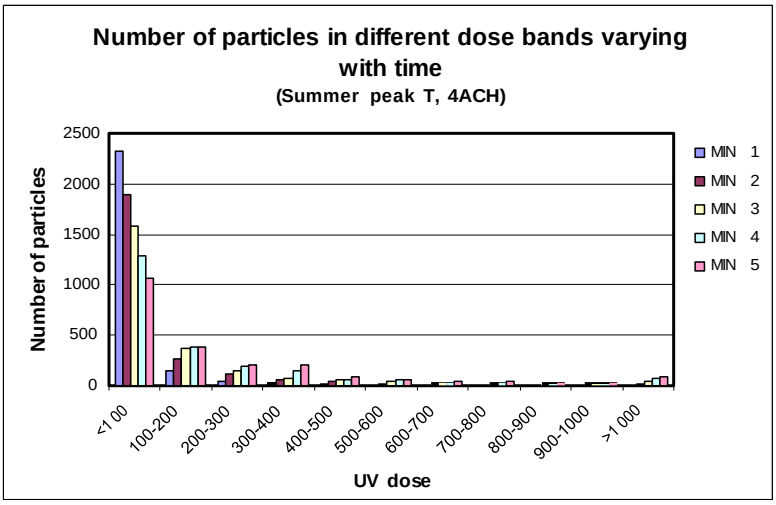


UV output of 20W, located at the wall near the bed

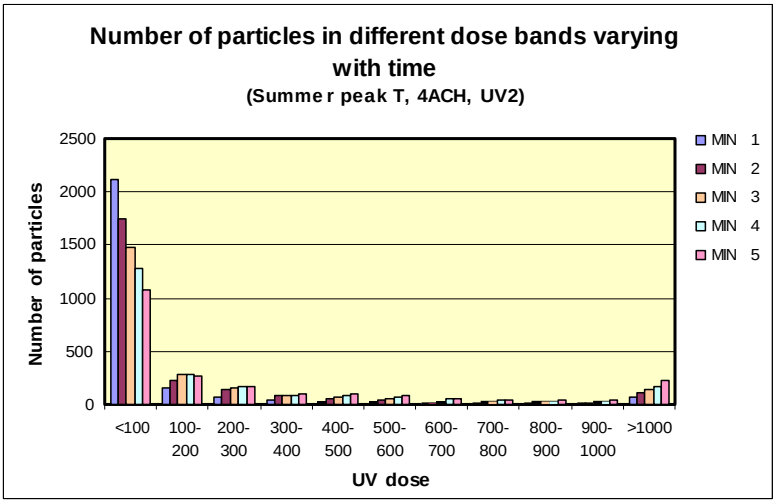


UV output of 40W, located at the wall near the bed

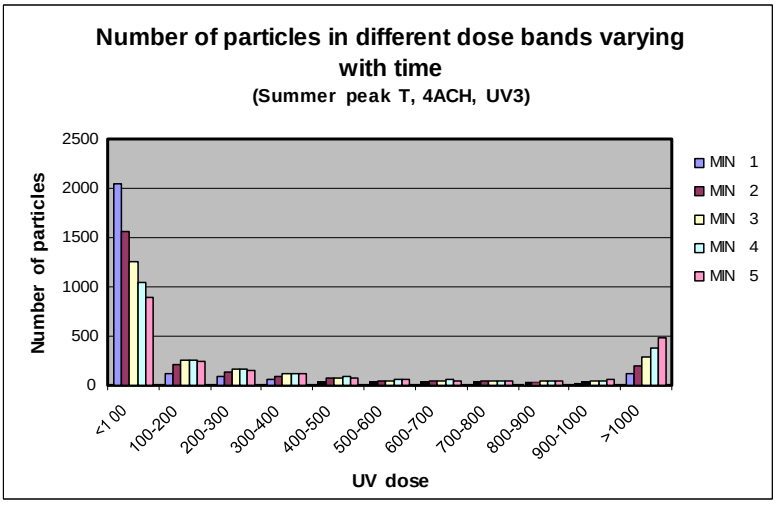
Case 25: Summer peak T, 4 ACH, high exhausts without baseboard heating



UV output of 10W, located at partition wall

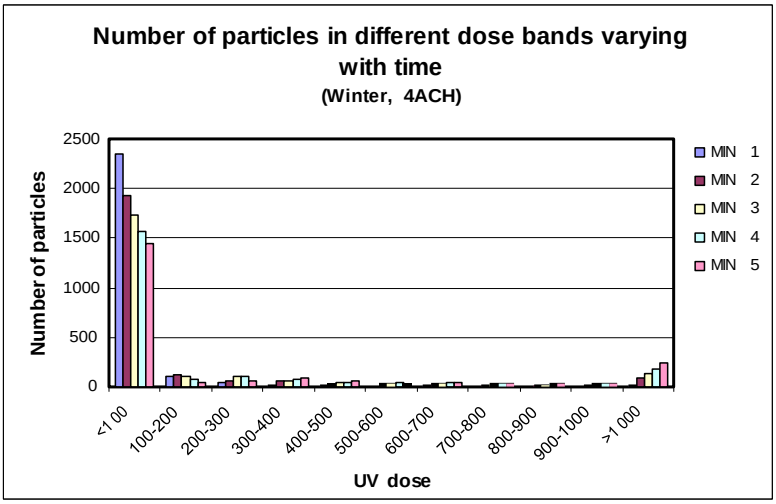


UV output of 20W, located at the wall near the bed

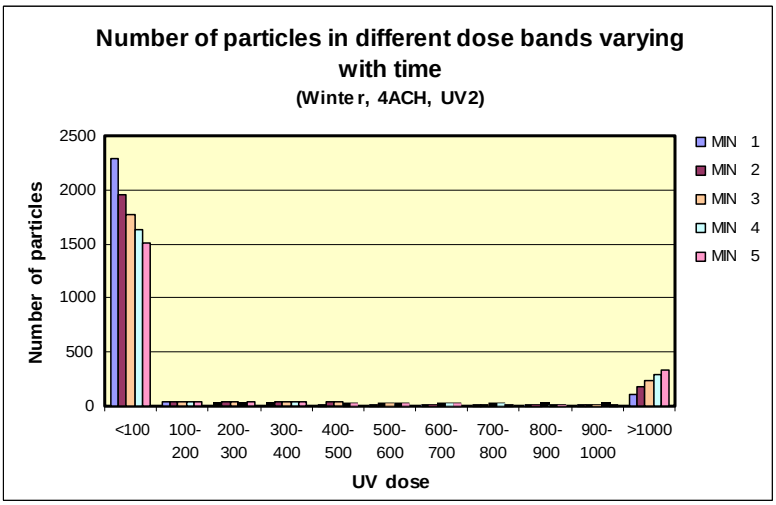


UV output of 40W, located at the wall near the bed

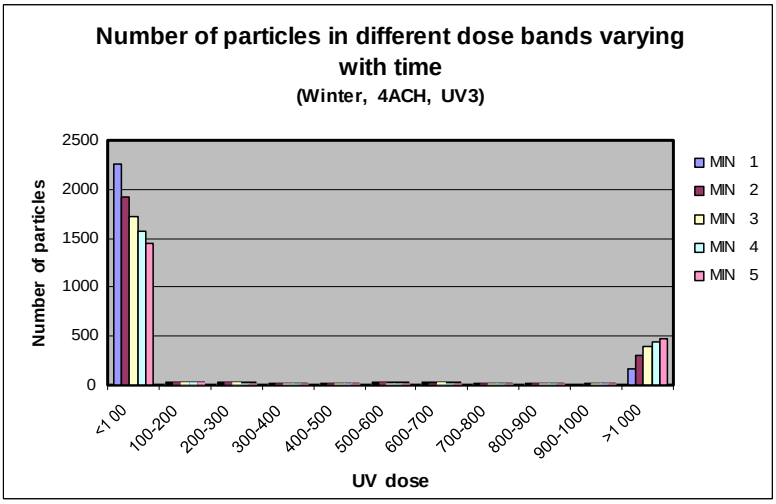
Case 26: Winter, 4 ACH, high exhausts without baseboard heating



UV output of 10W, located at partition wall

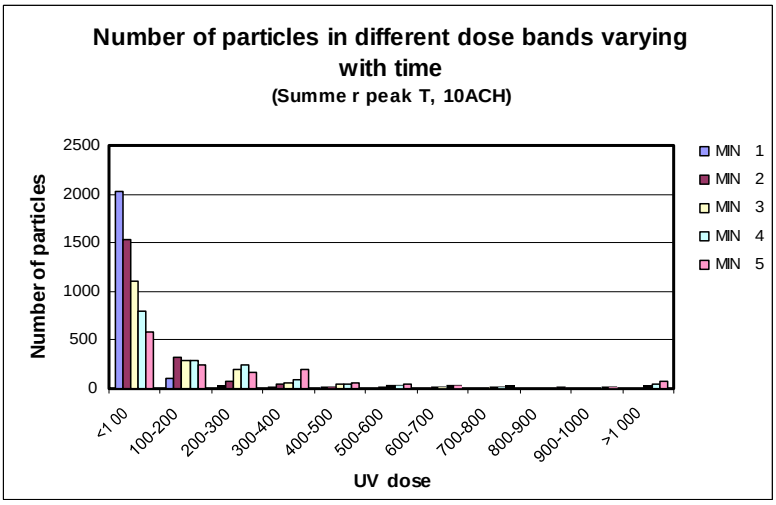


UV output of 20W, located at the wall near the bed

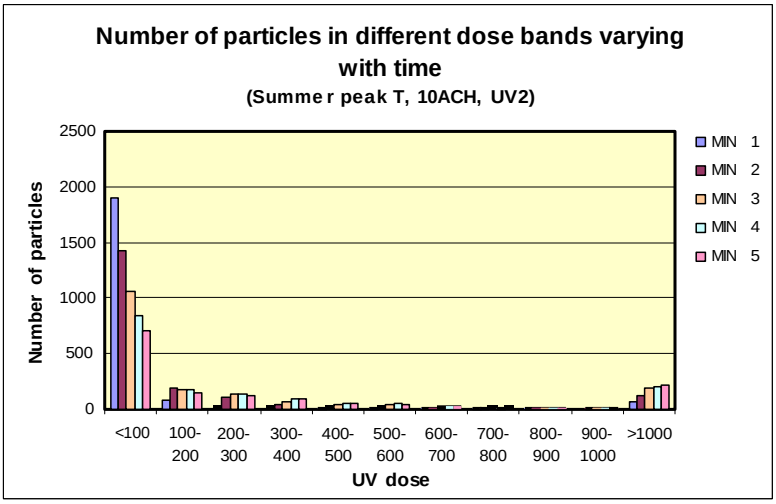


UV output of 40W, located at the wall near the bed

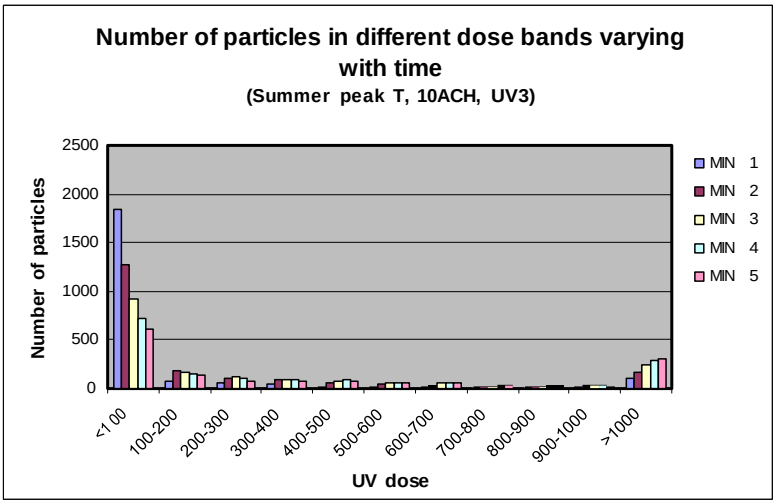
Case 27: Summer peak T, 10 ACH, high exhausts without baseboard heating



UV output of 10W, located at partition wall

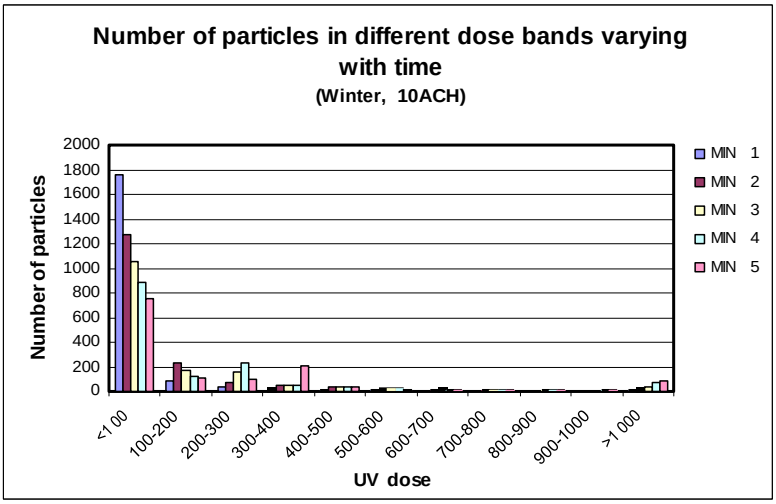


UV output of 20W, located at the wall near the bed

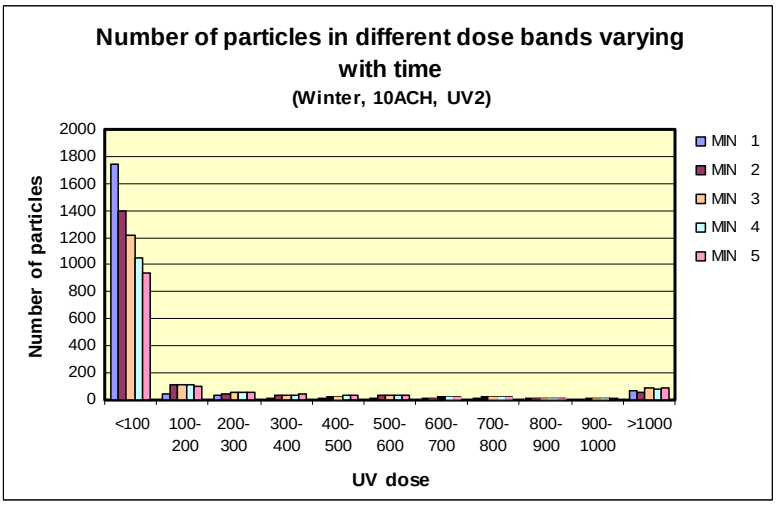


UV output of 40W, located at the wall near the bed

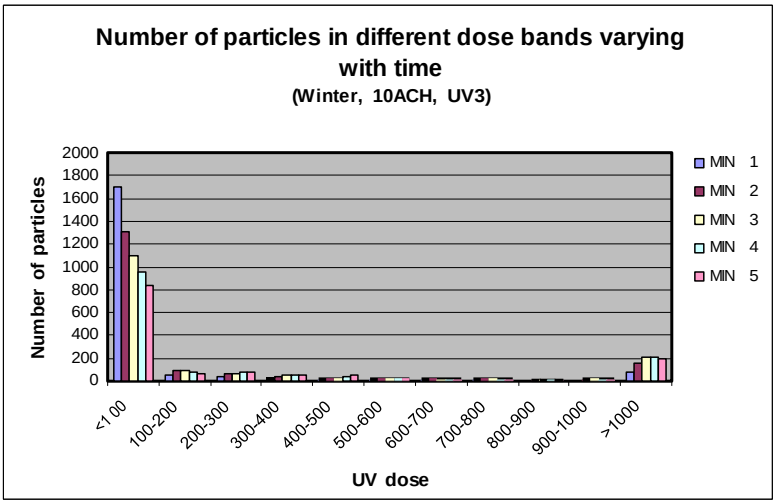
Case 28: Winter, 10 ACH, high exhausts without baseboard heating



UV output of 10W, located at partition wall

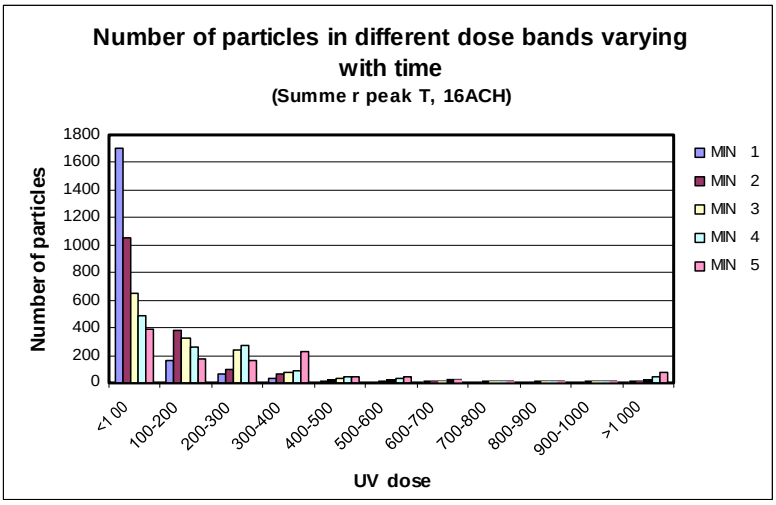


UV output of 20W, located at the wall near the bed

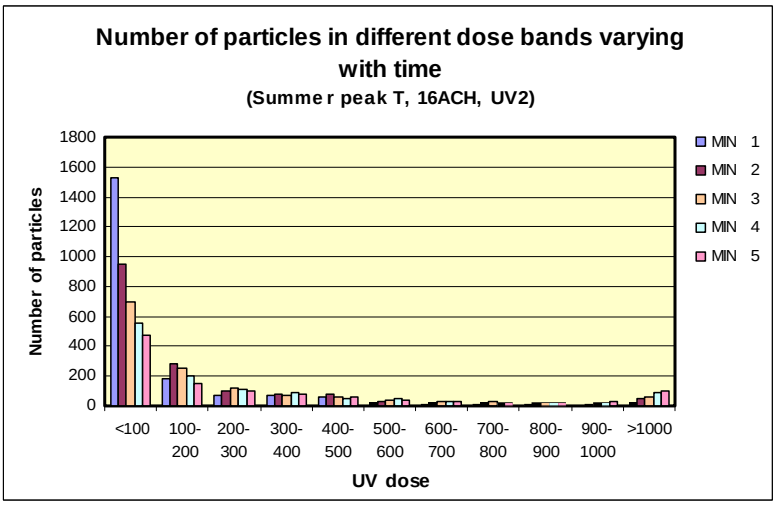


UV output of 40W, located at the wall near the bed

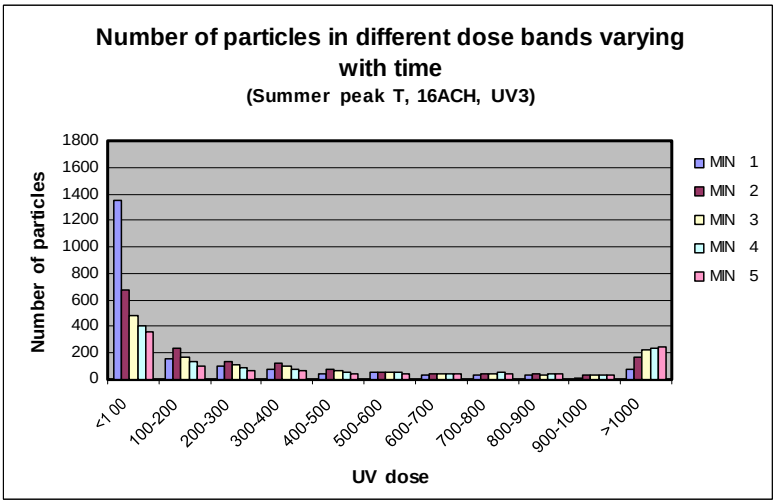
Case 29: Summer peak T, 16 ACH, high exhausts without baseboard heating



UV output of 10W, located at partition wall

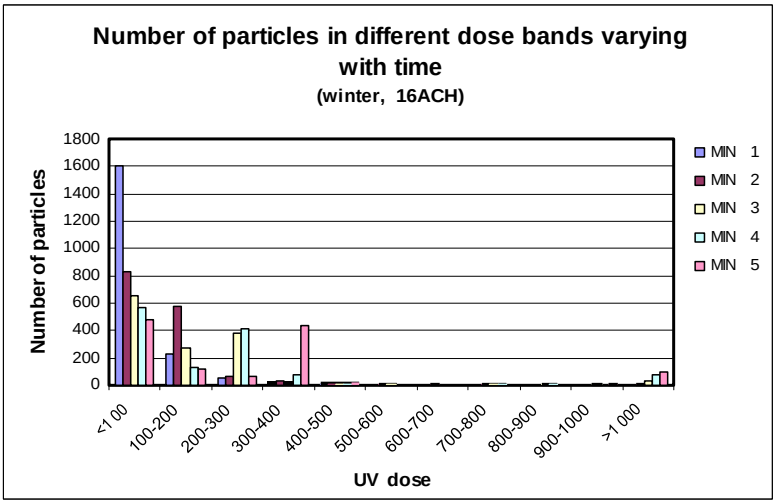


UV output of 20W, located at the wall near the bed

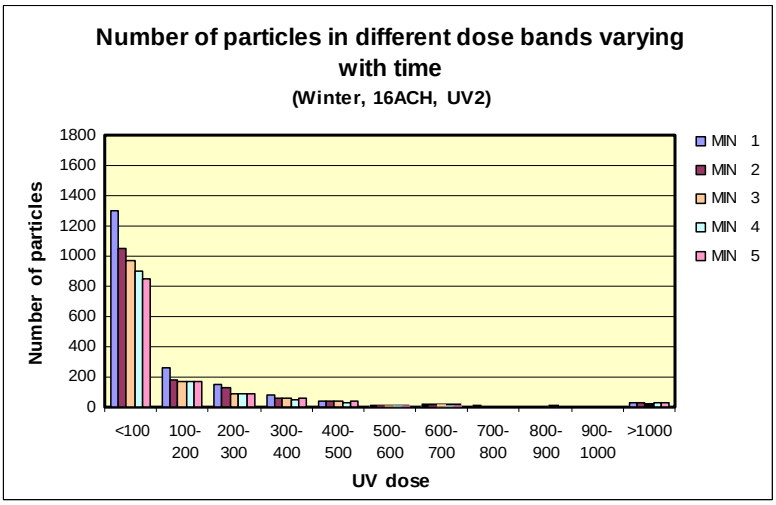


UV output of 40W, located at the wall near the bed

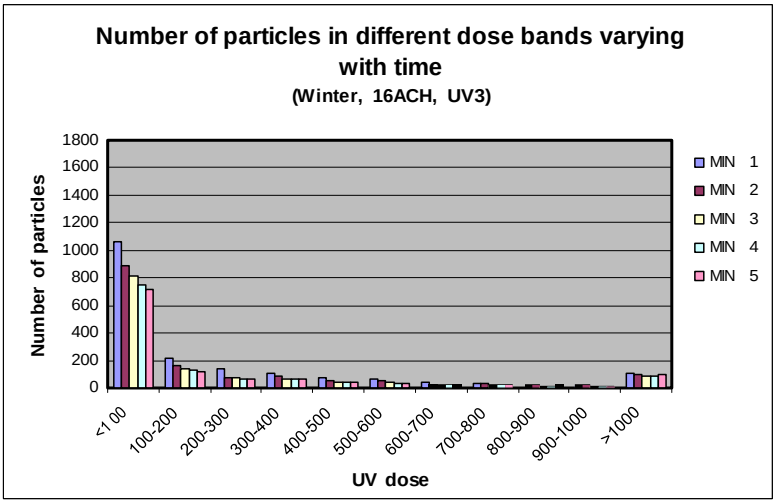
Case 30: Winter, 16 ACH, high exhausts without baseboard heating



UV output of 10W, located at partition wall

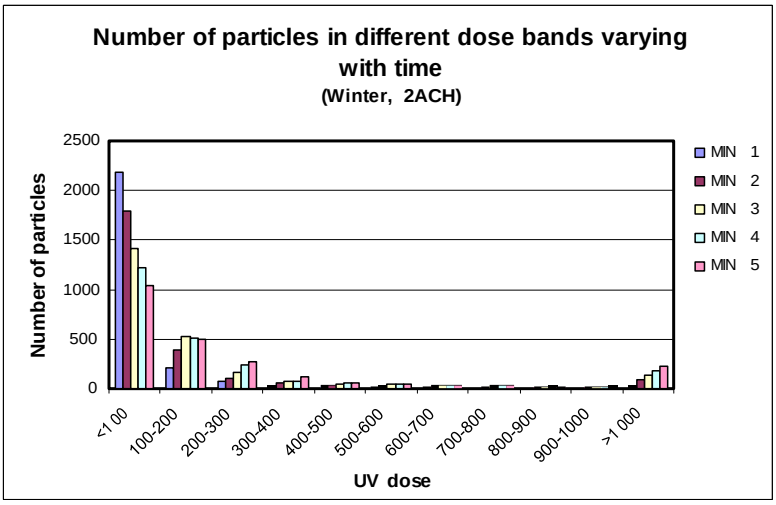


UV output of 20W, located at the wall near the bed

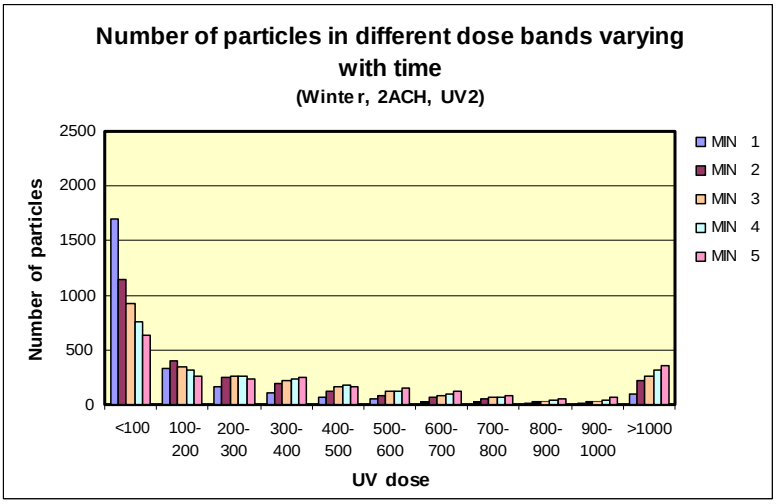


UV output of 40W, located at the wall near the bed

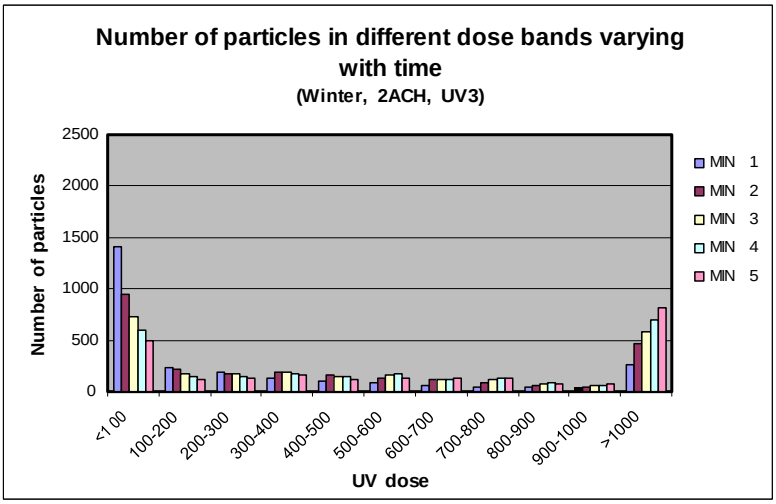
Case 31: Winter, 2 ACH, high exhausts with baseboard heating



UV output of 10W, located at partition wall

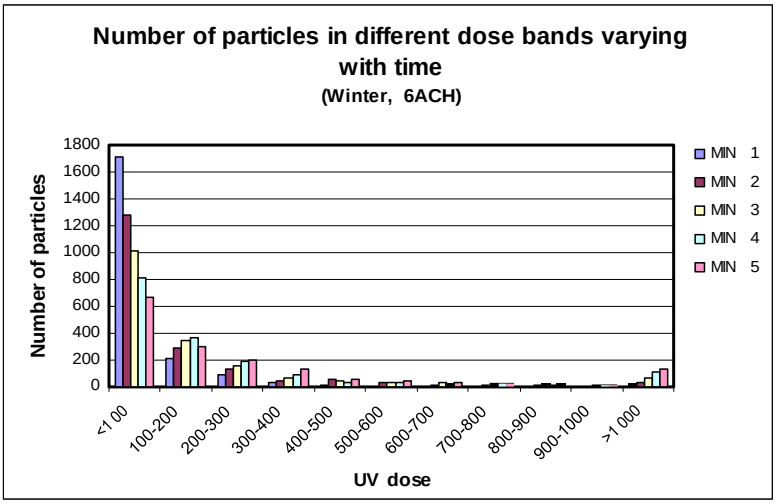


UV output of 20W, located at the wall near the bed

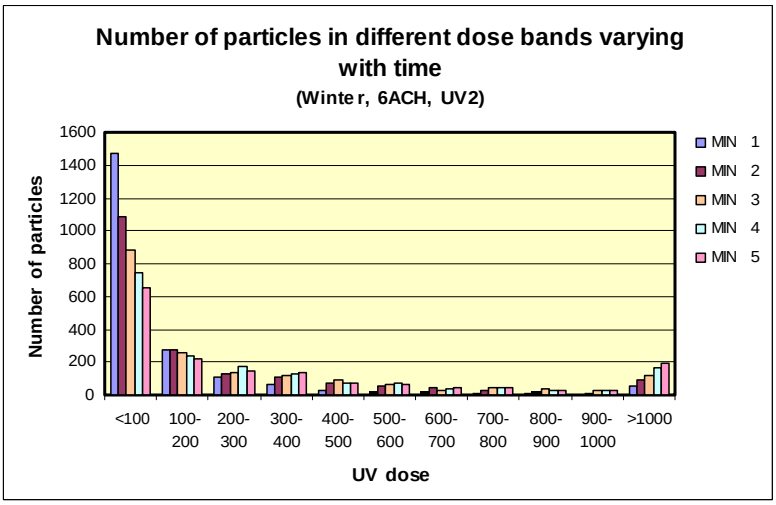


UV output of 40W, located at the wall near the bed

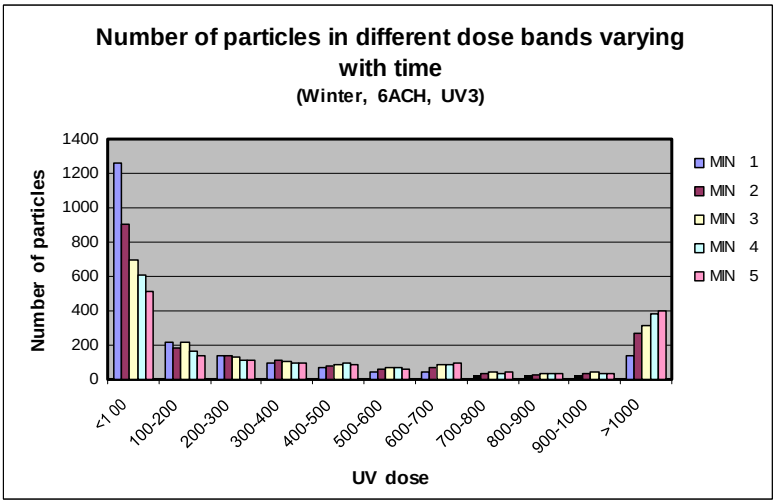
Case 32: Winter, 6 ACH, high exhausts with baseboard heating



UV output of 10W, located at partition wall

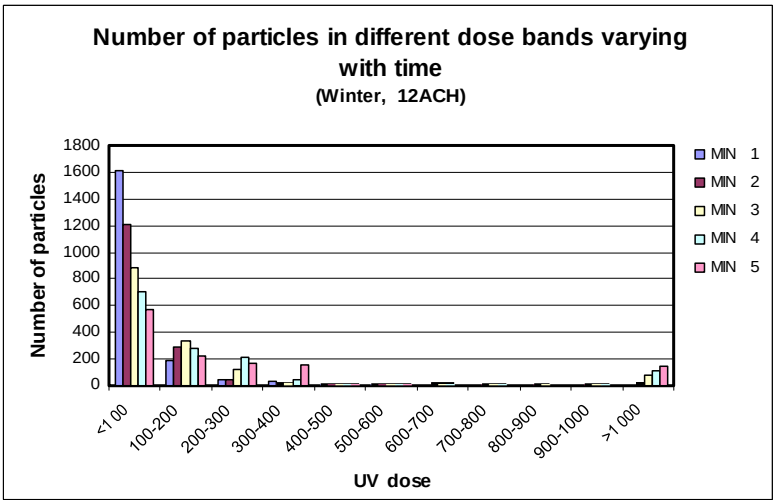


UV output of 20W, located at the wall near the bed

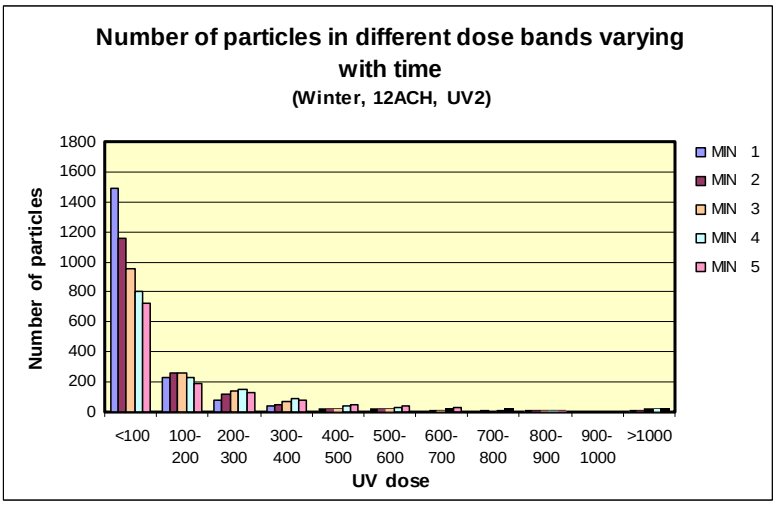


UV output of 40W, located at the wall near the bed

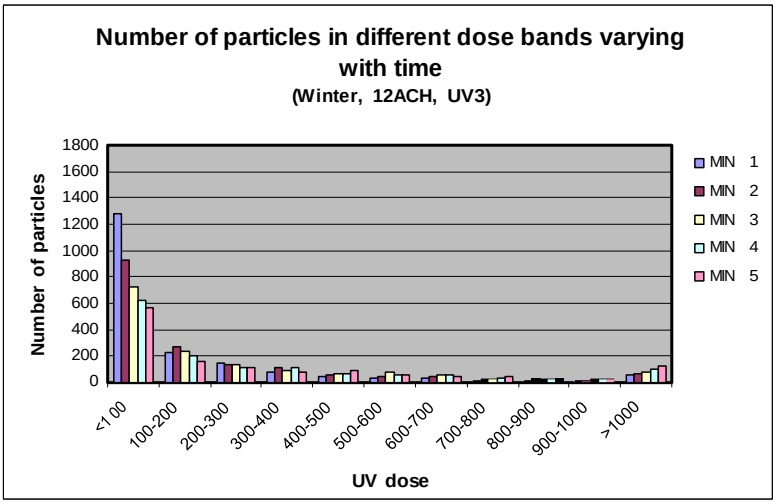
Case 33: Winter, 12 ACH, high exhausts with baseboard heating



UV output of 10W, located at partition wall

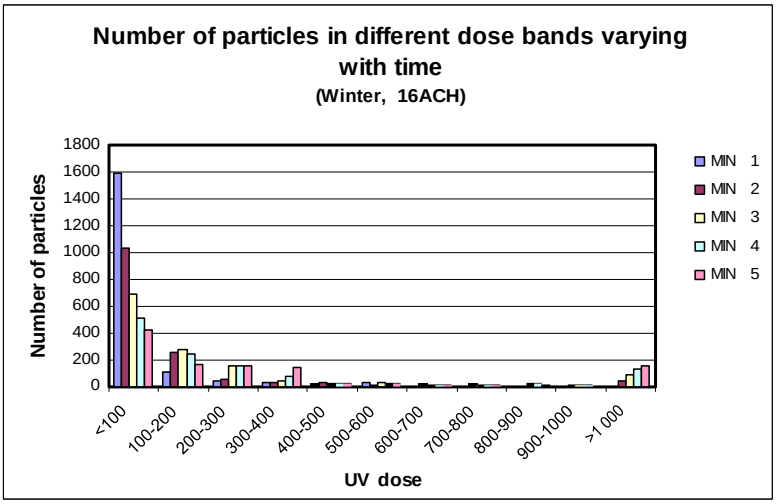


UV output of 20W, located at the wall near the bed

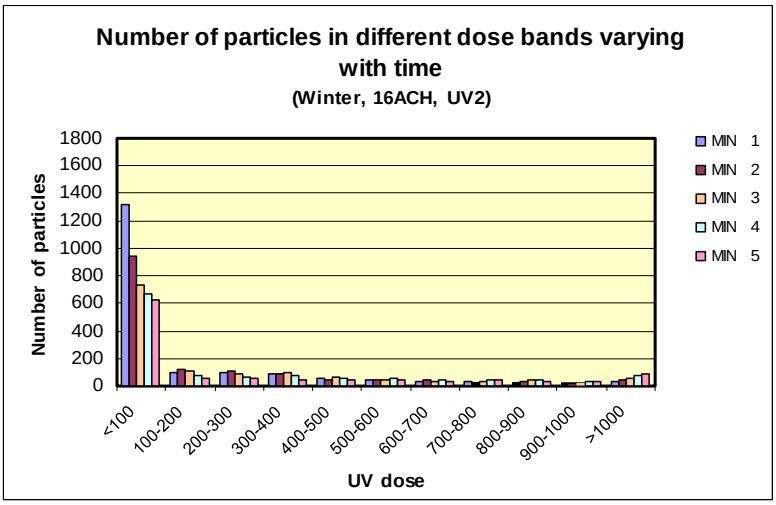


UV output of 40W, located at the wall near the bed

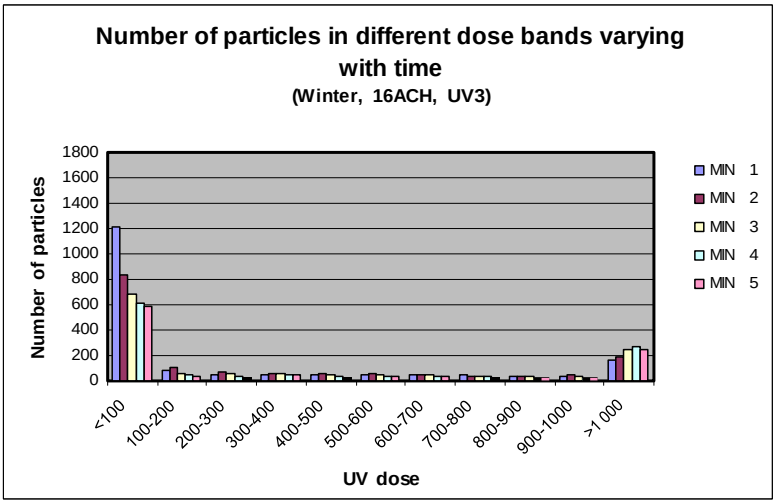
Case 34: Winter, 16 ACH, high exhausts with baseboard heating



UV output of 10W, located at partition wall

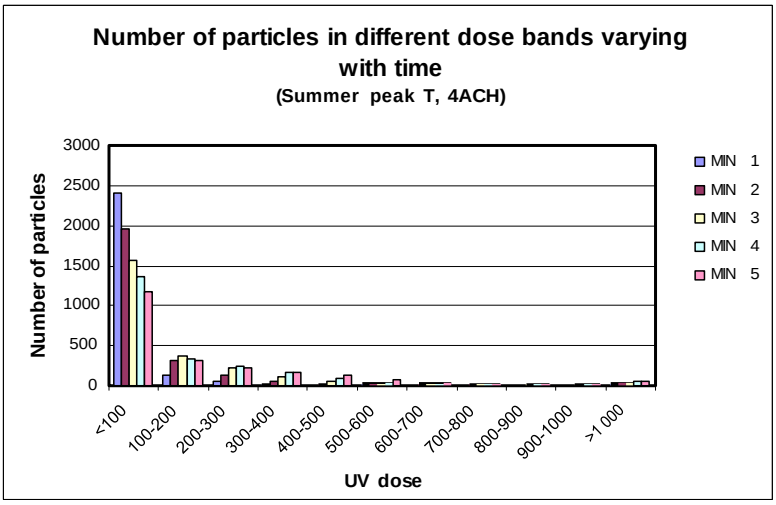


UV output of 20W, located at the wall near the bed

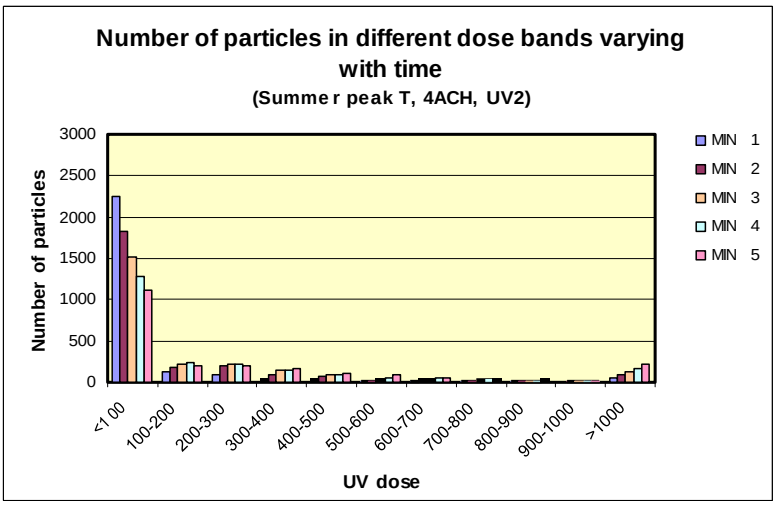


UV output of 40W, located at the wall near the bed

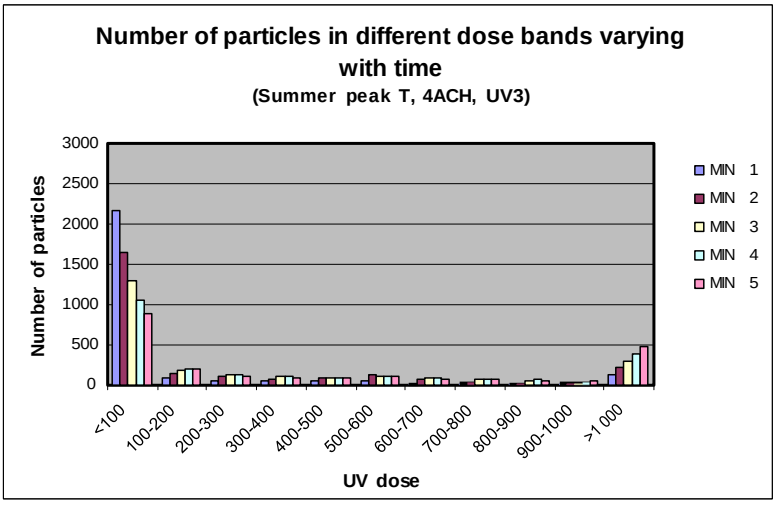
Case 35: Summer peak T, 4 ACH, low exhausts with pressurization



UV output of 10W, located at partition wall

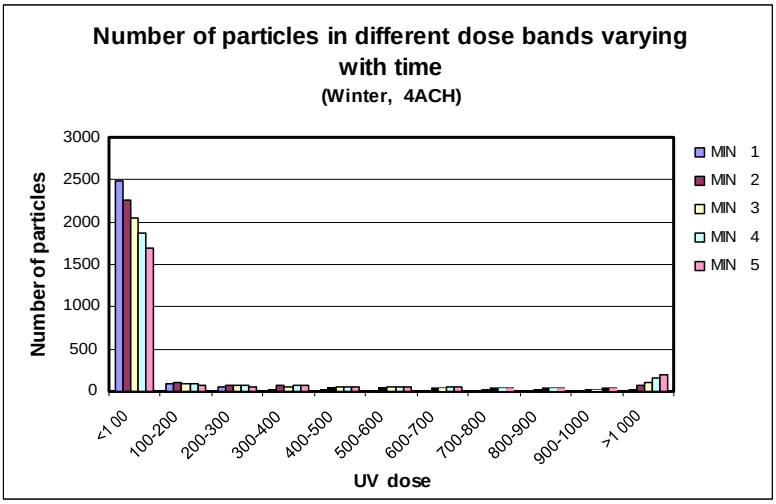


UV output of 20W, located at the wall near the bed

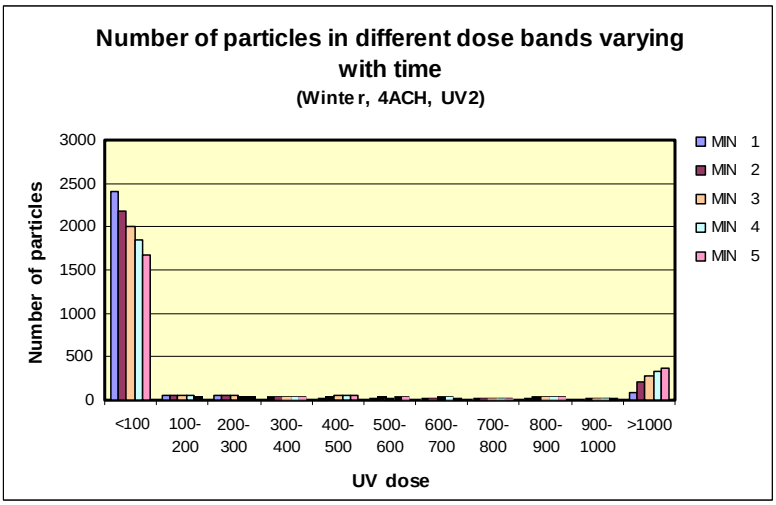


UV output of 40W, located at the wall near the bed

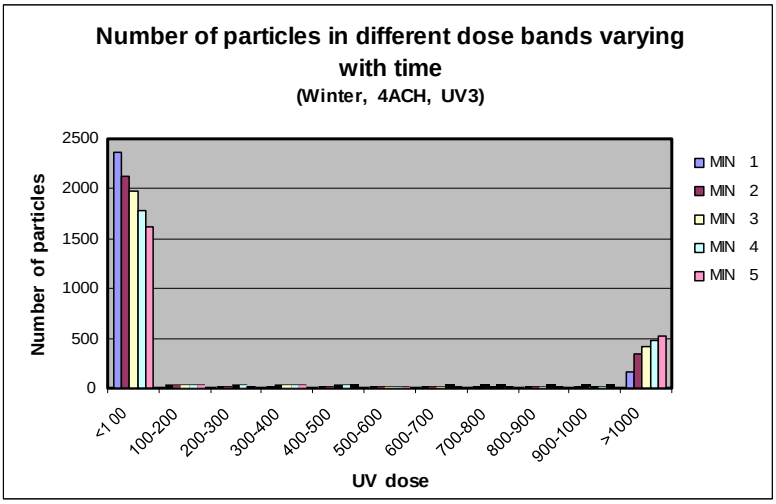
Case 36: Winter, 4 ACH, low exhausts with pressurization



UV output of 10W, located at partition wall

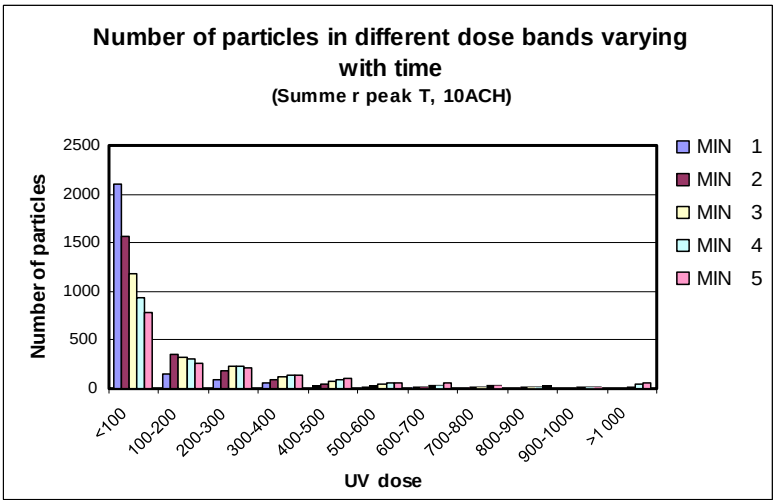


UV output of 20W, located at the wall near the bed

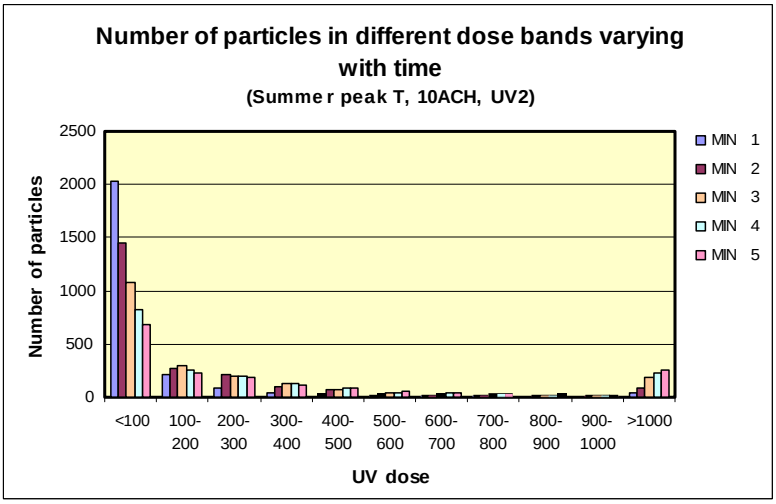


UV output of 40W, located at the wall near the bed

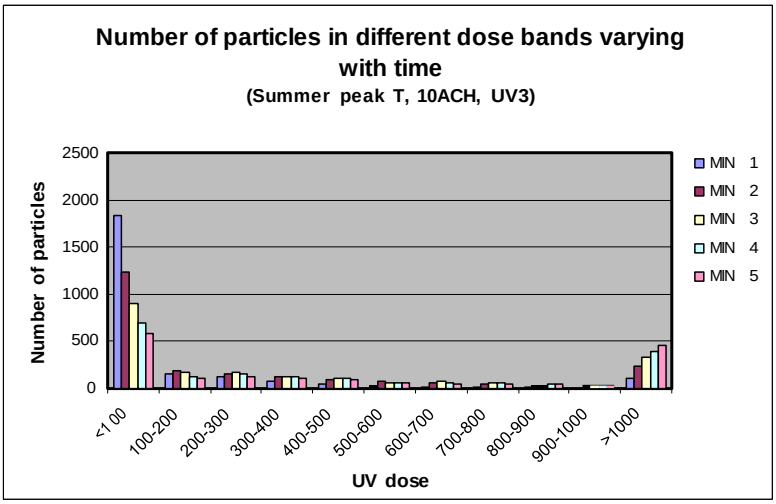
Case 37: Summer peak T, 10 ACH, low exhausts with pressurization



UV output of 10W, located at partition wall

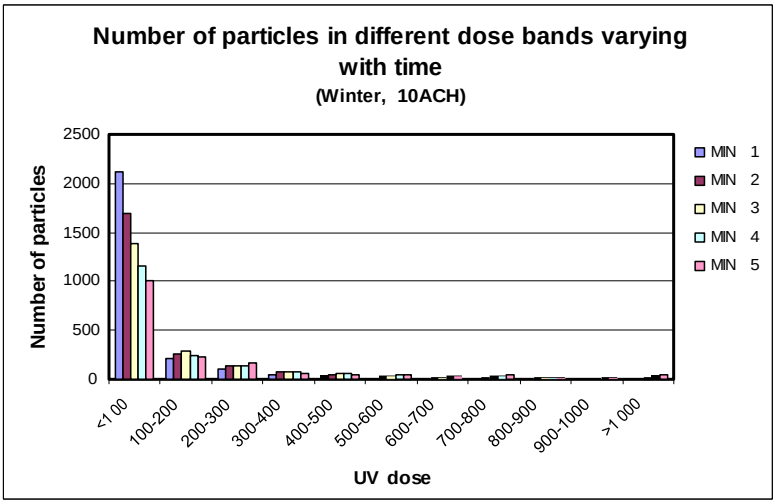


UV output of 20W, located at the wall near the bed

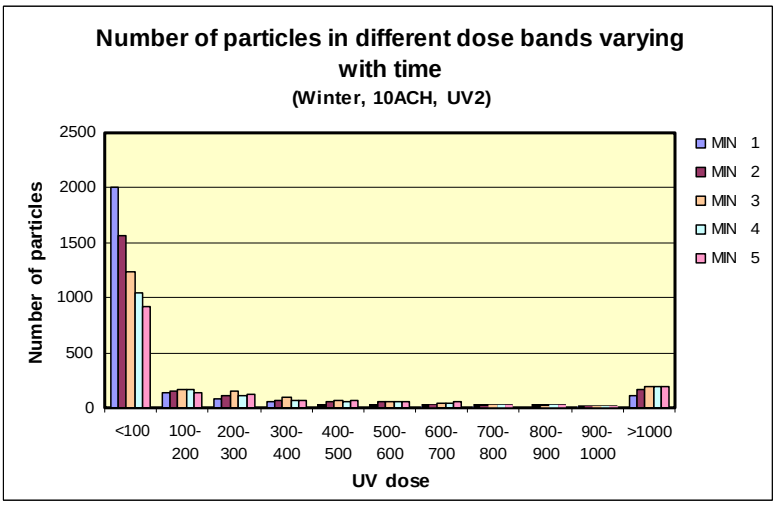


UV output of 40W, located at the wall near the bed

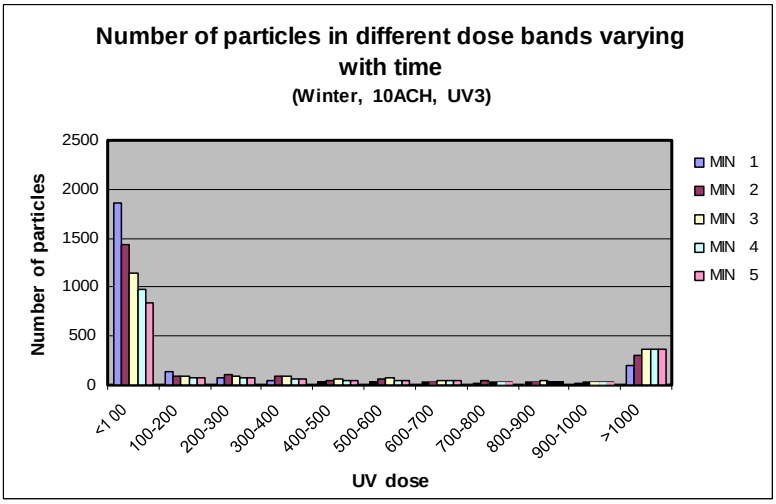
Case 38: Winter, 10 ACH, low exhausts with pressurization



UV output of 10W, located at partition wall

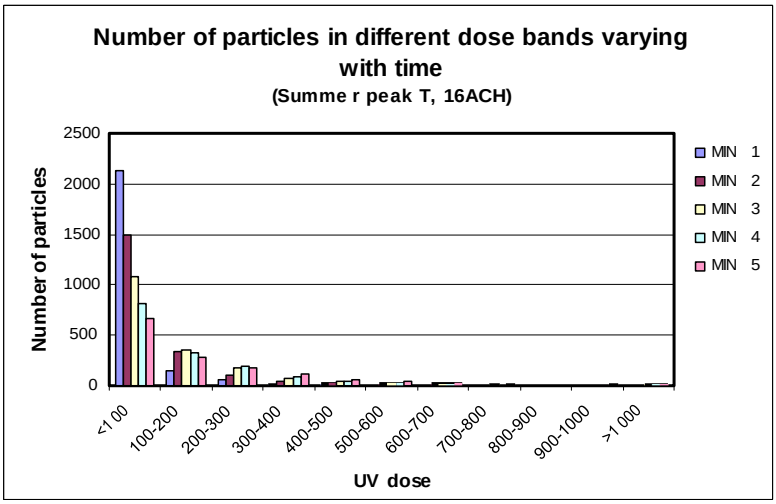


UV output of 20W, located at the wall near the bed

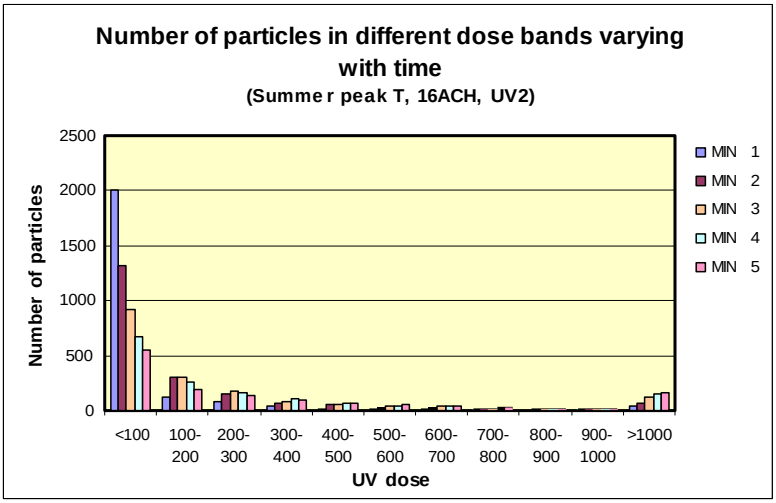


UV output of 40W, located at the wall near the bed

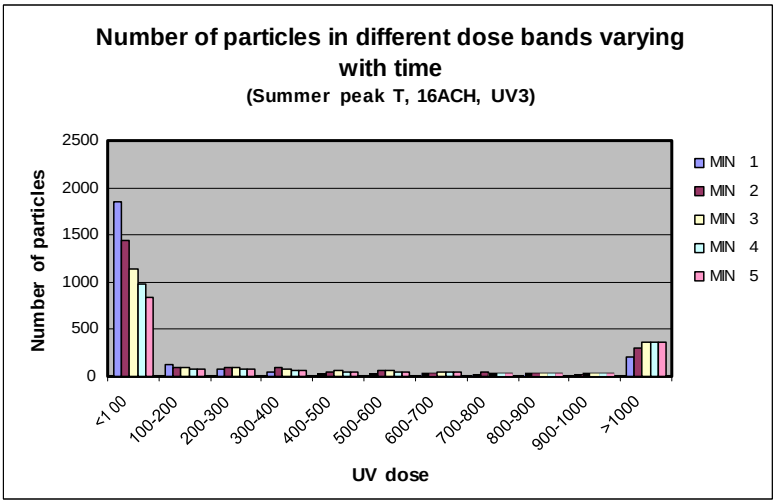
Case 39: Summer peak T, 16 ACH, low exhausts with pressurization



UV output of 10W, located at partition wall

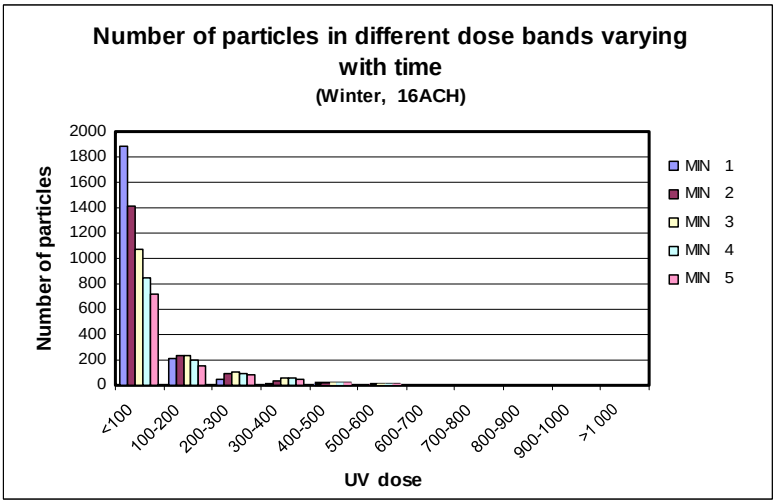


UV output of 20W, located at the wall near the bed

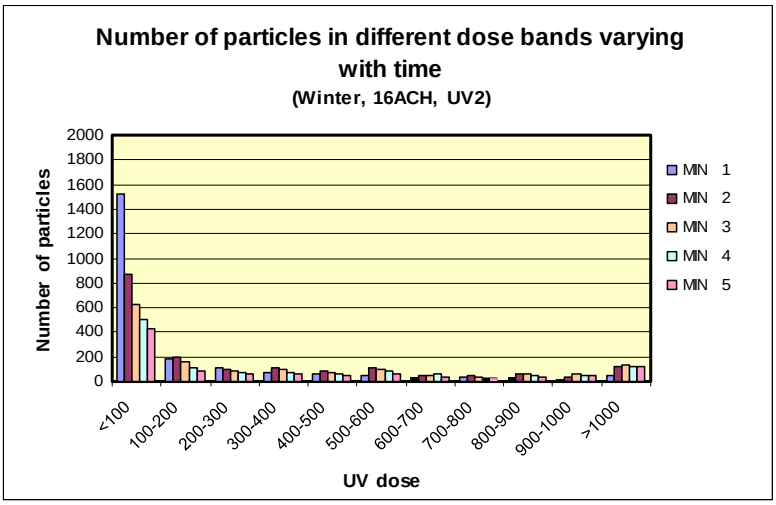


UV output of 40W, located at the wall near the bed

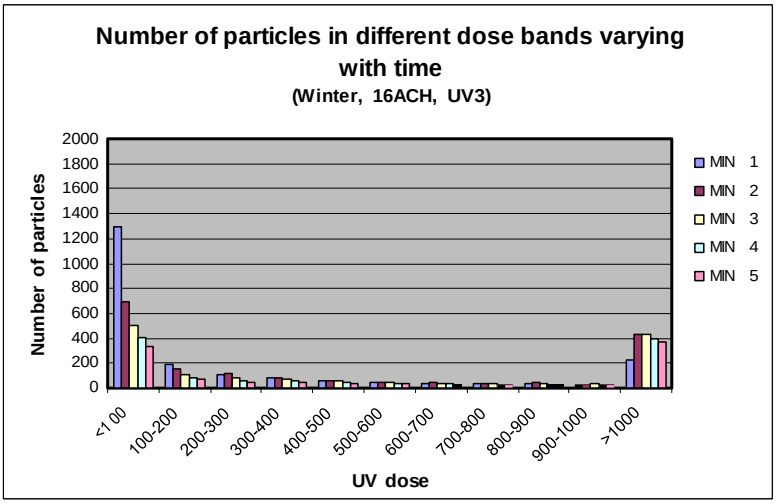
Case 40: Winter, 16 ACH, low exhausts with pressurization



UV output of 10W, located at partition wall



UV output of 20W, located at the wall near the bed



UV output of 40W, located at the wall near the bed

5.3.20 Values of Killed, Vented and Viable Particles After 5 Minutes

The number of vented, killed and viable particles after 5 minutes for the three different UV locations and intensities are included in Tables 5.3 to 5.5 below. These values are given for both the group and individual killing methods.

One item which stands out from the analysis is that the group killing method generally results in a greater number of killed particles (and hence lesser number of viable particles) than the individual killing method. The primary consequence of this is that the increase in killing rate on increasing UV intensity is more impressive for the group killing method than the individual killing method. However, the basic conclusions drawn from the study can be equally applied to both the group and individual killing methods. As highlighted in Section IV (4.2), there is no consensus on the correct method to account for the killing of the bacterium, although the individual killing method numbers appear to be more consistent. This topic is therefore a good subject for further research.

The following points can be made from the tables:

1/ The addition of baseboard heating is equivalent to an increase of around 6 ACH in terms of the number of viable particles. This can be seen on comparing the viable numbers for Cases 14 and 22 in Table 5.3, which have been highlighted in red.

2/ Beyond 6 ACH for summer cases and winter cases with baseboard heating, and 10 ACH for winter cases without baseboard heating, increasing the ventilation rate results in only relatively modest decreases in the number of viable particles.

3/ The addition of UVGI offers a clear advantage over increasing the ACH in the ventilation system. For example, for the UV1 case, an increase from 6 to 16 ACH results in a drop of 30% in the viable particle total if UVGI was not present for summer cases. However, the introduction of UVGI results in a reduction of 68% in the number of viable particles at 6 ACH. The numbers used for this calculation are highlighted in orange in Table 5.3.

4/ The reduction in the number of viable particles on doubling the UV intensity for summer cases and winter cases with baseboard heating at 6 ACH is around 20%. The numbers used for these calculations are highlighted in green in Tables 5.4 and 5.5. This indicates that increasing the UV intensity is not necessarily cost effective. This will be commented on further in the next section.

Table 5.3 Vented, Killed and Viable Particles After 5 Minutes for UV1

Case	Weather Condition	ACH	UV location: UV1					
			Vented out	Group killed	Indiv. killed	Group viable	Indiv. Viable	Viable number if UVGI not included
Case1	Min. T	2	181	875	624	486	370	2519
Case2	Peak T	4	425	1325	1337	1227	1050	2275
Case3	Min. T	4	462	820	730	1568	1560	2238
Case4	Peak T	6	562	1613	1631	826	689	2138
Case5	Min. T	6	591	826	720	1503	1463	2109
Case6	Peak load	8	789	1594	1549	762	614	1911
Case7	Peak T	8	810	1292	1284	999	838	1890
Case8	Min. T	8	707	1095	1042	1185	1109	1993
Case9	Peak load	10	939	1689	1575	632	551	1761
Case10	Peak T	10	851	1344	1367	875	710	1849
Case11	Min. T	10	828	1490	1419	932	794	1872
Case12	Peak load	12	862	1432	1459	864	654	1838
Case13	Peak T	12	1006	1215	1256	840	664	1694
Case14	Min. T	12	1241	1208	1153	834	683	1459
Case15	Peak load	14	1022	1400	1428	713	582	1678
Case16	Peak T	14	1119	1155	1166	798	647	1581
Case17	Min. T	14	1528	854	884	682	581	1172
Case18	Peak load	16	1162	1270	1293	731	586	1538
Case19	Peak T	16	1212	1107	1179	779	596	1488
Case20	Min. T	16	1696	974	1002	486	370	1004
Case21	Min T	2	99	1982	1848	884	791	2601
Case22	Min T	6	553	1618	1614	858	741	2147
Case23	Min T	12	1144	1451	1482	634	490	1556
Case24	Min T	16	1755	993	1015	473	348	945
Case25	Peak T	4	476	1562	1555	996	789	2224
Case26	Min T	4	593	1149	836	1320	1423	2107
Case27	Peak T	10	1222	1263	1189	620	510	1478
Case28	Min T	10	1351	973	829	809	745	1349
Case29	Peak T	16	1521	1186	1144	415	312	1179
Case30	Min. T	16	1453	1066	1067	510	407	1247
Case31	Min T	2	323	1763	1683	824	774	2377
Case32	Min T	6	1082	1276	1274	661	517	1618
Case33	Min T	12	1405	986	1021	606	468	1295
Case34	Min T	16	1591	949	957	423	345	1109
Case35	Peak T	4	452	1423	1437	1056	917	2248
Case36	Min T	4	330	913	750	1562	1660	2370
Case37	Peak T	10	954	1397	1381	792	662	1746
Case38	Min T	10	992	1137	1083	1026	900	1708
Case39	Peak T	16	1286	1147	1163	675	541	1414
Case40	Min. T	16	1645	858	881	648	549	1055

Table 5.4 Vented, Killed and Viable Particles After 5 Minutes for UV2

Case	Weather Condition	ACH	UV location: UV2					
			Vented out	Group killed	Indiv. killed	Group viable	Indiv. Viable	Viable number if UVGI not included
Case1	Min. T	2	200	1555	575	280	362	2500
Case2	Peak T	4	414	1866	1374	768	1007	2286
Case3	Min. T	4	453	1647	691	1037	1620	2247
Case4	Peak T	6	557	1813	1574	692	754	2143
Case5	Min. T	6	562	1167	682	1294	1536	2138
Case6	Peak load	8	797	1974	1730	423	500	1903
Case7	Peak T	8	847	1625	1277	687	790	1853
Case8	Min. T	8	684	1895	1050	584	1129	2016
Case9	Peak load	10	944	2065	1629	322	533	1756
Case10	Peak T	10	787	1591	1377	784	742	1913
Case11	Min. T	10	817	2451	1498	103	791	1883
Case12	Peak load	12	831	1905	1721	510	498	1869
Case13	Peak T	12	1015	1511	1325	581	616	1685
Case14	Min. T	12	1222	2356	1491	58	508	1478
Case15	Peak load	14	1037	1772	1563	458	463	1663
Case16	Peak T	14	1071	1539	1309	524	614	1629
Case17	Min. T	14	1531	1513	1214	386	453	1169
Case18	Peak load	16	1114	1633	1465	480	489	1586
Case19	Peak T	16	1287	1383	1206	528	521	1413
Case20	Min. T	16	1690	1643	1295	280	362	1010
Case21	Min T	2	120	2463	2156	228	479	2580
Case22	Min T	6	514	2158	1829	403	590	2186
Case23	Min T	12	1094	1805	1651	471	482	1606
Case24	Min T	16	1798	1401	1171	333	258	902
Case25	Peak T	4	499	1753	1453	833	877	2201
Case26	Min T	4	594	1949	809	610	1503	2106
Case27	Peak T	10	1218	1473	1148	516	621	1482
Case28	Min T	10	1348	1227	729	628	911	1352
Case29	Peak T	16	1588	1206	1106	431	375	1112
Case30	Min. T	16	1444	1005	853	800	752	1256
Case31	Min T	2	325	2127	1884	418	606	2375
Case32	Min T	6	1064	1546	1290	441	583	1636
Case33	Min T	12	1382	993	935	707	635	1318
Case34	Min T	16	1579	948	818	570	581	1121
Case35	Peak T	4	452	1907	1479	710	888	2248
Case36	Min T	4	343	1996	761	652	1643	2357
Case37	Peak T	10	968	1665	1429	567	600	1732
Case38	Min T	10	1041	1829	1099	517	910	1659
Case39	Peak T	16	1314	1458	1250	446	486	1386
Case40	Min. T	16	1658	1743	1298	183	375	1042

Table 5.5 Vented, Killed and Viable Particles After 5 Minutes for UV3

Case	Weather Condition	ACH	UV location: UV3					
			Vented out	Group killed	Indiv. killed	Group viable	Indiv. Viable	Viable number if UVGI not included
Case1	Min. T	2	195	2222	651	61	263	2505
Case2	Peak T	4	417	2402	1660	258	762	2283
Case3	Min. T	4	420	2239	783	448	1567	2280
Case4	Peak T	6	554	2245	1799	299	566	2146
Case5	Min. T	6	615	1847	710	725	1479	2085
Case6	Peak load	8	839	2379	1906	60	360	1861
Case7	Peak T	8	857	2246	1526	207	587	1843
Case8	Min. T	8	640	2488	1101	141	1122	2060
Case9	Peak load	10	944	2401	1780	77	428	1756
Case10	Peak T	10	852	2044	1648	287	496	1848
Case11	Min. T	10	794	2554	1608	1	704	1906
Case12	Peak load	12	892	2347	1927	89	311	1808
Case13	Peak T	12	1009	1923	1556	269	461	1691
Case14	Min. T	12	1237	2432	1581	3	481	1463
Case15	Peak load	14	1046	2230	1789	71	296	1654
Case16	Peak T	14	1103	1905	1522	264	506	1597
Case17	Min. T	14	1510	2031	1350	111	414	1190
Case18	Peak load	16	1143	2177	1698	101	331	1557
Case19	Peak T	16	1264	1784	1381	325	424	1436
Case20	Min. T	16	1714	2068	1456	61	263	986
Case21	Min T	2	108	2696	2226	6	438	2592
Case22	Min T	6	577	2502	1974	67	451	2123
Case23	Min T	12	1102	2112	1794	249	392	1598
Case24	Min T	16	1754	1723	1336	230	323	946
Case25	Peak T	4	464	2235	1677	327	725	2236
Case26	Min T	4	622	2372	865	154	1427	2078
Case27	Peak T	10	1217	1847	1285	226	542	1483
Case28	Min T	10	1325	1678	850	221	857	1375
Case29	Peak T	16	1588	1626	1292	198	298	1112
Case30	Min. T	16	1496	1406	1027	478	700	1204
Case31	Min T	2	326	2571	2014	37	479	2374
Case32	Min T	6	1070	1938	1422	95	479	1630
Case33	Min T	12	1388	1345	1118	454	536	1312
Case34	Min T	16	1586	1308	905	332	553	1114
Case35	Peak T	4	457	2383	1725	271	689	2243
Case36	Min T	4	339	2592	844	78	1562	2361
Case37	Peak T	10	991	2191	1599	115	483	1709
Case38	Min T	10	1059	2442	1225	59	839	1641
Case39	Peak T	16	1292	1881	1401	229	430	1408
Case40	Min. T	16	1656	2018	1460	9	305	1044

5.3.21 Cost Analysis of Inclusion of UVGI Against Increased Ventilation Rate

In terms of costs associated with the inclusion of UVGI, some of the following numbers are taken from First et. al, Part II (1999):

1/ Hospital grade HVAC units average \$30 – 35/ ft^2.
2/ For UVGI costs, a New York facility paid \$7.60/ ft^2 for 41W per 200 ft^2, while one in Birmingham paid \$11.30/ft^2 for 67W per 200 ft^2. For the purposes of interpolation, the lower figure has been used for UV1, while the higher figure has been used for UV2 and UV3.
3/ The operating costs in terms of cfm per year are approximately \$1.50 to \$5 per cfm per year, depending on the cost of utilities and location of the facility. For the purposes of the calculations, a value of \$3 per cfm per year is assumed.
4/ The electrical costs are \$0.1kW/h.

On the above basis, the inclusion of the 38W lamp used in UV1 would cost approximately \$1408 for installation in a 200 ft^2 room, plus \$33 a year to operate. The UV2 configuration would cost approximately \$2563 to install, plus \$66.50 a year to operate, and the UV3 configuration would cost approximately \$3845 to install, plus \$100 to operate. In contrast, the cost associated with increasing the ACH in a 1800 ft^3 facility by a single ACH is \$90 per year.

Based on the numbers given in the previous section, the inclusion of UV1, which would reduce the number of viable particles at 6 ACH by almost 70%, would cost \$1742 over a 10 year period for a 200 ft^2 room. However, the cost of increasing the ACH from 6 to 16 would cost \$9000 over the same period, and only yield a reduction of around 30%. The costs clearly indicate the benefit of the inclusion of UVGI.

The cost of moving from the UV2 system to the UV3 system would mean a difference of \$1615 over a ten-year period (\$3229 for ten years for the UV2 system for a 200 ft^2 room, \$4844 for ten years for the UV3 system), and would only reduce the number of viable particles by 20%.