Equatorial Journal of Engineering (2018) 1-8
Journal Homepage: www.erjournals.com
ISSN: 0184-7937

ADAPTATION OF AN AIR-CONDITIONING SYSTEM FOR USE IN A 100-SEATER CAPACITY AUDITORIUM, IN NIGERIA

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ABSTRACT

Designing an air-conditioning system for the utmost comfort of occupants in a 100-seater hall, demands patience and competence. The designer must have a good grasp of psychrometric chart. Certain conditions in the in-door and out-door of the auditorium were factored into this analysis. These gave a mixing temperature of 25.25 ^{o}C. The situation of infiltrations occasioned by number of doors, windows, and other gaps in the wall governed the design. Based on the parametric assumptions made, the cooling capacity of the plant, Q_C, equals 18.60 KW; and the water condensation rate of the plant, $\mathbf{w_r}$, approximates to 0.004 Kg/s. Factors directly affecting thermal comfort of the human are: air temperature, moisture content of the air, radiant exchange and air movement. These, considered together, enabled us to estimate the mixing condition of wet and dry air.

Keywords: Air-Conditioning System, 100-Seater Capacity Auditorium, Psychrometric Chart, Cooling Capacity of the Plant, Mixing Condition.

How to cite this article: Madu, K. E. (2018). Adaptation of an Air-Conditioning System for use in a 100-Seater Capacity Auditorium, in Nigeria. *Equatorial Journal of Engineering* (2018) 1-8.

INTRODUCTION

Auditorium space types are areas for large meetings, presentations, and/or performances. Auditorium space type facilities may include assembly halls, exhibition halls, and theatres. They are usually designed to accommodate large audiences. As such, they tend to have wide spans, and are multiple-stories high, in order to accommodate seating, sightlines, and acoustical requirements. Raised stage/dais floors and special lighting equipment are often required as well. Typical features of auditorium space types include the list of applicable design objectives elements as outlined below

Sloped Floors: Sloped floors, with level terraces for each row of seating, help provide the proper sightlines from the audience to the stage. Note that the bottom and intermediate rows should be directly accessible from entry levels to allow for compliant accessible seating position.

Fixed Seats: Typically, fixed seats with tilting upholstered seat and back, integral arm and tablet arm are provided with articulated back, for maximum occupant passage space between rows.

Special Lighting: Dramatic lighting systems include front lighting, foot lighting, spot lights, follow spot lights, beam lights, and flood lights. There are, also, a projection room/booth with manual and programmable lighting controls, and a space for the spot light operator. Lighting systems should be flexible to accommodate various performance venues in the auditorium.

Special Acoustical Design: Quality acoustical characteristics are important in auditorium spaces so that performances and presentations can be clearly heard and understood. For performance spaces and general presentation spaces, recommended noise criteria (NC) rating ranges from NC-20 to NC-30; recommended sound transmission class (STC) rating ranges from STC 40 to STC 50. Strategies to achieve the recommended NC and STC ranges include, for example: Type II vinyl wall covering and fabric covered acoustical wall panels for the interior wall finish in the auditorium; Type II vinyl wall coverings for the stage area; Type II vinyl wall coverings for 1/3 of the front of the orchestra (audience) sidewalls and fabric covered acoustical panels for 2/3 of the back of the orchestra (audience) sidewalls, fabric covered acoustical panels for rear walls; and a plaster and plywood combination characteristics for the ceiling.

Increased Cooling capacity: Usually, air-conditioning systems for auditorium spaces are sized and zoned to accommodate varying internal loads, which are a function of audience size, performance lighting loads, and projection equipment. Air handling units (AHUs) with increased cooling capacity should be zoned separately for the auditorium, lobby, projection spaces, stage areas, and audience seating areas.

Air-conditioning is that branch of engineering science which deals with the study of conditioning of air for human comfort. This discipline, in its broad sense, also deals with the conditioning of air for industrial purposes, food processing, storage of food and other materials (Khurmi and Gupta, 2008).

Strictly speaking, *human comfort* depends upon physiological and psychological conditions. Hence, it is difficult to define the term without some ambiguities. There are many definitions given for this concept by different bodies; but the most acceptable definition (from the subject point of view) is given by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). According to this group (ASHRAE, 1997), human comfort refers to that condition of mind, which expresses satisfaction with thermal environment. The building of most auditoria in Nigeria, pose the problem of ill-ventilated atmosphere and suffocation during sessions. Major parts of the building exposed to sun; the roof being heated throughout the day (Madu, 2018). Hence, the need to design air cooling system for the comforts to the occupants in a 100-seater capacity auditorium, during longer programs (Wane and Nagdeve, 2012). actors directly affecting thermal comfort of the human are: air temperature, moisture content of the air, radiant exchange and air movement. It is the job of the thermal engineer to decide on the values of these factors, and design a system to maintain them within practical and economical limits; when the outside environment for most of the time (and in some cases continuously) will be hostile to this endeavor (Thornley, Partner, Roger and Partners, 1969).

The history of air-conditioning is antique. Since prehistoric times, snow and ice were used for cooling. The business of harvesting ice during winter and storing for use in summer became popular towards the late 17th century (Nagengast, 1999). This practice was replaced by mechanical ice-making machine. The 2nd century Chinese mechanical engineer and inventor, Ding Huan, of the Han dynasty, invented a rotary fan for air-conditioning, with seven wheels 3 m (10^{I}) in diameter and manually powered by prisoners of the time (Needham, 1991). In the 17th century, the Dutch inventor, Cornelius Drebbel demonstrated “turning summer to winter” as an early form of modern air-conditioning for James 1 of England, by adding salt to water (Laszlo, 2001). Modern air-conditioning emerged from advances in chemistry, during the 19th century, and the first large-scale electrical air-conditioning was invented and used in 1902, by an American inventor Willis Carrier. Carrier’s invention controlled not only temperature, but also humidity. In 1945, Robert Sherman of Lynn, Massachusetts invented a portable, in-window air-conditioner that cooled, heated, humidified, dehumidified, and filtered the air.

MATERIALS AND METHOD

The normal heat load pattern would be: net sensible heat gain and net latent heat gain. The following expression is given for the space to be air-conditioned. A meeting is scheduled to take place at a university auditorium, with an expected audience of 100 occupants, to the maximum. It is required to air-condition the hall to take care of the comfort of the occupants. The hall is to be maintained at 20 ^oC db, and 50 % RH. Out-door air of 35 % proportion, at a temperature of 35 ^oC db, and 23 ^oC wb, mixes with the in-door air. The air circulation rate (in the hall) is estimated at 25 m^3/hr/occupant. The estimated heat gain in the hall (exclusive of infiltration) is 230,000 KJ/hr of which 30% appears as latent heat. Assuming a barometric pressure of 1.01325 bar, and an air-off-coil temperature of 26 ^oC db in-door and 12 ^oC db out-door; we are to design a system on psychrometric chart, showing all conditions.

RESULTS AND DISCUSSION

The conditions as indicated are captured in the psychometric chart (cf. **Appendix 1**)

Point 1=> Outdoor Condition: 0.35 x 35 = 12.25 ^oC
Point 2=> Indoor Condition: 0.65 x 20 = 13.00 ^oC
Therefore, Mixing Condition: 12.25 ^oC + 13.00 ^oC = 25.25 ^oC. The mixing temperature is the dry-bulb temperature of the mixing air.

25 m^3/hr/Person ≡ 2500 m^3/hr = 0.694 m^3/s

Note: Volumetric Flow Rate, V = ṁ x v; where v = specific volume, and ṁ = Mass flow Rate

Specific Volume at Point 1 = 0.891

$\therefore \dot{m} = \frac{0.694}{0.891} = 0.7789$ Kg/s

From Point 1 to Point 4, we experience latent heat due to infiltration
Enthalpy at Point 1, h_1 = 68.1 kJ/Kg
Enthalpy at Point 2, h_2 = 39.5 kJ/Kg
Enthalpy at Point 3, h_3 = 49 kJ/Kg
Enthalpy at Point 4, h_4 = 54 kJ/Kg

Similarly,
Humidity Ratio 1, w_1 = 12.75 g/Kg = 0.0128 $Kg_{Water}/Kg_{Dry\ Air}$
Humidity Ratio 2, w_2 = 7.3 g/Kg = 0.0073 Kg/Kg
Humidity Ratio 3, w_3 = 0.0092 Kg/Kg
Humidity Ratio 4, $w_4 = w_2$

$\Delta(P_1 - P_4)$ = Sensible Heat

Sensible Heat Rate due to Infiltration, $Q_{S_{inf}} = \dot{m}(h_4 - h_2)$ = 11. 29 kJ/s

Latent Heat Rate due to Infiltration, $Q_{L_{inf}} = \dot{m}(h_1 - h_4)$ = 18. 10 kJ/s

It has to be noted that the infiltrated air is due to crevices in the door, windows, and cracks in the wall.

Sensible Heat, Q_S = 0.7 X 230,000 = 161000 kJ/hr
= 44.72 kJ/sec

Total Heat Gain, Q_T = 230,000 kJ/hr

Latent Heat, Q_L = 0.3 x 230,000 = 69,000 kJ/hr = 19.17 kJ/sec
Q_S = 0.7 x 230,000 = 69,000 kJ/hr = 44.72 kJ/sec

$Q_{ST} = Q_S + Q_{S_{inf}} = 56.06$ kJ/sec

$Q_{LT} = Q_L + Q_{L_{inf}} = 37.27$ kJ/sec

Recall, 2500 m^3/hr = 0.694 m^3/s

Sensible Heat Ratio, SHR, is calculated thus;

$$SHR = \frac{Q_{ST}}{Q_{ST} + Q_{LT}} = 0.6$$

h_5 = 25.0 kJ/Kg

w_5 = 0.0045 Kg/Kg

The humidity ratio of the in-door air, **w**, can be analytically calculated, thus;

$$W = \frac{0.622Pa}{P - Ps}$$

Note: $RH = \emptyset = \frac{P_a}{P_s} = \frac{Partial\ Pressure}{Saturation\ Pressure}$

From Saturated Water – Temperature Table (cf. **Appendix 2**)
P_s @ 20 °C = 0.02337 mPa

$$0.5 = \frac{P_a}{0.02337}$$

P_a = 0.5S x 0.02337 = 0.011685 mPa

Therefore, $\mathbf{w} = \frac{0.622\ x\ 0.011685}{1.01325 - 0.2337}$

= 0.007256 kJ/Kg

The percentage of saturation of the in-door air, $\boldsymbol{\varphi}$, is usually determined using the following mathematical relation;

$$\boldsymbol{\varphi} = \emptyset\ \frac{P - P_s}{P - P_a} = 0.5\ x\ \frac{1.01325 - 0.02337}{1.01325 - 0.011685} = 0.4962;$$
where P = Barometric Pressure
The mass flow rate of entry air, has the value;

$$\dot{m} = \frac{0.694}{0.891} = 0.7789\ Kg/s$$

It follows that water condensation rate, $\mathbf{w_r}$, from the plant is calculated using the relation;
$w_r = \dot{m}\ (w_3 - w_5)$

w_r = 0.7789 (0.0092 – 0.0045) = 0.003661 Kg/s

Similarly, the cooling capacity, Q_C of the plant equals;
$Q_C = \dot{m}\ (h_3 - h_5)$
Q_C = 0.7789 (49 – 25) = 18.60 KW

Due to the cooling effect produced in the evaporator, some quantity of water is generated. To calculate the amount of this water, we perform the following computation;

$\dot{m}$ x 3600 = 0.7789 x 3600 Kg/hr = 2804.04 Kg/hr

In 2 hours, the quantity of water equals;

0.7789 x 3600 x 2 = 5608.08 Kg

It could be inferred, from the above analysis, that the cooling capacity of the plant is a function of the mass flow rate of air, $\dot{\mathbf{m}}$; and enthalpies at points 3 and 5. Any increase in these values, bring about a corresponding increase in the cooling capacity of the plant; and vice versa. In the same vein, the humidity ratio of the in-door air varies directly as the partial pressure and inversely as the saturation pressure of the space to be air-conditioned. In psychrometry, when the relative humidity is 100 %, everywhere is literarily, water. Relative humidity, therefore, is pressure dependent. Saturation pressure changes with changing ambient temperature.

CONCLUSION

To guarantee the effectiveness and feasibility of the above enterprise, certain conditions must be put in perspective. These include: ambient conditions such as temperature and relative humidity, season of the year during which the design is done, condition of the space/room in which the air-conditioner is to run. The performance of the system, depends on the operating parameters. When the in-door and out-door conditions change, a new and different output is obtained.

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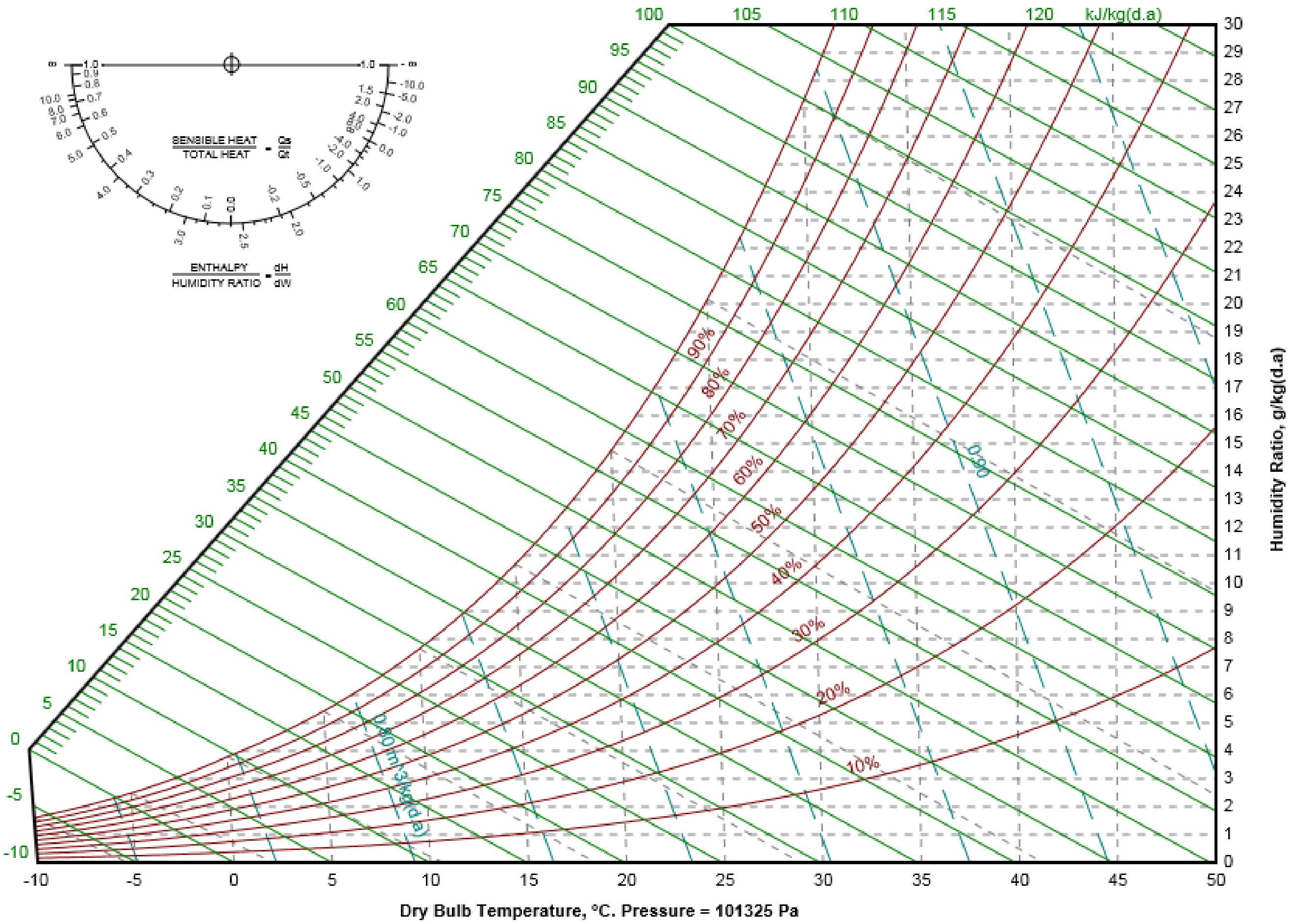
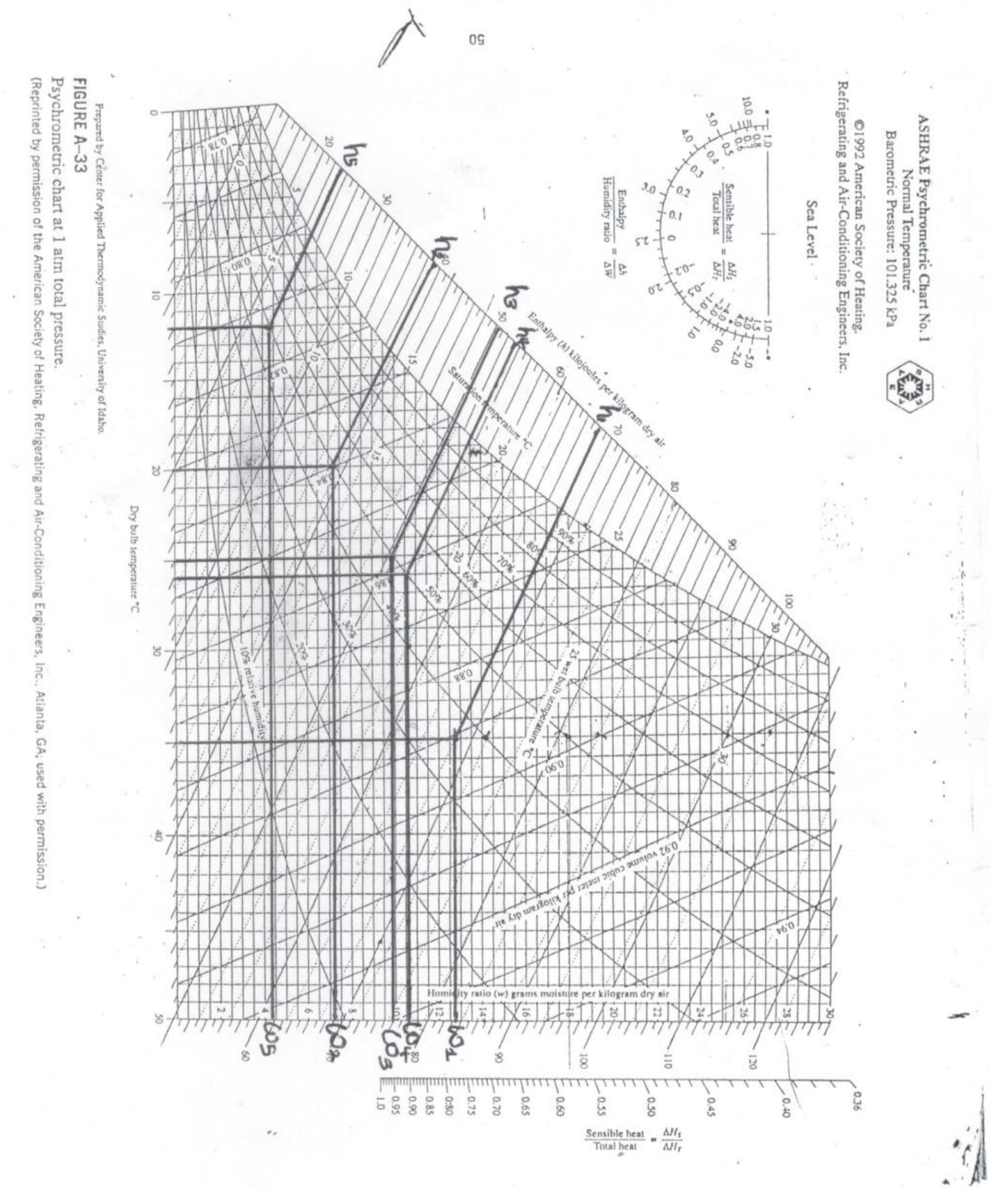
APPENDIX 1a: PSYCHROMETRIC CHART



APPENDIX 1b: DESIGN ON PSYCHROMETRIC CHART



APPENDIX 3

Saturated Water, Temperature Table

Table C.1b Saturated Water, Temperature Table (Metric Units)

		Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg · K)		
T, °C	p, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.010	0.0006113	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
2	0.0007056	0.001000	179.9	8.4	2378.1	8.4	2496.6	2505.0	0.0305	9.0738	9.1043
5	0.0008721	0.001000	147.1	21.0	2382.2	21.0	2489.5	2510.5	0.0761	8.9505	9.0266
10	0.001228	0.001000	106.4	42.0	2389.2	42.0	2477.7	2519.7	0.1510	8.7506	8.9016
15	0.001705	0.001001	77.93	63.0	2396.0	63.0	2465.9	2528.9	0.2244	8.5578	8.7822
20	0.002338	0.001002	57.79	83.9	2402.9	83.9	2454.2	2538.1	0.2965	8.3715	8.6680
25	0.003169	0.001003	43.36	104.9	2409.8	104.9	2442.3	2547.2	0.3672	8.1916	8.5588
30	0.004246	0.001004	32.90	125.8	2416.6	125.8	2430.4	2556.2	0.4367	8.0174	8.4541
35	0.005628	0.001006	25.22	146.7	2423.4	146.7	2418.6	2565.3	0.5051	7.8488	8.3539
40	0.007383	0.001008	19.52	167.5	2430.1	167.5	2406.8	2574.3	0.5723	7.6855	8.2578
45	0.009593	0.001010	15.26	188.4	2436.8	188.4	2394.8	2583.2	0.6385	7.5271	8.1656
50	0.01235	0.001012	12.03	209.3	2443.5	209.3	2382.8	2592.1	0.7038	7.3725	8.0763
55	0.01576	0.001015	9.569	230.2	2450.1	230.2	2370.7	2600.9	0.7678	7.2243	7.9921
60	0.01994	0.001017	7.671	251.1	2456.6	251.1	2358.5	2609.6	0.8310	7.0794	7.9104
65	0.02503	0.001020	6.197	272.0	2463.1	272.0	2346.2	2618.2	0.8934	6.9384	7.8318
70	0.03119	0.001023	5.042	292.9	2469.5	293.0	2333.8	2626.8	0.9549	6.8012	7.7561
75	0.03858	0.001026	4.131	313.9	2475.9	313.9	2321.4	2635.3	1.0155	6.6678	7.6833
80	0.04739	0.001029	3.407	334.8	2482.2	334.9	2308.8	2643.7	1.0754	6.5376	7.6130
85	0.05783	0.001032	2.828	355.8	2488.4	355.9	2296.0	2651.9	1.1344	6.4109	7.5453
90	0.07013	0.001036	2.361	376.8	2494.5	376.9	2283.2	2660.1	1.1927	6.2872	7.4799
95	0.08455	0.001040	1.982	397.9	2500.6	397.9	2270.2	2668.1	1.2503	6.1664	7.4167
100	0.1013	0.001044	1.673	418.9	2506.5	419.0	2257.0	2676.0	1.3071	6.0486	7.3557
110	0.1433	0.001052	1.210	461.1	2518.1	461.3	2230.2	2691.5	1.4188	5.8207	7.2395
120	0.1985	0.001060	0.8919	503.5	2529.2	503.7	2202.6	2706.3	1.5280	5.6024	7.1304
130	0.2701	0.001070	0.6685	546.0	2539.9	546.3	2174.2	2720.5	1.6348	5.3929	7.0277
140	0.3613	0.001080	0.5089	588.7	2550.0	589.1	2144.8	2733.9	1.7395	5.1912	6.9307
150	0.4758	0.001090	0.3928	631.7	2559.5	632.2	2114.2	2746.4	1.8422	4.9965	6.8387

		Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/(kg · K)		
T, °C	p, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
160	0.6178	0.001102	0.3071	674.9	2568.4	675.5	2082.6	2758.1	1.9431	4.8079	6.7510
170	0.7916	0.001114	0.2428	718.3	2576.5	719.2	2049.5	2768.7	2.0423	4.6249	6.6672
180	1.002	0.001127	0.1941	762.1	2583.7	763.2	2015.0	2778.2	2.1400	4.4466	6.5866
190	1.254	0.001141	0.1565	806.2	2590.0	807.5	1978.8	2786.4	2.2363	4.2724	6.5087
200	1.554	0.001156	0.1274	850.6	2595.3	852.4	1940.8	2793.2	2.3313	4.1018	6.4331
210	1.906	0.001173	0.1044	895.5	2599.4	897.7	1900.8	2798.5	2.4253	3.9340	6.3593
220	2.318	0.001190	0.08620	940.9	2602.4	943.6	1858.5	2802.1	2.5183	3.7686	6.2869
230	2.795	0.001209	0.07159	986.7	2603.9	990.1	1813.9	2804.0	2.6105	3.6050	6.2155
240	3.344	0.001229	0.05977	1033.2	2604.0	1037.3	1766.5	2803.8	2.7021	3.4425	6.1446
250	3.973	0.001251	0.05013	1080.4	2602.4	1085.3	1716.2	2801.5	2.7933	3.2805	6.0738
260	4.688	0.001276	0.04221	1128.4	2599.0	1134.4	1662.5	2796.9	2.8844	3.1184	6.0028
270	5.498	0.001302	0.03565	1177.3	2593.7	1184.5	1605.2	2789.7	2.9757	2.9553	5.9310
280	6.411	0.001332	0.03017	1227.4	2586.1	1236.0	1543.6	2779.6	3.0674	2.7905	5.8579
290	7.436	0.001366	0.02557	1278.9	2576.0	1289.0	1477.2	2766.2	3.1600	2.6230	5.7830
300	8.580	0.001404	0.02168	1332.0	2563.0	1344.0	1405.0	2749.0	3.2540	2.4513	5.7053
310	9.856	0.001447	0.01835	1387.0	2546.4	1401.3	1326.0	2727.3	3.3500	2.2739	5.6239
320	11.27	0.001499	0.01549	1444.6	2525.5	1461.4	1238.7	2700.1	3.4487	2.0883	5.5370
330	12.84	0.001561	0.01300	1505.2	2499.0	1525.3	1140.6	2665.9	3.5514	1.8911	5.4425
340	14.58	0.001638	0.01080	1570.3	2464.6	1594.2	1027.9	2622.1	3.6601	1.6765	5.3366
350	16.51	0.001740	0.008815	1641.8	2418.5	1670.6	893.4	2564.0	3.7784	1.4338	5.2122
360	18.65	0.001892	0.006947	1725.2	2351.6	1760.5	720.7	2481.2	3.9154	1.1382	5.0536
370	21.03	0.002213	0.004931	1844.0	2229.0	1890.5	442.2	2332.7	4.1114	0.6876	4.7990
374.136	22.088	0.003155	0.003155	2029.6	2029.6	2099.3	0.0	2099.3	4.4305	0.0000	4.4305