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Ground-Based Solar UV Radiation Monitoring Technique Using Photocell

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Abstract: This paper presents Solar UV radiation monitoring technique using a photo voltaic cell. The data obtained by such technique can be used to calculate the UV index and measure risk of UV exposure. UV irradiance at the surface is affected by the solar elevation, total ozone, clouds, aerosol, surface albedo etc. This paper presents results from the designed instrument to evaluate the UV index. The data obtained from such method will have benefit in installation, maintenance, data transfer and operational cost. This paper highlights the development and initial validation of standard UV data along with the portable embedded device for personalized UV monitoring which is based on a novel programming technique, photo Voltaic Cell as UV sensor, and a microcontroller PIC16F877A. This portable personalized UV monitoring device just provides the tentative UVI as it does not take the depth of ozone layer into account. Rough estimation of UVI can be obtained with such embedded system.

Introduction

Ultraviolet (UV) radiation is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than high energetic radiation like X-rays, lying in the range 10 nm to 400 nm, with energies from 3eV to 124 eV. It is so named because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet. UV light is found in sunlight and is emitted by electric arcs and specialized lights such as black lights. It can cause chemical reactions, and causes many substances to glow or fluoresce. [Navid Amini, Computer Science Department, University of California, Los Angeles, CA 90095, USA A wireless embedded device for personalized Ultraviolet monitoring (cs.ucla.edu)]

The Global Solar UV index (UVI) determines the level of solar UV radiation on the Earth's surface (Maddodi and Setaluri, 2008, HKO (Hong Kong Observatory), 2008). The foremost intention of the UVI is to provide easy concept to the public about the skin damaging UV radiation.

The value of the index ranges from zero and upward while index of '0' corresponds to zero UV irradiation. The higher the index value, the greater is the potential for damage to the skin and eye, and thus lesser is the time for harm to occur. The UV index is an open-ended linear scale as:

$$UVI = k\int_{250}^{400} E.s\,d\lambda$$

where **'E'** is the solar spectral irradiance expressed in W/m^2/nm) at wavelength λ and ***'dλ'*** is the wavelength interval used in the summation. **'s'** is the erythema reference action spectrum, and **'k'** is a constant equal to 40 m^2/W (NOAA-EPA Brewer Network, NEUBrew UVindex.pdf). World

Health Organization as categorized the level of UV in different extent and is summarized in Table 1.

Table 1: UV Index category

UVI	Extent
0-2	Low
3-5	Moderate
6-7	High
8-10	Very High
11,12 and +	Extreme

UVI can be determined with measurement or from model calculations. Two types of measurement techniques are used to calculate the UVI. For the ground based measurement, Spectroradiometers that use the above formula and Broadband radiometers that are calibrated and programmed in order to give UVI directly are used.

The personalized UV monitoring device used in this study is an approach to monitor the UVI for the particular time to provide the indication of strength at any place with an economic way. Solar Radiation and Aerosols in Himalayan Region (SAHR) is monitoring the UV radiation in Nepal installing NILU-UV multi channel radiometer that measures UV irradiances at five channels with center wavelengths at 305, 312, 320, 340 and 380 nm. The channel bandwidths are approximately 10 nm at full width half maximum (FWHM). In addition, the sixth channel measures photosynthetic active radiation (PAR) in the wavelength region 400-700 nm. The optical part of the instrument consists of a Teflon diffuser, silicium detectors and high quality bandpass filters. Implementation of the personalized UV monitoring device is cheap and can be installed in every location of concern. Being a cheap approach to monitor UVI, personalized UV monitoring device can be installed in more cities. Acquiring the data of the intermediate regions would help to develop UVI map of the city or the whole country itself.

Major flaw in forecasting of the UVI of certain large area by the weather stations is due to the difference in the effects of ozone, atmospheric pollutants, and aerosols. This alters UV intensity and it is not taken into account during calculation. This is prominent especially in urban areas. While on the other hand, the forecast does not take into account variable surface reflection (e.g., sand, water, concrete or snow), which can substantially increase individual’s exposure at the mountains, water banks or on snowy-slopes.

Methodology

The NILU-UV radiometer was used to calibrate the personalized UV measurement system developed. The dose rate obtained from the NILU-UV multichannel radiometer is used to calculate the UVI. Thus calculated UVI is the standard UVI for further testing using this instrument.

The hardware and software structure of the proposed personalized UV device are explained in the proceeding subsections.

System Design:

Figure 1 shows the schematic diagram of the personalized UV monitoring device. The UV sensor is the Photo Voltaic (PV) cell. The analog voltage from the PV panel is fed into the microcontroller (PIC16F877A) where analog to digital conversion is done by the analog to digital converter (ADC). The analog voltage fed from the input-output (I/O) of the microcontroller is converted into 10 bits digital signal and the microcontroller calculates the voltage. This calculated digital voltage is stored into the memory of the microcontroller. The system is designed in such a way that the microcontroller takes the voltage from the PV cells at an interval of five minutes and stores the digitized value of the voltage in the memory. The interface between the microcontroller and the computer is done through serial to USB which extract the data stored in the memory of the microcontroller. The application tiny-boot-loader was used to communicate between the microcontroller and the computer (serial to USB communication).

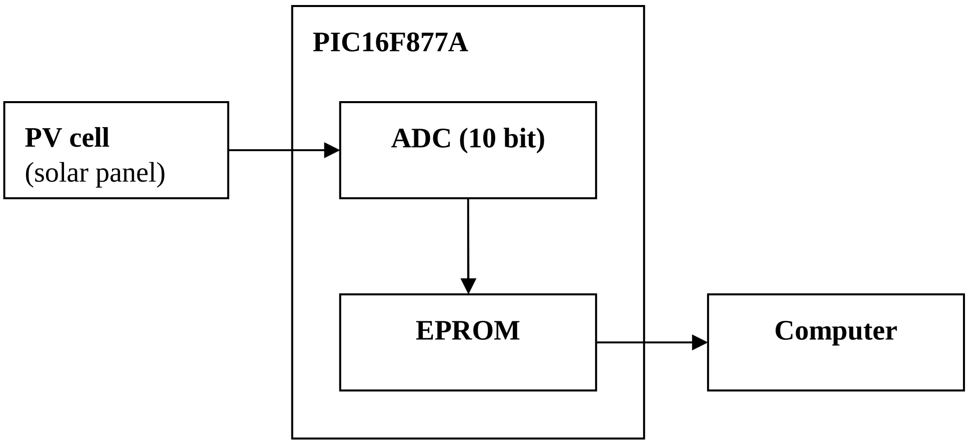


Figure 1

Calibration and Testing:

The output of the personalized UV monitoring system was the voltage taken every five minutes. This personalized system was placed in the premises of the Pulchowk Campus, Institute of Engineering (IOE) where the NILU-UV is installed. The regression line is drawn. Comparing the output voltage from the microcontroller with the standard UVI to get the conversion formula an empirical relation was derived as shown below.

Calculated UVI = $b_1 + b_2 * \text{voltage}$

where b_1 and b_2 are the coefficients of the regression line.

Hence the UVI is calculated using above formula.

Regression Statistics

Multiple R	0.96
R Square	0.91
Adjusted R Square	0.91
Standard Error	0.33
Observations	38.00

	Coefficients	Standard Error
Intercept	0.05	0.13
X Variable 1	4.09	0.21

$$\text{Output UVI} = b_1 + b_2 * \text{voltage}$$

Then the regression coefficients are used to further calculation of UV. The test was carried for two days with different weather conditions and the results are tabulated in appendix.

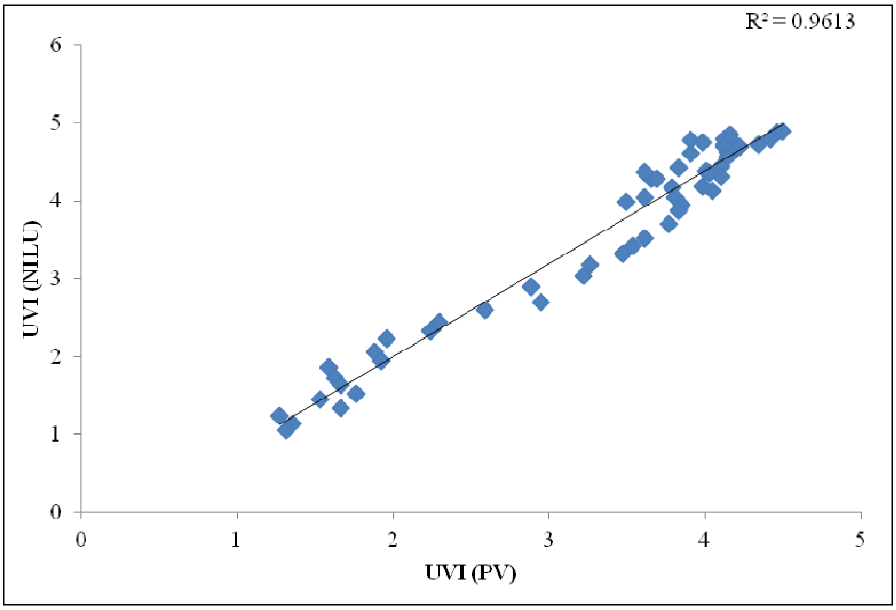
The personalized UV monitoring device was left for testing after its calibration. The error percentage was calculated to determine the efficiency of the personalized UV monitoring device. The test was carried out on different weather conditions, one on the sunny day and the other on the cloudy day. As stated earlier the result gives the indication of the level of UVI since the ozone concentration during calibration and real time measurement will not be same.

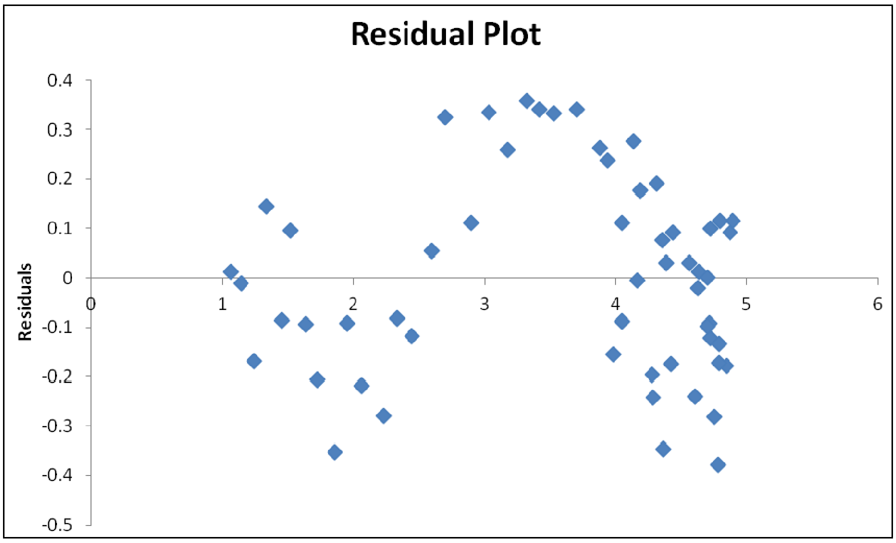
RESULTS

The relation between the voltage provided by the sensor (PV cell) and NILU-UV during calibration is given in table 2 to obtain regression line. The statistics of the data is also shown in the same table. The table below shows the relation between the output voltage with the standard UVI i.e. UVI from the NILU-UV. The table is used to draw the regression line between the voltage and the UVI from the NILU-UV. UVI at a place is calculated every five minutes using the output voltage and the regression coefficients.

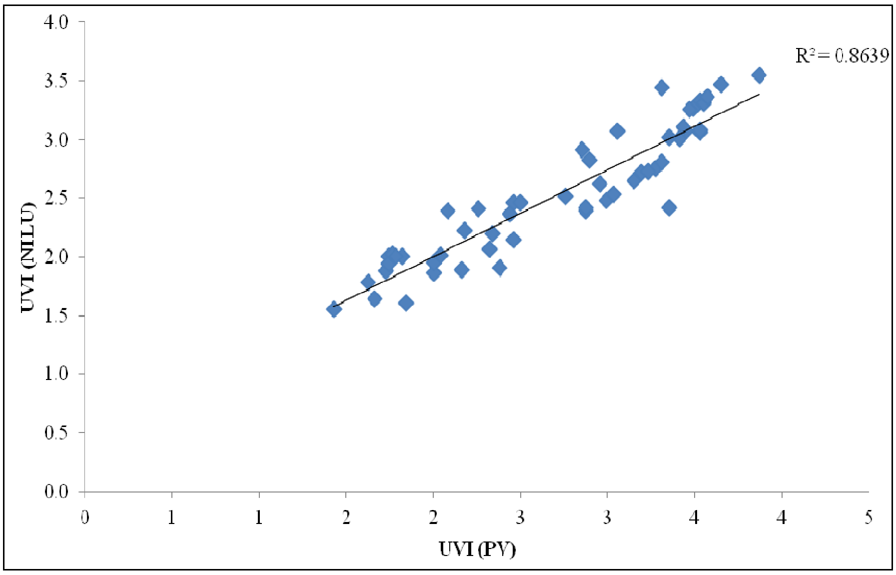
Scatter Diagram and Residual Plot:

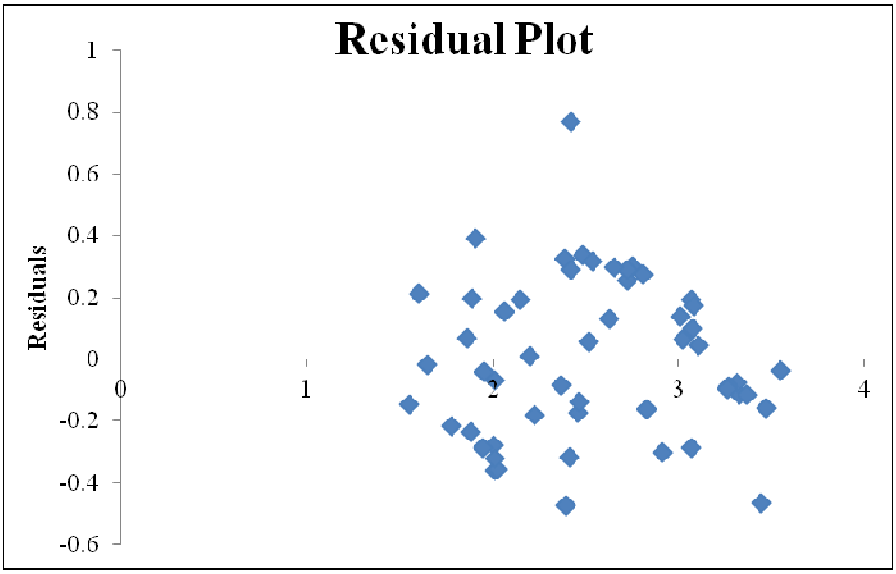
Day 1:





Day 2:





The scatter diagram depicts how much the variable fits to the regressed line. If the residual square is higher, the variables fit to the regressed line. The square of residual of the first test is higher in comparision with the second thus the output of first test is highly correlated with the line of regression.

Whereas the residual plot shows the variation of the variable (UVI-PV) with the average value of UVI. This shows how much the UVI of PV deviates from the average value of UVI. The values of day 1 are less scattered than the day 2.

Conclusion

In this paper we adopt Photo Voltaic Cell as UV sensor to implement a real-time and personalized UV monitoring. The personalized UV monitoring device explained in this stuey can be put on the location of interest. It is not obtrusive and is portable in nature. Since the system is small, economical, it proved to be very feasible.

As the device was implemented in the premises of Pulchowk Campus, IOE, the effect of the ozone layer was not considered in the calculation of UVI. The depth of ozone layer was assumed to be same in the test site throughout the measurement period.

The PV based UVI monitoring device is unable to measure the UVB present in the solar radiation as it got absorbed by the plastic cover present in the PV cell. On the other hand the analog voltage from the PV cell is due to UVA along with some part of visible rays near UVA, which gives the tentative UVI of the site. Thus the UVI calculated is the approximation. Some part of visible rays near UVA provides the sensor the energy that is changed into analog voltage which is roughly near to the energy of UVB missed out by the sensor. Hence the personalized UV monitoring device roughly estimates the UVI at a place.

Since, the personalized UV monitoring device is economical, portable and easy to implement, installation in numerous locations is easy once if a look up table is made for different ozone level. Hence the UVI map of certain location of interest can be generated with the result. This would help to validate the Satellite UV data.

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APPENDIX

Table 2: Calculation of UVI (PV) comparing with UVI (NILU-UV)

Output (HEX)	Output (DEC)	voltage (mV)	Calculated UVI	Standard (dose rate)	standard UVI
cf	207	0.99	4.12	0.11	4.29
d4	212	1.02	4.22	0.11	4.32
d2	210	1.01	4.18	0.11	4.26
d4	212	1.02	4.22	0.10	4.15
d6	214	1.03	4.26	0.10	4.08
d7	215	1.03	4.28	0.10	3.99
da	218	1.05	4.34	0.10	3.97
cd	205	0.98	4.08	0.10	3.93
68	104	0.50	2.10	0.07	2.65
78	120	0.58	2.41	0.07	2.85
68	104	0.50	2.10	0.07	2.79
76	118	0.57	2.37	0.06	2.25
71	113	0.54	2.27	0.07	2.76
71	113	0.54	2.27	0.07	2.69

6f	111	0.53	2.24	0.07	2.61
6f	111	0.53	2.24	0.06	2.52
6b	107	0.51	2.16	0.06	2.51
67	103	0.49	2.08	0.06	2.37
66	102	0.49	2.06	0.06	2.27
64	100	0.48	2.02	0.06	2.21
61	97	0.47	1.96	0.05	2.09
5f	95	0.46	1.92	0.05	1.99
5c	92	0.44	1.86	0.05	1.92
59	89	0.43	1.80	0.05	1.89
53	83	0.40	1.69	0.04	1.76
5e	94	0.45	1.90	0.04	1.67
5c	92	0.44	1.86	0.04	1.66
5d	93	0.45	1.88	0.04	1.54
61	97	0.47	1.96	0.04	1.45
5f	95	0.46	1.92	0.03	1.35
5e	94	0.45	1.90	0.03	1.28
4d	77	0.37	1.57	0.03	1.20
4a	74	0.36	1.51	0.03	1.12
45	69	0.33	1.41	0.03	1.05
39	57	0.27	1.17	0.02	0.99
2c	44	0.21	0.92	0.02	0.91
2d	45	0.22	0.94	0.02	0.83
21	33	0.16	0.70	0.02	0.77

Table 3: Calculation of UVI (PV) corresponding to PV voltage, Day 1

Output (HEX)	Output (DEC)	Voltage (mV)	Calculated UVI	Standard (dose rate)	Standard UVI	% error
af	175	840	3.49	0.10	3.98	12.33
b5	181	868.8	3.61	0.10	4.05	10.80
be	190	912	3.79	0.10	4.16	9.04
b7	183	878.4	3.65	0.11	4.29	14.88
b5	181	868.8	3.61	0.11	4.37	17.34
b9	185	888	3.69	0.11	4.28	13.80
c0	192	921.6	3.83	0.11	4.42	13.50
c4	196	940.8	3.91	0.12	4.60	15.17
cf	207	993.6	4.12	0.12	4.72	12.75

e0	224	1075.2	4.46	0.12	4.88	8.62
e2	226	1084.8	4.49	0.12	4.90	8.19
d1	209	1003.2	4.16	0.12	4.84	14.10
c4	196	940.8	3.91	0.12	4.78	18.23
c8	200	960	3.98	0.12	4.75	16.16
de	222	1065.6	4.42	0.12	4.80	7.92
d0	208	998.4	4.14	0.12	4.71	12.11
cf	207	993.6	4.12	0.12	4.79	13.92
d1	209	1003.2	4.16	0.12	4.79	13.10
d0	208	998.4	4.14	0.12	4.62	10.44
d2	210	1008	4.18	0.12	4.63	9.75
da	218	1046.4	4.34	0.12	4.72	8.10
d4	212	1017.6	4.22	0.12	4.70	10.14
cf	207	993.6	4.12	0.12	4.70	12.23
d0	208	998.4	4.14	0.11	4.56	9.18
ce	206	988.8	4.10	0.11	4.44	7.53
c9	201	964.8	4.00	0.11	4.39	8.76
ca	202	969.6	4.02	0.11	4.36	7.64
ce	206	988.8	4.10	0.11	4.31	4.87
c8	200	960	3.98	0.10	4.18	4.78
cb	203	974.4	4.04	0.10	4.13	2.15
bf	191	916.8	3.81	0.10	4.04	5.85
c1	193	926.4	3.85	0.10	3.94	2.28
c0	192	921.6	3.83	0.10	3.88	1.36
bd	189	907.2	3.77	0.09	3.71	-1.59
b5	181	868.8	3.61	0.09	3.52	-2.46
b1	177	849.6	3.53	0.09	3.42	-3.37
ae	174	835.2	3.47	0.08	3.32	-4.57
a3	163	782.4	3.26	0.08	3.18	-2.58
a1	161	772.8	3.22	0.08	3.03	-6.14
90	144	691.2	2.88	0.07	2.89	0.38
93	147	705.6	2.94	0.07	2.70	-8.95
81	129	619.2	2.59	0.06	2.60	0.34
72	114	547.2	2.29	0.06	2.45	6.16
6f	111	532.8	2.24	0.06	2.33	3.97
61	97	465.6	1.96	0.06	2.23	12.08
5d	93	446.4	1.88	0.05	2.06	8.53
5f	95	456	1.92	0.05	1.95	1.39

4e	78	374.4	1.59	0.05	1.86	14.46
50	80	384	1.63	0.04	1.72	5.58
52	82	393.6	1.67	0.04	1.63	-2.00
57	87	417.6	1.76	0.04	1.52	-16.18
4b	75	360	1.53	0.04	1.45	-5.35
52	82	393.6	1.67	0.03	1.34	-24.73
3e	62	297.6	1.27	0.03	1.24	-2.86
42	66	316.8	1.35	0.03	1.14	-18.73
40	64	307.2	1.31	0.03	1.06	-23.80

Table 4. Calculation of UVI (PV) corresponding to PV voltage, Day 2

Output (HEX)	Output (DEC)	Voltage (Volts)	Calculated UVI	Standard (dose rate)	Standard UVI	% error
a1	161	772.8	3.19	0.07	2.72	-17.29
a5	165	792	3.27	0.07	2.75	-18.93
97	151	724.8	2.99	0.06	2.48	-20.53
ac	172	825.6	3.41	0.08	3.01	-13.24
b2	178	854.4	3.53	0.08	3.07	-15.10
b2	178	854.4	3.53	0.08	3.08	-14.53
b2	178	854.4	3.53	0.08	3.33	-5.98
c3	195	936	3.87	0.09	3.55	-8.90
a7	167	801.6	3.31	0.07	2.81	-17.89
a3	163	782.4	3.23	0.07	2.73	-18.57
a7	167	801.6	3.31	0.09	3.44	3.78
b3	179	859.2	3.55	0.08	3.31	-7.08
a9	169	811.2	3.35	0.06	2.42	-38.49
a9	169	811.2	3.35	0.08	3.02	-10.88
ae	174	835.2	3.45	0.08	3.08	-12.13
b0	176	844.8	3.49	0.08	3.27	-6.69
9f	159	763.2	3.15	0.07	2.65	-18.91
91	145	696	2.87	0.06	2.39	-20.31
b4	180	864	3.57	0.08	3.36	-6.09
99	153	734.4	3.03	0.06	2.53	-19.72
b8	184	883.2	3.65	0.09	3.47	-5.19
78	120	576	2.38	0.05	1.91	-24.62
ad	173	830.4	3.43	0.08	3.11	-10.35

65	101	484.8	2.00	0.05	1.86	-7.43
95	149	715.2	2.95	0.07	2.63	-12.54
91	145	696	2.87	0.06	2.42	-18.70
af	175	840	3.47	0.08	3.26	-6.36
65	101	484.8	2.00	0.05	1.96	-2.36
9a	154	739.2	3.05	0.08	3.07	0.50
92	146	700.8	2.89	0.07	2.83	-2.43
7c	124	595.2	2.46	0.05	2.15	-14.50
5d	93	446.4	1.84	0.04	1.60	-14.96
7c	124	595.2	2.46	0.06	2.46	0.14
75	117	561.6	2.32	0.05	2.06	-12.46
6d	109	523.2	2.16	0.05	1.89	-14.37
90	144	691.2	2.86	0.07	2.91	1.91
69	105	504	2.08	0.06	2.39	13.04
58	88	422.4	1.74	0.05	2.01	13.18
67	103	494.4	2.04	0.05	2.01	-1.44
5c	92	441.6	1.82	0.05	2.01	9.12
52	82	393.6	1.63	0.04	1.78	8.74
8b	139	667.2	2.76	0.06	2.52	-9.45
76	118	566.4	2.34	0.06	2.20	-6.33
57	87	417.6	1.72	0.05	1.88	8.40
58	88	422.4	1.74	0.05	1.95	10.32
72	114	547.2	2.26	0.06	2.42	6.41
6e	110	528	2.18	0.06	2.23	2.11
7e	126	604.8	2.50	0.06	2.46	-1.39
54	84	403.2	1.67	0.04	1.65	-1.14
59	89	427.2	1.76	0.05	2.02	12.73
7b	123	590.4	2.44	0.06	2.37	-3.08
5a	90	432	1.78	0.05	2.01	11.18
48	72	345.6	1.43	0.04	1.55	7.99