TAKING THE "LEED" IN INDOOR AIR QUALITY: DOES CERTIFICATION RESULT IN HEALTHIER BUILDINGS?

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ABSTRACT

Indoor Air Quality (IAQ) has been an area of growing concern with the increasing knowledge of health hazards associated with contaminants, particularly in high occupancy buildings where residents may be exposed to high levels of nuisance dust and other contaminants. Leadership and Energy in Environmental Design (LEED®) certification, which is awarded to buildings that prioritize sustainability and efficient resource use, has been increasingly sought in new construction. As LEED-certified buildings become more commonplace, it is worthwhile to consider whether these new building practices improve IAQ for its occupants. This study compares particulate matter (PM) concentrations in 12 LEED-certified buildings to 12 analogous non-LEED certified buildings on the University of Utah campus. Real-time air sampling was conducted in each building for PM measurements and a Wilcoxon signed rank test was conducted to compare PM levels. A statistically significant difference was found between LEED certification and PM concentrations, with LEED-certified buildings containing, on average, approximately half the PM of their non-LEED counterparts. These findings suggest that LEED certification is worth the financial investment, as it may lead to improved IAQ for residents. However, further research on other contaminants is warranted, including the characterization and comparison of formaldehyde and carbon dioxide levels.

KEYWORDS

Indoor Air Quality (IAQ), Particulate Matter Concentrations (PM), LEED-Certified Buildings, Sick Building Syndrome (SBS)

1. INTRODUCTION

Indoor air quality (IAQ) has become a paramount issue of concern for researchers, legislators, and regulatory bodies worldwide. Poor IAQ has been linked to negative health outcomes, including asthma, allergies, wheezing, and high oxidative stress [1–3]. The World Health Organization characterizes IAQ as particulate matter (PM) in the air in conjunction with several other compounds, including volatile organic compounds (VOC), carbon monoxide

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(CO), radon, and formaldehyde (HCOH) [4]. One key component of IAQ is PM, particularly those particles sized 2.5–10 micrometers in diameter ($PM_{2.5}$, PM_{10}). High concentrations of these particles have been linked to respiratory conditions, pulmonary disease, asthma, and other related conditions [5].While many efforts relating to IAQ have been focused on the home, the US Environmental Protection Agency (EPA) noted an increase in reported health problems resulting from poor IAQ in offices and other high-occupancy buildings [6].

Health effects linked to poor IAQ are estimated to affect up to 60% of workers [7]. One unique health condition associated with poor IAQ is sick building syndrome (SBS), or when building occupants experience location-specific respiratory symptoms and general malaise that cannot be contributed to any specific cause [8]. Among the known culprits of SBS are high concentrations of carbon dioxide, VOCs, bacteria, and PM [9]. Gyntelberg et al. suggested that different elements of IAQ contributed to different symptoms, finding significant correlations between increased levels of PM (i.e., dust) and mucous membrane-related symptoms, as well as with dizziness and malaise [10]. Maintaining IAQ in the service of health can be a complex enterprise, as high levels of respirable dust can become trapped in buildings, while chemical and biological contaminants can enter from indoor sources (e.g., adhesives, copy machines, cleaning agents) or outdoor sources (e.g., motor vehicle exhaust) [11]. High levels of foot traffic and occupancy rates have also been identified as sources of PM and a reduction in IAQ [12].

Several studies have identified appropriate mechanical or natural ventilation as one means of countering SBS [13–15]. Norhidayah et al. found that decreased ventilation rates were more strongly correlated to a prevalence of SBS than the presence of carbon monoxide and fungal particles alone [16]. Regulatory bodies have responded by either legislating ventilation of hazardous workplaces (e.g., nail salons) [17] and by regulating permissible air contaminant levels [18].The EPA has instituted standards for ambient PM_{10} and $PM_{2.5}$, with levels restricted to no more than 150 $\mu g/m^3$ and 35 $\mu g/m^3$ per every 24 hours, respectively [19]. Occupational Safety and Health Administration (OSHA) workplace standards, which are more relevant for workers in high-occupancy buildings, dictate that the 8-hour time-weighted average (TWA) be no greater than 15 mg/m^3 for total particulate matter (i.e., PM of all sizes), and no greater than 5 mg/m^3 of respirable (generally <4 micrometers) particulate matter [18].

One promising avenue towards minimizing SBS and improving IAQ has been the incorporation of "green building" techniques, such as the incorporation of natural ventilation (i.e., windows) and high-efficiency particulate air (HEPA) filters [20, 21]. Green buildings, which seek to use sustainable materials and reduce energy use, are in need of further investigation to see how they may improve individual worker health [22]. Research conducted in this area is often qualitative (i.e., based on self-reported reactions to building and environment), but suggests that green building is linked to improved physical symptoms associated with SBS [23], improved cognitive function [24], and overall job satisfaction [25]. These claims are further supported by studies such as those conducted by Newsham et al. and Hult et al. that have added quantitative components (measurement of PM and VOCs, respectively) [23, 26]. However, in order to truly understand the impact of green building, there remains a need to standardize building practices and conduct extensive monitoring [27].

To standardize green building practices, the United States Green Building Council created the Leadership in Energy and Environmental Design® (LEED) certification [22]. LEED certification is awarded based on building performance in seven areas: indoor environmental quality, sustainable sites, water efficiency, energy and atmosphere, materials and resources, innovation, and regional priority credits [28]. These topics are evaluated and scored to generate an overall score and certification level: Certified, Silver, Gold, or Platinum [29]. However, there can be considerable variability in the design, function, and construction even among LEED buildings that have been scored to the same level of certification. Many elements inherently involved in green building, including increased ventilation, outdoor air delivery monitoring, use of low-emitting materials during construction (adhesives, sealants, paints, etc.), and indoor chemical and pollutant source control either directly or indirectly tend to improve IAQ [30]. LEED buildings also frequently incorporate an IAQ management plan both during construction and before occupancy [31]. However, IAQ measures are not necessary to achieve LEED certification [32], and, as Steinermann et al. notes, the incorporation of green building practices and products may reduce IAQ [33].

Quantitative studies aiming to evaluate one or more aspects of IAQ in LEED buildings have found mixed results. Several challenges exist in monitoring green buildings, including appropriate building pairings, the complex and multifaceted nature of IAQ, and confounding factors of temperature, humidity, and outdoor air conditions. Batterman et al., when comparing CO_2 levels in LEED and non-LEED educational buildings, found that LEED certification in itself was not linked to lower levels [34]. Another study by Stephens et al. that measured ultrafine particulate matter concentrations found that air filters required for LEED certification do reduce PM, but require additional upgrades to see a more profound improvement in air quality [35]. Newsham et al. tested for contaminants (CO_2, ozone levels, formaldehyde) and found lower levels in LEED buildings; however, levels were below required or recommended limits in all buildings [23]. Other studies examining PM levels in green buildings have been mixed in their results. A study conducted by Coombs et al. found that levels of pollutants in low-income housing (including PM, sulfur, VOCs) did not substantially alter following a LEED-certified renovation [36]. Xiong et al. monitored IAQ, including CO_2, PM, and formaldehyde, and concluded that while there was some evidence to LEED buildings to improved IAQ, more rigorous and sensitive sampling methods were needed [37]. Debate regarding the cost-effectiveness of LEED building for improved IAQ continues [38].

However, green building, particularly LEED-certified building, continues apace. One example of this is the University of Utah, a R1 university located in Salt Lake City, which requires all new buildings costing over $2.5 million required to achieve at least Silver LEED certification [39]. While this policy supports the university's goals of sustainability, associated costs with LEED certification can range from $20,000–$60,000 [40]. At the time of this writing, the University of Utah had 17 LEED-certified buildings (one Platinum, eight Gold, six Silver, and two Certified) [41]. With the costs associated with achieving this on the university campus, it bears questioning if certification results in healthier buildings for occupants.

For the purposes of this pilot study, researchers chose to focus solely on PM levels, with the eventual goal of developing this research into a more comprehensive study of IAQ. Indoor PM levels in matched LEED-certified and non-LEED-certified buildings at the University of Utah were examined. The hypothesis was that there would be significantly lower PM levels in LEED-certified buildings compared to non- LEED certified buildings of a similar size and type.

2. METHODS

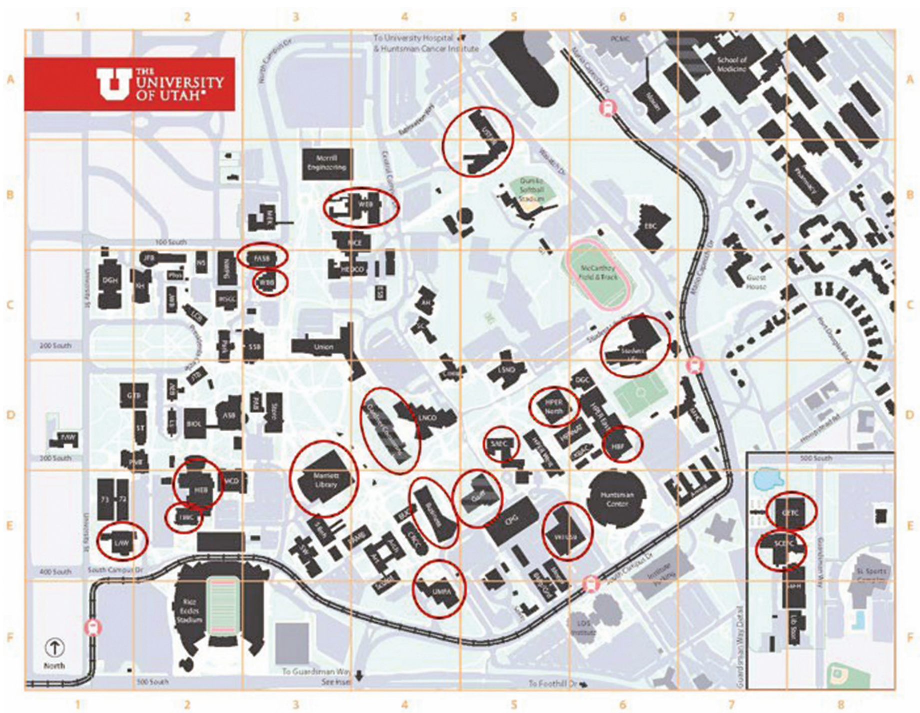
In order to accurately compare PM levels in LEED and non-LEED buildings, buildings were selected in order to minimize potential confounding from differences in use, size, location and

FIGURE 1. Two analogous building pairs: the Utah Museum of Fine Arts (non-LEED) and the Utah Natural History Museum (LEED) [42, 43].

elevation. The buildings monitored in the study were located on both the main and (adjacent) health sciences campuses of the University of Utah. Buildings were paired according to function (e.g., museum, educational building, recreation facility, etc.) and similar size. See Figure 1 for an example of paired buildings.

Given that 5–10 samples from each similar exposure group (SEG) is generally considered sufficient for initial assessments [44], the researchers decided to select 12 pairs of buildings (24 buildings in total) to substantiate any statistical significance found. As the size of the University

FIGURE 2 University of Utah main campus map. Locations sampled are circled [46]. Not depicted are five other buildings located in the Health Sciences area (top righthand of map).



MAIN CAMPUS AREA

FIGURE 3. TSI DustTrak II Aerosol Monitor 8532.

of Utah campus is 1,535 acres [45], proximate locations were chosen for each building pair to minimize confounding. See Figure 2 for building positions on campus.

The pairing strategy (choosing analogous locations) was also utilized for the places inside the buildings where sampling was performed. Wherever the sampling was done in the LEED-certified building, it was performed in an analogous location of the comparison building. Lobbies/reception areas were the most common location, followed by classrooms, then open study areas.

Due to the decision to focus on proximity and function, several factors were not paired between the buildings, including the level of LEED certification, design variation (e.g., number of windows), and the presence of any renovation activities (present in one building alone).

Particulate concentrations were quantified using the TSI DustTrak II Aerosol Monitor 8532 (TSI, Shoreview, MN). This device provides a real-time particulate concentration of particles with diameters between 1 and 10 micrometers (i.e., essentially equivalent to PM_{10}); however, it does not differentiate between these sizes. The aerosol monitor's fan draws in air and collects it in the optics chamber to expose it to a light-scattering laser photometer that provides a particulate concentration [47]. The monitor is depicted in Figure 3.

The monitor was placed on an elevated surface (e.g., counter, table, desk) to position the sampling port within a typical human breathing zone. For each 10-minute sampling period, the monitor provided a readout of three values: a minimum, maximum, and an averaged total concentration. All three values were recorded manually in Microsoft Excel. Real-time samples were taken between 10/9/18 and 10/16/18, with one additional day of sampling on 10/31/18.

The time of day in which sampling took place varied according to building location and convenience, but was concentrated in the afternoon hours between 1:30 to 5:00 p.m. The earliest sampling start time was 10:15 a.m., and the latest was 5:15 p.m. Initially, the study design had included only one sampling period of ten minutes. However, following the sampling of the first four pairs of buildings, the decision was made to obtain two 10-minute sampling periods per building in order to obtain data that would be more representative of building inhabitant activity. The first four buildings were then sampled a second time, so that each building was sampled twice.

PM levels in LEED-certified buildings were compared with those of the non-LEED-certified buildings through several statistical analyses. Descriptive statistics were analyzed using Microsoft Excel (Microsoft, Redmond, Washington) and inferential statistics were calculated in SAS (SAS Institute, Cary, North Carolina). Initial calculations included measures and comparisons of measures of central tendency for each population. Assessment of normality was performed using Microsoft Office's Excel statistical package.

As the data were found to not be normally distributed, the non-parametric equivalent to a paired t-test, the Wilcoxon Signed-Rank test, was used to assess whether there was a difference between the PM in the LEED and non-LEED buildings. This was calculated using Statistical Analysis Software (SAS, Cary, NC).

3. RESULTS

A total of 24 buildings, 12 LEED-certified and 12 non-LEED-certified, were assessed. All but two of the pairings shared proximity and function; in the case of the museums (Pairing 1), function was prioritized over proximity, while in Pairing 5, proximity was chosen over function. See Table 1 for a complete list of LEED and non-LEED-certified buildings, their function, and LEED certification (if applicable).

The vast majority of sampling (88%) occurred between the afternoon hours of 1:30–5 p.m. Most buildings (58%) were sampled between the hours of 2 and 4 p.m. Measurements prior to 1 p.m. (i.e., after 11:00 a.m.) were taken only in Pairings 1 and 2, and in both cases were accompanied by a set of measurements taken after 1 p.m.

All buildings were sampled twice. As none of the data were corrupted, and there were no apparent outliers, each measurement was included in the study (48 total data points). As the study was conducted over fall break for the University of Utah, inhabitant activity was generally minimal (chiefly constrained to staff and a few faculty members). Average foot traffic per building (based on visual observation) was eight people per sampling period. The means, medians, modes, as well as the maximum and minimum airborne particulate concentrations across all buildings, LEED-certified, and non-LEED-certified, is depicted in Table 2.

Note that the average concentration in non-LEED-certified buildings was found to be almost double that of their LEED-certified counterparts. The paired sample comparison can be seen in Figure 4.

The data were tested for skewness and found to be positively skewed with a value of 1.46. The SAS output provided a Signed-Rank test statistic of 66 with a p-value of 0.0025. Given the p-value of 0.0025 was meaningfully less than the alpha level of 0.05, the null hypothesis was rejected, which indicates the difference between the mean particulate concentrations is significant.

TABLE 1. LEED-certified and non-LEED-certified buildings with their certification levels.

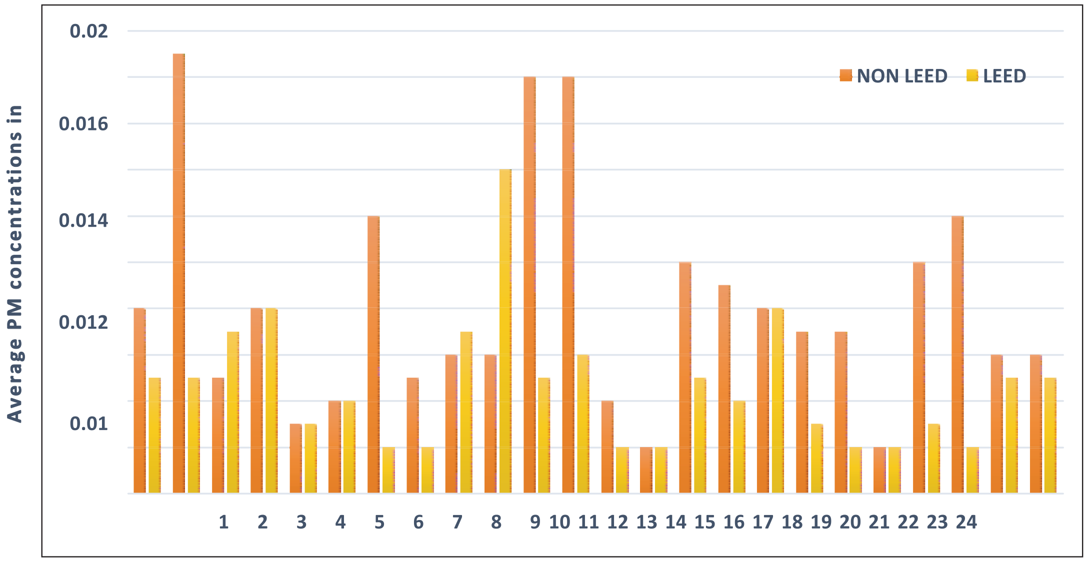
Pairing Number	LEED-certified building name	Level of Certification	Non-LEED-certified building name	Function
1	Utah Natural History Museum	Gold	Utah Museum of Fine Arts	Museum
2	Jon M. and Karen Huntsman Basketball Facility	Gold	HPER north	Recreation
3	Spencer Fox Eccles Business Building	Silver	J. Willard Marriott Library	Library
4	Beverley Taylor Sorenson Arts and Education Complex	Silver	Garff Executive Education Building	Education
5	V. Randall Turpin Building	Gold	George S. Eccles Student Life Center	Education/ Recreation*
6	Thatcher Building for Biological and Biophysical Chemistry	Silver	Henry Eyring Chemistry Building	Education
7	S.J. Quinney College of Law	Platinum	Ken and Carolyn Gardner Commons	Education
8	Spence and Cleone Eccles Football Center	Silver	George S. Eccles Tennis Center	Recreation
9	Frederick Albert Sutton Geology Building	Gold	William C. Browning Building	Education
10	James LeVoy Sorenson Molecular Biotechnology	Gold	John and Marva Warnock Engineering Building	Education
11	Ray and Tye Noorda Oral Health Sciences Building	Silver	Dumke Health Professionals Education Building	Education
12	Eccles Health Sciences Education Building	Certified	Eccles Institute of Human Genetics	Education

* indicates building pairing that was chosen by proximity rather than similar function.

TABLE 2. Descriptive statistics for samples from LEED (n = 24), non-LEED (n = 24), and all buildings (n = 48).

	LEED-Certified mg/m^3	Non-LEED-Certified mg/m^3	All Buildings mg/m^3
Mean	0.005	0.008	0.006
Median	0.005	0.007	0.005
Mode	0.002	0.006	0.002
Min	0.000	0.010	0.000
Max	0.120	0.259	0.259

FIGURE 4. Particulate concentrations in paired samples of LEED and non-LEED-certified buildings. Each bar represents a 10-minute sampling period. Analogous building pairs are positionally juxtaposed.



4. DISCUSSION

The particulate measurements in the LEED-certified buildings were observed to be significantly less, on average, than the non-LEED-certified comparison buildings. This marks a departure from previous research, which found mixed results in comparative tests [36] or inconclusive results in a case study [37]. The focus on IAQ and individual health is also comparatively novel, particularly in its focus on quantifying air pollutants. Much of current literature on LEED-certified buildings centers around general issues of sustainability and worker comfort rather than the presence or absence of contributing factors to IAQ. As PM is considered to be a significant contributor to reduced IAQ and subsequent adverse health effects, this finding is well-worth additional investigation.

This study was the first of its kind conducted on this particular university campus and had several strengths in its design. In order to minimize confounding, buildings in close proximity to each other were selected. Furthermore, the categorization of the buildings (e.g. museum to museum) ensured that similar building use, foot traffic, and air flow would be controlled for.

Previous research has suggested that building inhabitant activity may be a more substantial contributor to PM than building design [36]. Therefore, the fact that the buildings were sampled over fall break, resulting in lower foot traffic across all buildings, was a strength. Furthermore, the number of buildings chosen for sampling ensured the validation of the statistical significance of the findings.

However, one factor to consider is that one of the non-LEED-certified buildings, the Garff Executive Education Building, during the time of sampling, was still under renovation (the addition of a café). While sampling was conducted at a position removed from the renovation, the additional construction likely raised the particulate concentration in the building overall.

This building presents a quandary: as the construction in the building is new, it is likely similar to other LEED-certified buildings, but renovation creates additional particulate matter within the building.

One difficulty in studying LEED-certified buildings is the difference between buildings in terms of certification levels. Furthermore, levels of certification are not necessarily an accurate indicator of positive IAQ interventions, as even the Bronze level can be achieved without taking any measures in that area. One LEED building did present with higher concentrations of PM; this building was renovated to obtain LEED certification, with only nine of seventeen possible IEQ points attained [48]. It is possible that there is a notable difference between new construction and renovation in terms of IAQ improvement. Controlling for this factor would help eliminate confounders.

Longer sampling times might improve the generalizability of results; an eight-hour sampling period could possibly produce a larger data set and a more accurate reflection of how PM concentrations change over the course of a day and in response to greater numbers of building occupants. In addition, the time of year (October) was such that environmental temperatures were still fairly moderate; a study that measured indoor PM concentrations during weather conditions that would necessitate greater air circulation may well produce different results.

Another meteorological factor that might influence PM include relative humidity, which can affect how quickly PM settles out of breathing zones [49]. Furthermore, the study focused only on PM rather than a general assessment of IAQ. The inclusion of other IAQ indicators (e.g., CO_2, formaldehyde, etc.) should also be included in future studies to provide a broader understanding of how LEED certification affects building environmental quality.

Future research should take steps to address these limitations by conducting 8-hour and/or 24-hour sampling in all four seasons. In order to account for atmospheric pressures and local ambient PM levels, researchers should also consider the possibility of a multi-campus study. Another possible avenue for research would be to differentiate between LEED-certified buildings that specifically incorporated positive IAQ recommendations and those that did not. However, the significantly different PM levels observed in this study speak to the need for future studies, especially as LEED certification is currently being pursued in new construction across education, government, and industry.

5. CONCLUSION

This study compared particulate matter levels in analogous LEED and non-LEED-certified buildings on a university campus. Descriptive and inferential statistics suggest that PM levels in certified buildings are statistically significantly lower than those of non-certified buildings, with PM levels in the non-LEED buildings approximately twice as high as those measured in their LEED counterparts. These findings suggest that the current hypothesis that LEED buildings decrease PM presence and adverse worker health effects is likely one to consider in future studies.

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7. APPENDIX A: WILCOXON SIGNED RANKS CRITICAL VALUE TABLE [50].

	alpha values						
n	0.001	0.005	0.01	0.025	0.05	0.10	0.20
5	--	--	--	--	--	0	2
6	--	--	--	--	0	2	3
7	--	--	--	0	2	3	5
8	--	--	0	2	3	5	8
9	--	0	1	3	5	8	10
10	--	1	3	5	8	10	14
11	0	3	5	8	10	13	17
12	1	5	7	10	13	17	21
13	2	7	9	13	17	21	26
14	4	9	12	17	21	25	31
15	6	12	15	20	25	30	36
16	8	15	19	25	29	35	42
17	11	19	23	29	34	41	48
18	14	23	27	34	40	47	55
19	18	27	32	39	46	53	62
20	21	32	37	45	52	60	69
21	25	37	42	51	58	67	77
22	30	42	48	57	65	75	86
23	35	48	54	64	73	83	94
24	40	54	61	72	81	91	104
25	45	60	68	79	89	100	113
26	51	67	75	87	98	110	124
27	57	74	83	96	107	119	134

	alpha values						
n	0.001	0.005	0.01	0.025	0.05	0.10	0.20
28	64	82	91	105	116	130	145
29	71	90	100	114	126	140	157
30	78	98	109	124	137	151	169
31	86	107	118	134	147	163	181
32	94	116	128	144	159	175	194
33	102	126	138	155	170	187	207
34	111	136	148	167	182	200	221
35	120	146	159	178	195	213	235
36	130	157	171	191	208	227	250
37	140	168	182	203	221	241	265
38	150	180	194	216	235	256	281
39	161	192	207	230	249	271	297
40	172	204	220	244	264	286	313
41	183	217	233	258	279	302	330
42	195	230	247	273	294	319	348
43	207	244	261	288	310	336	365
44	220	258	276	303	327	353	384
45	233	272	291	319	343	371	402
46	246	287	307	336	361	389	422
47	260	302	322	353	378	407	441
48	274	318	339	370	396	426	462
49	289	334	355	388	415	446	482
50	304	350	373	406	434	466	503

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