Benefits of Adjustable Speed Fans for Bulk Potato Storage Ventilation Systems

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Introduction

Potato storage facilities require air movement through the pile of potatoes to remove field heat immediately after harvest, to control humidity and to remove the products of respiration during the storage period. Traditionally, banks of single speed fans have been used to circulate air through the pile. The highest ventilation rate is required at cool down after harvest, thus the fan capacity is sized to this requirement. In Wisconsin, fans are typically sized at 20 cubic feet per minute (cfm) per ton of potatoes. Once the potatoes are cooled to storage temperature, the ventilation requirement is significantly less, but since the fans were sized for cool down, the ventilation rate is much higher than necessary. Traditionally the ventilation rates have been reduced by cycling fans on and off for periods of several hours during the day to reduce ventilation and energy costs. A typical schedule might be operating the fans for 6 hours followed by a period of 6 hours with no ventilation.

Adjustable speed fan controls can be used to reduce ventilation rates after field heat has been removed so potatoes are not over ventilate. As the ventilation rate is reduced with an adjustable speed controller, the energy consumption is also reduced as a function of the cube of the fan speed. A 1995 study in Maine of potato storage ventilation estimated a 55-60% energy savings was possible with adjustable speed fans. A recently completed study in Idaho reported energy savings ranging from 33% for potatoes stored for 60 days, up to 45% energy savings for potatoes stored more than 125 days. Other data from storage facilities in Idaho indicated savings of up to 60% with the use of adjustable speed fans. All studies indicated no loss in the quality of the potatoes. During a presentation at the Wisconsin Potato and Vegetable Growers Annual meeting in 2003, University of Idaho researcher, Gale Kleinkopf, suggested that a low constant air flow was likely more desirable than periods of high air flow followed by periods of no air flow. This is possible with the use of an adjustable speed fan controller while also getting significant reduction in electric costs. The weather conditions at harvest are slightly different in Wisconsin than in Idaho and Maine and the building layouts and air distribution systems may also be different than other potato growing regions. In the fall of 2004 with the cooperation of a Wisconsin grower, a study was undertaken to replicate the Idaho study (Oberg and Kleinkopf - 2004) to determine if the Idaho study findings would apply to Wisconsin's potato storage facilities. This paper will summarize the results.

Objective

The study had two objectives. First, compare the energy use of two identical storage facilities, one with the traditional constant speed fans and another storage bin with adjustable speed fans. The second objective was to determine if there was any difference in the shrinkage losses (mass loss of the potatoes) between the different air handling systems.

Facility Description
The storage facility used had two air handling systems each with two 25,000 hundred weight storage bins (four bins total). Each bin was 46.5 feet wide by 95 feet long at the base and had outside walls along the bin length (95-foot) that sloped inward so the bin got narrower as the height increased. The air handling systems were on opposite ends of the building and independent from each other. Each air plenum ran half the length of the building with the bins on each side of the plenum. The air was distributed into the potatoes through culverts that were laid on the floor as the bins were filled with potatoes. The culverts had two rows of vent holes about 60 degrees apart. When the culverts were positioned on the floor, the air vents were facing the floor with one row on either side of the contact point with the floor. The culverts fit into access holes at the base of the air plenum and extended into the potatoes approximately 42 feet of the 46.5-foot width of the bin. The rows of culverts were spaced at 8-foot increments with the first one starting 3 feet from the end wall. The potatoes were piled 16 feet high except at the door end where the pile was sloped down to approximately 10 -12 feet high against a 12-foot high bulkhead wall. The air was supplied to the piles by two 10 HP, 230 volt 3-phase fans with a combined capacity of 57,000 cfm at a static water pressure of 1.5" in both air handling systems. This would result in an air flow of 22.8 cfm per ton of potatoes. One system, bins 63 and 64, was outfitted with a Danfoss VLT 6000 series adjustable speed drives to allow for the adjustment of fan speeds. The fans operational time and air intake louvers position for fresh air were controlled by an Industrial Ventilation, Inc. control panel (Nampa, Idaho). The stored potatoes were a Russet Norkotah variety harvested and put into storage between September 23 and September 26, 2004. The potatoes were held until mid-May when the first bin was unloaded for marketing. Bin 64 was emptied between May 17 and 19, Bin 63 was emptied starting on May 19 and was finished on May 24, Bin 58 was emptied June 6 and 7, while bin 57 was emptied June 8 and 9.

Procedure
Shrinkage Monitoring
Shrinkage losses were determined by placing bags of potatoes of known weights in a grid pattern in the potato pile as the bins were filled and then retrieving the bags and re-weighing them when the bins were unloaded. Red mesh onion bags (11.5" x 19" with a drawstring, weighing an average of 14.6g per bag) were filled with approximately 10 pounds of potatoes and weighed before going into storage. Potatoes used to fill the bags were randomly selected from the conveyors as the potatoes entered the building. The only screening done in selecting potatoes was to not knowingly use potatoes that were already exhibiting visible rot or were grossly formed. Bags were filled as needed so potatoes from different field locations were selected. The average gross weight of the bags was 4763g (10.50 lbs.) with a range of 4391g (9.68 lbs.) for the lightest to 5336g (11.76 lbs.) for the heaviest sample. A plastic numbered auction tag (3" x 2.5") was placed inside each bag for identification and the bag was tied shut. The bags of potatoes were weighed on a Mettler-Toledo PL6000-S gram scale entering storage and on a Mettler PM6 scale upon being removed from storage. Both scales have a capacity of 6 kg with a resolution of 0.1g. Weights were recorded to the nearest whole gram. There is dirt on the potatoes that readily falls off onto the scale platform so the scale was cleaned and re-tare often. The bags of potatoes were placed in the pile of potatoes in a grid pattern that had three levels with 24 bags per level. The levels used were 3 feet, 8 feet and 13 feet from the floor. At each level the 24 bags of potatoes were arranged in 4 rows across the width of

the bin by 6 rows down the length of the bin. The rows across the width were placed 5 and 17 feet from the side walls based on measurements at the floor level. Therefore the bags along the outside wall were closer to the outside wall at the 13-foot level than at the 3-foot level because of the inward sloping wall. The rows down the length of the bin were placed at 5, 17, 39, 56, 73 and 88 feet from the back wall of the bin with the exception of the 13-foot level where the last row of bags were placed at 80 feet instead of 88 feet due to the pile sloping downward to the bulkhead wall. If they had been placed at 88 feet they would have been on top of the pile and exposed in the outer rows along the side walls. The gross weight of the bag and the location in the pile were recorded as bags were placed into storage. The bags of potatoes coming out of storage were collected and set aside in the storage building by the grower and were weighed within 24 hours of being removed from the pile. The bags were weighed as found unless they had excessive caking of dirt on the bag, in which case the dirt was gently removed from the mesh bag as best possible before weighing. A few bags had visible water on the potatoes or bag so they were allowed to dry for up to 30 minutes before weighing. Seventy two bags were placed in each of the four bins, and 71 bags were successfully retrieved from 3 bins and 69 from the fourth bin. Reasons for losses included holes in bags, un-tied and rotted potatoes in two cases.

<u>Energy Monitoring</u>

Energy was monitored using HOBO U12 4-channel data loggers (part no. U12-008) with 100-amp (part no. CTV-C) current transformers. The 100-amp current transformers were used on two of the three wires feeding each of the 10 HP 3-phase fans when the project was set up. After more than a month of problems with the data logger on Bins 63 and 64, the data logger was replaced and moved to a different position away from the control panel. At that time the 100-amp current transformers were replaced with 50-amp units (part no. CTV-B) and only one wire lead was monitored from each fan. Amperage data was collected every 15 minutes in both air handling systems.

<u>Environmental Monitoring</u>

The air temperatures and relative humidity (RH) was measured at various locations in the air handling system. The temperature of the potatoes and air temperatures in the plenum and the return air flow were measured. The relative humidity of the return air flow was also measured.

To collect environmental data, we used a HOBO Micro Station Logger (part no. H21-002) equipped with a combination temperature/RH sensor (part no. S-THA-M017) and two 12-bit temperature sensors (part no. S-TMB-M017). The temperature/RH sensor was used in the return air flow and had a resolution of 0.4°C (0.7°F) for temperature readings and 0.5% for RH and an accuracy of +/- 0.7°C (1.3°F) and +/-3% RH. The temperature/RH sensor was hung from the railing of the catwalk between the two bins, facing down so moisture or dirt could not fall directly onto the sensor. The 12-bit temperature sensors were used for measuring plenum air and potato temperatures and had a resolution of 0.03°C (0.054°F) and an accuracy of +/-0.2°C (0.36°F). The temperature of the potatoes was measured in one bin for each air system by burying a temperature sensor in the potatoes about 30 feet from the bulkhead wall and 3 to 5 feet from the plenum wall about 3 to 4 feet above the floor. The plenum temperature sensor was placed about 40 feet from the fans at a height of about 8 feet hanging in the air stream. The relative humidity sensor has a wide accuracy range and was being used at the extremes of its limits to provide accurate readings. The relative humidity readings were being used to look for gross differences between the air handling systems rather than absolute values. Temperature data was collected every 15 minutes.

Storage Management

The management of the air handling system was controlled by the grower with no limitation. The grower kept a written log of changes in set-point temperatures, fan speeds, air temperatures, potato temperatures, ozonation and supplemental refrigeration from October to April.

Results

Data Acquisition

As mention earlier, problems were experienced with the HOBO U12 data loggers in bins 63 and 64 recording amperage draw. No useable data was collected until November 18, 2004. During this period the ventilation system controller only runs the fans when the outside air temperatures are cooler than the potatoes. An additional storage facility (bin 66) with an adjustable speed fan was being monitored that is not included in this study. Comparing the hours of fan operation of bins 57 and 58 to bin 66, the difference was 10 hours for the 50 day period of operation or 12 minutes per day. This difference is less than the sampling rate, so using the fan operation profile from bins 57 and 58 and adjusting the motor amperage draw based on the percent speed recorded on the bin data sheet was considered a good approximation of the lost data. A demand curve was recorded before the bin was unloaded so the amperage draw was known for the percent speed setting on the adjustable speed drive (ASD) control. See Table A in the appendix. Another data logger failure occurred in bins 63 and 64 from April 12 until the bins were unloaded in mid-May. There was not sufficient data to estimate the energy usage during this period and therefore was omitted from the study.

Energy Savings

According to the fan laws, the air flow output of a fan is directly related to its rpm (revolutions per minute). Therefore if the fan rpm is half, then the fan output is half. The energy to power a fan, according to the fan laws, is the cube of the rpm. Therefore

$$HP_2 = (RPM_2/RPM_1)^3 \text{ x } HP_1$$

where subscript 1 represents the fan operation at full speed and subscript 2 represents the fan operation at a reduced fan speed. The power consumption is reduced to 42% at 75% of full speed and 13% power draw at 50% of rated fan speed. Table 1 indicates the percent of full speed power a fan will use at different speeds when controlled with an ASD. It is not recommended that motors be operated at less than 30% of rated speed due to excessive heat build up. The ASD will consume about 2 to 3% of rated load to operate, so at full rated load, an application with an ASD will consume 103% of the power needed if an ASD was not used.

An adjustable speed drive is a computerized electronic device that can change the speed of 3-phase motors. The cost of these devices once only made sense for high value operations, but due to reductions in the costs of computer and micro processors, adjustable speed drives (ASD) are now economical for many different applications. For potato storage facilities, ASD are typically manually adjusted as the facility manager sees the need.

Table 1 – Power Demand as a Function of Fan Speed

Percent of full speed	100%	95%	90%	80%	70%	60%	50%	30%
Percent of full load power	103%	86%	73%	51%	34%	22%	13%	3%

Amperage values were recorded by the data logger along with a date and time stamp. The voltage for the system was measured at 240 volts, 3-phase. Power factor was not measured but was assumed to be similar for both systems and was omitted from power calculations. The data was transferred to a spreadsheet and the power demand and energy usage calculated using equation #1 and #2.

1) Power Demand (KW) = amperage x voltage x [square root(3)]/1000

2) Energy Usage (kWh) = power demand x time (hrs)

The power consumption for each time stamp was calculated assuming the power draw was constant since the last data measurement. The energy data from bins 57 and 58 and bins 63 and 64 was grouped by month starting on October 1, 2004 through April 12, 2005. The power demand and energy consumption was compared on a monthly basis. The maximum demand for each month was used for the comparison since peak demand charges by the utilities are generally based on the maximum 15-minute peak period in any billing period.

Tables 2 and 3 below are summaries by month of hours of fan run times, percent of hours fans operated per month, energy use in kWh and peak demand month by month for bins 57 and 58 with a constant speed fan and bins 63 and 64 with adjustable speed fans.

Table 4 summarizes the differences between the two air handling systems. The manager of the storage facility ran the adjustable speed fans 1296 ***more*** hours than the constant speed fans yet the ASD reduced energy use by 63% over the storage period of October through mid-April. The months with the largest energy savings were the winter months of January, February and March. The month with the least energy savings was October during cool down, but the ASD still provided a 27% savings in energy costs. The cost savings in electrical energy cost for bins 63 and 64 was $2083 from October through April compared to bins 57-58. The demand savings was also significant. Once the potatoes reached the storage temperature of 40°F, the fans were run at 50% speed, providing 0.5 cfm per hundred weight and drawing only 3.5 to 4.4 KW, a savings of over 23 KW compared to using constant speed fans. During the study period the demand reduction ranged from 4.9 KW in October to 25 KW in February. The reduction in demand charges amounted to $1235 for a total cost savings of $3272 for this one air handling system. The approximate installed cost for adjustable speed drives for a potato storage bin is between $ 150 and $200 per horsepower. Based on this range the ASD would cost between $3000 and $4000 total to control the two 20 hp fans for bins 63 and 64. Assuming the energy savings will pay for the capital investment, the payback is 0.9 to 1.25 years.

Table 2 – Energy Data – Bins 57 / 58 – Constant Speed Fans

	Fan Run Time (hours)	Monthly Fan Run Time (%)	Energy Use (kWh)	Demand (KW)
Oct 2004	469	63	12242	27.7
Nov 2004	456	61	12328	28.5
Dec 2004	356	48	9716	29.4
Jan 2005	365	49	10103	28.8
Feb 2005	335	45%	9263	28.7
March 2005	490	66%	13513	28.5
April 2005 #	125	46%	3441	28.9

- data from April 1 to April 12, 10:07 AM

Table 3 – Energy Data – Bins 63 /64 – Adjustable Speed Fans

	Fan Run Time (hours)	Monthly Fan Run Time (%)	Energy Use (kWh)	Demand (KW)
Oct 2004	469	63%	8842	22.8
Nov 2004	534	74%	4709	12.9
Dec 2004	734	99%	4140	7.1
Jan 2005	744	100%	2613	4.6
Feb 2005	650	97%	2181	3.7
March 2005	633	85%	2130	3.7
April 2005 #	128	47%	1686	19.1

- data from April 1 to April 12, 10:07 AM

Table 4 – Energy data – Summary of Differences between Bins 57 / 58 and Bins 63 / 64

	Fan Run Time Difference		Energy Savings		Cumulative Energy Savings		Demand Reduction	
	(Hours)	(%)	(kWh)	(%)	(kWh)	(%)	(KW)	(%)
Oct 2004	0	0	3400	27.8	3400	28	4.9	18
Nov 2004	78	13	7619	61.8	11019	45	15.6	55
Dec 2004	378	51	5576	57.4	16595	48	22.3	76
Jan 2005	379	51	7490	74.1	24085	54	24.2	84
Feb 2005	315	52	7082	76.5	31167	58	25	87
Mar 2005	143	19	11383	84.2	42550	63	24.8	87
Apr 2005 #	3	1	1755	51.4	44305	63	9.8	34
Totals	1296	28	44305	62.8				63

- data from April 1 to April 12, 10:07 AM

Table 5 shows the date, percent speed of the fans and average potato temperature as recorded by the grower’s control system to give a sense of how the fan speeds were managed. Figure 1 shows the same information graphically.

Table 5 – Bins 63 / 64 – Fan Speed Changes

Date	Sept 24	Sept 29	Oct 1	Oct 15	Oct 27	Nov 2	Nov 22	Nov 29	Dec 14	Dec 22	Jan 5	April 6
Potato Temp (°F)	loading	-	56.7	55.9	53.2	51.9	44.7	44.0	42.6	42.6	42.0	44.9 Refr.
Fan Speed	50%	75%	98%	90%	75%	65%	80%	65%	60%	55%	50%	90%

Refr – Supplemental refrigeration turned on

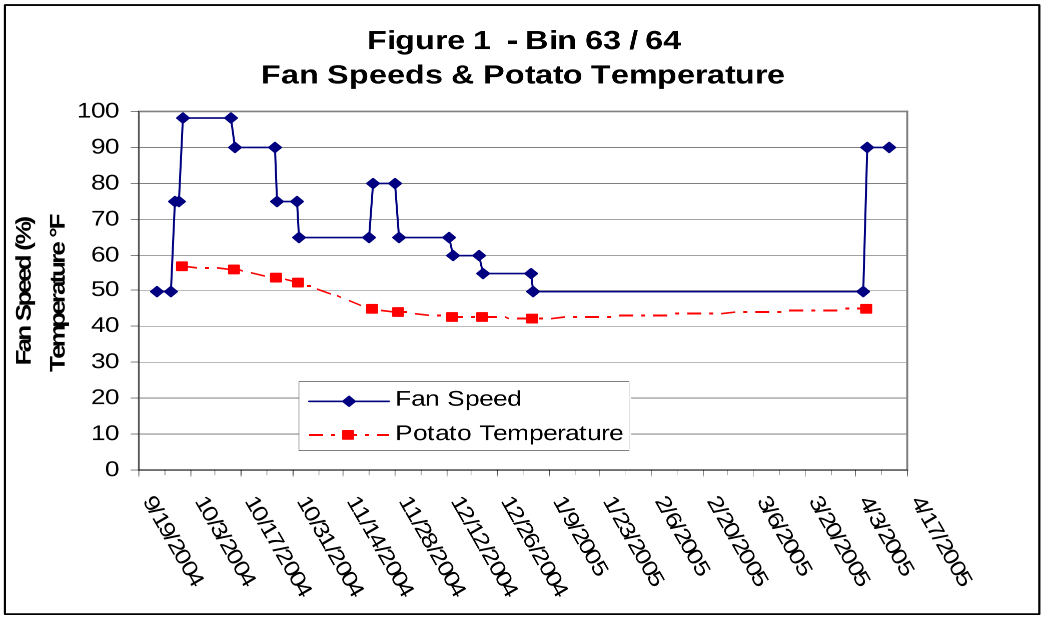

Table 6 indicated the average period length fans were running, average period length fans were off and percent of time per month fans were operated in bins 57 and 58.

Table 6 – Bins 57 / 58 – Fan Operational Mode Profiles – Monthly Averages

	Average Period Length Fans On (Hours)	Average Period Length Fans Off (Hours)	Percentage of Time Fans Operated (%)
Oct 2004	Variable (18:21)	Variable (10:34)	63
Nov 2004	4:47	2:47	61
Dec 2004	4:10	4:34	48
Jan 2005	4:02	4:13	49
Feb 2005	3:56	3:58	45
Mar 2005	5:58	3:08	66
Apr 2005 #	Variable (12:10)	Variable (8:51)	45

- data from April 1 to April 12, 10:07 AM

Shrinkage losses

Quality changes are an important consideration when making management changes. One of the questions to answer is if there is any increase or decrease in the change weight of the potatoes in storage or any other issues such as increased spoilage. This study did a scientific evaluation of the potential change of weight of the potatoes during the storage period. The average percent shrinkage loss was 4.55% for bins 57 and 58 and 4.03% for bins 63 and 64. The overall average shrinkage loss difference of 0.52% was statistically significant (P<0.01) when comparing bins 57 and 58 (constant speed fans) with bins 63 and 64 (adjustable speed fans) over the period of storage. Table 7 shows the average shrinkage losses per layer and for the whole bin for each of the four bins and the combination of bins 57 and 58 which are ventilated with constant speed fans and bins 63 and 64 that used an adjustable speed fan.

Table 7 – Average Percent Shrinkage Loss

Sample Level Above Floor	Bin 57	Bin 58	Bin 63	Bin 64	Bins 57-58	Bins 63-63
	Constant Speed Fan		Adjustable Speed Fan		Constant	Adjustable
3 ft	4.17%	4.74%	3.57%	3.65%	4.46%	3.61%
8 ft	4.49%	4.75%	4.17%	4.12%	4.62%	4.15%
13 ft	4.65%	4.60%	4.33%	4.37%	4.63%	4.30%
Averages	4.40%	4.70%	3.98%	4.05%	4.55%	4.03%

The most important parameter for achieving low shrinkage losses of stored potatoes is to maintain a relative humidity level greater than 95%. Humidity is the key. Shrinkage losses could be expected to be greater than 7% after 8 months of storage at 90% RH, while the shrinkage loss would be slightly less than 4% at 95% RH and under 2% if the RH is consistently 98% (Oberg 2004). Temperature and ventilation are other important parameters. Table 8 contains data on the percent relative humidity and potato temperatures during the 6.5 months of storage. The potato temperatures between bins 57 / 58 and bins 63 / 64 are consistently within a degree Fahrenheit of each other except for October and April when the temperatures are 1.3°F and 1.4°F, respectively. The differences may be partially due to the accuracy of the temperature sensors of +/-0.36°F and +/-1.3°F. The measured RH values are near 100% most of the time which keeps

Table 8 – Environmental Data in Bins

	Bin 57 / 58 Ave RH%	Bin 57 / 58 Min. RH%	Bin 57 / 58 Potato Temp. (°F)	Bin 63 / 64 Ave RH%	Bin 63 / 64 Min. RH%	Bin 63 / 64 Potato Temp. (°F)
Oct 2004	98.2	88.2	54.9	98.3	86.2	53.6
Nov 2004	98.8	77.8 [1]	47.0	98.7	95.8	46.4
Dec 2004	99.6	99.2	42.3	99.4	98.2	41.5
Jan 2005	100	99.7	42.0	99.8	99.2	41.0
Feb 2005	100	98.2	41.9	100	99.8	41.0
Mar 2005	99.9	91.8	42.1	100	96.8	41.2
Apr 2005 #	98.6	87.8	43.4	98.85	93.2	42.0

\# - data from April 1 to April 12, 10:07 AM, [1] – November 3, 8.5 hours less than 95% RH.

shrinkage to a minimum. The minimum relative humidity was similar in each air handling system. The exception was on November 3 there when the relative humidity dropped to 77.8% for a period of 8.5 hours in bins 57 and 58. The minimum relative humidity level during October, late-March and April likely corresponded with the intake of outside air for cooling.

Conclusions

This study shows that a large energy savings is possible with the use of adjustable speed drives to control fan speed in potato storage without any detrimental affects on the quality of the stored potatoes. The study found a 63% savings in electrical use and demand load reduction for an overall cost savings of $3272. The payback based on energy savings alone is about 1 year. Growers can expect to reduce energy costs by 25 to 40% for short term storage (30-90 days) and up to 65% for longer term storage with the use of adjustable speed drives. ASD fans also reduce electrical demand which saves money during the months when fans speeds can be reduced.

This is only the third study of adjustable speed drives for potato ventilation and the second to show a reduction in shrinkage loss when ASD are used to control fan speeds. The study found 0.5% less shrinkage loss of potatoes in bins that were ventilated with ASD fans. The value is consistent with finding by Oberg and Kleinkopf who reported shrinkages of 0.4% to 1.7%. This may sound like a small amount, but due to the mass of potatoes being stored, it can add up. In the bins studied, the reduction in shrinkage was worth about $1250 per air handling system per year based on a value of $5 per hundred weight. The total value of the adjustable speed drive for one ventilation system at this facility was over $4500 per year. Further study of shrinkage loss using different flow rates and operational regiments would increase the confidence that lower flow rates can reduce shrinkage losses.

There is a lack of information and guidelines on storage management with respect to air flows at different stages of storage. There are design guidelines for the maximum air flows for storage bins but limited information on how much of a reduction in air flow can achieved before affecting potato quality during storage. The typical assumption is that if one is running constant speed fans 4 hours on and 4 hours off or running the fans 50% of the time, then running the ASD fans at 50% would be equivalent. In this study the grower ran the fans down to 11 cfm per ton or 50% of rated speed and ran the fans continuously during the winter months with good results. Further study should focus on establishing some guidelines for management strategies when using adjustable speed fans.

Appendix

Table A1 - Fans Amperage Draw & Demand versus Percent Speed - Bins 63/64

Percent Speed	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	98%
Fan Motor Amperage	7.9	10.1	12.9	16.5	20.4	24.8	29.4	35.3	41.8	48.7	54.9
Fan Demand (KW)	3.3	4.2	5.4	6.9	8.5	10.3	12.2	14.7	17.4	20.2	22.8

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