Cambridge Assessment International Education

Cambridge IGCSE

Cambridge O Level

Cambridge Upper Secondary Science Competition regional winner

How to most effectively light up a classroom?'

An investigation of the use of solar tubes to reduce energy usage in school.

Judge's comments:

The group drew on secondary sources and used these to produce a very detailed background brief. This brief directly informed the research design.

The design includes a good representative number of test subjects. The practical and experimental work presented challenges which were overcome through a sensible approach to design changes.

The group returned to their brief in the determination of the data. The data were collected accurately and compared to the requirements of the research design to ensure the brief was fulfilled. These aspects indicate good developing skills in scientific research.

The students chose a topic directly relevant to their immediate environment. From their research they recognized both the limitations of their conclusions for wider applications and the areas where these conclusions would be useful.

How to most effectively light up a classroom?

Background research

Through this investigation we wanted to find a way to reduce the energy usage in our school. The reason it's good to reduce energy consumption is that the electricity used to power the lamps could be used for something else and when the electricity was made in power stations greenhouse gases like carbon dioxide were produced. The more electricity needed and produced the more greenhouse gases. Greenhouse gases are the cause of global warming and the changes to the world's climate and ecosystems.

We had noticed that many classrooms had all the lights on in the classroom even when it was bright and sunny outside and/or when they were not in the room (We found this information out from giving a survey to some teachers in the school). All of the lights in the classroom switch on with the same switch, this means that when just a little bit of extra light is needed in addition to the sun coming from the windows, all the lights are switched on and energy is wasted.

Electricity costs could be reduced by making sure the lights are turned off when the room is empty and by only turning on the amount of lights needed at that time. However this would only reduce costs slightly and we wanted a better solution. We researched ways of using natural sunlight as a way to light up a room and found solar tubes, which are reflective tubes that guide the sunlight into a room from the roof and disperses it into the room. So why not save energy and money by replacing the lights in the classroom with solar tubes which are: simple, effective, free once installed, using natural light instantly and no electricity (12).

Another option using the sun's energy would be to install solar panels which would produce their own electricity to power the lights in the room and therefore reducing the electricity bills. However they would be too expensive to install at the school.

In 2019, the average national solar panel cost was $3.05/watt in the USA. The average solar panel system size in the U.S is approximately 6 kilowatts (kW), therefore an average solar panel system would cost $12,810 after tax credits. In the school it would of course be a much higher cost. However to install a solar tube would only cost $500 - $1000 (1) if installed professionally or $200 - $400 (1) if installed by yourself.

Solar tubes would be like the lamps in the ceiling of the room (replacing them), making the room brighter during the day when the light coming in through the windows would not be enough to light up the room. A 25.4 cm in diameter solar tube is the equivalent of 3 100 watt bulbs and it is enough to light up 18.6 m^2 of floor area and a 35.6 cm in diameter solar tube can light up 27.9 m^2 of floor area (2)

However there are also days like in winter when either the sun is only out for a few hours in the middle of the day or it is very cloudy and dark outside. The idea of using instant sunlight and solar tubes to light up the room would on the other hand not work when it is dark outside or no sunlight. However the hours of sunlight in Sweden during the winter is during the hours that we are in school.

After deciding that solar tubes were the solution we researched their impacts on the environment and how they work. Solar tubes are essentially a reflective tube through which light enters and reflects off the sides down into a room. They have a disperser on the end to distribute the light evenly throughout the room you wish to light up. We then decided to do an investigation on the most efficient arrangement of solar tubes in the classroom. To do this we designed solar tubes with different radii and conducted an experiment on the light intensity of our scaled down

proportionate classroom (we made the classroom without windows so that we could make sure it worked in a place like for example a warehouse which has no windows) to see how to maximise their effect. The question we want to answer with our investigation is: “How to most effectively light up a classroom?”

We wanted to do a project benefiting the environment as right now the planet and the environment really needs our help. Solar tubes are a great invention and should definitely be used more as they don’t use any electricity made in power stations and they work just as great as lamps. Here in Sweden climate changes are already beginning to show. For example in the south of Sweden due to rising sea levels, areas such as Falsterbo, Höllviken and Skanör are at risk of going under water and being flooded by big waves (3) (4). In addition to this threat there is also the risk of droughts like the one in Sweden (6) last summer and more frequent forest fires is also a problem caused by climate change (7). Some problems that we do not face in Sweden but are massive problems caused by climate change and air pollution around the world are coral bleaching (8) and smog (9). Using solar tubes in schools around the world could solve these problems because reducing energy usage from non-renewable sources like fossil fuels. This would reduce the rate of climate change and contribute to reversing it.

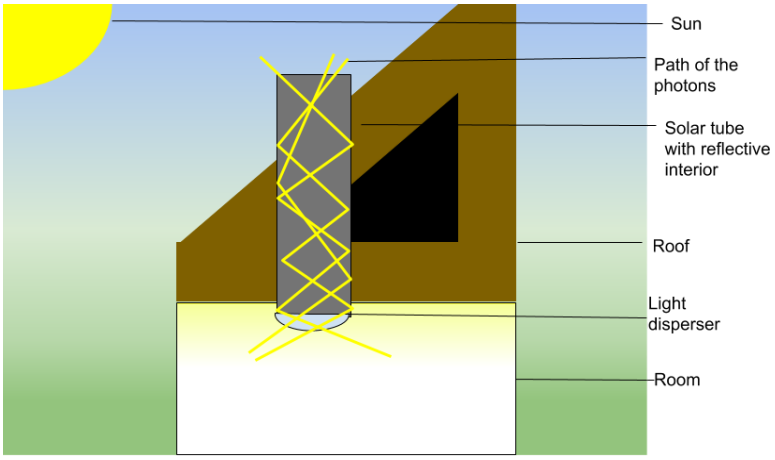

Figure 1: *Shows a diagram of a room with a Solar tube*

Objective

The objective of our investigation was to find a way to reduce energy usage, more specifically through light usage, in our school to benefit the environment and also our school’s energy bill.

Hypothesis

We predict that using different sizes of solar tubes will affect the light intensity and that using the most (4 small solar tubes) will give the highest light intensity.

Variables

Independent:

- Solar tube radius, 3 cm (x4), 4.24 cm (x2) and 6 cm (x1)

Dependent:

- Light intensity inside the box

Controls:

- The total aperture area of the different sized solar tubes to be able to test which size is the most effective at lighting up the classroom
- White walls for the box because the classroom walls are white and since white reflects the most light, therefore the light intensity will be the highest (11)
- No external is light allowed into the box to keep the test fair

Materials & Equipment used

We needed a lot of material and equipment to be able to complete our experiment including:

- LUX light meter
- Reflective shock blanket
- Cardboard
- Card
- Glue gun + glue
- Masking tape
- White paper
- Cardboard knife
- One paper clip
- Scissors

Method

Our original plan or method was to create a box which would represent one of the lamps in the classroom. However we soon realised that this would require a bit too much cardboard since we had to make the box a fourteenth of the room which was 11 m^3. We decided to not go with this and instead to work on a much smaller cardboard box which would represent the entire room in a scale of 1 cm : 12.5 cm. This meant the cardboard box was going to be in the dimensions 68 cm by 54 cm by 22 cm.

1. First we drew out the dimensions of the box, 22 cm by 54 cm by 64 cm, and added spaces for flaps so we could put the box together.
2. Secondly we glued the box together and covered the edges in masking tape
3. Then we made the solar tubes with card and a shock blanket. The solar tubes radii were 3 cm, 4.24 cm (but we could only measure to within a mm) and 6 cm. We calculated the circumference to measure the sizes of card for the solar tubes.
4. Then we cut out the holes for the solar tube in the box, one big in the middle, two medium ones on either side and four small ones at respective quarters of the top
5. Before the experiment we coated the inside of the box with white paper.
6. We carried out the experiment in 2 different weather conditions, cloudy (11400 lx) and sunny (80000 lx). We measured light intensity using a LUX meter and repeated the experiment 3 times for each solar tube size.

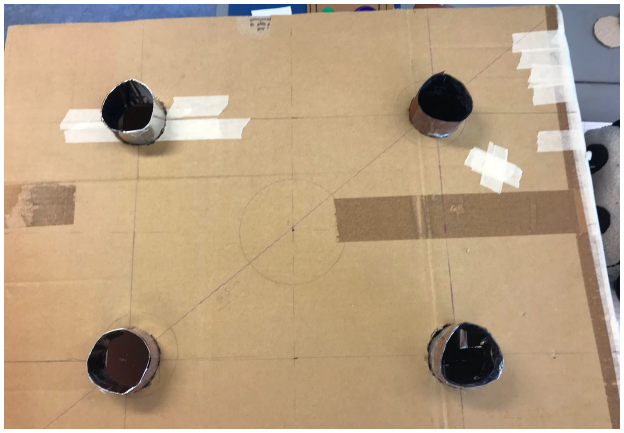

Figure 2: *Shows a birds eye view of our box fitted with the smallest solar tubes*

Table 1: *Shows the results from our experiment*

Radius of solar tube (cm)	Light intensity outside of the box during testing (lx)							
	11400 (cloudy)				80000 (sunny)			
	Light intensity in box (lx)				Light intensity in box (lx)			
	repeat 1	repeat 2	repeat 3	avg.	repeat 1	repeat 2	repeat 3	avg.
3	260	160	260	227	1630	1904	1851	1795
4.24	320	480	270	357	2450	2370	2340	2387
6	1000	1930	1580	1503	2630	2610	2550	2597

Table 2: *Shows the results from our experiment*

	Light intensity outside of the box during testing (lx)							
	11400 (cloudy)				80000 (sunny)			
	Light intensity in box (lx)				Light intensity in box (lx)			
All solar tubes in the box	repeat 1	repeat 2	repeat 3	avg.	repeat 1	repeat 2	repeat 3	avg.
	2210	2190	2350	2250	7360	7300	7250	7303
Corner of the box for 6 cm radius solar tube	260	338	310	303	1930	1430	1320	1560

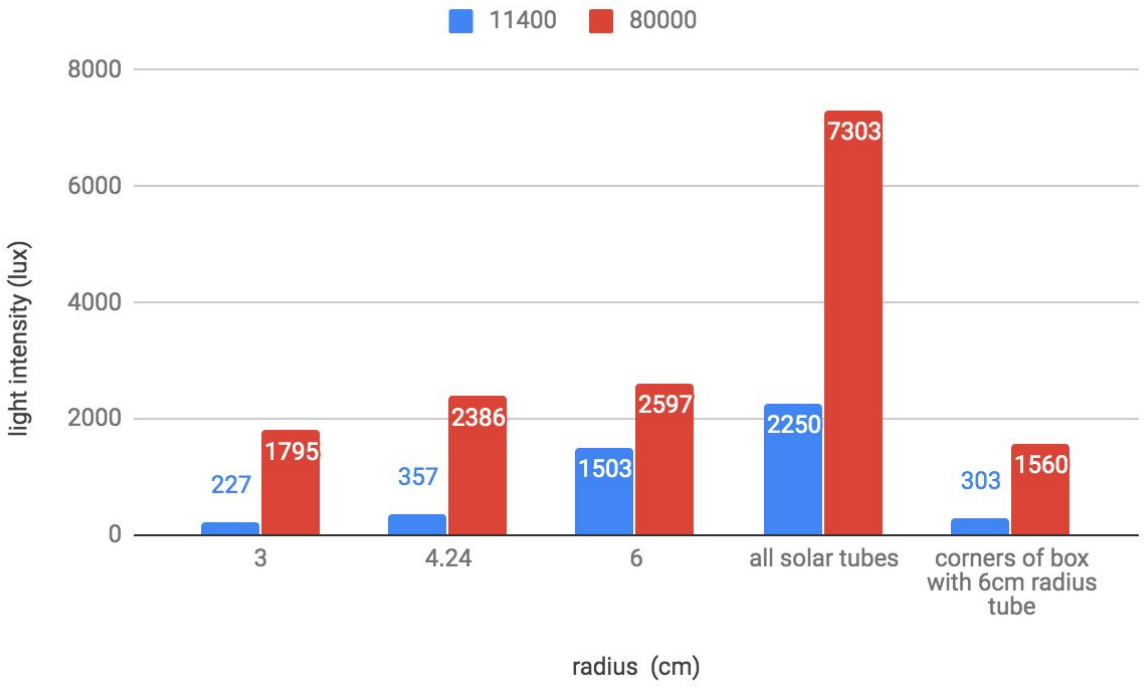

Figure 3: *A column graph showing our results. The blue and red columns show the difference in the light intensity inside the box when it was sunny (red) compared to when it was cloudy (blue) outside.*

Conclusion

To conclude our experiment we can say that, as you can see in the tables above, when it was sunny outside (80,000 lx) the inside of our box had a light intensity that was good enough for reading and writing. This is because the light intensity required for you to be able to read well is 500-1000 lux (5) (in our classroom there is an average of 1151 lux) and since this was true for all sizes of solar tubes we can conclude that on a sunny day having solar tubes of any size as a light source will be enough for you to be able to do normal class work. However days are not always sunny and as we discovered even when it is not very cloudy the light intensity can drop significantly. From a light intensity of 80,000 on a sunny day to a light intensity of only 11,000. This causes a problem since with the lower light intensity outside there was only a average light intensity of 300 with the different sized solar tubes, since the big solar tube only gave a light intensity of 303 lux in the corners of the box it would render part of the classroom useless so we can ignore the fact that in the center of the box the light intensity was over 1000 lux. This is below the light intensity required for reading so an additional light source would be required on cloudy days, this can be in the form of lights. You might think that our solar tube idea has failed to save energy consumption in our school but using solar tubes would still save a lot of energy on days that are sunny or partly sunny. So in conclusion the solar tubes would provide enough light on days that are at least partly sunny to do normal classwork and thus would save energy however an alternative light source that does not rely on the weather would be needed to compensate for the lack of natural light on cloudy days. An example of this alternative light source could be small desk lights.

Our results suggest that the the middle sized solar tubes (radius 4.24cm) which was not what we predicted it to be. This is because in our results the smaller solar tubes provided a much lower average than the middle sized ones and the big solar tube also provides a lower average in the corners, even though they provide the highest average in the middle their low average in the corners makes it so that only the middle of the room would be used. This concludes that the middle sized solar tubes would be the best for lighting up a classroom because they provide an even spread compared to the big solar tubes and also a provide more light than the smaller solar tubes.

Further improvements

The LUX meter was quite hard to read reliably since the light intensity level fluctuated a lot meaning that it was hard to tell when it had reached a definitive level. We should also have compared the surface area of the reflective shock foil used instead of the aperture area, this is because We should also have put some translucent material on the end of the solar tubes to disperse the light more effectively in the room because one problem we had that could possibly have affected the results was that the light intensity increased mainly directly underneath the solar tube which is why we also measured in the corner of the box when using that one. However, it gave an unfair disadvantage to the small solar tubes which increased the light intensity mostly in the corners. So if we had had something to disperse the light evenly it would have been easier to measure and compare the light intensity fairly.

Further implements

Sweden may not be the best place to use solar tubes all year round taking into account the arctic winter, however Yuma in Arizona is proven to be the sunniest city on Earth with 11 hours of sunlight each day on average and around 4000 hours of sunlight on average each year so that would be a good place to use solar tubes (10). Solar tubes have proved to be an effective way of lighting rooms up and they are also very cheap so using them in schools is very good because it means the schools have money to spare for more important things like textbooks and school supplies. However, it can also be used at home by private people who want to either be more energy efficient, pay lower energy bills or both.

Our sources

(1) https://news.energysage.com/how-much-does-the-average-solar-panel-installation-cost-in-the-u-s/
(2) https://www.houselogic.com/remodel/painting-lighting/solar-tubes-beat-skylights/
(3) https://nyheter24.se/nyheter/919468-klimathotet-mot-skane-kan-hamna-under-vatten
(4) https://www.expressen.se/kvallsposten/har-dranks-den-skanska-orten-kan-forsvinna-fran-kartan/
(5) https://www.interior-deluxe.com/advice-central/learn-more-about-good-reading-lighting/
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(11) https://web.archive.org/web/20081121124227/http://www.iaeel.org/iaeel/Archive/Right_Light_Proceedings/Proceedings_body/BOK4/RL4shao.pdf
(12) https://solabrite.com/pros-cons-solar-tubes-vs-skylights/

Pre-investigation sessions: These sessions were spent looking around for ideas on topics to investigate which we found pretty quickly we wanted to investigate energy saving. So our next problem was coming up with an investigation which took us really long but eventually we decided, with some input from our teacher, to investigate solar tubes. So we started researching what they were and how they worked. This was an extremely slow process which we should have spent less time on.

Start of investigation

Week 1: We made a survey for teachers to fill in. we also chose the teachers from a variety of different subjects and different genders who were most likely to fill in our table. The table was to record how many hours a day they have their lights turned on so we can calculate how much energy is used by lights every week we printed out the tables and handed them to the teachers we had chosen and asked them to fill them in.

Week 2: We looked at the lights and calculated how much energy they used per hour. We also planned what materials we were going to need and buy for the experiment.

Week 3: Today we collected the sheets filled in by the teachers the previous week. Three out of five had filled the records in daily while the other two forgot and filled it in afterwards from memory (not very accurate). We used that information to calculate how many hours a week they have their lights on for. We counted the number of bulbs in each of the rooms that the teachers were in. We then calculated the energy used in each room from the power per bulb and the amount of hours during the week.

Week 4: We brought in an electricity meter to measure the amount of energy one light uses. We plan to leave it at the light for nearly five days. We started measuring monday afternoon (15:40) and are leaving it on until friday. We also planned how we were going to create the cardboard box and solar tube.

Week 5: We had a bit of a change of a plan after consulting our teachers. We originally planned to make an $11m^3$ cardboard box but obviously that was way too large. So we are making a cardboard box that is 68*54*22 cm so $80784cm^3$ or $0.080784m^3$. We also changed our investigation slightly to asking the question how many solar tubes with the same total aperture area do we need to light up our physics room. We also had a problem with the electricity meter because everytime the lights were turned off the electricity meter turned off and it needed to be reset every time it was turned on which wasn't done so we didn't get the measurements for a week. So we measured it for an hour today. We also began to construct the cardboard box.

Week 6+7: We continued creating our cardboard box, a scaled down version of the physics classroom. All the other classrooms in the school are of the same size and ratio so the experiments results will be able to be applied to any of the classrooms. We made all the six sides by cutting out in cardboard with flaps for assembling together. We made flaps on all the sides as it was better to have extra and have to cut them out than having one too little

and having to redo a side. Two of the sides we measured wrong so had to redo those sides. We also put all the sides together and the box was finished, however we left one side open to be able to put in the solar tubes and see if there were any holes were light was coming in.

Week 8: We sealed the holes in the box to stop light from coming in. This is to make the experiment as fair as possible. We also made a door so that we could look into the “room” when the side which we didn’t seal was temporarily sealed. We started the presentation as well.

Week 9: This week we calculated how big the solar tubes were going to tube so that comparisons of size and distribution were fair. We decided that the total surface area of the circles at the end of the cylinders had to be the same total surface area.

Week 10: We realised that we needed to make the tubes shorter because not enough light came in when they were so tall. Also we realised that if they were that size and were scaled up they would be huge in real life. So we spent the time cutting them, however then we realised that the tubes turned too wrinkly when cut so we laminated the tubes and cut them again. We also started working on the presentation.

Week 11: We realised that the laminated tubes where pretty useless, they took away the reflective ability of the mirror shock blanket. So we made new smaller solar tubes only 5 cm high and finished making them. We also made the inside of the box white as all the classrooms in the school have white walls. There is also a big difference in the reflectiveness of white and dark brown colour so we realised that that would affect how brightness of the room with the same power of light.

EXPERIMENT: The actual experiment we carried out over the course of 3 breaks we measured the light intensity outside each time and then the light intensity inside with the different sizes of solar tubes. We were way too slow at getting to the actual experiment. Everybody in our team was willing to help even though it was break which was good because we couldn’t have done it without everybody being there. We also measured the light intensity in the physics room to have something to compare our results to.

Week 12:
This week we spent writing the investigation and doing the presentation for the year 7’s in our school.

Individual Reflections - team member 1

Pre-investigation sessions: I was sick for many of these sessions so I had to go along with what my teammates decided but I would still say that I got to share my ideas and my teammates definitely listened and I was happy with the solar tube investigation.

Start of investigation

I think we worked slightly too slow here however we did everything thoroughly which was good. I think that we are communicating effectively and sharing out tasks. As the deadline approached we realised that we needed to work more efficiently and I think that this was when started to work best as a team because everybody knew that they needed to work but still communicate so things weren't done twice. I think that throughout most of the building process Me and Mathilda alternated being leaders because Mathilda was better at the some parts of the building but I was better at getting everybody engaged and splitting up the tasks.

EXPERIMENT: During the experiment everybody was working together to conduct the experiment but we all had different equally important tasks. However for some parts of the experiment one team member was not able to be present however, this did not really present any problems and it was not her fault that she was not able to be present.

After experiment:
We shared out the tasks of doing the report and the presentation so nobody had too much to do and we split it so that I did the presentation alone because it was easier than the report and Erik and Mathilda did the report together and then we checked each other's to see if there was anything we would add that they hadn't thought of. I think that that was a very effective way to split up the workload between us. When we presented One team member was unfortunately not able to be present however we were able to present fine anyway so it did not really matter.

Me as a team member
I often took on the role as a leader, I gave out tasks to people and made sure they were engaged in the project. I made sure Erik double checked my presentation so that he knew what to say and that he thought it was done. The I checked everybody's written work to make sure it was fine. So something I could improve on is to trust my team members to get the work done and do it well, however I did have to add somethings to the work I checked. I could also have made sure we had an effective plan from the beginning to prevent us from having to make a new plan.

Individual Reflections - team member 2

Planning stage: During the planning stage I feel like we split up the work well and everyone did their part. However we had trouble deciding exactly what we were going to do, which sometimes resulted in long conversations. This wasted a lot of time and is something we should have done better.

Preparing for Experiment: During the preparation stage we were able to work well because we had a common goal in mind. However we ended up changing the experiment as we went along because we realised that some things weren't going to work, this rendered some previous work useless and is one of the things I think we should have done better.

Building the things (box): In the building stage most thing went well, like optimising the building process by spreading out the work and always knowing what we were doing. I feel like we worked better as a team in this section.

Doing the experiment: During some of this part of our investigation one of our team members, Mathilda, was not able to be present. However doing the experiment with one less person worked fine even though it would have been slightly more efficient to be three people rather than two

Writing the report + doing the presentation: This section was also one of our strongest since we were able to split the work between us, Me and Mathilda did the report while Maud did the presentation. We also worked together on the reflection since it involved all of us. Doing the presentation to the year seven's in our school was actually easier than I thought. This is because they were able to grasp pretty much everything we said and also listened well and wanted to ask questions at the end.

Individual Reflections - team member 3

For the first weeks of the project we ended up doing things that proved to be unnecessary and repeating tasks. For example we asked the teachers in school how long they had their lights on during the day and if they switched them off when they left the room or not. This information we didn't actually need in the end, however it did make the teachers think about only turning on the lights when they really needed to. This was good as the aim and initial idea was to save on energy in the school. However we worked well as a team, communicated well on ideas with Maud who was sick a few times in the beginning, and accepted and listened to each other's ideas. All team members came with their own ideas. For example I suggested that we do the inside of the box white and Erik advised that we measure the light intensity in the corners of the box. Me and Maud were doing most of the work in the beginning and taking on roles as leaders, so sometimes there wasn't that much work left for Erik to do.

As the deadline was approaching we hadn't gotten that much done as we had been working ineffectively, however we started working really hard and well as a team. All team members were fully engaged and we all worked together on the project. For example during the experiment we were all involved and doing different tasks which meant it went quicker. For the presenting and final write ups we split up the tasks, me and Erik did the report and Maud did the presentation. This is what we should have done at the beginning of the project as well.

Overall I thought I was a hardworking team member who was fully engaged in the project however at the end of the project I couldn't put in as much input as I would have wanted because I was away. I gave my ideas and suggestions on the project and listened to my teammates ideas as well. To improve I should have made sure all team members had something to do and trusted them to do it well.