Independent Activity Period January 2016 MIT. This report is complemented by a research study focusing on design explorations of a test site, using solar updraft tower principles.

Experiments with Solar Updraft Tower Models

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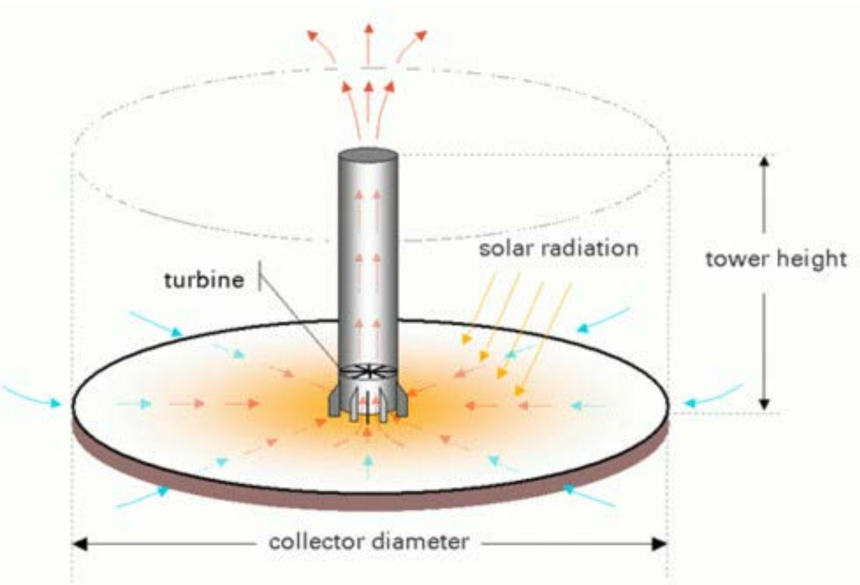


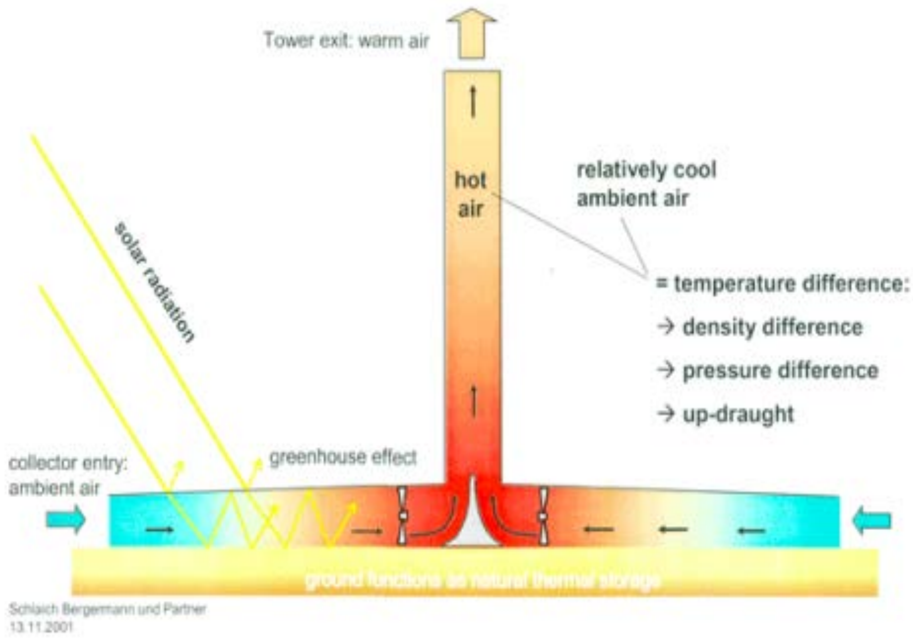
1. Introduction

1.1 What is SUT?

The solar updraft tower is a renewable - energy power plant for generating electricity from solar power. It comprises of the tower, collector and generator.

1.2 How does it work?

The sun heats up the air under the collector through a greenhouse effect. The less dense (lighter) hot air rises and rushes up the tower causing a chimney effect. This airflow drives wind turbines and thus, the power output depends primarily on the rising air velocity, which is a function of absorbed solar energy.



1.3 Precedence

Tower	Chimney Height (m)	Tower Diameter (m)	Apron Area (sq.m)	Apron height (m)	OUTPUT (Power generation)	INDEX Ch.Ht/ Apron Area	INDEX Apron Area / Ch.Ht
MANZANARES, Spain (Built 2002)	195	10	45,000	2	50kW	0.004333	230.769
Gaboronte, Botswanna (Built 2005)	22	1	160	No data	No data	0.1375	7.2727
Australian Govt (Planned 2002)	1000	130	38.5×10^6	No data	200MW	2.59×10^{-5}	38, 484
Greentower, Nambia (planned 2008)	1500	280	37×10^6	No data	400MW	4.05×10^{-5}	24, 667
Jinshawan Tower (China)	No data	No data	No data	No data	200kW	No data	No data
Arctic Solar Updraft Tower (Canada)	No data	No data	No data	No data	Unknown	No data	No data
Ciudad Real Torre Solar	750	No data	3.5×10^6	No data	40MW	No data	No data

1.4 Review of Buildings at MIT

Six buildings were reviewed at MIT and examined for their potential as solar updraft power. Each has a large atrium which is a surrogate for the tower/chimney.

1. Old MIT Media Lab
2. New MIT Media Lab
3. Strata Center Building
4. Brain and Cognitive Sciences Building
5. Great Dome @ Building 10
6. Dome Lobby @ Building 7

Please refer to **Appendix A** for more information and presentation.

2. Theoretical Formulation for Power Output and Efficiency of SUTs

In our consideration, we identified three variables that would influence the power output of the SUT: A_{apron}, **area** of apron, H_{tower}, **height** of tower and D_{tower}, **diameter** of tower.

Power is generated from the wind turning the turbine. For now we set aside the base efficiency of the turbine and assume it has 100% efficiency, hence the power output is simply dependent of the wind velocity and the area covered by the turbine.

$$P = \frac{1}{2}\rho c_p A_{turbine} v^3$$

The Area, A, is simply the diameter of the tower at the point where the turbine is placed. For our setup, we use the most general case for the tower and assume it has uniform diameter throughout.

$$A_{turbine} = \frac{1}{4}\pi D_{tower}^2$$

The velocity of the air, v, is caused by the convection flow of the air due to heating from the Sun. Additionally the air exits at the top of the tower where the temperature is cooler. Hence, the velocity of the air is given by the following:

$$v = \sqrt{2gH_{tower}\frac{\Delta T}{T_a}}$$

Where ΔT represents the difference in temperature between the heated gas at the bottom of the tower and the top of the tower and T_a represents the ambient temperature of the air at the top. Subbing in both (2) and (3) into (1), the entire equation then becomes the following:

$$P = \frac{1}{2}\rho c_p \left(\frac{1}{4}\pi D_{tower}^2\right)\left(2gH_{tower}\frac{\Delta T}{T_a}\right)^{1.5}$$

$$= \frac{\sqrt{2}\pi}{4}\rho c_p g^{1.5} D_{tower}^2 H_{tower}^{1.5}\frac{\Delta T^{1.5}}{{T_a}^{1.5}}$$

The temperature of the ambient air at the top of the tower decreases by 10K per every 1000m, while the temperature of the air at the bottom of the tower is dependent of the amount of energy absorbed by the Sun.

$$T_a = T_g - \frac{10H_{tower}}{1000} = T_g - 0.01H_{tower}$$

$$\Delta T = T_{heated} - T_a = \left(T_g + GA_{apron}\right) - \left(T_g - 0.01H_{tower}\right)$$

$$= GA_{apron} + 0.01H_{tower}$$

Where G represents the power absorbance coefficient per unit area, assuming that the energy absorbed remains constant throughout the entire area. The final equation then becomes:

$$P = \frac{\sqrt{2}\pi}{4}\rho c_p g^{1.5} D_{tower}^2 H_{tower}^{1.5} \frac{(GA_{apron} + 0.01H_{tower})^{1.5}}{(T_g - 0.01H_{tower})^{1.5}}$$

To find the most significant variable influencing the power output, we have to find the variable with the highest coefficient of power.

$$P = \frac{\sqrt{2}\pi}{4}\rho c_p g^{1.5} D_{tower}^2 H_{tower}^{1.5} \frac{(GA_{apron} + 0.01H_{tower})^{1.5}}{(T_g - 0.01H_{tower})^{1.5}}$$

$$\equiv D_{tower}^2 H_{tower}^{1.5} A_{apron}^{1.5}$$

From the above analysis, we see that the most **important variable is the Diameter of the Tower followed by the Height of the Tower and Area of Apron.**

3. Design of Experiment

3.1 Space Measurement

Available Space:
Classroom of 15ft 5” (whiteboard) by 15ft 10” [About 4.7m by 4.826m]
Classroom height of 11ft available [3.3528m]

3.2 Experiment Design

Experiment Number	D	H	A_{apron}	H_{apron}	Remarks
1 (Control)	*8”*	*8 ft*	*10ft x 10ft*	*1.5 ft*	*Control*
2	12”	8 ft	10ft x 10ft	1.5 ft	Wider Chimney
3	8”	4 ft	10ft x 10ft	1.5 ft	Lower Chimney
4	8”	8 ft	7ft x 7ft	1.5 ft	Smaller Apron

Order of Experiments: 1,3,2,4

3.3 Procedure

- Arrange the physical setup
- Note initial values ($T_{ambient}$; T_{Top}, T_{Bottom}; v_{Top}, v_{Bottom}; $V_{Turbine}$, $I_{Turbine}$)
- Turn on the heat lamps and start the timer.
- Record 1st reading at 15 minutes
- Take interval readings every 15 minutes.

3.4 Bill of material for Mechanical Structure

S/N	Item	Qty
1	Chimney 8"	3
2	Chimney 12"	2
3	Plastic Foil 10ft x10ft	1
4	Scrap wood	-
5	Ground material 10ft x 10ft	1
6	Turbine (0.1v - 20v)	1
7	Anemometer	2
8	Resistor (1W rating, 10 ohms)	5
9	Thermocouples (data logger with memory or arduino)	3
10	'Euro Style' wire connector	1 row
11	Arduino	1
12	Conducting Wires & Jumper Wires	one bundle
13	Alligator clips	10
~~14~~	~~Breadboard~~	~~1~~
15	Strings (twine or nylon)	2 balls
16	Heat Lamps	15

17	Retort stand	5
18	Ladder	2
19	Multimeter (or 1 voltmeter & Ammeter)	2
20	Epoxy	2
21	Duct tape	5
22	Hot Glue gun and Glue	1 pack
23	Measuring Tools	Fabrication studio
24	Plywood or acrylic 5mm thick	2 pcs of 15”x15”

3.5 Bill of Material for Electrical Components

No.	Product	Qty	Link
1	Pyle PMA90 Digital Anemometer / Thermometer for Air Velocity, Air Flow, Temperature	2	http://www.amazon.com/Pyle-PMA90-Anemometer-Thermometer-Temperature/dp/B009TQ6ILQ/ref=pd_sim_sbs_469_2?ie=UTF8&dpID=410HWMv3ZXL&dpSrc=sims&preST=_AC_UL160_SR160%2C160_&refRID=1E49ZA5WA3FK5W0S219C
2	DC Project Motor Generator	1	http://www.amazon.com/Pacific-Sky-Power-Project-Generator/dp/B00L9MFGZM/ref=sr_1_21?ie=UTF8&qid=1452202980&sr=8-21&keywords=wind+turbine
3	DC Motor: 6331K59	1	http://www.mcmaster.com/#dc-motors/=10kzjnk
4	Aluminium Fan Blade: 17545K41	1	http://www.mcmaster.com/#propellers/=10kzjzt

5	Aluminium Fan Blade: 17545K44	1	http://www.mcmaster.com/#propellers/=10kzjzt
6	Etekcity MU600 Digital Multimeter / DMM / Multi Tester with hFE Measurement	2	http://www.amazon.com/Etekcity-Digital-Multimeter-Tester-Measurement/dp/B00B7CS3UY/ref=sr_1_2?ie=UTF8&qid=1452203628&sr=8-2&keywords=multimeter
7	SE TL10 10-Piece Test Lead Set with Alligator Clips	1	http://www.amazon.com/SE-TL10-10-Piece-Alligator-Clips/dp/B0002KRABU/ref=pd_sim_469_2?ie=UTF8&dpID=416glZKpG5L&dpSrc=sims&preST=_AC_UL160_SR160%2C160_&refRID=0A6NX61K4BCVZWR4F49K
8	E-Projects - 10 Ohm Resistors - 1/4 Watt - 5% - 10R (100 Pieces)	1	http://www.amazon.com/E-Projects-Ohm-Resistors-Watt-Pieces/dp/B00BVCC0XQ/ref=sr_1_4?ie=UTF8&qid=1452204407&sr=8-4&keywords=resistor+10+ohms

4. Fabrication

4.1 Fabrication of Chimney

A plastic cone is used as the base of our prototype solar chimney. Holes were drilled at equal spacing for securing of support wires.
Rectangular sections of the cone were cut off to allow for air flow from under the apron to the chimney.
Paper "Quik-Tubes" were used as our chimney. These are joined together and air-sealed using duct tape.

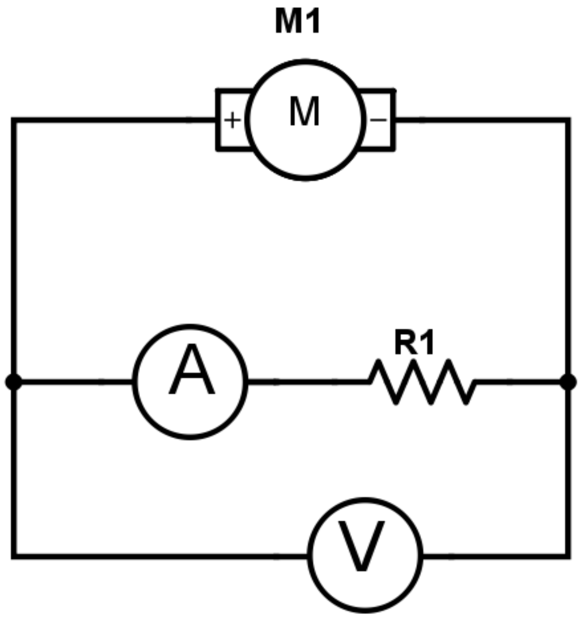
4.2 Fabrication of Ground

Foam sheets act as the "ground" of the entire setup. They are selected to be white so as to prevent the ground from absorbing all the light (and thus, heat), allowing the air inside the apron to absorb more heat to create a larger temperature differential.

To help identify the middle of the setup, a cross was made from four corners of the ground. After positioning the chimney, the point was marked for future reference.

4.3 Fabrication of turbine

The turbine was made of a DC motor and an appropriately sized fan blade. After attaching the blades to our motor, the entire setup was attached to a flexi glass support which is then hot glued to the insides of our chimney. The two fan blades selected were 7" and 10" and were intended to fit our chimneys with inner diameter of 8" and 12" respectively.



4.4 Electrical setup

With data that states the 7mW output of Botswana's Solar Tower, the circuit was scaled small as our power output is predicted to be in the milliwatts range. Resistors of 0.25W rating were purchased as we do not need the higher power ratings for this experiment.

A basic schematic as shown below connecting the motor generator M1 to a resistor load R1 is used, along with the measuring tools Ammeter and Voltmeter. A 10 resistor is used as R1. Alligator clips act as connecting wires between the various parts.

4.5 Fabrication of Apron

For our apron, a large roll of semi-transparent plastic film was bought. We then cut out a sheet of plastic, with an opening in the centre to fit over the chimney. Fishing lines were tied from the chimney base to surrounding chairs to suspend the plastic sheet, letting it act as our apron.

4.6 Setup of Heat Lamps

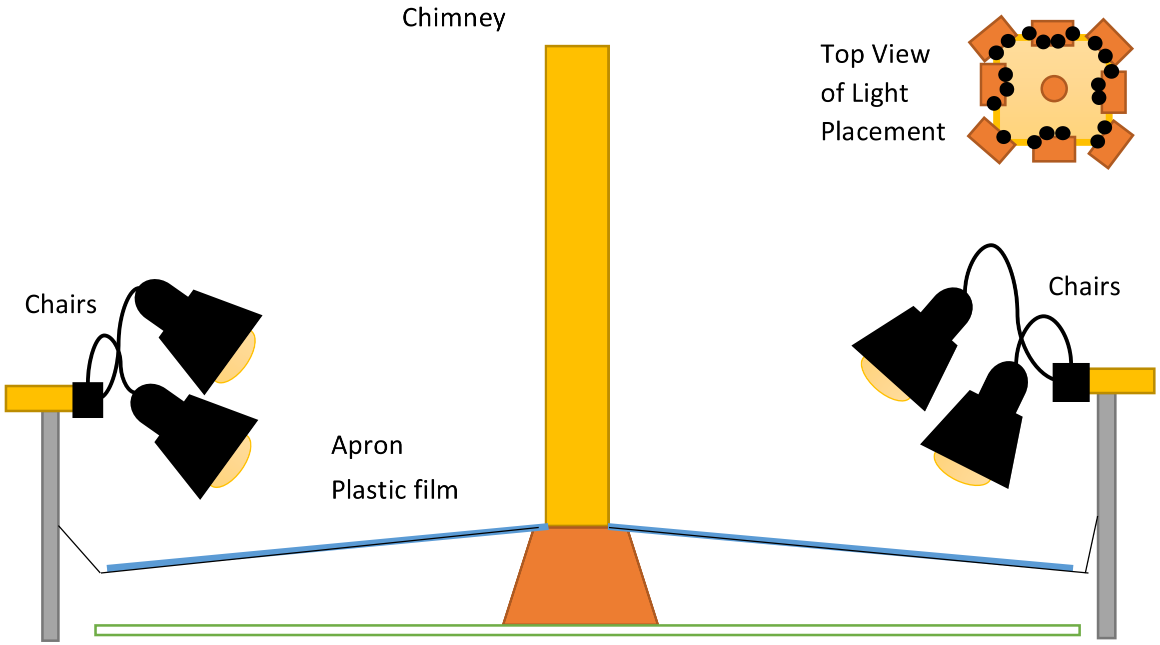
Initially, heat lamps were mounted unto chairs at the sides. However, we realized that such a setup produced not only nonlinear light rays, but also did not provide enough heating to our setup. Later, they were hung on metal rods, suspended above the apron. These simulate the uniform incident sunlight that would strike the apron if the experiment was outdoors.

5. SUT Experimental Setups

Our team had many difficulties trying to get the setup of our scale to work within an indoor environment. This posed several challenges: need for strong heat input, closed system due to room settings and ratio of size of setup to size of room.

Between each setup, we would evaluate the problems of the current setup and effect changes one at a time to determine the necessary conditions needed for our experiment to work.

5.1 Set Up 1



Features:

- Chimney Height: 8 ft
- Chimney Diameter: 8 in
- Apron Height: 3 in to 8 in
- Apron Area: 100 sq ft
- Apron Material: White Flame-Retardant Plastic
- Ground Material: White Cardboard
- Number of Heat Lamps: 20 (125 watts each)
- Placement of Heat Lamps: Attach heat lamps to chairs at edge of apron, evenly spaced

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	0.0	23.5	0.0	23.0	0.00	0.00	0.00
15	0.0	25.3	0.0	24.8	0.00	0.00	0.00
30	0.0	25.5	0.0	25.1	0.00	0.00	0.00
45	0.0	25.5	0.0	25.2	0.00	0.00	0.00

Data Analysis and Observations:

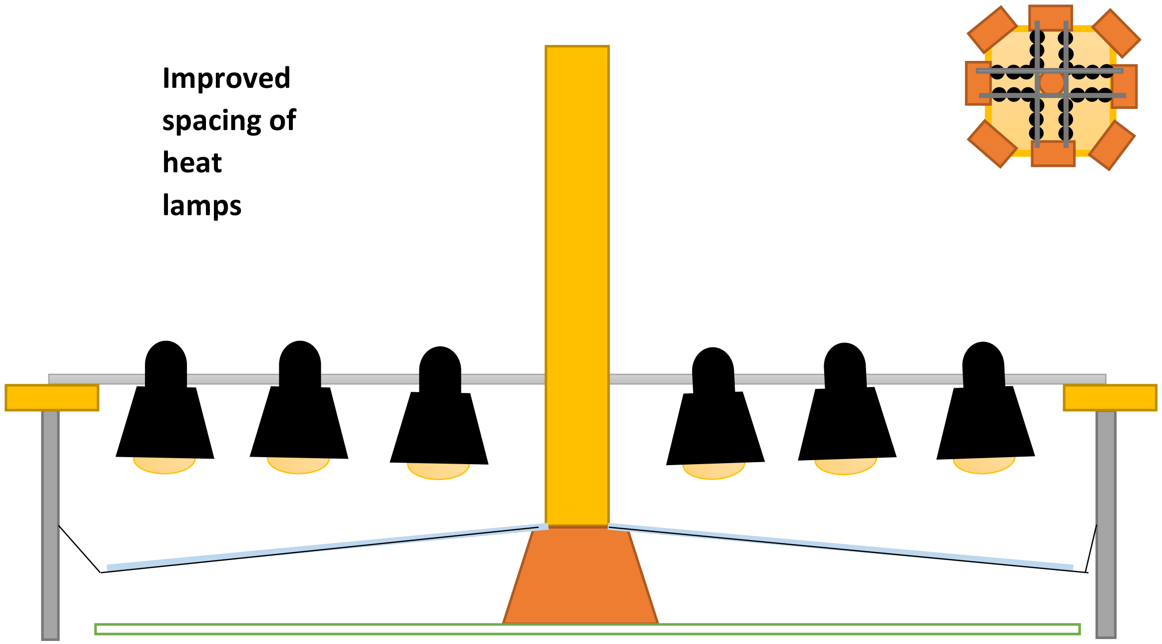
- Low maximum temperature achieved at bottom of tower and slow increase in temperature
- Temperature at top of tower consistently increased in tandem with bottom temperature signalling low dissipation of heat lost and causing small temperature difference
- Room felt warm while temperature at bottom remains low, suggesting a significant loss in heat captured by setup due to reflection
- Temperature started hot at the top and cold at the bottom when it should be inversed in open system scenarios

Problems Identified:

- White plastic sheets reflects most visible light and infrared radiation, hence significantly reduce heat transferred through radiation
- Lamps are too far away, resulting in too much heat loss due to long distance of heat source to object being heated

- Closed system, hence causing hot air to reside at the top of the room and cold air at the bottom, this is opposite in an open system (the atmosphere) and caused the mechanism driving the SUT to not work as well. Though eventually the bottom gets hotter, it is likely only true for the air within the apron and the area close to the apron.
- Closed system, size ratio of setup to room to small, prevents heated air from flowing and causes heat to accumulate in the room

5.2 Setup 2



Modifications:

- Apron Material: Replaced with Thinner Partially Clear Plastic
- Number of Heat Lamps: increased to 24 (125 watts each)
- Placement of Lamps: Arranged in a grid with 3 lamps on each arm,
- stretching out in 4 directions, each directions has 2 arms

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	23.9	21.6	0.0	0.0	0.00	0.00	0.00
15	25.4	28.9	0.0	0.0	0.00	0.00	0.00
30	26.6	30.8	0.0	0.0	0.00	0.00	0.00
45	27.1	31.3	0.0	0.0	0.00	0.00	0.00

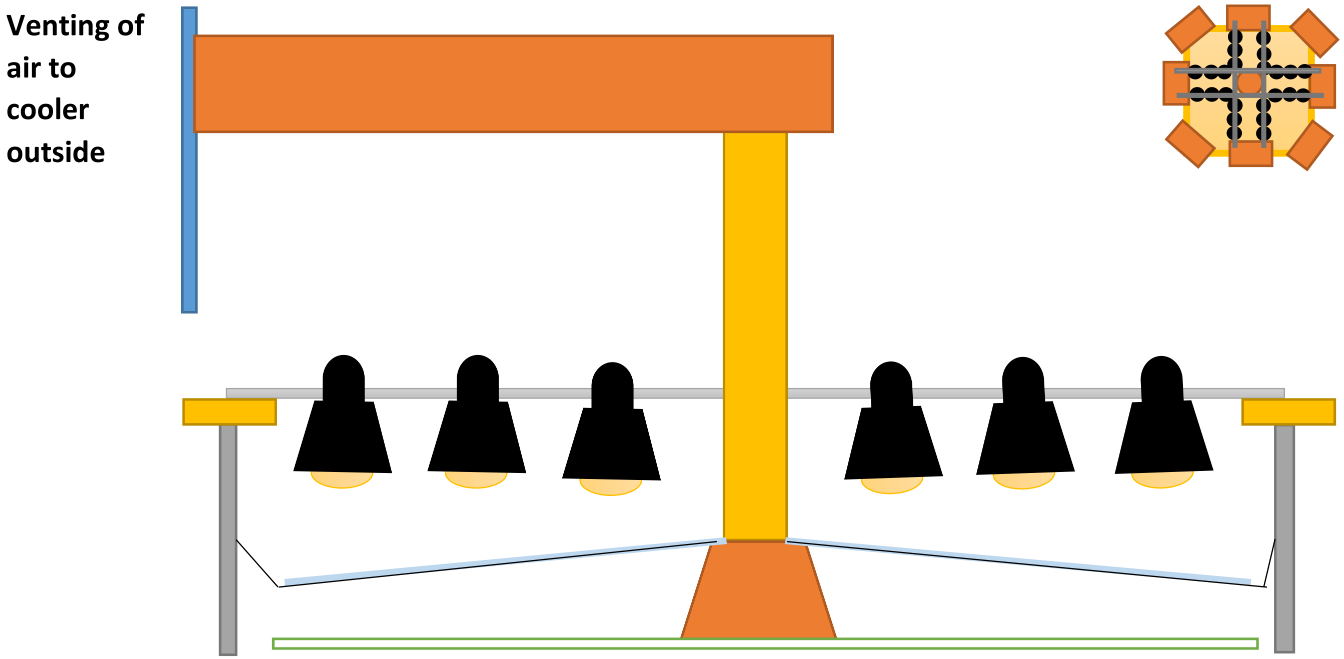
Data Analysis and Observation

- Moderate maximum temperature and temperature increase achieved at the bottom of chimney
- Temperature at top of tower still remain close to that of bottom and the temperature difference at equilibrium remains relatively small
- Temperature difference at the start still inversed from open system conditions

Problems Identified:

- Closed system, hence causing the air in the room to be warmer at the top and cooler at the bottom
- Closed system, size ratio of setup to room is too small, prevents heated air from flowing and causes heat to accumulate in the room
- Large size of apparatus causes low clearance from the roof, hence preventing a proper convection flow from being established, and instead only cause the temperature above the chimney to rise

5.3 Setup 3



Modifications:

- Added a chute to direct heated air outside of the room through a window

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	23.9	21.2	0.00	0.00	0.00	0.00	0.00
15	25.4	27.3	0.24	0.42	0.00	0.00	0.00
30	26.6	28.1	0.10	0.36	0.00	0.00	0.00
45	27.1	28.2	0.36	0.50	0.00	0.00	0.00

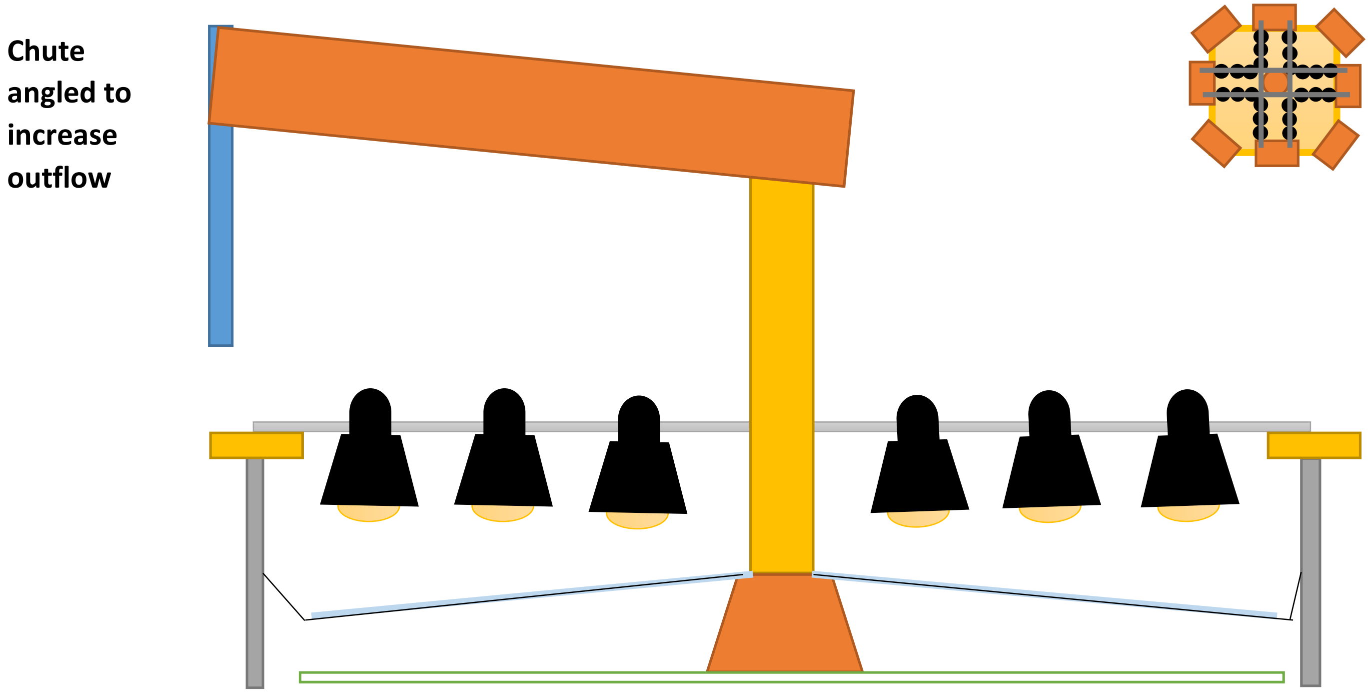
Data Analysis and Observation

- Maximum temperature and temperature at bottom of chimney noted some increase compared to previous setup
- However, temperature at top of chimney and its increase remains significantly high when compared to the maximum temperature and increase in temperature at the bottom
- Wind speed detected might be due to wind coming from outside the chute, however, as the speed at the bottom is greater than the top, there is high chance it might be air current in the right direction
- Although a chute was added, the inversed temperature difference still occurs despite the top being exposed to the cooler (~0C) winds outside

Problems Identified:

- Heated air unable to escape despite use of chute, likely due to lack of elevation which causes heated air to not flow out properly

5.4 Setup 4



Modifications:

- Chimney: 7.5ft
- Elavation of chute: 0.5:7.5

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	21.8	21.5	0.10	0.36	0.00	0.00	0.00
15	25.2	28.3	0.18	0.36	0.00	0.00	0.00
30	26.0	29.2	0.36	0.50	0.00	0.00	0.00
45	26.3	29.5	0.24	0.36	0.00	0.00	0.00

Data Analysis and Observation

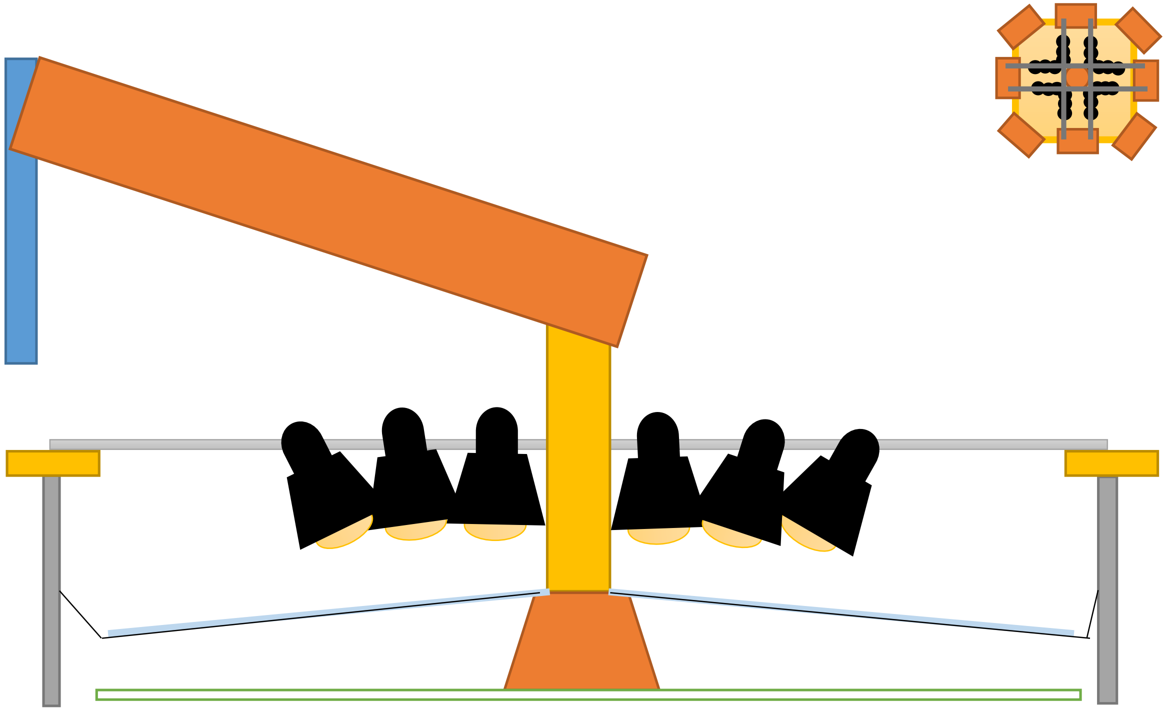
- Maximum temperature and teperature increase at the bottom remains relatively similar to previous setup with a small increase
- Maximum teperature and temperature at top still remains similar to previous experiment with a small increase
- Wind speed from start to end of experiment only changed a little, equivilant wind speed due to convection heating is lower than actual readings
- Inversed temperature still evident though is already much smaller than previous setups before heat lamps are turned on

Problems Identified

- Heat concentration still not enough, intensity of heat lamps too low to cause significant flow
- Size ratio of amount air heated to input power is too low, requires a smaller volume of air or higher input heat
- Height of elavation might still be too low, require extra elavation to help hot air escape more easily

5.5 Setup 5

Increased angle of chute, clustered heat lamps to increase heat to apron



Modifications:

- Chimney: 6.5ft
- Elevation of chute: 1.5:7.5

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	22.0	21.8	0.0	0.28	0.00	0.00	0.00
15	27.3	32.7	0.42	0.36	0.00	0.00	0.00
30	28.4	34.4	0.18	0.28	0.00	0.00	0.00
45	28.9	35.0	0.18	0.24	0.00	0.00	0.00
60	29.0	35.1	0.28	0.18	0.00	0.00	0.00

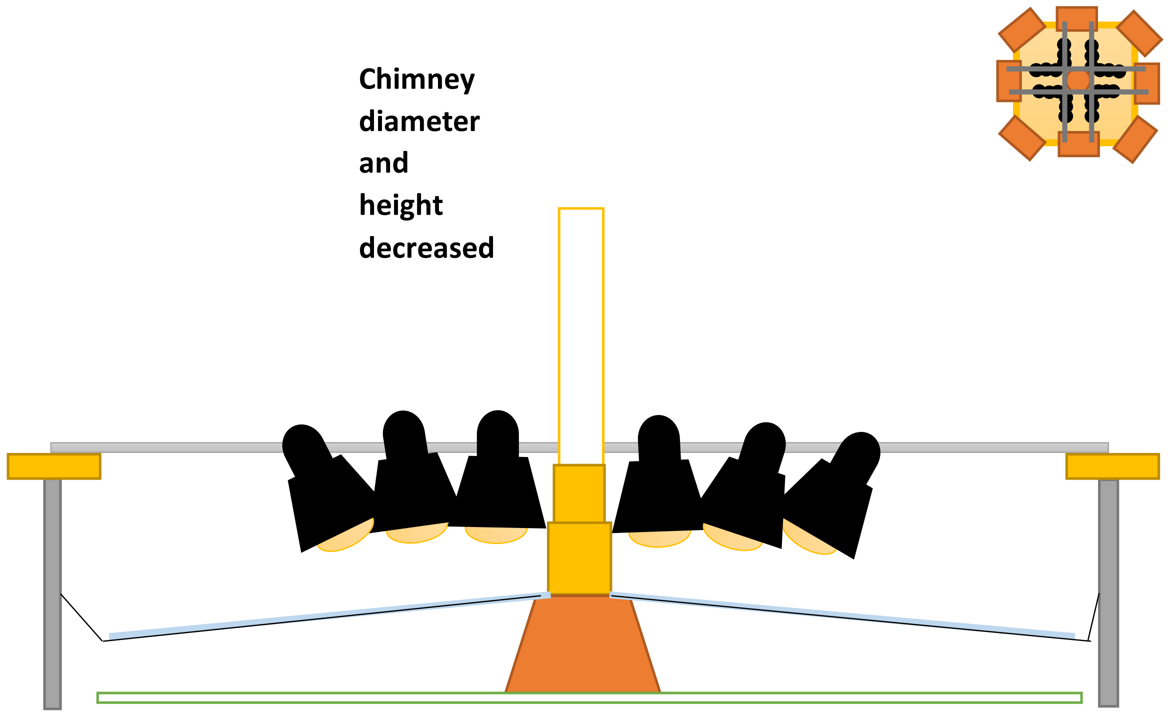
Data Analysis and Observation

- High maximum temperature and temperature increase at bottom suggesting that clustering the heat lamps work very well
- However this meant that he actual effective area of the apron is reduced and the amount of air heated is significantly less
- Small increase in amount of heat loss at top of chimney compared to bottom of chmney, hence resulting in a larger temperature difference
- Initial starting temperature still inversed from an open condition, however the difference is even smaller than previous experiments
- Wind from outside observed to blow into our chute, as evident from the faster readings at the top compared to the bottom, hence wind speed in this epxeriment might not be accurate

Problems Identified:

- Size ratio of amount of air heated to input power is too low, requires a smaller volume of air or higher input heat
- Chimney diameter too large, hence expected wind speeds is appreciately less than what could be measured
- Presence of cold air blowing into chute from outside, might affect results and prevent proper air flow in the opposite dierection
- Plastic sheets reflecting too much radiation, causing lost in energy gathered by setup

5.6 Setup 6



Modifications:

- Chimney Height: 3 ft
- Chimney Diameter: 4 in
- Removed Turbine due to Mismatch of Size

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	21.3	20.0	0.0	0.0	NIL	NIL	NIL
15	25.5	36.0	0.54	0.0	NIL	NIL	NIL
30	26.8	40.4	0.60	0.0	NIL	NIL	NIL
45	27.2	40.9	0.60	0.0	NIL	NIL	NIL
60	27.6	41.6	0.64	0.0	NIL	NIL	NIL

Possible Reasons for working:

- Smaller Chimney Diameter causes wind speed to increase, hence allowing more energy to be captured by anemometer
- Smaller size ratio of set up to room allows for proper convection current to be established
- Smaller size ratio of heat input to amount of air captured allows high enough heat concentration to cause noticeable flow in air

Areas of Improvement:

- Bringing setup outdoors. The sun would provide more energy per area (up to 3 times more) and would cover the entire apron area, in addition, having an open system allows heat at the top to dissipate more quickly allowing a higher temperature difference and hence higher wind speeds
- Adjust material of apron. More research has to be focused on enhancing greenhouse effect, the material have to allow more radiation through and trapping of the heat. The constraint is transparency and sturdy material
- Shape of apron. Due to the way the experiment was setup, we could not adjust the apron shape for effective capturing of the rising air, Ideally the apron should be rigid and properly shaped to direct wind with minimal loss

Limitations of Experiment

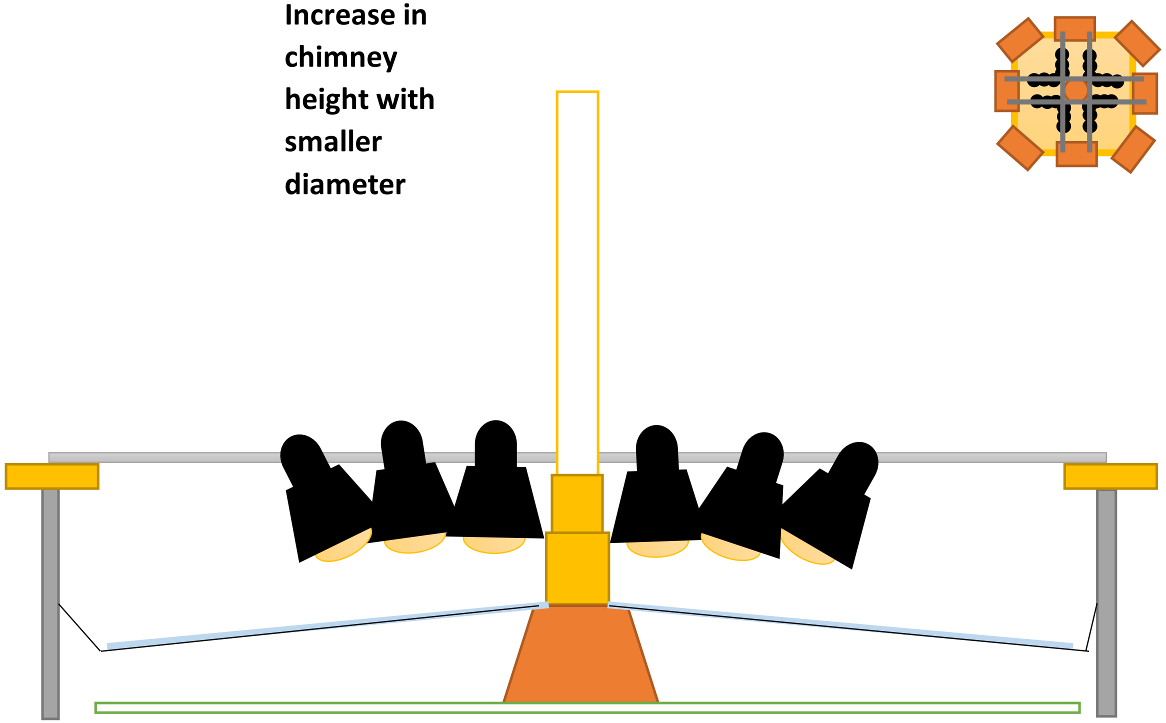
- An important factor we could not test was how the chimney height would affect efficiency of the experiment: it would influence the temperature and pressure difference of the chimney. However, this can still be mitigated by the fact that the actual chimney we were working on is also relatively short (about 8 ft) and such a setup would reflect this condition.

- Due to weather constrains, we were unable to carry out our experiments outdoors. A lot of the problems encountered could be attribute to the indoor limitations. This includes lack of sufficient power input using heat lamps instead of the sun, the closed system resulting in a lack of convection currents past a certain size, and distribution of hot and cold air in the room caused lost in efficiency due to negative temperature difference.

Other Concerns and Suggestions

- Temperature expected at bottom of chimney may reach 45C which could be unbearable for common human activities. This could be mitigated either by adding separate layer below glass which adjust the final amount of heat and light reaching the surface or using a material for the ground which would adjust the heat absorption and release rate. Alternatively, other activities such as agriculture could be carried out instead. The height of the apron may be adjusted as well.
- Efficiency of the system could be relatively small for the setup intended, other than generating electricity, using the setup as a passive cooling or heating system could be an additional advantage.

5.7 Setup 7



Modifications:

- Chimney Height: 6 ft

Results Obtained

Time/min	Ttop (C)	Tbot (C)	Vtop (m/s)	Vbot (m/s)	V (volt)	I (amp)	P (watts)
0	21.3	20.0	0.0	0.0	NIL	NIL	NIL
15	25.5	36.0	0.54	0.0	NIL	NIL	NIL
30	26.8	40.4	0.60	0.0	NIL	NIL	NIL
45	27.2	40.9	0.60	0.0	NIL	NIL	NIL
60	27.6	41.6	0.64	0.0	NIL	NIL	NIL

Results of setup 7 match those of 6, rendering chimney height as insignificant parameter apparently. However, it is believed that due to the small scale, such height difference does not make a difference. However, excessive height as originally suggested by Prof. Schlaich (who believes that with height, temperature difference increases due to the fact that temperature drops 1^{o}C every 100 meters of altitude) might not be directly proportional to the generated power and might be, in fact, disproportional to the generated power after certain height due to the gravity exerted on the hot air trying to rotate the mounted electrical turbine. In other words, it is a trade-off between the 1^{o}C temperature decrease every 100 meters of altitude, and velocity loss due to gravity force.

6 Experimentation Recommendations

If such an experiment is to be repeated, it is recommended to consider the following:

- Setting up the prototypes in an outdoors environment to avoid the closed loop temperature.
- Setting up the prototypes in a hot climate area to maximize solar energy exposure.
- Testing different material samples for apron material to understand heat losses.
- If possible, examine excessive chimney heights to understand the height effect, while varying the height parameter at constant and small intervals.

7 Test Site

7.1 Site Overview

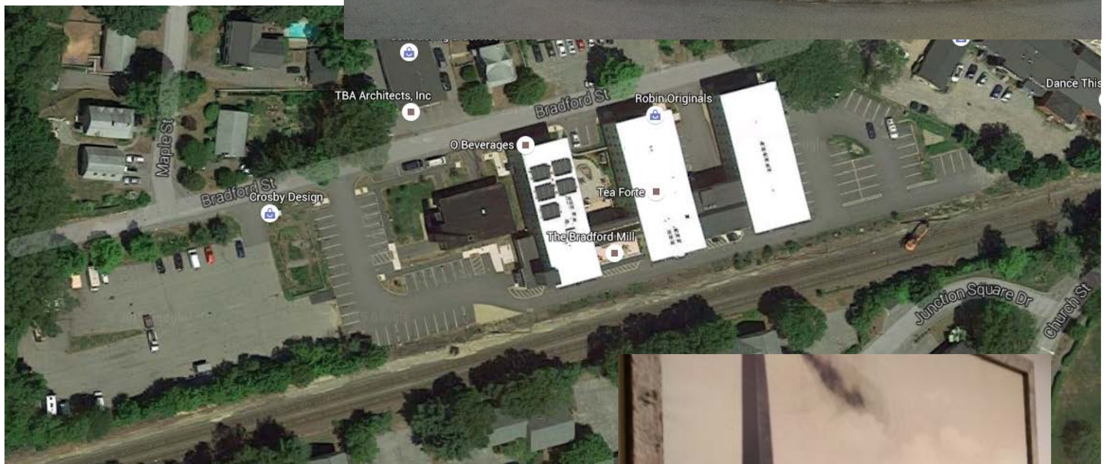
The site that has been considered for possible conversion into a solar chimney is an old boiler room of furniture factory built around 1890, in West Concord, Massachusetts, US. The area is a relatively quiet suburban environment conveniently with close proximity to the main transit lines.

7.2 Site Dimensions

Below shows the chimney and the possible area around it that could be used as a collector.

Chimney Dimensions

Dimensions	Value	Units
Height	80	Ft
Length (outer)	96	In
Breadth (outer)	96	In



7.3 Site Analysis

Background

The Old Bradford Mill used to be a factory and later a storage place for different companies during its early years due to its convenience beside the railway tracks. It later fell to a state of disrepair due to long period of neglect as a rented warehouse and was finally sold again in 2010. The new owners saw potential in its restoration and overhauled its interiors by reinforcing its structure and introducing other new technologies. The iconic chimney used to be part of the boiler room which was later decommissioned and replaced by electrical heating. Today, the Old Bradford Mill has since become a popular office location and has gained popularity as an icon in the town.

Traffic

The traffic through the area is moderate. The mill is located just behind a small shopping area which sees a fair amount of vehicles as the route is one of the main routes through this area. The location is near a train station - 'West Concord' - hence making the surrounding area popular. Although the offices in Old Bradford Mill are currently full, the traffic through the compound itself are those of workers and residences nearby making the area relatively quiet.

Limitations

While the Chimney is relatively tall as compared to the rest of the structures nearby, the absolute height of the tower would not result in a drop in normal atmospheric temperature due to elevated height. The elevated height would though provide the needed elevation to separate the temperature of heated air at its base to the top, and also possibly have access to colder winds and better ventilation due to its height advantage.

For the Apron, it is noted that unlike the proposed standard model in which the apron extends even on all sides, the dimension allowed for construction would possibly at most cover the entire parking lot length. This area is much wider on one side as compared to the other and some of the area towards the east of the chimney is covered by the main building itself. Hence, it might interrupt wind flow coming from that direction and reduce the effective area of the apron. However the remaining area is big as compared to the chimney height and might offset some of these advantages.

Finally, the site has mostly been preserved in its former form and it might be the wishes of most in that area to retain it. This might pose some challenge to the design team when it comes to developing a suitable add-on for both the chimney and apron over the site.

7.4 Potential SUT Action in the Test Site

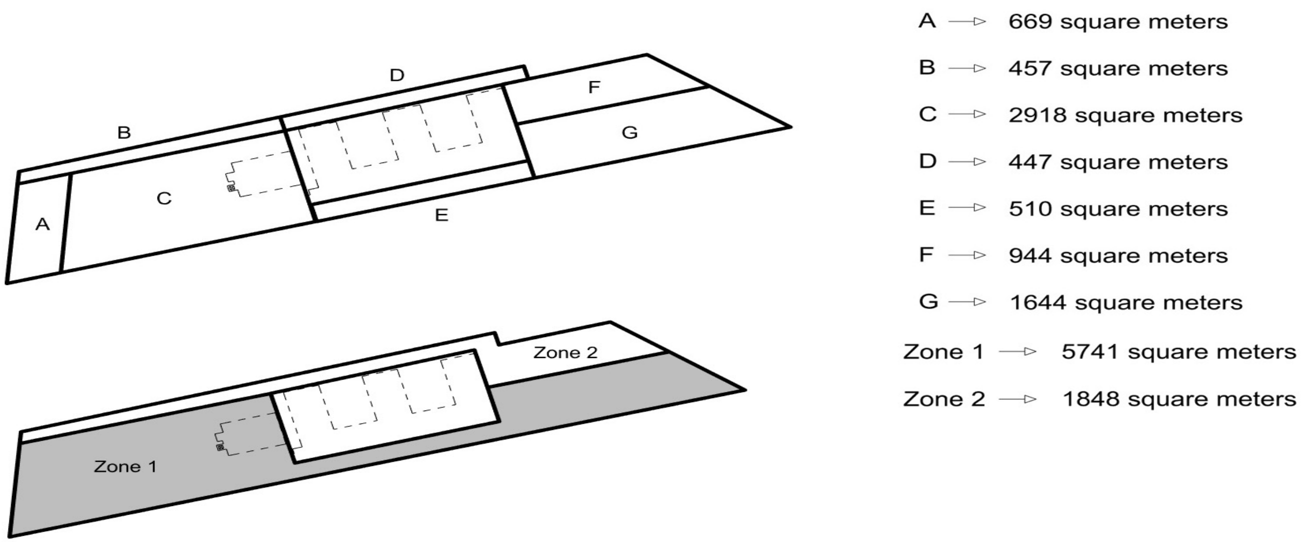
The following calculations consider the potential electric power generated should the subject site be converted into a solar chimney. This is a high level estimate, relying on online published sun hours and intensities.

Main parameters:

Dimensions	Value	Remarks
Chimney inner dimensions	6' by 6' 1.828 m by 1.828 m	-
Chimney Height (above apron level)	64' 19.5 m	Assumed apron height of ~5m
Turbine Area	2.6278 sqm	Circular
Temperature difference between the base and the top of the chimney	15° C	Based on the maximum achieved difference "experimentally" – this is a worst-case scenario as real solar energy is stronger than the experimental heat lamps used.

Apron Areas Diagram

The different possible apron installations are outlined in the bellow diagram to analyse the trade-off between solar energy absorbed and apron area.



Solar power available:

The bellow table summarizes the **solar power available** at the subject site, calculated for the different zones illustrated above.

Month	Power	A	C	E	G	Zone 1	B	D	F	Zone 2	Total Area
Avg (1998-2014)	W/m^2/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	MW/day
Jan	3681.63	2463	10743	1878	6053	21136	1683	1646	3475	6804	27.94
Feb	5374.08	3595	15682	2741	8835	30853	2456	2402	5073	9931	40.78
Mar	7440.74	4978	21712	3795	12233	42717	3400	3326	7024	13750	56.47
Apr	9907.50	6628	28910	5053	16288	56879	4528	4429	9353	18309	75.19
May	10978.47	7345	32035	5599	18049	63027	5017	4907	10364	20288	83.32
Jun	11683.66	7816	34093	5959	19208	67076	5339	5223	11029	21591	88.67
Jul	12301.02	8229	35894	6274	20223	70620	5622	5499	11612	22732	93.35
Aug	11041.14	7387	32218	5631	18152	63387	5046	4935	10423	20404	83.79
Sep	8900.76	5955	25972	4539	14633	51099	4068	3979	8402	16449	67.55
Oct	5888.93	3940	17184	3003	9681	33808	2691	2632	5559	10883	44.69
Nov	4047.86	2708	11812	2064	6655	23239	1850	1809	3821	7480	30.72
Dec	3088.97	2067	9014	1575	5078	17734	1412	1381	2916	5708	23.44
Anuual Avg (MW/day)		5.2592	22.9391	4.0092	12.9239	45.1313	3.5926	3.5140	7.4210	14.5276	59.66
Annual avg per sunny hours (kW/day/hr)		2.0878	9.1064	1.5916	5.1306	17.9164	1.4262	1.3950	2.9460	5.7672	23.68

Potential electric power generated (solar chimney effect):

The bellow table summarizes the **potential electric power that could be generated by solar chimney effect** at the subject site, calculated for the different zones illustrated above. Assuming a turbine efficiency of 30%, and a plant efficiency of 5%* (efficiency of conversion from solar to solar chimney effect).

Month	Power	A	C	E	G	Zone 1	B	D	F	Zone 2	Total Area
Avg (1998-2014)	W/m^2/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	MW/day
Jan	184.08	123	537	94	303	1057	84	82	174	340	1.40
Feb	268.70	180	784	137	442	1543	123	120	254	497	2.04
Mar	372.04	249	1086	190	612	2136	170	166	351	688	2.82
Apr	495.38	331	1446	253	814	2844	226	221	468	915	3.76
May	548.92	367	1602	280	902	3151	251	245	518	1014	4.17
Jun	584.18	391	1705	298	960	3354	267	261	551	1080	4.43
Jul	615.05	411	1795	314	1011	3531	281	275	581	1137	4.67
Aug	552.06	369	1611	282	908	3169	252	247	521	1020	4.19
Sep	445.04	298	1299	227	732	2555	203	199	420	822	3.38
Oct	294.45	197	859	150	484	1690	135	132	278	544	2.23
Nov	202.39	135	591	103	333	1162	92	90	191	374	1.54
Dec	154.45	103	451	79	254	887	71	69	146	285	1.17
Annual Avg (MW/day)		0.2630	1.1470	0.2005	0.6462	2.2566	0.1796	0.1757	0.3711	0.7264	2.98
		0.1044	0.4553	0.0796	0.2565	0.8958	0.0713	0.0697	0.1473	0.2884	1.18

* The assumption of 5% efficiency is following the widely known and practically proven photovoltaic (PV) panels efficiency of 20%. There is no established efficiency rate for solar chimney effect.

Potential electric power generated (Photovoltaic):

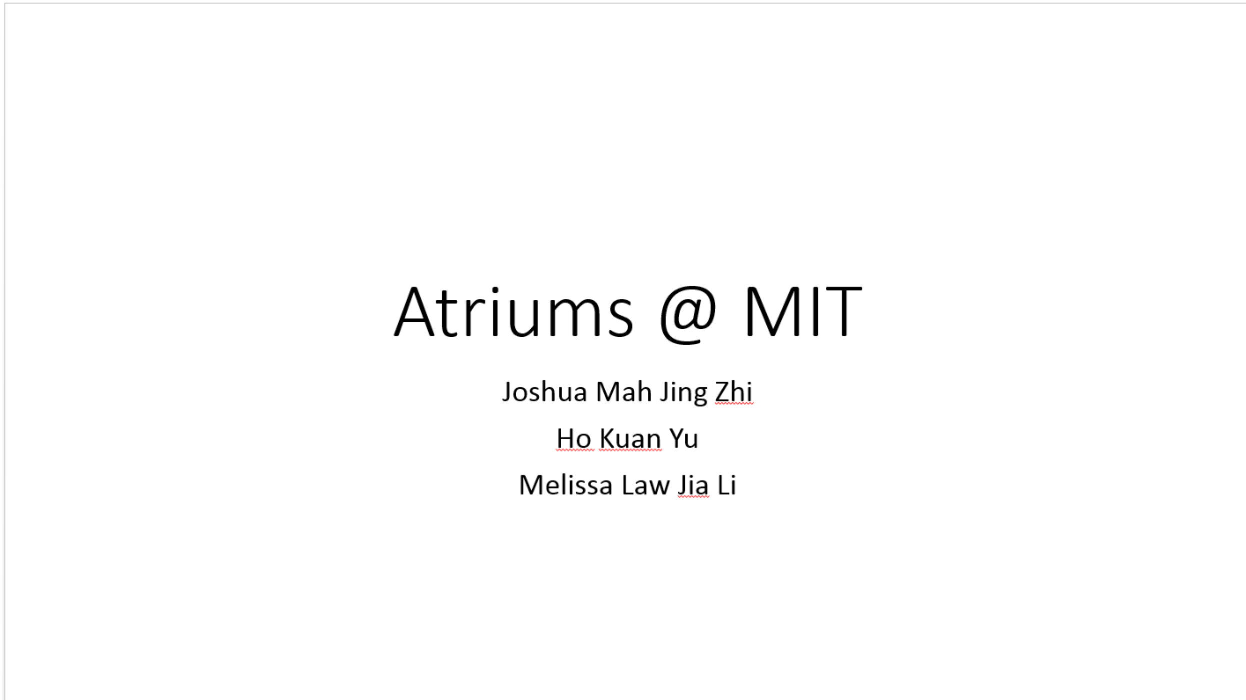
The bellow table summarizes the **potential electric power that could be generated by photovoltaic panels (PV)** at the test site, calculated for the different zones illustrated above. Assuming a PV efficiency of 20%* (from solar to PV).

Month	Power	A	C	E	G	Zone 1	B	D	F	Zone 2	Total Area
Avg (1998-2014)	W/m^2/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	kW/day	MW/day
Jan	736.33	493	2149	376	1211	4227	337	329	695	1361	5.59
Feb	1074.82	719	3136	548	1767	6171	491	480	1015	1986	8.16
Mar	1488.15	996	4342	759	2447	8543	680	665	1405	2750	11.29
Apr	1981.50	1326	5782	1011	3258	11376	906	886	1871	3662	15.04
May	2195.69	1469	6407	1120	3610	12605	1003	981	2073	4058	16.66
Jun	2336.73	1563	6819	1192	3842	13415	1068	1045	2206	4318	17.73
Jul	2460.20	1646	7179	1255	4045	14124	1124	1100	2322	4546	18.67
Aug	2208.23	1477	6444	1126	3630	12677	1009	987	2085	4081	16.76
Sep	1780.15	1191	5194	908	2927	10220	814	796	1680	3290	13.51
Oct	1177.79	788	3437	601	1936	6762	538	526	1112	2177	8.94
Nov	809.57	542	2362	413	1331	4648	370	362	764	1496	6.14
Dec	617.79	413	1803	315	1016	3547	282	276	583	1142	4.69
Annual Avg (MW/day)		1.0518	4.5878	0.8018	2.5848	9.0263	0.7185	0.7028	1.4842	2.9055	11.93
Annual avg per sunny hours (kW/day/hr)		0.4176	1.8213	0.3183	1.0261	3.5833	0.2852	0.2790	0.5892	1.1534	4.74

8 Appendix

Appendix A

Presentation Images for 'Atriums @ MIT', their viability for being converted into SUTs and suggestions made by our group.



Engineering Library Dome

Basic Dimensions

Atrium Diameter:

Outer 35m

Opening 8.2m

Atrium Height:

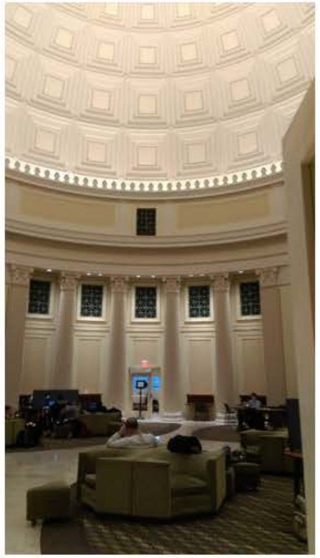
22.8m (4 Stories)

Other Properties

Elevation of Atrium:

22.5m (8 Stories)

Contains Multiple Layers in Dome used to House Books and Study Areas which Insulates Inner Layers



Surrounding Area:

- Infinite Corridor runs East-West through the Base
- North facing side occupied by a Small Exhibition Corridor which Opens up to a the Lobby of another Building
- South facing side opens up to the Killian Court which is the only open space nearby
- Open spaces a little further off includes the Massachusetts Street and Eastman Court

Suggestions:

- Convert Corridors to glass corridors which acts as wind tunnels in the building
- Elevate apron such that it merges from the bottom of dome
- Open up Library from Four sides at the ground level
- Turbine at the most narrow portion of the dome to allow maximum wind velocity to be captured
- Retain Books and Study are to use as Insulation

Little Dome at Building 7 Entrance

Basic Dimensions

Atrium Diameter:

Outer 22.8m

Opening 4.9m

Atrium Height:

35m (5 Stories)

Other Properties

Unlike the Great Dome, the little dome has an atrium which extends from the ground level

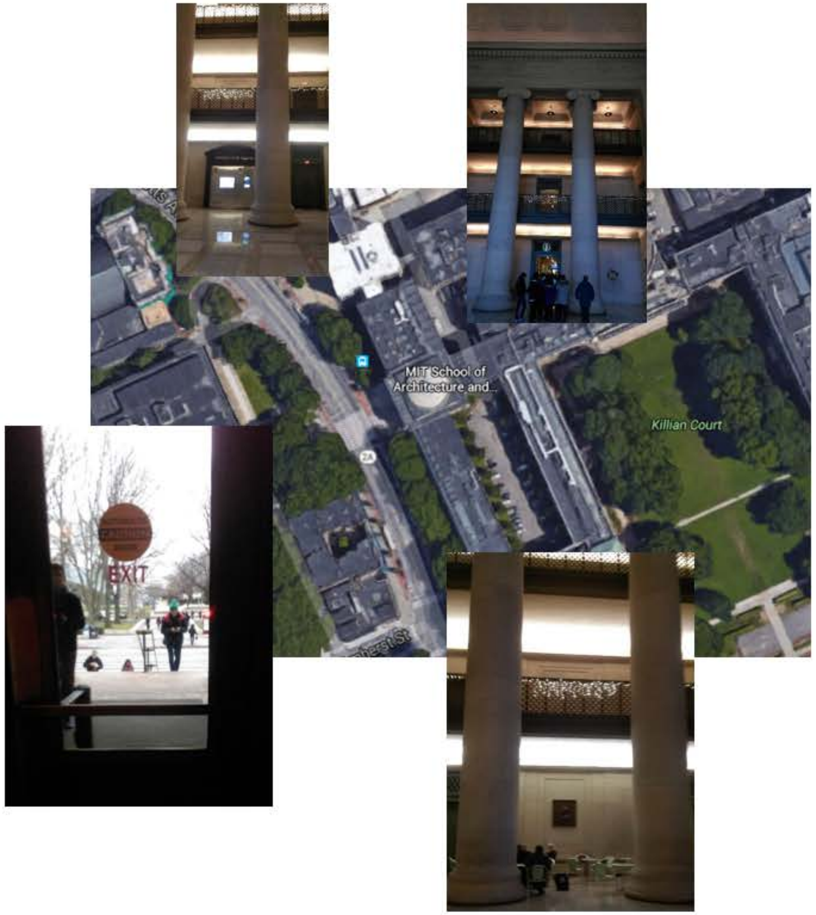
Surrounded by Indoor Bannisters

Surrounding Area:

- Infinite Corridor Extends from the East
- North-South Face have Stacked Corridors extending to two other buildings
- West Side Opens out the Open Space facing Massachusetts Street
- Open spaces a little further includes Killian Court to the East

Suggestions:

- Convert Corridors to glass corridors which acts as wind tunnels in the building
- Use Principles of Stack Ventilation to make use of Heat Generated in Corridors and Indoor Areas
- Apron to the West Can drop over and provide shelter for Massachusetts Street and the Open Space beside it
- Turbine at the most narrow portion of the dome to allow maximum wind velocity to be captured



Old MIT Media Labs

Basic Dimensions

Atrium Diameter:

18.0mx7.0m

Atrium Height:

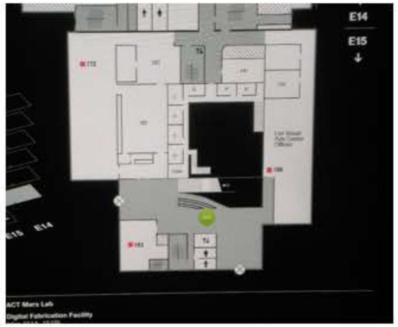
35m (5 Stories)

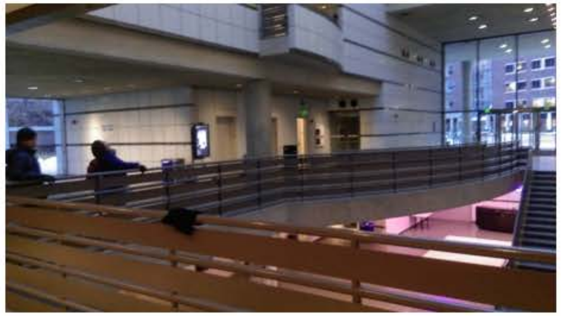
Atrium Layout:

2 Major Openings from the Street level

Small Elevation of about 1~2m

Surrounded by Offices Overlooking Main Atrium





New MIT Media Labs

Basic Dimensions

Atrium Diameter:

19.0mx12.0m

Atrium Height:

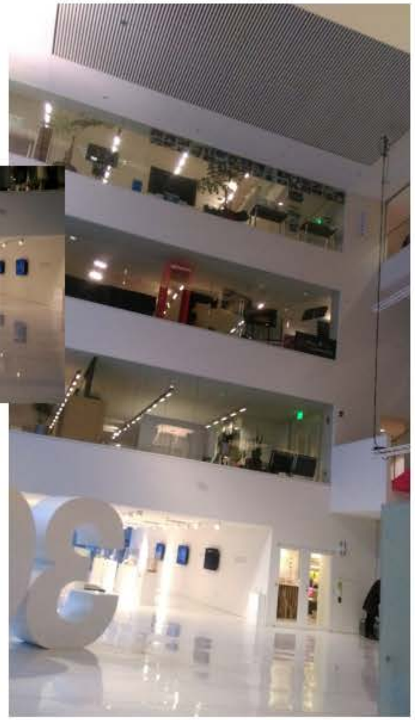
20 m(4 Stories)

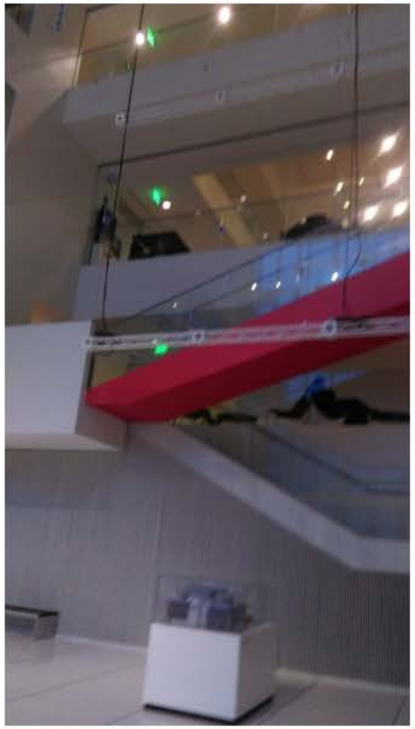
Atrium Layout:

3 Sides Open to Ground Level

1 Side Facing a Wall with other Displays

Must note that atrium does not fully connect to roof anymore





Surrounding Area

- Plenty of Open Area around Both Visual Arts Labs
- Open Spaces further Off Includes Parking lots at Hayward Street

Suggestions

- Large Apron that can cover open areas in between buildings that act as shelter
- Increase height of atriums in both cases
- Reduce Open where Turbines are placed for Higher Wind Speeds
- Use existing buildings as natural wind tunnels

Picower Institute for Learning and Memory

Basic Dimensions

Atrium Diameter:

30.0mx19.0m

Atrium Height:

20m (4-5 Stories)

Other Properties

Elevation of Atrium:

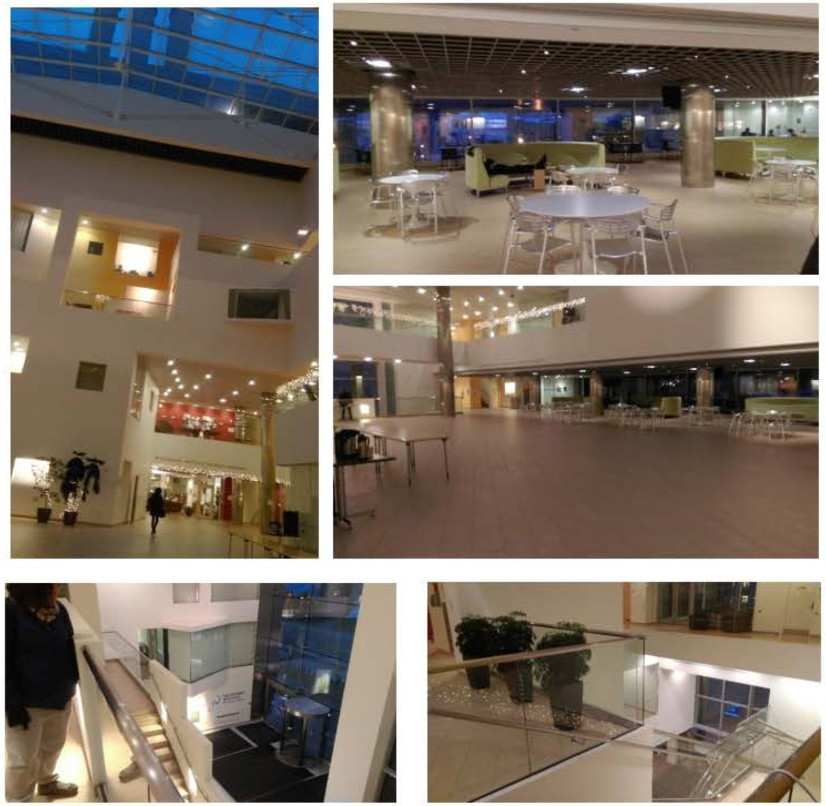
12m (3 Stories)

Atrium Layout

- 2 Sides Opened at Atrium Levels
- Others Filled with Offices facing Atrium

Entrances

- 2 Existing Entrances
- Side facing Statas Building has Broad Entrance with Large Area
- Other side is much smaller and Narrower

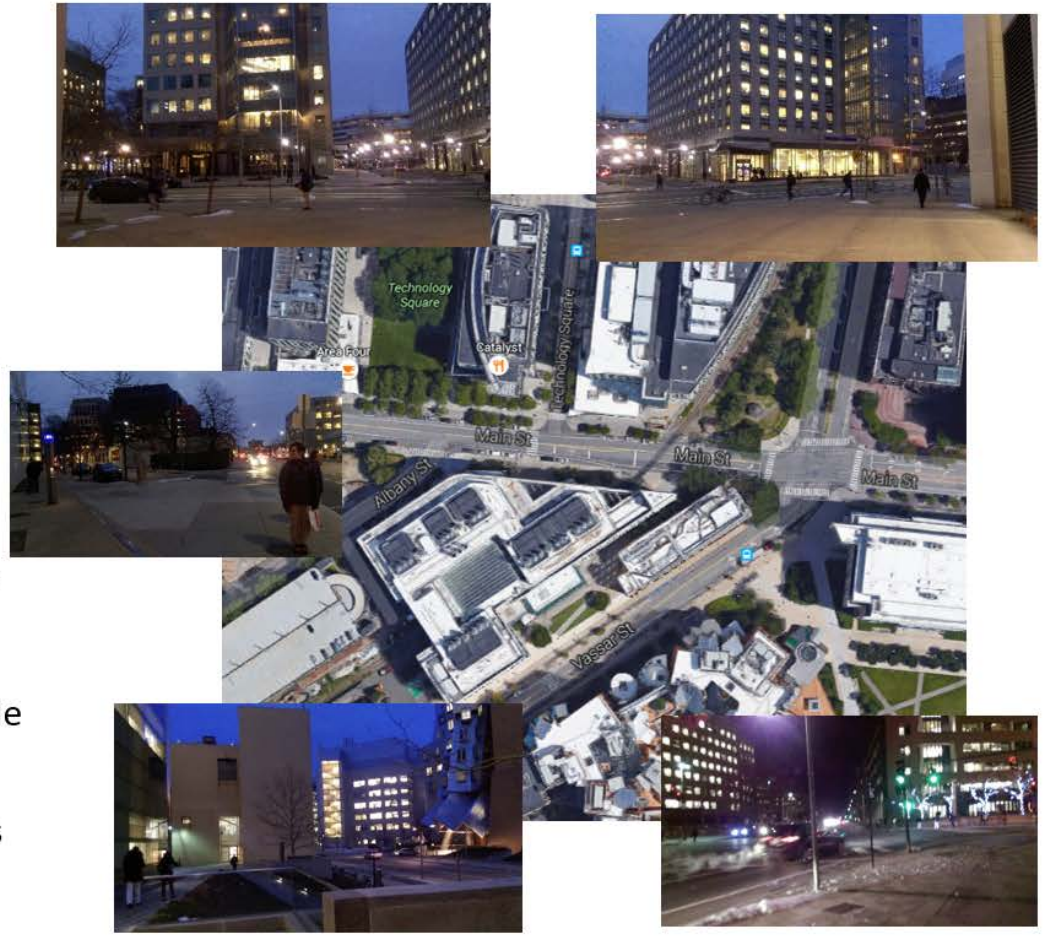


Surrounding Area

- Railroad cutting through Atrium
- Surrounded by Tall Buildings
- Natural Wind Tunnel formed by Existing Buildings
- Open Space at Technology Square, Main Street Junction and similar Junctions nearby, Courtyard beside Statas Building and Nearby Parking Lots

Suggestions:

- Reduce Atrium Diameter at the Top
- Increase Height of Tower
- Arching Apron to make use of Elevation, Cover Tall Buildings beside Building and Ease off over Open Spaces
- Utilize tall buildings further away as wind tunnels and Fashion Apron as Street Level Pedestrian Shelters



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