SOLAR UPDRAFT TOWERS
IN URBAN ENVIRONMENTS

MIT | January 11 to 21 | IAP 2016

Dr. Martin Scoppa (SUTD/MIT) | Instructor
Dr. Reinhard Goethert (MIT), Mr. Ahmad Azlon (Masdar Institute) | Advisors
Ms. Fatima Aqil AlShowab and Meera Saeed AlMheiri (Masdar Institute) | Teaching Assistants
Audrey Chin (SUTD), Ciera Gordon (MIT), Seah Jia Neng (SUTD) | Students
We would like to thank Mr. John Boynton, owner, and Ms. Tatiana Murnikova, manager, for their permission to use Bradford Mill as a test case for the Solar Updraft Tower research.
# TABLE OF CONTENTS

## INTRODUCTION

*PURPOSE OF THE WORKSHOP* ................................................................................................................. 4  
*SOLAR UPDRAFT TOWERS (SUTs)* .............................................................................................................. 4  
*BRADFORD MILL, WEST CONCORD, MA* .................................................................................................. 4

## THE BRADFORD MILL TEST SITE

*OBSERVATIONS* ................................................................................................................................. 5  
*ACCESS POINTS* ............................................................................................................................... 5  
*NATURAL ENVIRONMENT* .................................................................................................................. 5

## SITE SPECIFIC ANALYSIS

*SHADOWS ANALYSIS* ....................................................................................................................... 6  
*APRON-COLLECTOR AREA POTENTIALS* ............................................................................................. 7

## SITE VISIT | BRADFORD MILL

*FIELD SURVEY IMAGES* .................................................................................................................... 8  
*PRELIMINARY CONCEPTUAL SKETCHES* .......................................................................................... 11

## THREE ALTERNATIVES FOR A SOLAR UPDRAFT ENERGY STRATEGY

*ALTERNATIVE I - FOLDED APRON DESIGN | SEAH JIA NENG* .......................................................... 12  
*ALTERNATIVE II - ORGANIC APRON DESIGN | AUDREY CHIN* ...................................................... 14  
*ALTERNATIVE III - CURVED APRON DESIGN | CIERA GORDON* .................................................... 16

## EXPLORING THE URBAN CASE

*SOLAR UPDRAFT TOWERS AS FOOD PRODUCERS | CIERA GORDON* .......................................... 18  
*MANHATTAN WITH SOLAR UPDRAFT TOWERS | AUDREY CHIN* .................................................. 20  
*TAKING ADVANTAGE OF EXISTING HIGH RISES | JIA NENG* ...................................................... 22

## REFLECTIONS .................................................................................................................................. 24
**INTRODUCTION**

**Purpose of the Workshop**

This workshop brings together students and instructors from MIT, Masdar Institute (MI, Abu Dhabi), and the Singapore University of Technology and Design (SUTD), to explore architecture and design solutions that apply the principles of Solar Updraft Towers. Two situations are explored: the retrofitting of an existing building, and the opportunities and challenges that exist in building SUTs as integral components in the fabric of cities.

The first design exploration was conducted using Bradford Mill, Concord, MA, as an example of an existing structure with an abandoned factory chimney that can be repurposed by adding the apron, or collector, that collects hot air for the updraft to be generated.

The design explorations cover the urban scale and study the application of this technology at a larger scale. They address the possibility of using SUT’s in new urban developments, as well as the incorporation of aprons and chimneys in existing cities. The city used in this exploration was a section of Midtown Manhattan, New York.

The workshop encouraged collaboration and group discussions as the starting point for individual explorations. Thus, three design alternatives are presented in each case (retrofitting and new urban development), corresponding to the work of each individual student.

**Solar Updraft Towers (SUTs)**

Solar Updraft Towers have been increasingly studied and tested in the past years as an alternative for the generation of clean and renewable energy. SUTs have three main components: an apron-collector, a chimney, and a wind turbine generator. They operate by capturing solar radiation to heat the air beneath the collector - a structure resembling a greenhouse - which surrounds a chimney. Convection causes a hot air updraft in the tower by the ‘chimney’ effect and this airflow drives the turbines at the base of the chimney to produce electricity.

An early example of this technology is found in Manzanares, Spain. Capable of generating 50kW, this facility had a steel frame and plastic collector of 244 meters in diameter, and a 192.5 meters high chimney, 10 meters in diameter. It was built in 1982 (Schalich, 2005) and operated for 7 years. Departing from this experience, current hypothetical projects consider the construction of large scale facilities, with aprons of 2 miles or more in diameter, and 3000 feet tall towers (Enviromission, 2015)!

**Bradford Mill, West Concord, MA**

The site is comprised of an upgraded industrial assembly of buildings that are surrounded by a range of varied urban landscapes. It is primarily being repurposed for utilization in a more efficient manner and to accommodate a broader spectrum of uses than it currently does.

The structures are essentially office-buildings with a significant historical background not only to the owner, but also to the community. During the development process, the authenticity of the building would be taken into account and would be preserved.

The site retains an abandoned chimney structure that was formerly used as part of a factory for manufacturing furniture. The currently idle chimney could be effectively utilized in generating clean and sustainable energy to potentially supply the building’s energy demand by remodeling to perform like a passive, energy-generating solar updraft tower (SUT).
The Bradford Mill Test Site

Observations

The site is located in a small New England town. There are mostly traditional houses not more than three stories tall. While the low building density offers opportunities to intensify land use (constructing larger buildings that are taller and closer together), it is important to bear in mind that any new architectural addition should not alter the character of the place.

The commercial belt nearby offers a variety of stores, ranging from bakeries to hardware stores, shoe repair, furniture, etc. A park is next to the parking lot, presenting opportunities for certain type of activities happening under the apron to extend outwards. The programs under the apron could also be designed to complement the activities happening on the park.

The site’s proximity to a T-stop presents both constrains and opportunities. The T-stop provides the general public a convenient way to arrive at the site. This could encourage high human traffic whenever events are held. However, the frequency of the train is rather high, and the noise from the train can render the place unconducive for activities that require silence (e.g. an art gallery exhibition). Therefore, measures need to be taken to reduce the noise travelling to spaces under the apron. Additionally, there is no safety barrier to prevent people from stepping on the railway. This could be dangerous for visitors who may climb onto the tracks while being unaware of approaching trains.

Access Points

The site is located on a side street off of the main street in West Concord: Commonwealth Avenue. This is the main access point to the site. A second entry point is along Maple Street, a small side street that extends almost perpendicular to the site and eventually meets up with Commonwealth Avenue. A third pedestrian access point follows the railroad tracks off the main street and towards the site.

Natural Environment

Adjacent to the site is a large park. There is significant amount of vegetation around the site and throughout the town of West Concord, although the site itself is mostly parking and buildings. A marsh at the western end of the lot, creates additional constraints for the development of the apron that will collect the sun heated air.
The nearby buildings are short enough and far enough apart to not impede solar gains for the apron. The chimney itself is the only structure that would provide shade in that direction and its size is insignificant.
**Apron-Collector Area Potentials**

The full site surrounding the chimney and buildings can be broken up into several sections. The larger the area covered by the apron the more energy can be generated, but some areas might not be useful to include due to the cost and changing of the character of the site.

The main area is the parking lot space to the west of the chimney (Section C). Section A is 20% of the area that would have been included in this section that may be used for other development or is too close to the marsh.

Sections B and D follow the road next to the site and Section E follows the railway on the other side. Sections F and G include the parking space on the other side of the buildings, which may be difficult to connect as part of the apron but could provide valuable area. Zones 1 and 2 indicate a particular option for two aprons, one of which (Zone 2) would mainly cover the area along the road.

The simplest option would include only Section C, and adding other sections would increase the area but make construction and integration with the site more complex. For this reason, the exploration of alternative designs has, at this point, only considered the development of an apron over Section C.

![Diagram of Apron-Collector Area Potentials]

**Best Potential Zones**

- Total Area → 7589 square meters (excluding factory building and shaded area)
- A → 669 square meters
- B → 457 square meters
- C → 2918 square meters
- D → 447 square meters
- E → 510 square meters
- F → 944 square meters
- G → 1644 square meters

- Zone 1 → 5741 square meters (Best potential)
- Zone 2 → 1848 square meters
SITE VISIT | Bradford Mill
Characteristics of the site

The Commuter Rail station near the site

The park adjacent to the site

New apartments in Vicinity

The abandoned chimney of the old factory

The unused boiler room formerly venting in the chimney
Site visit: taking measure of the task

Presentation by John Boynton, owner of Bardford Mill

Design team in their studio
Parking lot ideal location of heat collecting apron above. Various uses could be located underneath: makets, exhibitions, sheltered parking.

Secondary area for possible apron collector at front of site. Requires less desirable longer distance for heated air travel to chimney.
There are three main areas which could be covered with heat collecting aprons:
The most feasible is the large parking area at the back of the site. Easy to cover, and useful for multiple purposes underneath. A secondary large area is covering the parking at the front but there may be considerable heat loss by the heated air in reaching the chimney. A third area is the access roads on both sides of the factory. They would provide much additional surface, but may obstruct the buildings (windows).
ALTERNATIVE I ‘Folded’

Seah Jia Neng

Apron-Collector feeding heated air into chimney to power turbine generator

Precedent: Origami Inspired Canopy, Andalusian village - Julio Barreno Gutierrez, 2015
OVERVIEW

Origami inspired apron with folded surfaces connected from the edge of the apron, sloping slightly upwards towards the chimney. The height of the folds at the edges of the apron varies to allow wind to flow through as well as marking out the entrances into the apron. Furthermore, certain areas of the apron is cut out to allow users to experience a changing of outdoor and indoor spaces.

Area of apron : 17564 m²
20% setback due to wetland

Cafe / Restaurant
Exhibition Space

Vary heights marking out the different entrances
Cut out of the apron, creating outdoor spaces

Programmable / Flexible Spaces

Public Activities
Food Trucks
Public Events
OVERVIEW

The apron consists of steel structures holding up a glass roof. The open space beneath the glass roof is flexible, it can be used as a single space for an event, or divided into smaller spaces with partitions for multiple programs to occur.

Inspired by the anatomy of a leaf, the structure of the apron branches out and spreads the glass roof across the site. The edges are made up of many curved profiles that could act as entry points, welcoming people from all directions.

To increase the energy capture, the glass apron can be expanded to include the other side of the warehouse, covering the available open spaces.

AREA
The glass apron covers an area of 1,658 sq. meters
Space under the apron could be used as a large, open air exhibition space. The exhibitions would be arranged in an organic manner, with the negative spaces becoming pathways for circulation.

The large space can also be divided into smaller space for different uses. For example, there could be many different restaurants/outdoor restaurants each with their own boundary.

The larger the apron, the larger the amount of energy captured. Should there be a need to generate more energy or to provide more space for use, the apron can easily be expanded using the same approach.
ALTERNATIVE III 'Curved Apron'

Ciera Gordon

ETFE is a strong, clear fluorine-based plastic polymer for apron-collector

The material is elastic and can handle a wide temperature range

Steel and glass canopies like those designed by Frei Otto (designer of the large tent-structures for Munich Olympics) are another option.
A Wide Range of Possible Uses Under Apron-Collector

Overview
- Smooth curves come to a point at the chimney, following a shallow gradient
- The curves are designed to channel air towards the turbine in the chimney
- Alternative uses under the apron include gardens, markets, retail, and parking.

Area Specifications
- Average height between 3 and 5 meters
- Highest point at 6.5 meters
- Total area is 2,700 m² but can be expanded
EXPLORING THE URBAN CASE | Solar Updraft Towers as Food Producers

Ciera Gordon

Overview
- Apron-Tower complexes surround the outskirts of the city
- Each apron acts as a greenhouse, with fields and gardens underneath
- The warm environment created by the capture of solar thermal energy under the aprons would allow growth of out-of-season produce
- Potential for manufacturing and processing plants underground, to be incorporated under aprons
**An ideal greenhouse under the apron**

- Approximately 10 degrees Celsius warmer than the exterior
- Air movement of 10-12 m/s
- Sunshine rich and well-lit

**What could be produced?**

- Cool Season: lettuce, broccoli, carrots
- Warm Season: tropical fruits, cucumbers, tomatoes, squash, etc.
- Hardy trees can form wind barriers to protect less resilient crops

A network of SUT cities
This alternative implements the solar updraft tower in an extremely subtle manner. Located in the middle of Manhattan, the chimney is incorporated into a superblock. The apron covers a large open area that could act as a sheltered, public garden. The ‘superblock’ contains residential apartments at the outermost core, followed by offices in the middle. This mixed used development could potentially derive most of its energy needs from the chimney and the glass apron.
Fitting into the urban context

This alternative uses 3 typical Manhattan blocks as the site for locating the apron-collector and the chimney, now a highrise mixed-use building. Given the large resulting area, it is essential to include pathways that allow for people to cut across the site, enhancing the potential for pedestrian movement. Nine squares resulted from defining new pathways, which produce smaller spaces for activities to take place independently.

A highrise building is placed in the middle of the site. Its atrium acts as the chimney and several additional towers, accommodating office and residential uses, are distributed surrounding this taller structure and form a single architectural unit.

The apron-collector extends to the boundaries of the site, providing a large area for heat collection and allowing varied uses underneath.

Possible public uses under apron

Urban Farming

Outdoor Exhibition Space

Farmer's Market
This concept makes use of the existing urban context of having high rise to low rise buildings. Chimneys could be added or modified in existing atriums of high rise buildings, and then, spanning the apron across the low rise buildings connecting the chimneys. The apron could be used to expand the use of streets, now covered, while also facilitating the introduction of vegetation as a carbon capture strategy.
A three step strategy

1. Identify the tallest buildings in the area

2. Add chimneys or modify existing atriums

3. Add apron, covering low rise buildings on site

Sheltered streets

Type of roads created
REFLECTIONS

In terms of findings, perhaps the most outstanding result of this workshop is relative to the rich variety of proposals for the integration of SUTs to the urban environment. In both cases -the retrofitting of a specific structure and the exploration of large scale urban interventions- students imagined and designed carefully contextualized structures whose qualities and projected function demonstrate that solar updraft towers can be adapted to serve as valuable additions to the urban realm.

We confirmed as well, the need and value of multi-disciplinary collaboration if these ideas are to grow into realities. The input from the studies conducted by the technical group led by Mr. Ahmad Azlon with the assistance of Ms. Meera Saeed AlMheiri from Masdar Institute, and SUTD students Joshua Mah Jing Zhi, Melissa Law Jia Li, and Ho Kwan Yu, provided key insights regarding the possibility of having asymmetrical aprons and off-center chimneys, resulting in a larger and richer exploration space when developing design alternatives.

A key concern that remains after this short period of experimentation is relative to the viability of this technology, particularly in terms of the costs involved in building aprons and chimneys, and the savings brought by the generation of energy. Undoubtedly, further research is needed in order to confirm the economic viability of SUTs given their large land requirements, the size and scale of their components, and specific issues regarding their operation.

Economic factors are a main concern, but we found that other areas warrant further study. Among them, research on materials whose properties could increase the efficiency of the overall system, while also opening opportunities for architecturally innovative solutions that are constructively feasible. The materialization of these structures was frequently discussed, although more focused and detailed studies are necessary. Further, the issue of shading in dense urban environments -which could affect the functioning of the apron- and a systematic approach to the evaluation of different climatic conditions remains to be studied in depth.

From a cost-benefit perspective, the added cost of an apron-collector – assuming one can use an existing chimney as is the Test Case – is somewhat balanced by the ‘free’ no-pollution electricity. Moreover, an important and with a potentially large benefit, there is the dual function of the apron: collecting solar heat, but also providing protected activities underneath; for example, markets, sheltered parking, agriculture, shopping, exhibits and so forth. For each of these there can be a charge, increasing the financial viability of the solar updraft energy approach.

The ideas developed and presented in this report, and the richness of the designs proposed in such a short period of time, encourage us to continue pursuing the question of the viability of SUTs in urban environments and helped, as well, in identifying and clarifying the key subordinate questions.

Selected references


EnviroMission Limited Website: http://www.enviromission.com.au

Acknowledgments

We would like to thank the generous support of the Singapore University of Technology and Design (SUTD) for funding this workshop. We would also like to thank the MIT/SUTD Collaboration office, particularly the gentle disposition of Mr. Jesse DeLaughter and Ms. Stephanie Lendall. We would also like to thank Mr. Jim Harrington, Facilities Manager at MIT School of Architecture and Planning. Finally, we would like to thank Mr. Jonathan Dessi-Olive for his valuable input in issues relative to the development of the design workshop.

Produced at MIT School of Architecture + Planning during IAP (Independent Activities Period) Cambridge, MA, January 21, 2016

An activity of SIGUS