A REPORT
ON THE POTENTIAL EFFECTS
OF SHADOWS
THAT WOULD BE CAST
CAST BY PROPOSED BUILDINGS
AT 960 FRANKLIN AVENUE
ON THE GREENHOUSES OF
THE BROOKLYN BOTANIC GARDEN

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TABLE OF CONTENTS

INTRODUCTION

What follows is a report regarding the potential effects of the shadows that will be cast on greenhouses of the Brooklyn Botanic Garden (BBG) by the proposed development to be located at 960 Franklin Avenue. The report depends upon a shadow study performed by Philip Habib & Associates, which is included in the Environmental Impact Statement (EIS) for the proposed 960 Franklin Avenue development. It assumes that the shadow study is in compliance with the guidance and methodology provided in the 2014 *City Environmental Quality Review (CEQR)Technical Manual* and accurately depicts the shadows that are expected to fall on the different buildings that form part of BBG's greenhouses and conservatories, its workhouses and its propagation houses. It makes no comment regarding potential effects of the shadows or other building issues on outdoor plants in the gardens.

The focus of this effort is to assess how the shadows might affect plants growing in the conservatory, greenhouse and workhouse buildings. I contacted experts from greenhouses and conservatories around the country (and in one case in Europe), and interviewed key personnel to get their assessments of what might happen to different classes and categories of plants in the greenhouses, given the shade that would be cast. I provided each contact with definite information on the times of day, duration, and times of year when shadows would be cast in different greenhouses. I paid particular attention to those greenhouses that contain plants that in nature would live in full sun during a part or all of their lives. These included desert plants, Mediterranean plants, and tropical plants. In the case of desert plants, I also interviewed one of the leading students of desert plants in the world. I also interviewed two very experienced greenhouse advisers from the firm Rough Brothers, the leading builder and maintainer of greenhouses – both commercial and botanical – in the nation. Among their recent conservatory projects was the renovation of Chicago's Garfield Park Conservatory.

My methodology relied heavily on interviews, because as my initial research showed and as a number of veteran public greenhouse managers and curators confirmed, there are a large number of species in each greenhouse, and many or most of these species have not been studied to determine exactly how much light they actually need. Data, therefore, is lacking. They suggested that, in many cases, it will be necessary to observe how the plants in fact respond to reduced light.

A number of the experts I interviewed suggested that one experiment would be useful. These experts included Marc Hachadourian of New York Botanical Garden, Clinton Morse of the University of Connecticut, Storrs, Karl Gercens of Longwood Gardens, and Ben Eiben of the Amazon Spheres. They suggested that I use a Photosynthetically Active Radiation (PAR) meter – that is a handheld device that allows me to quantify the incoming light that is in the range used by plant photosynthesis – to assess how much light reaches the key greenhouses in the Brooklyn Botanic Garden now. They suggested that I then find an existing tall building nearby with a size, aspect and distance that makes it comparable to the proposed building. They suggested that I take PAR readings in this shadow. All of the readings must be taken on the same day at as near the same time as possible. The PAR incident on the different places – when combined with the duration of shadow at that time – would allow me to estimate the percent reduction in daily light that is reaching the plants in the relevant greenhouse. This, they said, would help to quantify potential effects.

Accordingly, I purchased an Apogee Instruments PAR meter and took the readings during early September. For the date on which I took the readings, 11 and 13 September 2019, I found that the shadows cast by my analogue building near Temple Square in downtown Brooklyn – would not negatively affect plants that demand high light condition, provided it was a sunny day. On a cloudy day, however, the reduction in PAR light incident on the greenhouses might not be enough either for high light or medium light demanding plants. Thus, the shadows cast by the development's building would make the greenhouses more vulnerable in bad-weather years, when there were significantly more cloudy days than average.

This report will detail the responses of experts to the major questions at issue, as follows:

1. Is it likely that there will be an effect on the greenhouse plants caused by the shadows cast by the proposed building? How serious and of what kind might those effects be? When will the most serious issues, if any, occur?
2. Will some kinds of plants or some greenhouses be more affected than others?
3. Is there any feasible way to mitigate such effects as might occur, for example, by means of artificial lighting?
4. Will the change in photosynthetically available light (PAR) have an effect on the condition and health of the plants?

The Brooklyn Botanic Garden is among the nation's most important urban botanical gardens. It focuses on presenting to a large urban public as full a living picture of the world's plants and gardens as possible. Its greenhouses, therefore, are less focused on containing rare and difficult plants than they are on showing the visitors a broad range of the possibilities for plant growth in the world's major ecosystems. The Desert Pavilion, for example contains not only cacti and succulents from the American Southwest and Mexico, but from desert terrain in South America and in Africa as well. It is very important that the extremely broad range of plants be displayed to best effect for the thousands of yearly visitors.

EXECUTIVE SUMMARY

In summary, the following are the conclusions to which the study led:

1. There will be effects on the public conservatory plants caused by the shadows that will be cast by the buildings of the new development, as currently planned. Because I was not able to access the education, propagation and work houses, I was not able to report first hand on those spaces.

2. The following effects may occur, depending upon plant species and duration of shadows. These effects are listed in increasing order of severity. Most experts thought that the most serious effects would not occur on the majority of plants.
    a. Reduction in flowering or turning of flowers towards light source.
    b. Slowing of rate of growth
    c. Bending or stretching of plant bodies
    d. Decline of plant health

3. The plants most affected will be those that demand high light in their natural habitat. These include the entire desert collection, the high light-demanding plants of the Mediterranean collection, and overstory plants (chiefly palms) of the tropical collection.

4. Effects will be cumulative over years and will not be seen immediately.

5. Shadows cast during the growing season will have effects, but because there are much longer periods of light at that time, the plants are slightly less sensitive to changes. Any change of lighting in the short-day winter months will affect plants.

6. Because the individual plants in the greenhouses have mainly not been studied for their light needs, it is not possible to say in advance which plants will be affected and what the exact effects will be.

7. Years with above-average number of cloudy days will see increased rate of production of effects, since the shadows cast will worsen the low-light conditions caused by cloudy days.

8. Mitigation could be provided to some extent through the use of an app-managed LED lighting system, where needed.

All of the experts interviewed agreed that subjecting existing greenhouse collections to additional shade will have a noticeable effect. All agreed that the effects would not be seen immediately, but would be cumulative beginning in 2-3 years after the buildings are built. Most agreed that 1-1.5 hours of shade might not have a serious impact, but that increasing duration of shadows up to the 3-3.5 hours projected as maximum shadow in the shadow study would have increasingly serious effects. There was, however, disagreement on the effects of 3-3.5 hours of shade. Thus, it is likely that reduction in the duration of shadows would reduce the effects on the plants.

All agreed that while growing season shadow would be an issue, it would certainly be problematic to have any additional shading in winter, when daylight hours and solar intensity in the northeast are much reduced.

With increased hours of shadow during the growing season, some experts thought the effects would be significant, and others thought they would be minimal. The more serious effects might include the plants' stretching towards the light and so changing their typical (and attractive) growth habit. They might also include a reduction in flowering, or they might incline the flowers and even the entire plants to bend to face the best source of light. Some of the most sensitive plants might decline over a period of time, so that they would need to be replaced with more shade tolerant species.

Most experts believed that the plants most likely to be affected are those that in nature grow preferentially in full sun. The entire desert collection fits in this category, as do some of the Mediterranean plants and the overstory plants (chiefly palms) of the tropical collection. Plants that prefer part shade, like the understory plants of the tropical collection, might be affected little, if at all. Several experts noted, however, that even full sun plants may be able to tolerate considerably less than full sun. They noted that greenhouses in fact often use shade cloth or paint during the summer to reduce and diffuse sunlight. There is in fact shade cloth in summer evident on several Brooklyn Botanic Garden greenhouses.

Several experts raised an additional issue. They noted that although the plants might survive the changes, that the look of the greenhouses would be altered for the worse in the morning, reducing the number of visitors and changing their enjoyment of the public sites. In this case, there will not be more than a few minutes when visitors will be compelled to visit greenhouses that have been cast into shadow by the buildings. The reason is that the public pavilions and conservatories are almost all entirely out of shadow by 10 AM. Since these buildings do not open until 10 AM, visitors' experience will not be affected.

There was likewise considerable disagreement about the feasibility of using supplemental lighting to mitigate shadow effects. A number of very experienced greenhouse managers and curators said that artificial lighting, although rapidly improving, cannot imitate the energetics or match the wavelength range of natural solar light. Another cadre of experts, however – chiefly those working in greenhouses that use the latest developments in LED lighting – suggested that it might indeed be possible to mitigate shadow effects by the use of new kinds and intensity of LED lights. Some curators noted that to make a difference these lights would need to be located so close to the plants that they would obscure plants or make the sight of the plants less aesthetically pleasing. Others noted that there are now high-intensity and broad spectrum LED lights available that can fit unobtrusively against the existing greenhouse frames. These would not spoil the look of the plants, and according to these experts, the light cast by these fixtures is pleasing in itself, not harsh. It should be said, however, that the chief exponents were people managing the downtown-Seattle Amazon Spheres. Their lighting works well in an environment surrounded by tall buildings, they said, but they admitted that they had selected the plants for the conservatories because they are shade tolerant. They also noted that this lighting and the associated apps to run it properly are expensive. Each bulb of the Fluence VYPR slim-line series of LED lights – the type used in the Amazon Spheres – costs $800-1000. That does not include design, installation, monitoring or maintenance of the light system in the building. Dozens to hundreds of bulbs are required to light a large greenhouse.

THE LIGHT

Photosynthetically Active Radiation (PAR) is light in the range of 400-700 nanometer, chiefly in the visual range of solar electromagnetic radiation. This is the light that plants use both for growth and to power all of their activities and life. A little less than half of solar light is in the PAR range. About 60% of the sugars made in photosynthesis are used for growth, and the remainder to fuel processes that need energy, including self-defense and reproduction.

Photosynthesis is a chemical reaction chain whereby sugars are made out of sunlight, water and carbon dioxide. Two reactions are involved. The first, called the light reactions, create high-energy compounds using the energy of PAR radiation. In the second, called the Calvin Cycle, the plant uses the compounds to power the conversion of water and CO_2 into sugars, with oxygen as a waste product. In sunny conditions, plants will usually create more compounds in the light reactions than can be handled in the Calvin Cycle. There is thus often a dissipation of excess energy. Only when it is comparatively dark does the Calvin Cycle outrun the light reactions, offering more available conversion than the light reaction can power. Too much light is almost as dangerous to plants as too little light. Greenhouses often use a shade cloth or paint during the summer to diffuse the incident sunlight. Thus, the presence of shading alone in spring and summer does not necessarily create serious issues for the plants.

The question that we must answer is this: Will the amount of shading caused by the proposed buildings affect photosynthesis to the extent that many of the plants' form and flowering will be negatively effect and that some of the plants will decline and need to be replaced?

ASSESSMENT OF OVERALL EFFECTS

The key issue is at what point the reduction in available light will result in negative effects on the plants. This issue relates to both absolute and relative loss of light. Plants will require a minimum light duration to make the food necessary for their processes. They will need this light not only during the height of the growing season, but also in the winter months, when light is typically scarcer in the northeast. A loss of 2 hours of sunlight from a 12 hour day in June, for example, leaves still 10 hours of sunlight. This is likely more than enough to fuel almost any plant's life. A loss of 2 hours of sunlight on a winter day when there is only a 6.5 hour day, on the other hand, will mean a remainder of only 4.5 hours of sunlight. Particularly for plants whose native home is at much lower latitudes, this relative lack of sunlight in winter could have a serious effect.

The experts consulted had varied thoughts about the minimum light necessary for the plants to continue with good shape, adequate flowering, and relatively normal lives. There was no consensus, except that all thought that the increased shadows would have a measurable effect on the plants over time.

Mary Eysenbach and Peter Vrostos, greenhouse manager and chief horticulturist of the Lincoln Park Conservatory in Chicago, thought that 1.5 hours of reduction in light would not have a serious effect even on light-demanding plants. As the shadows approached the 3-3.5 hour reduction level, they felt that issues might arise including reduced flowering and some bending and stretching.

Francisca Coelho, former greenhouse manager at the New York Botanical Garden, thought that the longer shade durations might over time – beginning in about 2-3 years after the buildings are erected – cause some plants to show symptoms of decline. "The plants in high growing season need at least 8 hours of light," she said. "The 3 hours of morning light are particularly good for the plant. Only 6 hours is likely not enough." She thought that it might be necessary over time to change the plant palette to reflect the species that do well in the new light regime. She emphasized that good winter light was key to maintaining all of the plants in the greenhouses. Even a small loss of light during the winter, she said, might have a serious effect on the health and beauty of the plants.

Karl Gercens, greenhouse manager at Longwood Gardens, thought the situation might require changes, but would not be grave. "Full sun plants need about 5000 foot candles,' he remarked. "Even with some shade, they should be fine. We often have to whitewash greenhouses to diffuse sun, making incident light up to 60% less." (The foot candle number he suggested represents about half of the possible maximum sunlight.) Like Coelho, he emphasized that the managers would need to keep a close watch on plants to see which did not respond well to the new conditions. He suggested that it might be possible to improve the situation with lighting, but that in his view, it would simply be better to adjust the planting to those that tolerate the changed conditions. "If the buildings are 250 to 500 feet away from the greenhouses," he said, "the shade will be high shade, with a lot of refracted light." He said that this situation not only meant that the change from shade to sun would not be sudden, but also that there would likely be a good deal of incident light, even when the greenhouses were shaded. “When you talk about the general healthy growth of a plant,” he said, “4-6 hours qualifies as full sun. So that is not bad, particularly if the shade cast is high shade.” He did not believe that the time of the day when the light was available to plants was important.

Jimmy Groghan, manager of the venerable greenhouse at Smith College, also thought the situation serious but not disastrous. “It’s not going to kill anything,” he said. “It’s going to mean a reduction in growth potential over time.” In contrast to Coelho, he thought that the plants would not bend or stretch over time, given a maximum shading of 3-3.5 hours during the growing season. He was aware that during most of the growing season there was less than this maximum shading.

Marc Hachadourian, manager of the Nolin Greenhouses and curator of orchids at New York Botanical Garden, was concerned about both the length and quality of the shade. He felt that a sudden change from sun to shadow and back again could in itself be damaging to plants. With less than 6 hours of sun, he said, he thought that there could indeed be bending and stretching of the greenhouse plants. He was not convinced that the “high shade” noted by Gercens would make a significant difference.

“Greenhouses are houses of light,” said Paul Knuth, curator of the McNeeley Conservatory in St. Paul, MN. He noted their problems both with shadows cast and with very short winter days. He said that they had to light their tropical collection with artificial lighting during half the year, and that they have had to adjust their tropicals collection so it contains a greater number of shade tolerant plants. “Winter light is much more important for us than summer light,” he said. “From fall equinox to spring equinox is the crucial time.” Parts of their greenhouses are shaded by the conservatory in winter, and they do not use those greenhouses at that time.

The director of the Phipps Conservatory in Pittsburgh, PA, Juliana Razryadov, also noted significant effects caused by trees that shade parts of the conservatory. In the Palm Court and with the tropical forest plants, they are moving towards only shade tolerant species. They have to manage their orchid collection by moving plants to different greenhouses at different times of year.

The head of the greenhouse and conservatory restoration group at Rough Brothers, Cincinnati, OH – the nation’s leading builder and maintainer of large greenhouses, both commercial and conservatories – was fairly sanguine about the performance of display plants with that amount of additional shade. “If the greenhouses are used for mature specimens and people coming to look at them,” he said, “that could be in the no problem column. Even with the desert plants, if they are already established plants. I don’t think three and a half during a long-day part of the year would impact them.” A production greenhouse, on the other hand, where plants need to be grown for rapid growth and for sale or for setting out, might well be more affected by that amount of shade. In other words, he thought that growth might be slowed, but that most plants would not decline.

Clinton Morse, manager of the greenhouses which contain plants from 10 different worldwide biomes at the University of Connecticut, Storrs, also though that the effects would be manageable. “If there will only be a maximum of three or three and a half hours of shade maximum between 7 and 11 in the morning,” he said, “I think you will be ok. If it were more continuous, there would be a problem.” He did note an important aesthetic concern. “Morning light is nice, and afternoon light harsher,” he remarked, “so the visitor experience might be impacted.”

In summary, it appears that a minimum of 4-6 hours of light are necessary for basic long-term survival. A minimum of 6-8 hours during the growing season appears to be necessary for attractive and healthy growth. There was disagreement on this point, with some experts saying 8-10 hours is necessary. It is especially important to maximize light during the short days of the northeastern winter, so shading at that time may cause the most serious issue.

LIGHT-DEMANDING COLLECTIONS

All the experts interviewed agreed that plants demanding the highest light conditions – because of the growing conditions in their native lands – would be the most likely to be affected by shading, though the experts differed on the extent of these effects. “Good sun helps keep plants compact,” said Brian Sullivan, Vice President for the Conservatory at New York Botanical Garden. “Desert plants will need the most light, but you have to look at them in the specific greenhouse conditions to know just how much.” Ron Determann, curator of the conservatory of the Atlanta Botanical Garden, agreed. “The effect would be strongest on the Desert Collection,” he said. “New York is not that far north in latitude from the Mediterranean plants’ habitat, but it is far from the latitude of desert plants.” He emphasized how important it was for low-latitude plants to get as much light as possible during winter. Coelho warned that if there were large, well established plants in the desert collection, they might be affected in displeasing ways. “An old saguaro cactus, for example,” she said, “might bend towards the light, changing its form.” Coelho also emphasized the importance of having little or no shading during the short days of winter.

There was significant disagreement as to the seriousness of the effect. Hachadourian thought that shading on the desert collections that lasted for 3 hours for a month and a half might indeed have “a cumulative negative effect.” He said that the changes might force the Brooklyn Botanic Garden to get rid of the desert collection. Knuth thought that if light could be kept steady during the winter months, the collection could do relatively well. “If it is not so bad in January,” he said, “it will not be so bad overall.” Coelho thought that the changes in shading might require the Garden to change the species in the collection, though not entirely dismantle it.

John Trager, curator of desert plants at the Huntington Library in San Marino, CA, thought that the desert collection at the Garden might be able to remain at least mainly intact. “If the shading is fairly limited in duration,” he said, “it might not be a huge problem.” He did not, however, think that there would be no effect. “It may alter the ability of garden to carry out its mission,” he remarked. “If they can’t grow certain species successfully, they would have to adjust their holdings and collections.”

I sent him a list of most of the plants now growing in the desert collection at the Brooklyn Botanic Garden – a list I had compiled on a visit to the Desert Pavilion. “I don’t see anything particularly vulnerable on the spreadsheet,’ he said in response. “While the plants may not flower as well, they will probably survive and still be display-worthy.”

SHADOW EFFECTS ON GREENHOUSES AT BROOKLYN BOTANIC GARDEN

The greenhouses break naturally into four separate groups. First are the education greenhouses, the northernmost of the greenhouses. Next are the public conservatories and pavilions located in the center of the garden. Third are the workhouses and propagation houses east of the public conservatories and pavilions and adjacent to the garden edge. Fourth are the propagation and production tunnels located in the south part of the garden. The greenhouses, each given an identifying letter, are shown on Page 21. The table representing the total light and the shadow effects of the new buildings on the individual greenhouses begins on Page 22.

Greenhouses A-C are respectively, the Desert Plants Education Greenhouse, The Warm Temperate Plants Education Greenhouse, and the Tropical Plants Education Greenhouse. Although these are not open to the public, my observation from the outside suggested that at least one of these greenhouses has been converted into a dining room. Unlike all of the other greenhouses, these three are most shaded during the winter. Though they always have more than 4 hours of sunlight daily – typically 5 hours or above – these three greenhouses may suffer from low light in the winter. All three would not be shaded at all by the proposed buildings through the height of the growing season. However, it should be noted that these greenhouses are now shaded by large deciduous trees during the growing season.

Greenhouses D, E and F are three of the principal public greenhouses. They are, respectively, The Warm Temperate, Tropical and Desert Pavilions. These greenhouses are very little shaded or not shaded at all during the deep winter months. This is very good for their ability to withstand those short days, although as several experts pointed out, even brief shading in winter will have a cumulative effect. Although all three of these greenhouses receive considerably more morning shade during the height of the growing season – from April through August – each still receives at least 7-8 hours of sun during the day, and sometimes 9-10 hours of sun. When I showed Coelho a complete table of the sun and shadows experienced by these greenhouses during the whole year, however, she remarked that the changes in sunlight available, even if small, would still likely have a cumulative effect.

Greenhouses G. H and I represent the Bonsai Museum, the Conservatory Entry House and the Orchid Collection, respectively. All receive at least 6 hours of sunlight during the important winter months. All receive 7-10 hours of sunlight through the height of the growing season. Again, some effects may occur when the sunlight hours are less than 8, but the effects are not likely to be dramatic. The Entry House has many tropical plants that prefer some shade, and the Bonsai house currently uses shade cloth to reduce incident sunlight. In the case of the Bonsai collection, some adjustments might simply be made by reducing the use of the shade cloth.

Greenhouses J, K, L, M, N, and O are workhouses and propagation houses. I am told that these greenhouses are artificially lit. They are located adjacent to tall evergreens that grow at the edge of the Garden. The shadow study numbers may therefore not be accurate for these greenhouses, because they are shaded by trees and because they receive artificial light. These greenhouses often receive only in the 5-6 hour range during the winter. They receive 7-9 hours of sunlight during the growing season. I was not able to directly examine these greenhouses.

Greenhouses P, Q, R, S, T, U and V are nursery yards, propagation tunnels and production houses that serve the rest of the garden. I have been told that these tunnels are also artificially lighted. There will be little or no shade in these greenhouses during the winter months. There will be 7-10 hours of sunlight during the height of the growing season. I was not able to directly examine these greenhouses.

Several experts commented on the possibility that shaded greenhouses during visiting hours might not be attractive to visitors. It should be noted that the widest possible shade range for the Pavilions (D, E, F) is from 6:37 to 9:41 AM. Because the pavilions do not open until 10 AM, they will never be seen in shadow. Likewise, for the three public greenhouses G, H and I, the widest possible shade range is from 7:03 to 10:10 AM. Even at the moments of longest shadow, these greenhouses will only be in shadow for a few minutes of the visitor hours. We should also notice that distance of the proposed building from the Garden means that the shadow will be lighter than they would be were the buildings directly adjacent to the Garden.

MITIGATION: REDUCTION IN SHADOW DURATION AND/OR SUPPLEMENTAL LIGHT.

All experts agreed that reducing the duration of shadows would mitigate the effects on the plants. Although any additional shading might affect the plants over time, the extent and seriousness of the effects would very likely be mitigated by shorter durations of shadow.

The experts differed on the issue of supplemental lighting. Some who have managed greenhouses for many years were not optimistic about the prospects of such lighting. They noted that to be effective such lighting typically needs to be within 4 feet of the plants. Even though it may be kept back to 8 or 10 feet, others noted, it would still be in the viewshed of visitors, and so not desirable to public greenhouses.

Several experts noted that both for wide spectrum and for overall energetics that artificial lighting did not make a good substitute for sunlight. They noted that the light was not penetrating, and so could not reach from upper story to understory plants in the same way. They also noted that the spectra may be lacking in UV or far red light, or both, and that that lack could influence stretching and flowering of plants.

That said, Ron Determann and his student Ben Eiben, now a manager of the Amazon Spheres conservatories in Seattle, Washington, were much more sanguine about the use of artificial light. The Amazon Spheres are tropical conservatories located in the Amazon headquarters in downtown Seattle and surrounded by tall buildings. The managers there use artificial light at all times. The lighting consists chiefly of slim-line LED bulbs that are fit against the framework of the conservatories and so are not obtrusive. They are high energy bulbs that according to Eiben have a broad spectrum of light and cast a quality of light that is soft and relaxing, not harsh. The timing of the lighting is controlled by computers that continuously measure the Daily Light Integral, a standard measure of how much photosynthetically active light is reaching the plants, to adjust both the timing and intensity of the lighting. Determann felt confident about the ability of such lighting to mitigate light deficits, even in the desert collection. “You could very easily compensate with lighting from LED lights,” he said. “You can overcome those shortages. You can drive the lighting needs to absolute set points.” They have considered LED lights for their own desert collection in Atlanta – whose greenhouse has a dark west wall. They are deterred not by the quality of the lights but by the cost of the installation and operation.

Hachadourian noted that the propagation and workhouses of the Brooklyn Botanic Garden already use supplemental light, as commonly occurs in such greenhouses. (In addition, the workhouses and propagation houses at BBG are shaded to the east by tall coniferous trees.) I was not able to visit the nonpublic houses and so unable to make direct observations of their lighting situations.

EFFECT OF SHADING ON DAILY LIGHT INTEGRAL

How much less photosynthesis will occur if the greenhouses are to be shaded for the hours indicate in the shadow study? By taking PAR readings in the existing greenhouses, unshaded, and by comparing these to readings taken in shade similar to that that would be cast by the proposed buildings, at the nearly the same time, we can estimate the effect of the shadows on the amount of photosynthesis that can take place.

These numbers help to quantify the possible effects. They also help me to understand the comments made by the experts. As we shall see, on a day of full sun, a period of increased shadow may not be of great consequence, even to light-demanding plants. On a cloudy day, however, matters are very different. Even a period of a little more than an hour of additional shadow on a cloudy day may reduce the PAR illumination to a level below that need even by medium light-demanding plants. An above-average number of cloudy days in a given season may inflict a PAR light deficit on the plants in question, causing them to show effects over a period of years.

To perform the experiment, I selected a building that in its size and orientation resembles the buildings proposed to be built at 960 Franklin Avenue. This building is a 35-story tower located at 250 Ashland Place, just off Flatbush Avenue, in downtown Brooklyn. I measured the PAR incident at the Brooklyn Bears Garden and at Temple Square, both located 275-300 feet west of the base of the 250 Ashland tower. This created a rough analogue for the buildings proposed at 960 Franklin Avenue. Within a period of half an hour, I compared the readings taken at this location in both full sun and on a cloudy day, with readings taken both inside and outside the Desert and Warm Temperate Pavilions at the Brooklyn Botanic Garden, again on both a sunny and a cloudy day.

The PAR meter takes reading in PPFD, or Photosynthetic photon flux density. This reading measures the number of photons incident on a square meter of area per second. There is a standard formula in the industry to convert this reading into a Daily Light Integral (DLI) reading. The DLI is measure of photons incident for the light period specified, up to the full number hours of light for that day. To take measurements that reflected the conditions owing to potential additional shade on a greenhouse, I calculated a DLI using the PAR reading for the given greenhouse multiplied by the number of hours for which it lasted. I adjusted this reading for the potential shade by noting what percent of full sun light outside the pavilion was absent in the shade readings at 250 Ashland Place. To get the full DLI for that day, I calculated the DLI for the non-shadowed period of daylight that day and added it to the DLI for the shadowed period. Together, the two readings yield the rough DLI for that day.

Botanists use DLI to calculate how much light is needed by plants that are full-sun plants, part-sun plants and shade plants. The general ranges of DLI are as follows:

- 5-10 for low light-demanding plants
- 10-15 for medium light-demanding plants
- >15 for high light-demanding plants

On the morning of the 13^{th}, there was full sun both at Ashland Avenue and at the Brooklyn Botanic Garden. In full sun at the Ashland site – taking the readings at the same distance and orientation from the building as would be experienced by the BBG greenhouses in the shade of 960 Franklin Avenue – I came up with an average reading PPFD PAR reading in the shade of 515. The reading in full sun outside the Desert Pavilion at BBG averaged to 1150.

The shade reading at Ashland was 48% of the full sun reading outside the Desert Pavilion.

A reading taken a few minutes later inside the Desert Pavilion averaged 830.

If we assume that 48% of that reading would be available when the Pavilion was in shadow, then the shadow reading for inside the Pavilion is roughly 398.

On 13 September, the daylength was 9 hours 53 minutes. The Shadow Study indicates that 1.3 hours of that time would be spent in the shade of the proposed building.

For the 1.3 hours of shadow, the DLI is calculated at 1.86

For the remaining 8.5 hours of unshadowed day on 13 September, the DLI is 25.46

Adding these two calculations together to get the full reading for the day, we see that the total is 27.32. This is more than enough to supply a high light-demanding plant with all the light it needs.

Consider the difference, however, on the cloudy morning of 11 September.

The average reading in the Desert Pavilion on that day was only 250 in the ambient light of the cloudy day. If the shadow added by the proposed building were to reduce the incident light by 48%, then the reading under the building shadow would average only 120.

In that case, the DLI for the 1.3 hours of shadow would be only 0.56 and for the 8.5 hours of ambient daylight, only 7.88. The total DLI for such a cloudy day, then, would be 8.44. This figure is only at the high end of the light needs of a LOW light-demanding plant.

It is clear from these contrasting readings that while the lower incident light caused by a period of new shadow would have little effect on high light-demanding plants in full sun, it could have a significant effect on a cloudy day.

Given that cloudy days will occur with or without the added shadow, we might argue that the differential effect would be small. While that may true in the short term and in a year with an average number of cloudy days, in the long term and with some years of above-average cloudy days, the effects may result in the possible outcomes predicted by several of the experts: less flowering, stretching of plant forms, bending towards light, and even decline of certain species. All of the experts said the effects would be seen cumulatively over time, rather than immediately.

The PAR readings suggest that there is reason to believe that the added shadows will have a definite effect on the high light-demanding plants over time. As all experts agreed, there is not enough data for each species to tell ahead of time how it will react. That said, it is likely that some of the plants will be significantly affected by the reduction in available light.

EXPERTS CONSULTED

- Francisca Coelho, Conservatory Manager (Ret.), New York Botanical Garden
- Ron Determann, Conservatory Curator, Atlanta Botanical Garden, Atlanta, GA
- Ben Eiben, greenhouse manager, Amazon Spheres, Seattle, WA
- Mary Eysenbach, greenhouse manager, Lincoln Park Conservatory, Chicago, IL
- Karl Gercens, Greenhouse manager, Longwood Gardens, Kenett Square, PA
- Jimmy Groghan, Conservatory Curator, Smith College
- Marc Hachadourian, Manager of Nolin Greenhouses and Orchid Curator, New York Botanical Garden, Bronx, NY
- Fiona Inches, Glasshouse Manager, Royal Botanical Garden Edinburgh, Edinburgh, Scotland
- Paul Knuth, Conservatory Curator, Marjorie McNeely Conservatory, St. Paul, MN
- Juliana Razryadov. Horticulturist, Phipps Conservatory, Pittsburgh, PA
- Katie Schuler, Greenhouse Manager, Phipps Conservatory, Pittsburgh, PA
- Brian Sullivan, Vice President for Conservatory, New York Botanical Garden
- Rob Tanzer, Conservatory and Research Greenhouse Restoration Manager, Rough Brothers, Cincinnati, OH
- John Trager, Curator of Desert Plants, Huntington Library, San Marino, CA
- Peter Vrostos, Horticulturist, Lincoln Park Conservatory, Chicago, IL

FIGURE 1: Distances from 960 Franklin to BBG Greenhouses

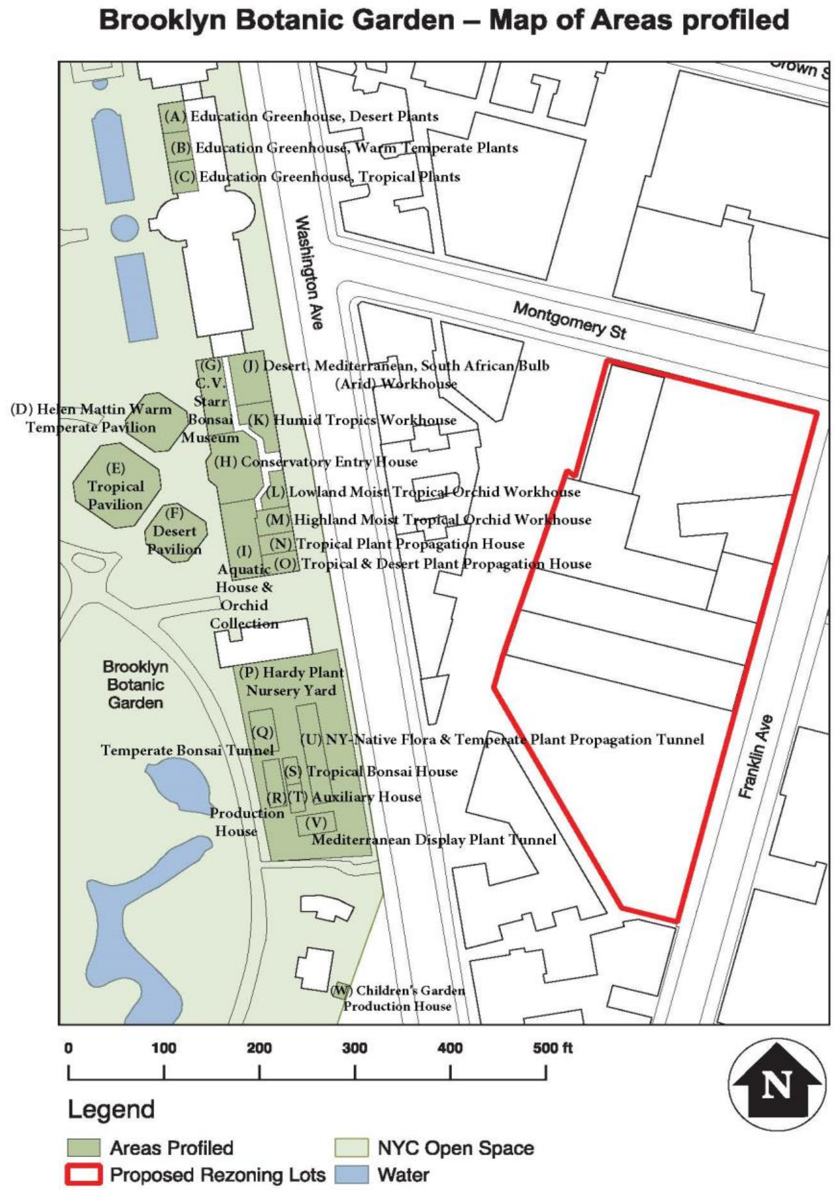

FIGURE 2: Lettered Key to BBG Greenhouses

SHADOW DURATIONS AND SEASONS: BBG GREENHOUSES

Map Letter	Greenhouse	Maximum range of hours	Hours/ Percent Daylight JAN	Hours/ Percent Daylight FEB	Hours/ Percent Daylight MAR	Hours/ Percent Daylight APR	Hours/ Percent Daylight MAY	Hours/ Percent Daylight JUN	Hours/ Percent Daylight JUL	Hours/ Percent Daylight AUG	Hours/ Percent Daylight SEP	Hours/ Percent Daylight OCT	Hours/ Percent Daylight NOV	Hours/ Percent Daylight DEC
Hours of Daylight			6 h 46 m	7 h 55 m	8h53m	10h13m	10h41m	12h4m	11h50m	10h51m	9h53m	7h54m	6h44m	6h02m
A	Education: Desert	7:48-10:20	1.5 21%	2.25 28%	0.5 6%	0 0	0 0	0 0	0 0	0 0	0.5 5%	2.25 28%	1.5 22%	1.25 21%
B	Education: Warm Temperate	8:44-10:30	1.5 21%	2.25 28%	1 11%	0 0	0 0	0 0	0 0	0 0	1 10%	2.25 28%	1.5 22%	1 17%
C	Education: Tropical	8:44-10:31	1.5 21%	2.25 28%	1.25 16%	0 0	0 0	0 0	0 0	0 0	1.25 13%	2.25 28%	1.5 22%	1 17%
D	Warm temperate pavilion	6:50-9:41	0.5 7%	1.25 16%	2 23%	2.75 27%	2.5 23%	1.25 10%	1.75 15%	1.75 16%	1.75 18%	1.25 16%	0.25 4%	.05 1%
E	Tropical Pavilion	6:27-9:29	0 0	0.75 9%	1.5 17%	2.5 24%	2.5 23%	2.5 21%	2.75 23%	2.75 26%	1.5 15%	0.75 10%	0 0	0 0
F	Desert Pavilion	6:27-9:40	0 0	0.75 9%	1.5 17%	2.5 24%	3 28%	3.25 27%	3.25 28%	3.25 30%	1.25 13%	0.75 10%	0 0	0 0
G	CV Starr Bonsai Museum	7:03-10:10	0.75 11%	1.75 22%	2.5 29%	3 29%	2.75 26%	1 8%	1 8%	3 28%	2.25 23%	1.75 23%	0.75 11%	0.5 8%
H	Conservatory Entry House	7:36-10:00	0.5 7%	1.25 16%	2.25 26%	3.25 32%	3.25 30%	3.25 27%	3.25 28%	3.25 30%	2 21%	1.5 19%	0.5 8%	0.5 8%
I	Aquatic and Orchid	7:36-9:54	0.25 4%	1 13%	2 23%	2.75 27%	3.25 30%	3.75 31%	3.75 32%	3.5 33%	1.75 18%	1 13%	0.25 4%	0 0
J	Desert, Medit, S AFr Workhouse	7:36-10:25	1 15%	2 25%	2.75 31%	3.25 32%	2.75 26%	0.75 6%	1.75 15%	2.75 26%	2.5 26%	2 26%	1 15%	0.75 12.5%
K	Humid Tropics Workhouse	7:36-10:14	1 15%	1.75 22%	2.5 29%	3.5 34%	3.25 30%	3 25%	3 25%	3.5 33%	2.25 23%	1.75 23%	1 15%	0.5 8%
L	Low Moist Trop Orchid Workhouse	7:36-10:10	0.75 11%	1.5 18%	2.25 26%	3.25 32%	3.5 33%	3.75 31%	3.5 30%	3.75 35%	2 21%	1.5 19%	0.75 11%	0.25 4%

Map Letter	Greenhouse	Maximum range of hours	Hours/ Percent Daylight JAN	Hours/ Percent Daylight FEB	Hours/ Percent Daylight MAR	Hours/ Percent Daylight APR	Hours/ Percent Daylight MAY	Hours/ Percent Daylight JUN	Hours/ Percent Daylight JUL	Hours/ Percent Daylight AUG	Hours/ Percent Daylight SEP	Hours/ Percent Daylight OCT	Hours/ Percent Daylight NOV	Hours/ Percent Daylight DEC
M	High Moist Trop Orchid Workhouse	6:50-10:14	0.5 7%	1.25 16%	2 23%	2.75 27%	3.5 33%	3.75 31%	3.75 32%	3.75 35%	1.75 18%	1 13%	0.5 8%	0.05 1%
N	Trop Plant Prop House	7:36-10:06	0.25 4%	1.25 16%	2 23%	2.5 24%	3.25 30%	3.5 30%	3.75 32%	3.5 33%	1.75 18%	1.25 16%	0.25 4%	0 0
O	Trop and Desert Prop House	7:36-10:10	0.25 4%	1.25 16%	1.75 22%	2.5 24%	3 28%	3.75 31%	3.75 32%	3.25 30%	1.5 15%	1.25 16%	0.25 4%	0 0
P	Hardy Plant Nursery Yard	7:36-9:45	0 0	0 0	1.5 18%	2 20%	2.75 27%	3.75 31%	3.75 32%	3 28%	1.25 13%	0 0	0 0	0 0
Q	Temperate bonsai Tunnel	6:27-8:49	0 0	0 0	0.75 9%	1.25 12%	1.75 17%	2.75 23%	2.75 23%	1.75 16%	0 0	0 0	0 0	0 0
R	Production House	6:50-8:16	0 0	0 0	0.05 1%	1.25 12%	1.25 12%	1.25 10%	2 17%	2.25 21%	0 0	0 0	0 0	0 0
S	Trop Bonsai House	6:50-8:36	0 0	0 0	0.15 2%	1.5 18%	1.25 12%	2.25 21%	2 17%	1.5 13%	1.5 18%	0 0	0 0	0 0
T	Auxiliary House	6:50-8:03	0 0	0 0	0 0	1 10%	1.5 14%	2 17%	1.75 15%	1.5 13%	0 0	0 0	0 0	0 0
U	NY Native and Temperate Prop Tunnel	6:50-9:01	0 0	0 0	1 11%	1.5 18%	2 19%	3 25%	2.75 23%	2 19%	0.75 8%	0 0	0 0	0 0
V	Medit Display Plant Tunnel	6:32-8:11	0 0	0 0	0 0	0.75 7%	1.5 14%	1.75 15%	1.75 15%	1.5 13%	0 0	0 0	0 0	0 0