Design Guidelines for Lighting Building Exteriors

Queen's University

2003

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Queen's University

Prepared for the Campus Planning & Development Department
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INTRODUCTION

This report provides the basis for a design guideline that governs lighting of building exteriors on the Queen's University campus. Light on buildings is an integral part of the nighttime environment, as important as lighting the streets and paths. It gives life to the campus, aids in identification and wayfinding, and increases safety.

A hierarchy of lighting is developed for all of the buildings, relating to location, urban context, and nighttime use. Buildings of cultural importance and historically significant buildings are emphasized. To enable the policy to be applied, building lighting is categorized into four levels of lighting presence. These levels cover the range of lighting requirements, from residences that have only an entrance light to campus icons that stand out against the night sky.

The lighting presence category for each building on campus is defined, providing information not only for evaluating the existing conditions, but also for planning new construction, renovations and upgrades.

The guidelines for lighting equipment, include light source selection, wattage ranges and fixture styles. Five buildings are presented as examples to show how the recommendations put forth can be applied to specific situations.

The guidelines are not intended as a how-to of exterior lighting, but as a resource to guide the overall lighting design of the campus. It is intended to be used as a guide by the University and by the professionals who will be involved in the lighting design for each building.

RATIONALE

Urban Context

There are many factors that affect the recommendation to light buildings on the campus. A hierarchy needs to be established to give direction to university staff and consultants to provide this light. This hierarchy will reinforce the architectural and landscape character already established. The building lighting will define streetscapes, reinforce views and vistas and highlight key structures. Buildings are reviewed based on their location, heritage, cultural importance and level of nighttime use.

Building location is the most important criteria when considering the application of light. A key part of the Master Lighting Strategy is the definition of spaces in contrast to one another, identifying and supporting areas of high nighttime traffic. Circulation routes are defined, with major vehicular and pedestrian routes receiving the most light. Light on the building façades that form the vertical aspect of these streetscapes further enforces this concept. Façades at the perimeter of quads and parks should be lit to further define these spaces and increase safety.

Historical buildings should be accented at night so that they are clearly identified as different than the surrounding structures. Historically significant buildings are the earlier buildings of the university or those of similar vintage, that are rated Excellent in the heritage evaluation, and are the buildings that most people view as historic because of their iconic image status.

Culturally significant buildings should also be identified in contrast to the surrounding environment, although not to the degree that the historical icons of the university warrant. Culturally significant buildings are those with specialized collections (libraries, art, artifacts) for general public use, facilities for social gathering and leisure activities, and which have significant night use.

Lighting Master Plan Influence

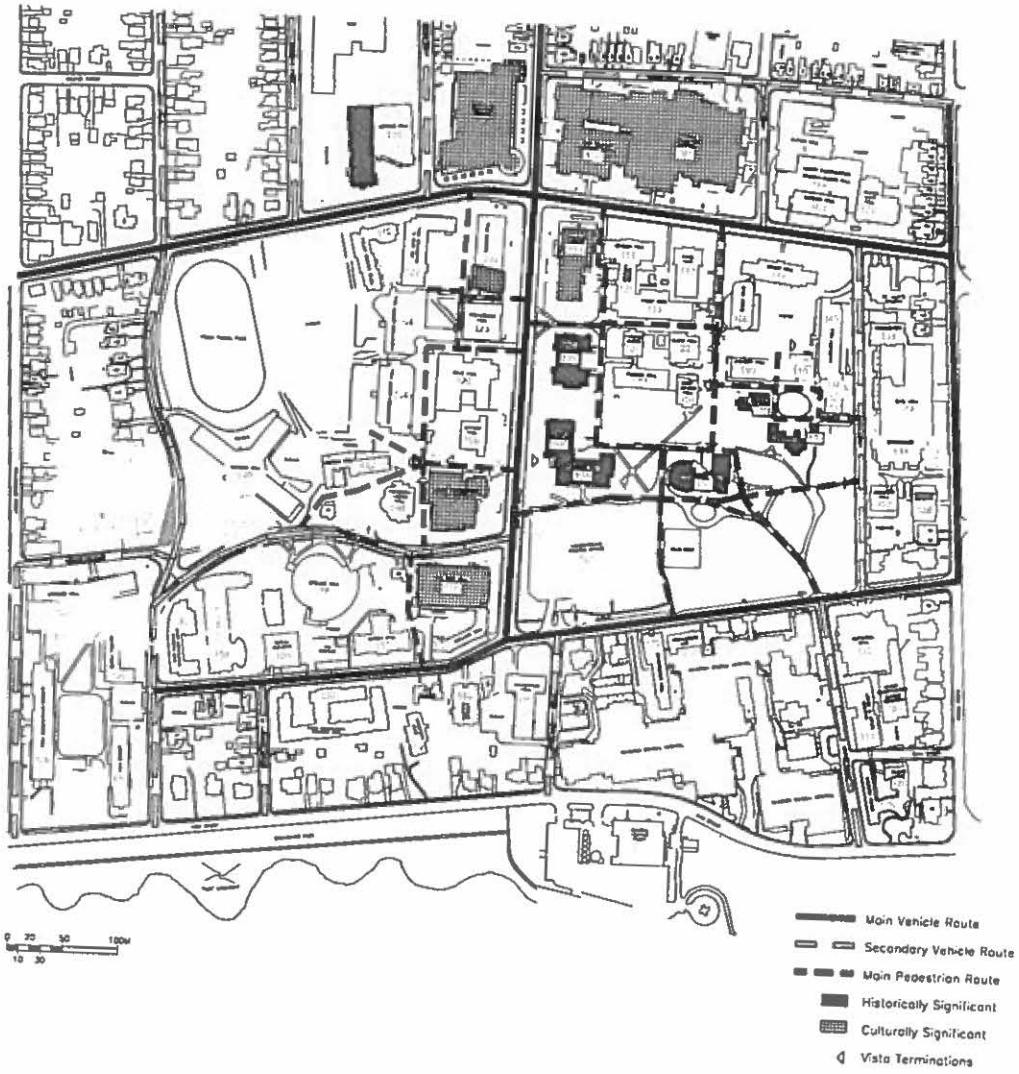
Queen's has committed to fully implementing the Lighting Master Plan, which includes pedestrian scale light fixtures throughout much of the campus. Lighting for building exteriors should be coordinated with and designed in the context of the Lighting Master Plan.

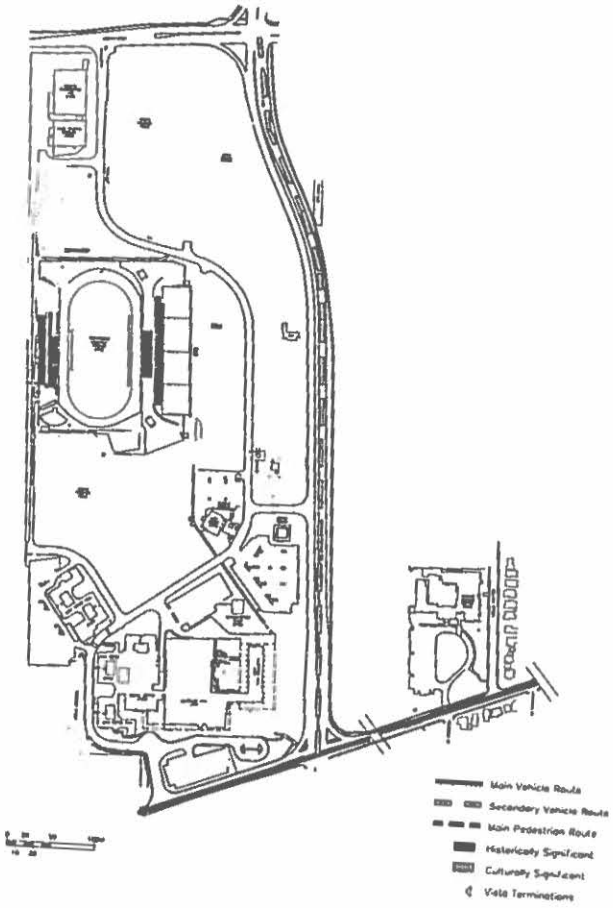
HIERARCHIES

The plan opposite indicates the urban planning contexts that are used in developing the hierarchy for building lighting. Most of the buildings that receive significant night use are situated along the vehicular routes that section the campus. The major pedestrian routes are well used at night, and link several exterior spaces. Façades that form the terminus of views receive particular attention. Culturally important buildings and historic structures are indicated. For clarity, minor pedestrian paths are not shown.

Culturally Significant Buildings
Douglas Library, Stauffer Library, Agnes Etherington Art Centre, John Deutsch University Centre-Physical Education Centre-Jock Harty Arena Complex, Dunning Auditorium (the one level addition to Dunning Hall) and Ban Righ Hall.

Historic buildings
Victoria School, Summerhill, Grant Hall, Kingston Hall, Theological Hall, Ontario Hall, and Old Medical Building.


Main Vehicle Route
Secondary Vehicle Route
Main Pedestrian Route
Historically Significant
Culturally Significant
Vista Terminations


Main Vehicle Route
Secondary Vehicle Route
Main Pedestrian Route
Historically Significant
Culturally Significant
Vista Terminations

LIGHTING PRESENCE

The Lighting Presence designations provide criteria for the relative brightness of each building façade on the campus.

1. Bright – Significant Icon-Status Buildings

- The building is an icon at night, bright enough to contrast with adjacent elements
- Façade is fully lit, with a variety of lighting intensities
- Architectural details and key elements are highlighted with directed lighting
- Decorative lighting poles can be used at building entrances, to define courts and plazas, and extend the nighttime 'footprint' of the building to the sidewalk
- Glowing elements / brightly lit materials provide strong highlight at main entrances
- Secondary entrances may also receive decorative lighting elements
- Fixtures can be placed at any height on façade, including positions that require special maintenance considerations
- Halogen / Incandescent lighting can be used, although more energy efficient sources are preferred

2. Illuminated Façade – Important Buildings

- Façades are visible from a distance, outline of building softly glows
- Building elements are visible with major elements distinguished
- Main entrances indicated with glowing fixtures
- Fixtures are positioned only where they can be accessed without special equipment
- No halogen/incandescent lighting to be used for floodlights / accent lights

3. Form Revealed – Majority of Buildings

- Façade is lit by ambient lighting, mostly from 'master plan' pedestrian scale light fixtures.
- Visible but not brightly lit, the outline of the building form is apparent from a distance
- Main entrances indicated by glowing elements
- No ground-mounted floodlighting hardware used to illuminate façade
- No halogen/incandescent lighting to be used for floodlights / accent lights

4. Dark – The Rest

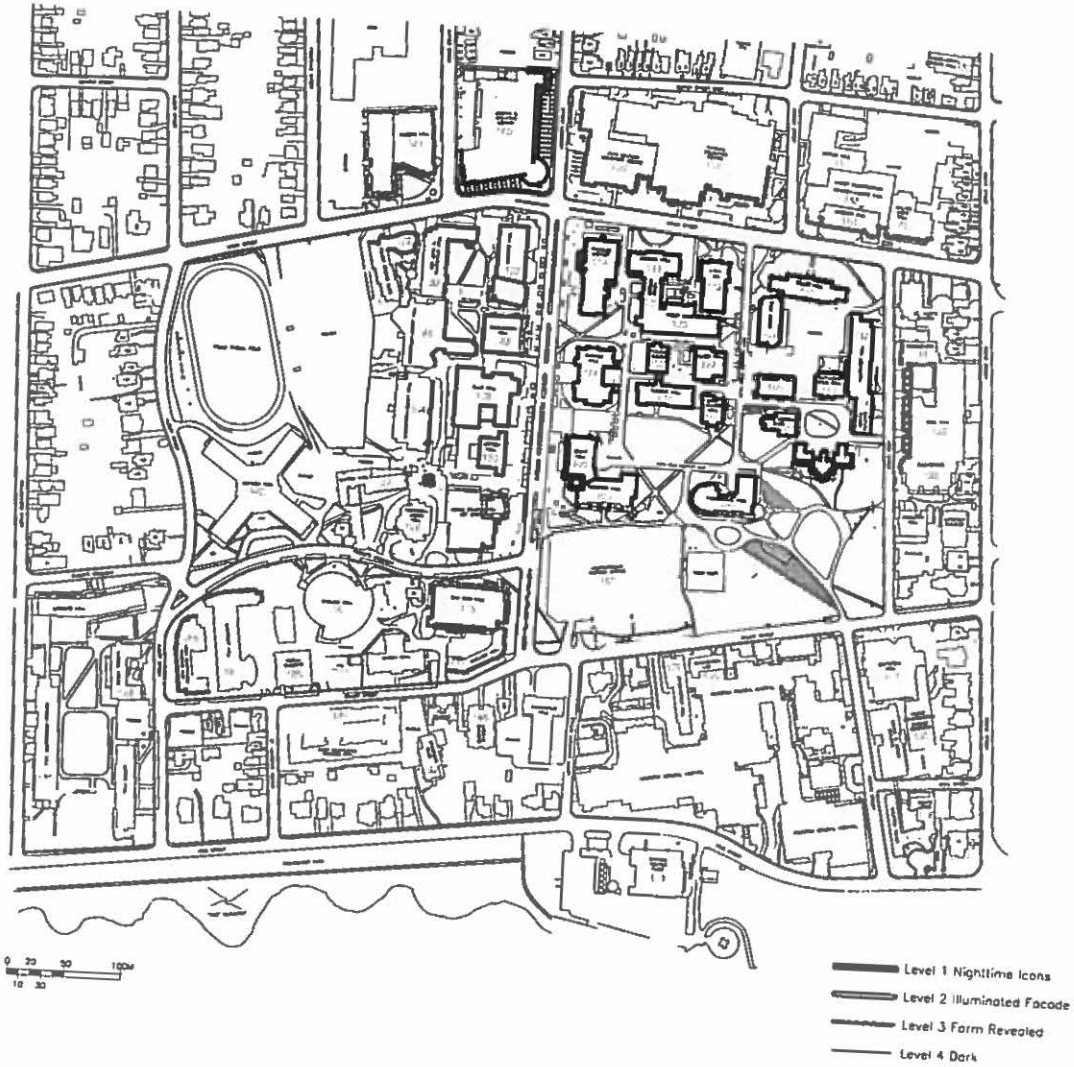
- Lighting only at entrances, building façades are not illuminated
- Entrances do not require glowing fixtures
- Outline of building form not obvious from a distance

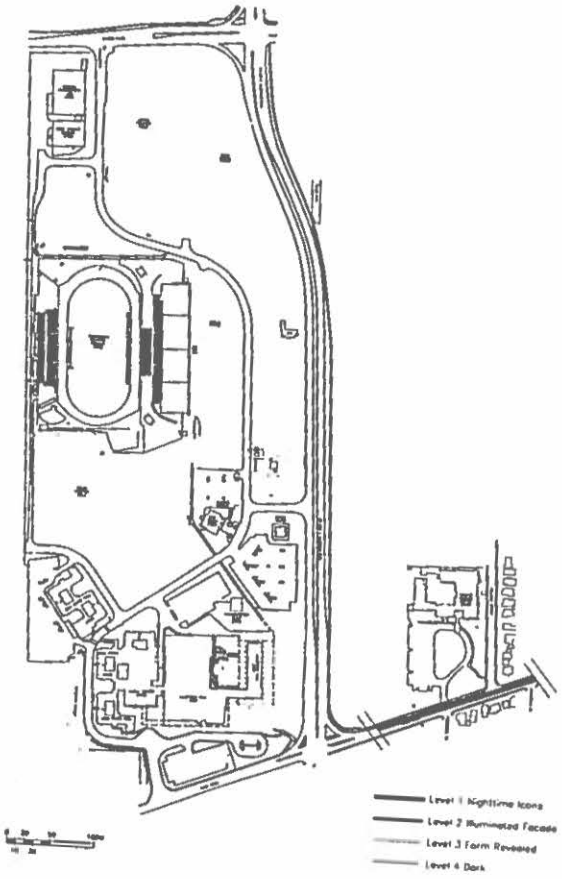
LIGHTING PRESENCE (con't)

The plan opposite indicates the recommended lighting presence for each of the building façades on campus. This plan takes into account all of the rationale for building lighting, including hierarchy of streetscapes, building types and urban context.

The plan indicates the recommended presence, not the current situation. Some existing buildings are overly bright, such as Goodes Hall. Other structures, such as the tower at Grant Hall, do not have enough presence currently.

Most of the level 3 (Form Revealed) façades will be adequately lit by the pedestrian scale light fixtures when the Lighting Master Plan is fully implemented. Many of the buildings will still require increased illumination at entrances, and the removal of glaring, inappropriate fixtures.


Level 1 Nighttime Icons
Level 2 Illuminated Facade
Level 3 Form Revealed
Level 4 Dark


Level 1 Nighttime Icons
Level 2 Illuminated Facade
Level 3 Form Revealed
Level 4 Dark

LUMINANCE

Lighting Metrics

In order to provide a numerical basis for the lighting presence recommendations, we suggest the use of Luminance as the preferred metric. The metrics of lighting are complex, as the human visual system adapts over a wide range of stimuli to enable vision. For this reason, the use of numerical comparisons for exterior lighting should only be used as a general guide, and not a rigidly applied policy.

Luminance, measured in units of candela per meter squared (cd/m^2), is the preferred metric because it describes how bright an object appears. It is much more meaningful than illuminance, measured in lumens per meter squared (lux), which only describes how much light impacts a surface. To understand the difference, the following comparison is provided:

Luminance vs. Illuminance

Light Surface

Illuminace: 200 lux
Luminance: 50 cd/m^2

Dark Surface

Illuminace: 200 lux
Luminance: 2 cd/m^2

Context

The human visual system adapts to the environment, adjusting its response based on the range of brightness within the field of view. It is only capable of seeing within a 1-100 range of luminance. It is important to manage the luminance of the brightest objects in the field of view (normally a direct view of a light fixture) in order to enable the eye to see appropriately. Due to the 1-100 range, if you are looking past a fixture that has a luminance of 400 cd/m^2, you won't be able to properly see anything below 4 cd/m^2. This is significant because the average luminance of a façade will often be below 4 cd/m^2.

Luminance Ratios
Each presence level has an appropriate range of luminance (all units are luminance is cd/m^2):

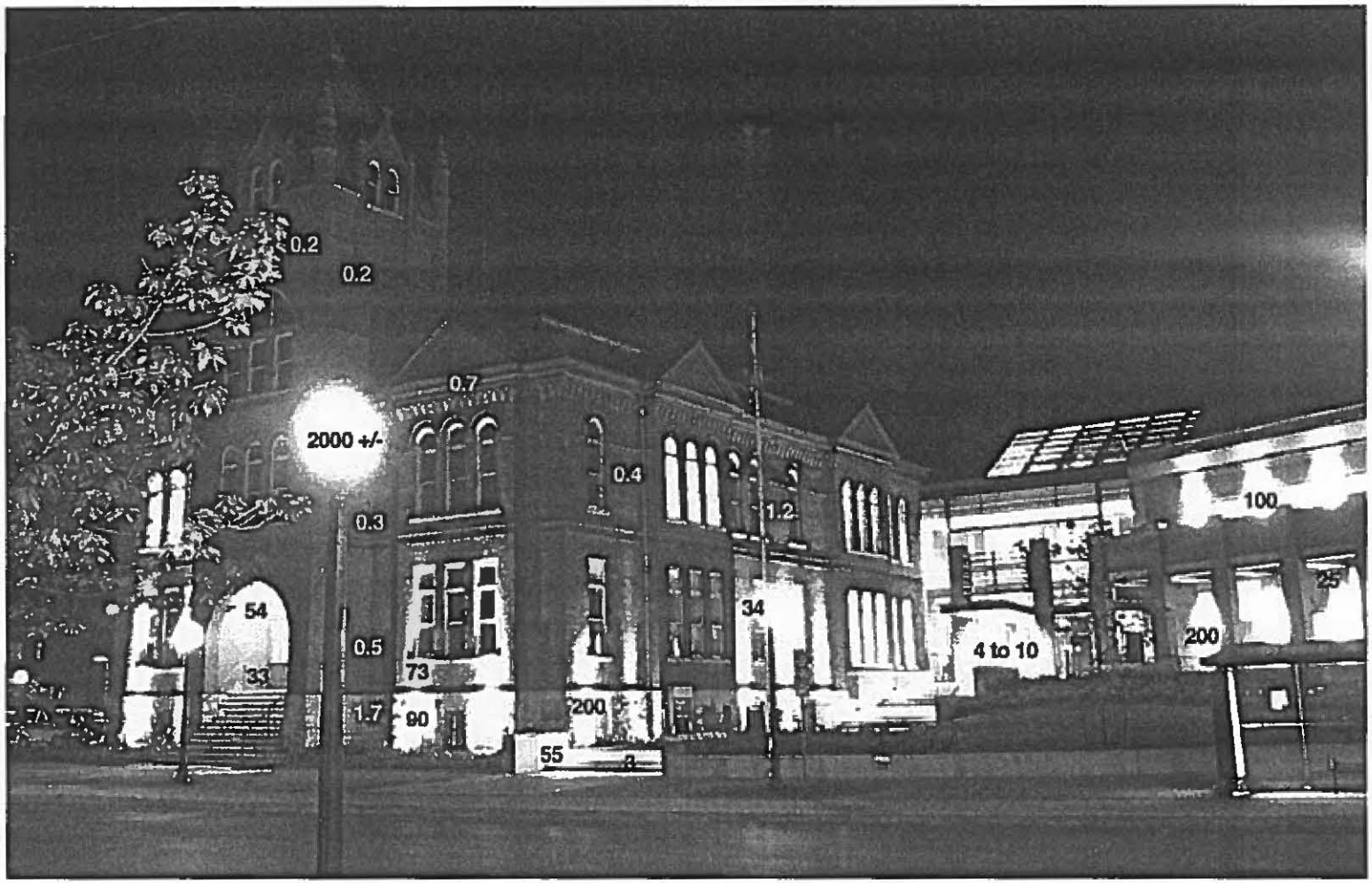
	Façade	Highlight (max)
1. Nighttime Icons	10 to 40	50
2. Illuminated Façade	5 to 20	30
3. Form Revealed	0.2-2	25
4. Dark	-	-

The picture opposite provides examples of luminance measurements taken from the façade of Goodes hall. The current lighting design includes areas that are softly lit, highlights that are overly bright, and interior lighting that competes with the façade.

1. Nighttime Icons — The façade at the lower floor is close to a level 1 presence. The highlights from the uplights would still be overly bright at more than 200 cd/m^2.

2. Illuminated Façade — The upper level has a good level 2 presence. The façade is well illuminated, with soft accents. Details of the brickwork are obvious, but the façade is not bright. The light in the windows provides a good accent.

3. Form Revealed — The tower has a level 3 presence. The presence of the tower is obvious, but without the surfaces being brightly lit. The outline of the tower softly glows revealing the geometry of the structure.



Goodes Hall – Luminance Measurements

DESIGN GUIDELINES

Entrances
Building entrances are an important part of lighting the building. They should be clearly visible from a distance, with the main entrance easily identified. This assists pedestrians in finding their way and provides a visual focus to the façade.

The lighting of entrance areas is key to nighttime security. These areas receive a lot of pedestrian traffic, especially people who are waiting to be picked up late at night. They are also the first destination for someone who feels that they are at risk. It is very important that they be well lit without glaring light sources. People waiting should be able to clearly see the streetscape, to identify possible attackers. Lighting the area to be visible from a distance can deter crime, as it increases the perception that there will be witnesses.

Interior Lighting
Buildings with significant glazing offer both lighting opportunities and potential problems. Interior lighting that integrates well into the appearance of the façade can provide a pleasing lantern effect. This can provide all the necessary presence to a façade, with the additional benefit of being much simpler to maintain and energy efficient. Interior lighting that is too bright, has inappropriate views of glaring fixtures, or is irregular in pattern can make even the best-lit façade unappealing.

The use of light control devices (blinds, screens or shades) and automatic lighting controls (dimmers, timers and photocells) to manage the affect of interior lighting will often provide more benefit than attempting to overcome the impact by adding more exterior floodlights.

Residence buildings are a special case. The façades of residences are best left dark, allowing the changing light coming from the rooms to reveal the ebb and flow of the student life within.

Pathways and Landscaped Areas
The area immediately surrounding each building should also be considered when evaluating and designing the building lighting. Paths to entrances should be well lit, especially if they include seating areas. Loading docks, garbage storage and other service areas may be lit by building mounted fixtures, but they should be as discrete as possible, and only use cutoff-type fixtures.

EXAMPLES

Five buildings are shown as examples. The existing conditions are described, including the current lighting presence. Proposed lighting applications are briefly described, with the effect of the lighting modifications rendered. These examples can be used to compare the existing conditions of other buildings, to determine the direction of any modifications or additional lighting needs.

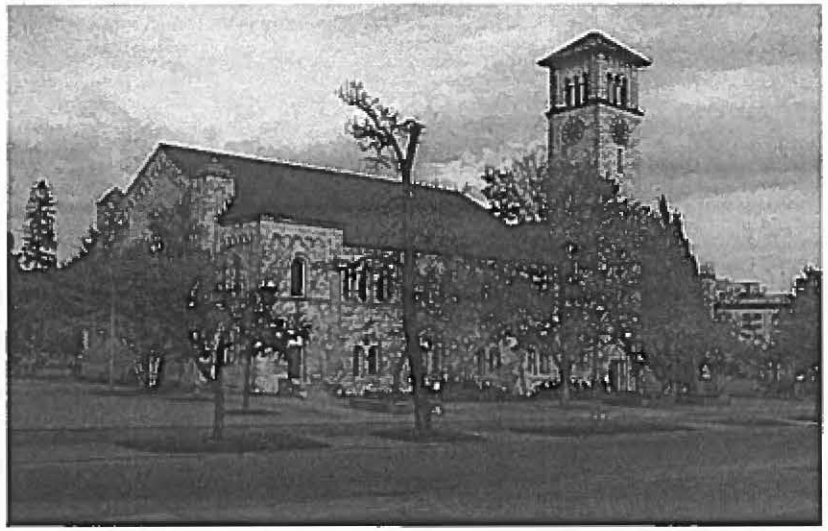
Grant Hall
An example of a level 1, iconic building that is symbolic of the University and deserves significant attention.

Goodes Hall
A level 2 building that is overly lit given its hierarchy in the nighttime environment

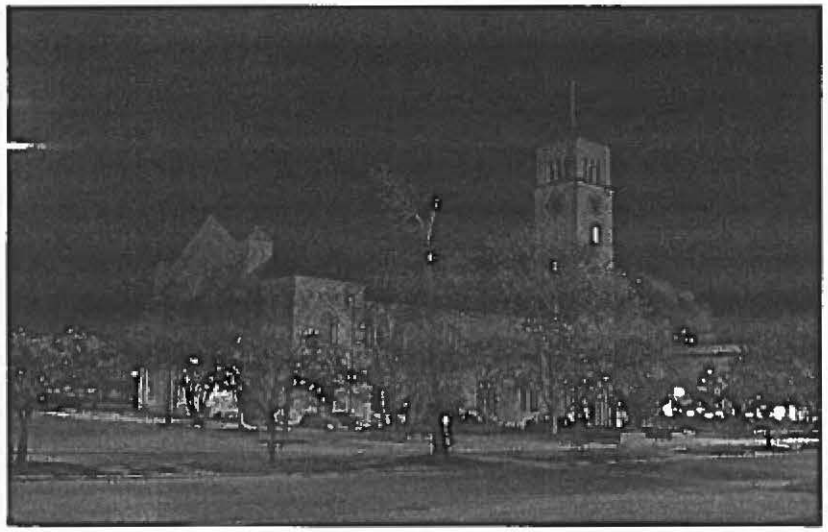
Jackson Hall
A level 3 façade that is well lit by the pedestrian post-top fixtures.

Chernoff Hall
A good example of the influence of interior lighting on the exterior appearance of a building.

Agnes Etherington Art Centre
Located at a high traffic area, the front and back of this building are treated individually.



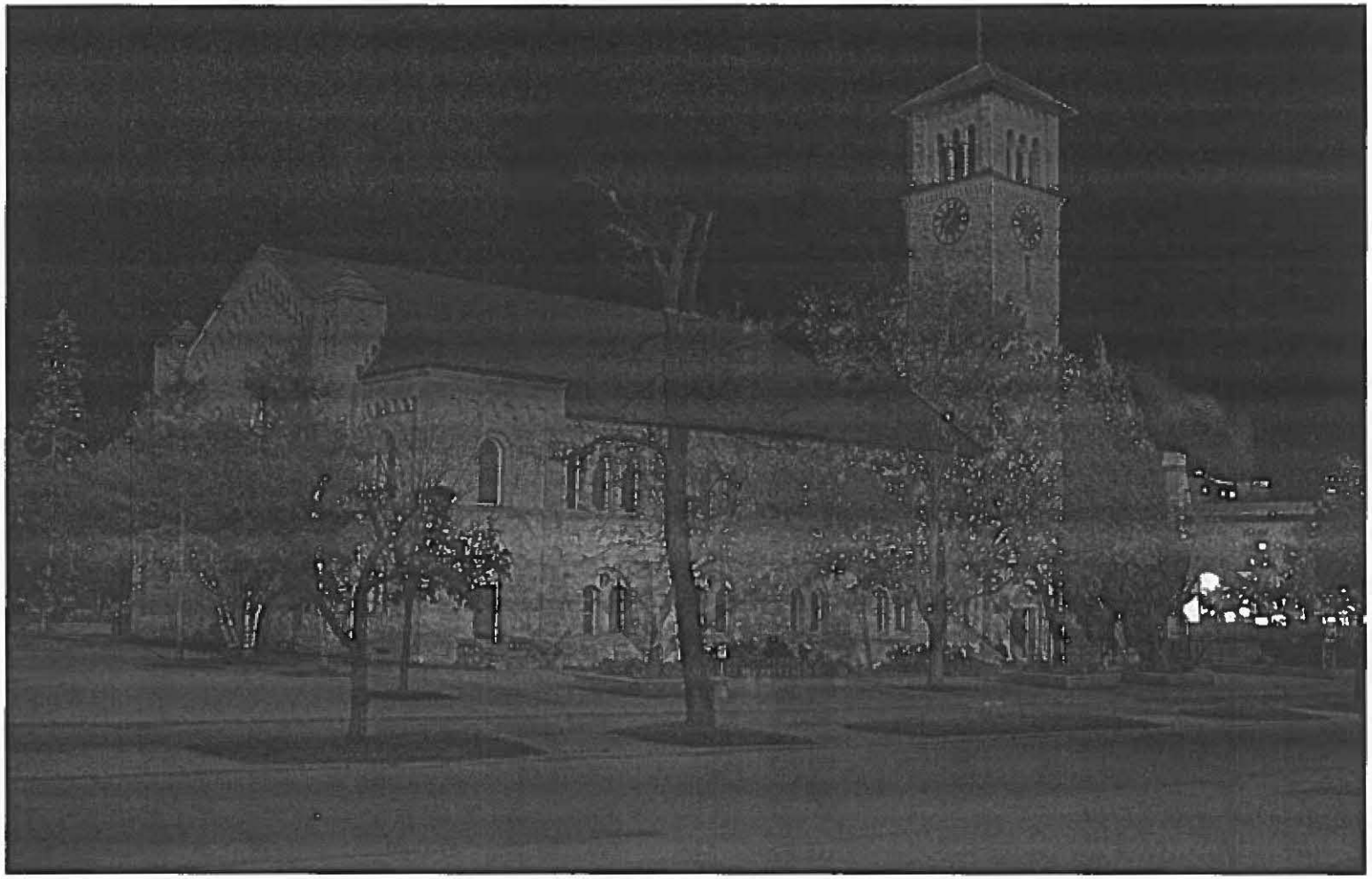
Day View



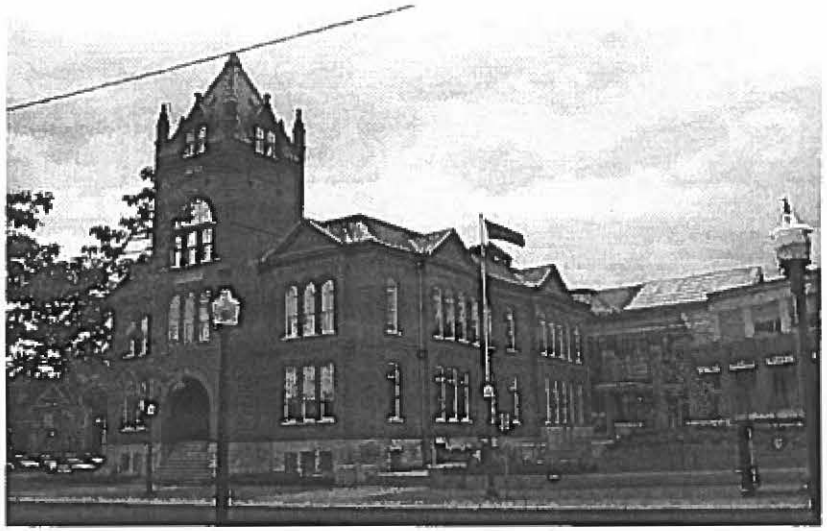
Night View

Grant Hall

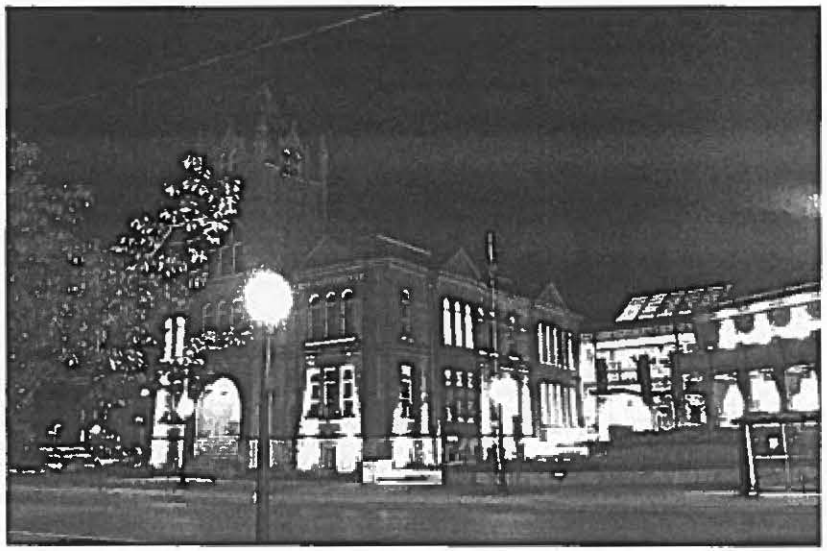
This pair of joined heritage buildings are one of the clear #1 "Icon" lighting examples. Probably the best way to give these fine stone facades the right light is to create a soft, 'moonlight' flood of light from the ground or short poles. Additional accents could feature the clock and tower top.



Proposed Lighting



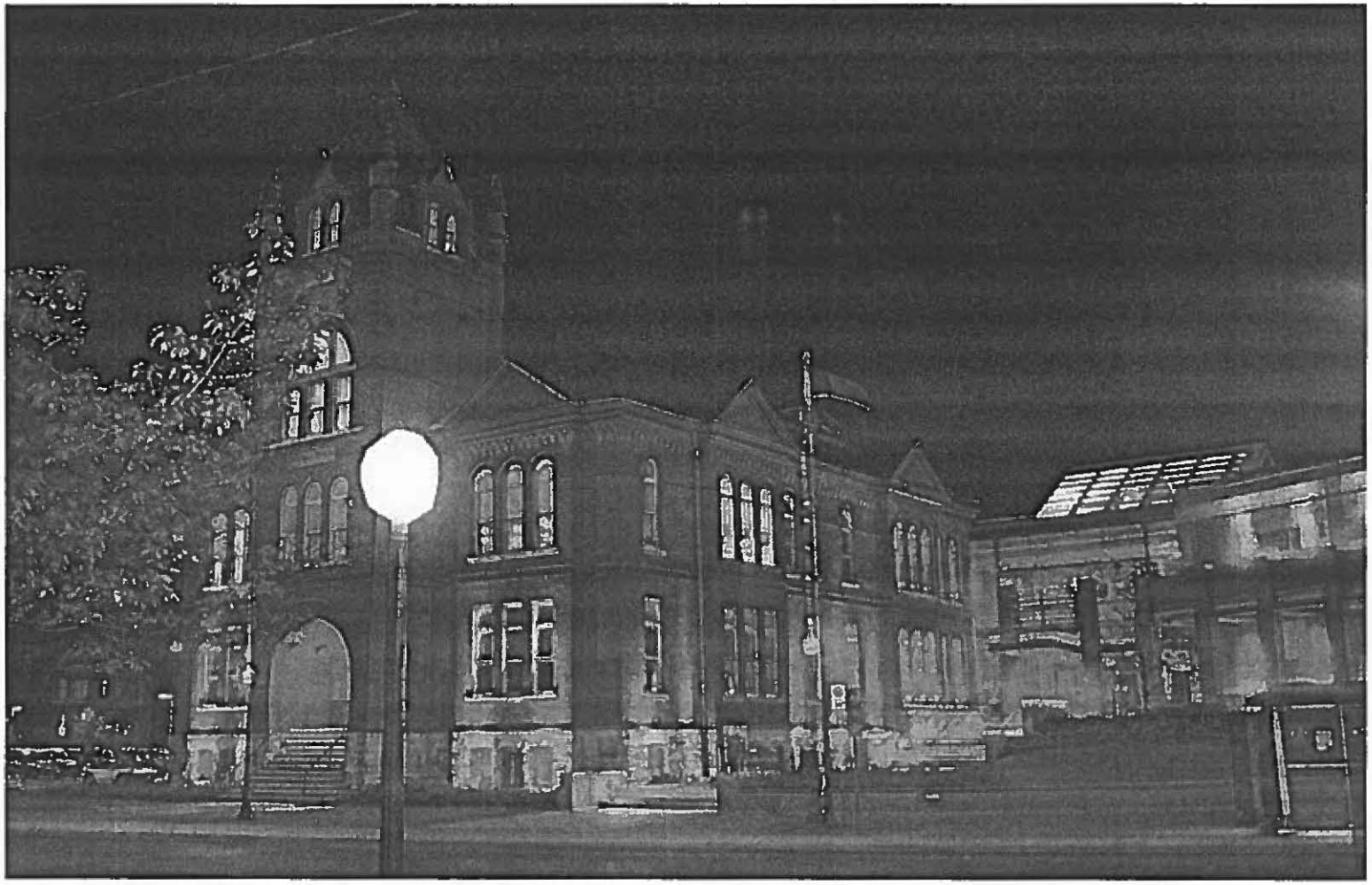
Day View



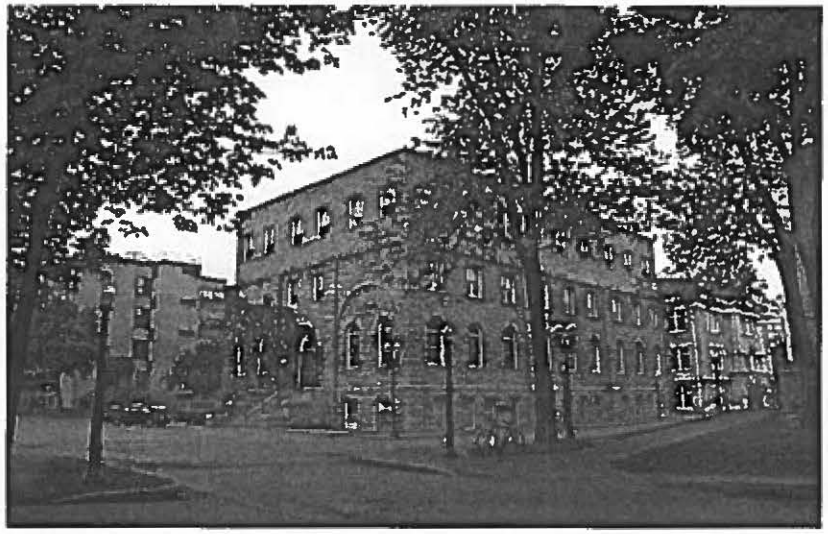
Night View

Goodes Hall

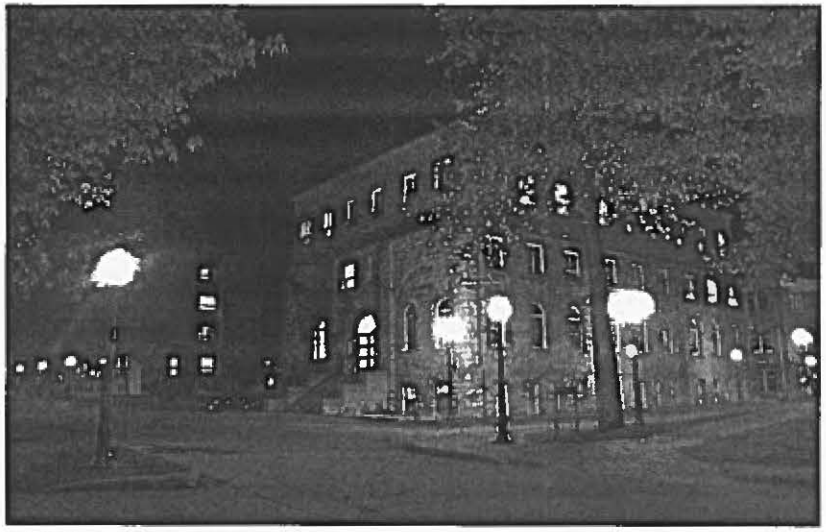
This renovated old school building and its new extension have recently been lit with a fairly elaborate exterior lighting system. This project serves as an example of the need for guidelines. If Queens would put this site in the #1 Icon group, this lighting is close to appropriate. As a #3, Form Revealed, it would be over lighted. Some of the new lighting does its job of lighting but many lights are too bright. (Refer to the luminance example for a better understanding of the excessive contrast in this building.) The luminance must be managed to fall within a recommended range for each category.



Proposed Lighting



Day View

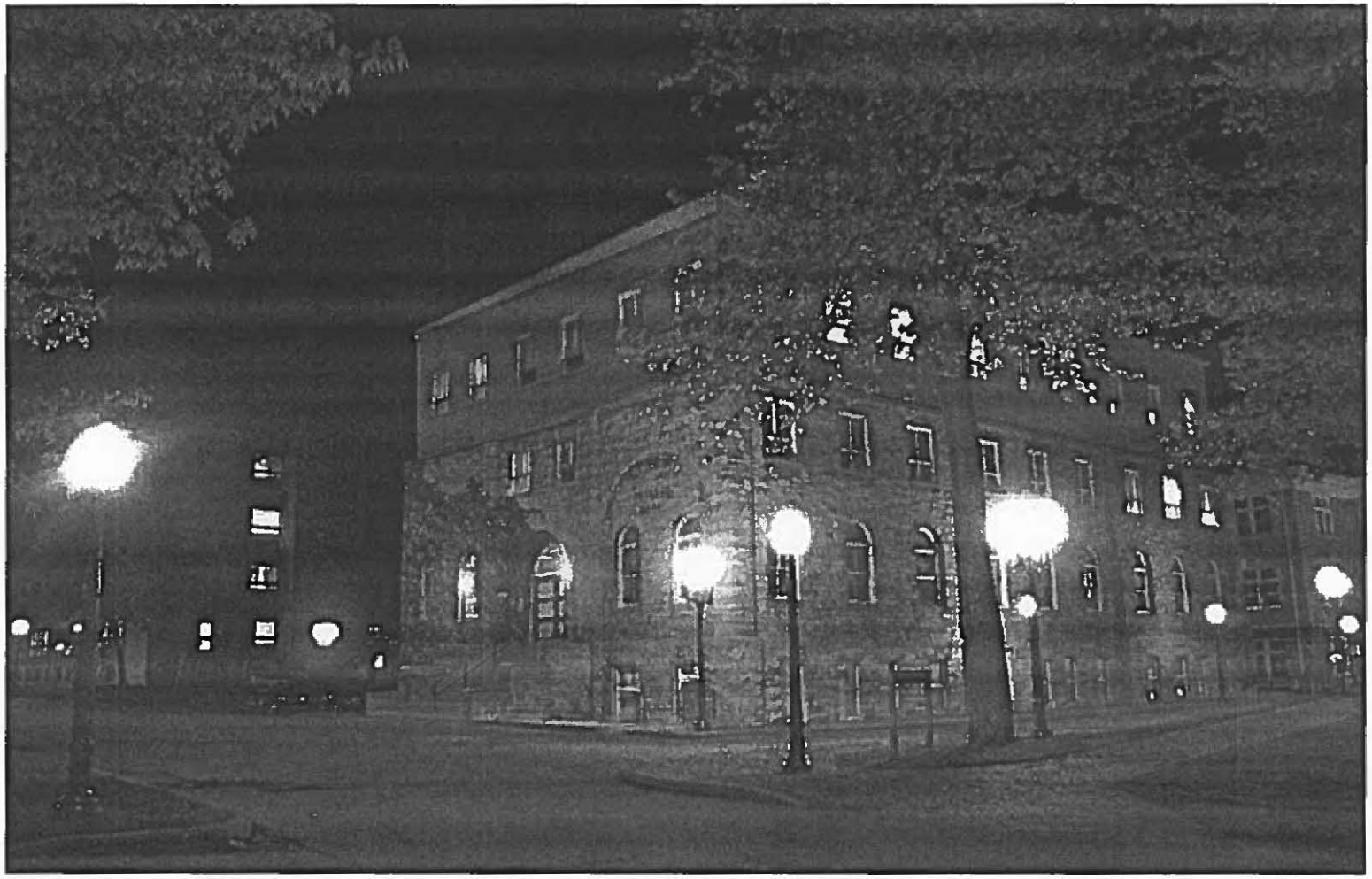


Night View

Jackson Hall

Jackson Hall is an example of a #3 Form Revealed building with an historical and position presence that requires revelation at night. The two most visible facades are on pathways which are or will be lit with the post top standard lights. The light from these fixtures does a very good job of providing the appropriate amount of light to these vertical surfaces.

Presently, the two post top lights, one at each side of the entrance, give the right emphasis to this important focus point. A problem with this entrance, typical of many on campus, is that the switching is in the building and therefore these lights are often not turned on. It is important to install timers or photocells on these essential building lights to assure that they remain on whenever the campus is active at night.



Proposed Lighting

Day View

Night View

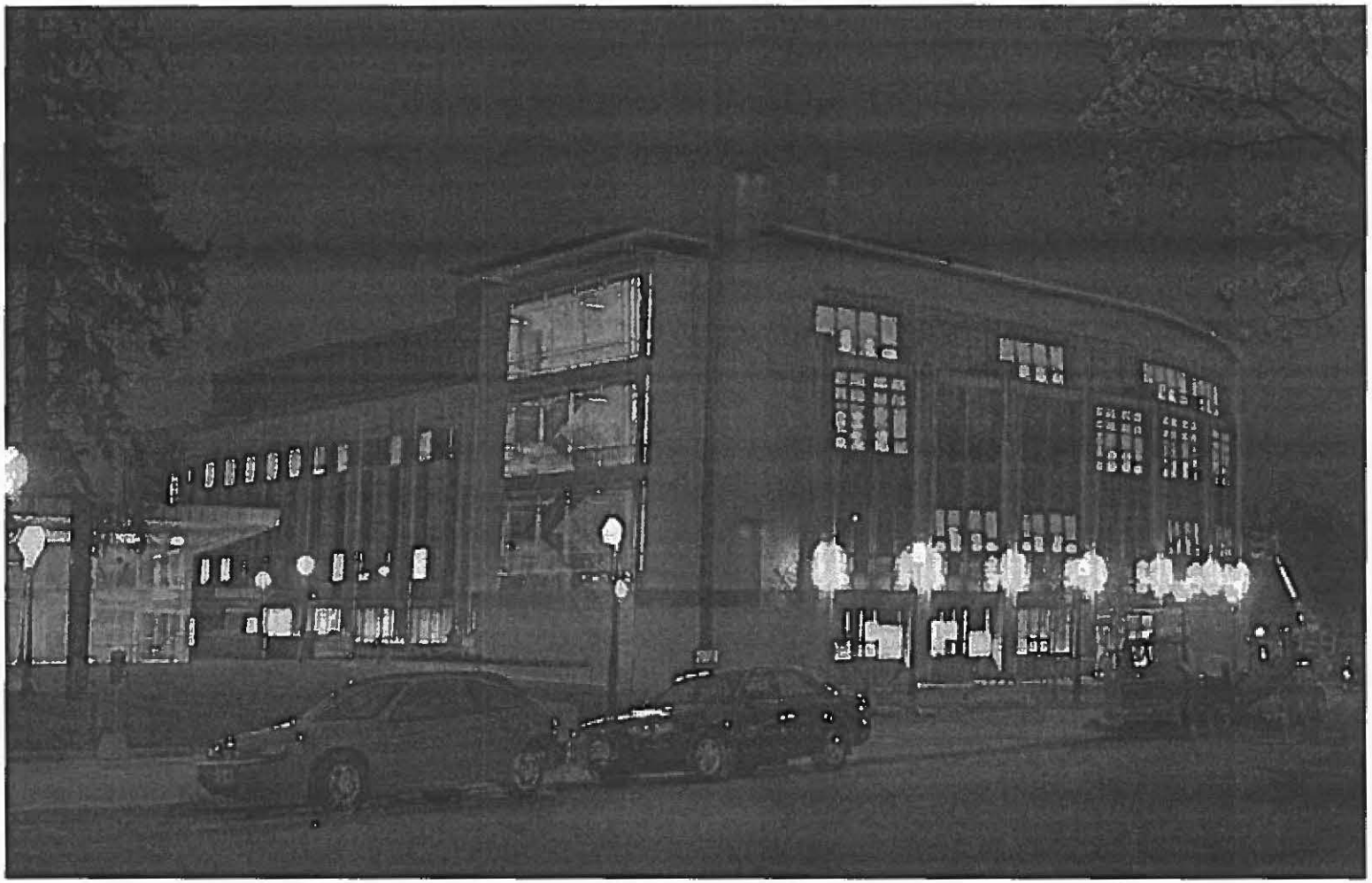
Chernoff Hall

This new building, with various glass facades, serves as a good example of the impact of interior lighting on the exterior experience, both positive and negative. As a category 3 Form Revealed building, the facades must balance with the surroundings.

Existing levels of interior lighting in the stairs are too high, making the stairs stand out inappropriately.

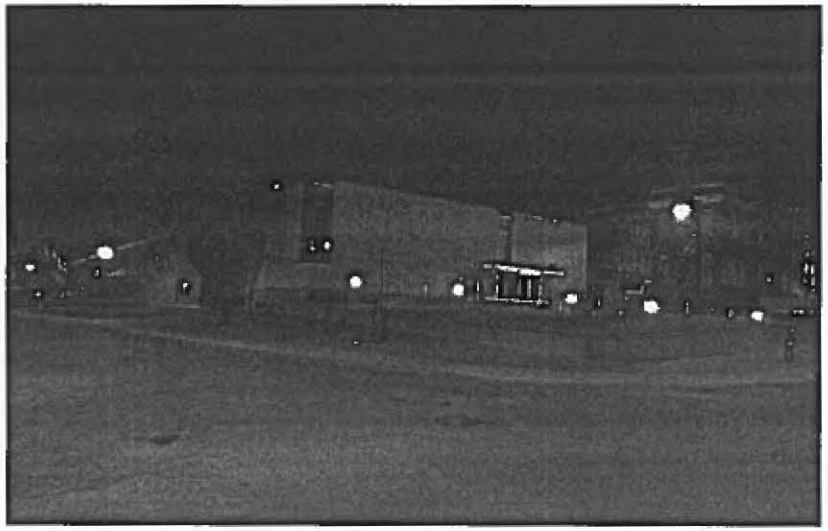
In addition to the light on the façade provided by the standard post top lights, appropriate levels of interior light should be circuited to remain on during active campus evenings. The absence of subtle lighting from the large window areas is a missed opportunity.

Lighting in the Chernoff Auditorium foyer should only be on when the facility is in use. This serves as an indicator to pedestrians that there is activity within.



Proposed Lighting

Day View

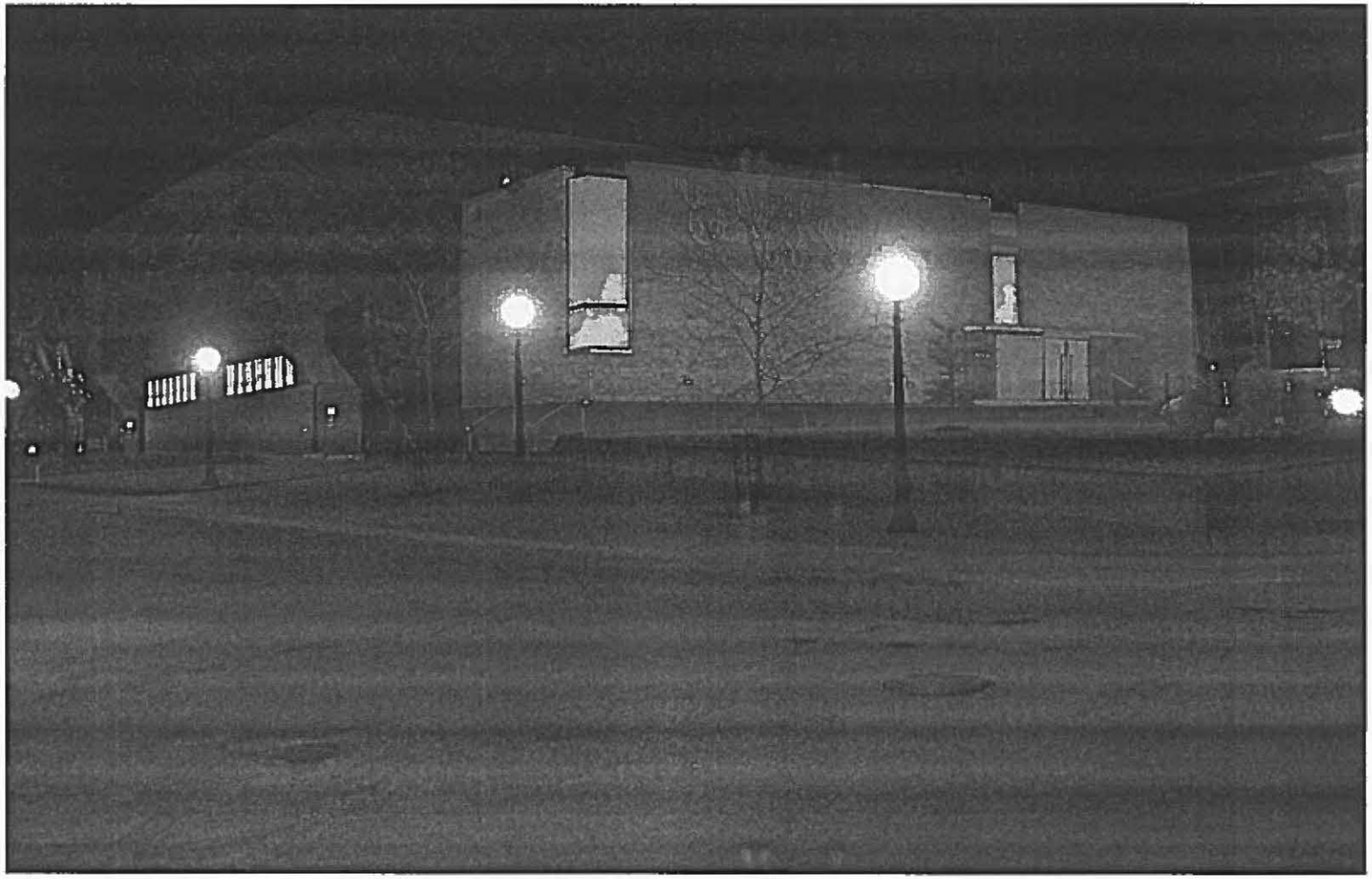


Night View

Agnes Etherington ART Centre (front)

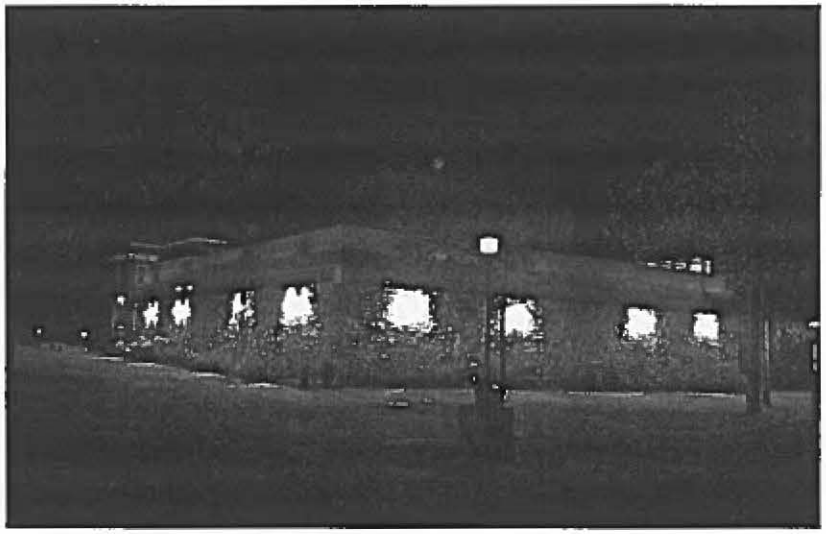
This new building, situated so that all of its facades face important pathways, requires modification of the existing lighting. The historic house is a level 2 Illuminated Façade, with the rest of the building in Group 3, Form Revealed. The front, street façade presently gets most of its light from a poorly placed sodium security light on the neighboring building. Small lights on the front wall have little effect. There is no light on the dark brick section along Queen's Crescent.

The front façade should be illuminated with small floodlights on the ground. The side will be fine when the post top lights are installed. Interior lights, especially at the entrance, should be switched to remain on during active evenings.



Proposed Lighting

Day View



Night View

Agnes Etherington Centre (Back)

The back of this building is situated on one of the most active pedestrian areas. Security type lights are extremely bright, so much so that the astronomers have made complaints. They not only impair the visibility of the structure, they make the entire space uncomfortable.

The back walls would be greatly improved by changing the existing wall lights to a soft glowing fixture that back washes the wall surface. These lights will not be required when the Lighting Master Plan is implemented, as standard pedestrian fixtures will provide the ambient lighting onto the façade.

Proposed Lighting

APPLICATION GUIDELINES

Light Pollution
Light pollution is the light that is lost to the sky. Reducing this unwanted light spill is both an environmental and social concern. Light pollution comes from light directly emitted from a fixture as well as light that is reflected from the ground and building materials to the sky. The simple answer is to eliminate any fixtures that point upwards, but this does not take into account that there are desirable uses of uplighting. There must be a balance between the benefits of uplighting and the amount of light lost to the sky.

Interior lighting can also contribute to light pollution, particularly light in skylights that are lit at night to emphasize the skylight well as an architectural feature. This is a valid concept, and can add to the exterior appearance of the building. Skylights should be lit to the lowest levels that achieve the desired results. Many skylights are over-lit, with light directly onto the glazing, which is directly to the sky.

The following steps should be taken to reduce light pollution:

- Area lighting for parking lots, loading docks and similar applications should be IES full cutoff type fixtures
- Floodlights and in-grade uplights should be controlled so that as much light as possible impacts building materials. This usually requires louvers or 'barn doors' to restrict the distribution.
- Glowing fixtures should have a minimal uplight component.
- Skylights should have only enough interior lighting to achieve the desired effect.

Light Trespass
Light trespass is defined as unwanted light from a neighboring property. Two concerns regarding light trespass are spill and glare. Spill is unwanted light on an adjacent property, whether direct or indirect. Glare is the excessive brightness from a source directly within an observer's view. Sources of glare can also be temporarily disabling, preventing a person from seeing well under otherwise light conditions. Interior lighting can also contribute to light trespass through windows and skylights.

The following issues should be considered to minimize light trespass:

- Inspect adjacent areas to identify potential problems during the design process.
- Select lighting equipment with appropriate optical control devices to minimize spill light.
- Consider how the fixtures will be seen, from pedestrian, driver and building occupant viewpoints.

Light Sources

The recommendations reflect current thinking, based on current technology, and can be revised as technology changes. Light sources selected for building lighting should be white light sources that are energy efficient, have long lamp life and good colour rendering characteristics.

Induction Lighting	The campus has adopted the QL Induction lamp system from Philips Lighting for the pedestrian scale light fixtures throughout the campus. The use of these lamps for building lighting is encouraged due to their long lamp life.
Metal Halide	The preferred light source for exterior building flood lighting and accent lighting. Ceramic arc tubes should be used wherever possible. For general façade lighting applications, warm colour temperatures around 3000° K are preferred. Pulse start lamps should be used for lamps above 150w. Where possible, electronic ballasts should be used.
LED (light emitting diode)	LED's are encouraged as a light source, particularly when maintenance access is a concern, as their very long life allows them to be placed in locations that would be too costly to maintain with traditional light sources. The colour properties of the source should be carefully considered and mocked up.
Fluorescent	The use of fluorescent or compact fluorescent lamps is encouraged. Equipment selection should consider the effect of cold temperatures on light output.
Halogen/Incandescent	These lamps should be used sparingly, preferably in applications that have easy maintenance access (the lanterns at a building entrance for example). They should only be used where there is not a more energy-efficient alternative available.
High Pressure Sodium	The use of high-pressure sodium lamps is not acceptable for general use on the campus. It should only be considered for floodlighting when the desired effect is to achieve a warmer, yellowish tone on specific materials of a building façade.
Low Pressure Sodium	Low pressure sodium lamps are not acceptable for use in any application.

Lighting Equipment

Directional Lighting	Directional lighting includes floodlights, spotlights, uplights mounted to a façade and other building accent lights. Lamps should not be visible at normal viewing angles. Baffles, lenses, louvers or other glare control devices should be integral to the fixture to prevent discomfort glare. The fixture should be able to be relamped without removing or adjusting any of the glare control devices. The smallest possible fixtures should be used. Aimable fixtures require durable locking components to set the aiming angle in both pan and tilt orientations.
Glowing Fixtures	Fixtures that, as part of their design, include luminous panels or surfaces (lanterns, globes, etc should not use HID sources above 100w or other sources above 150w. Fixtures above 50w Metal Halide or 100w Halogen should not have direct views of the light source at normal viewing angles.
In-Grade Uplights	The use of in-grade uplights should be minimized. These fixtures require much higher levels of skilled maintenance than other lighting types. Installations should have more than adequate drainage to ensure the least water contact possible. Faceplates should be flush with adjacent materials to reduce tripping hazards and damage due to snow removal. The temperature of lens material should be considered when fixtures are located in areas of pedestrian activity.
Area Lights	Building mounted area lighting is not directly in the scope of this report, but has an impact on the effectiveness of the façade lighting and appearance of building form. Generally, area lighting should not be placed on buildings. Exceptions are small areas that are immediately adjacent to buildings such as loading dock platforms. Luminaires should meet IES full cutoff criteria (no wallpacks).

Lighting Equipment (cont)

Accessibility	Lighting hardware should be easily accessible by ladder, window or rooftop. Fixtures requiring other maintenance equipment (bucket truck, lift, etc) should be group relamped according to specific schedules. Equipment can be mounted on adjacent structures (rooftops, service buildings, etc) but with the above-mentioned glare and light trespass tightly controlled.
Durability	Lighting equipment should be sufficiently durable to withstand vandalism. Steel mesh cages should protect particularly vulnerable fixtures. It is important to consider the impact of the appearance of any cages or other protective devices on the distribution of light from the fixtures.
Manufacturer	High quality, original design product is preferred over 'knock off' manufacturers. Canadian products should be used whenever possible. Manufacturers product that is already in place on the campus and that has received positive reviews by the maintenance staff should be used. This simplifies the maintenance process by reducing the quantities of spare fixtures and parts required.

PROCESS

Implementation - Existing Buildings
Each building should be assigned a priority for lighting interventions. Safety and security, maintenance and appropriate lighting presence levels should be considered equally.

Implementation – New Buildings
The design of lighting for new buildings and renovations must be coordinated with and in the context of the Lighting Master Plan. New buildings should be assigned a lighting presence level that reflects their location, size, impact on the streetscape and anticipated nighttime traffic. The architects should prepare a report that indicates that nighttime appearance of the building for review by the departments of Campus Planning and Development and Physical Plant Services. A lighting design specialist could be hired as needed to review work by the architects. It is important to manage the appearance of new buildings to a level that incorporates them into the campus environment. There is a tendency when constructing a new building to evaluate them without regard for the surroundings, resulting in a building that is too bright and stands out inappropriately.

CONCLUSION

This report provides the design guidelines for building lighting on the Queen's University campus. It provides recommendations for lighting levels throughout the campus, and provides an overview of the many factors that must be considered.

Implementing the guidelines will require an examination and analysis of each application. The Lighting Master Plan, Lighting Presence level, views of the building, existing hardware and architectural style should be examined. Appropriate lighting applications must balance the desired effect with issues of energy conservation, maintenance costs, and equipment expense.

This guideline is a resource for the University in making informed decisions regarding building lighting. It should also be used when the University commissions design professionals, as a starting point regarding many aspects of building lighting design.

APPENDICES

Appendix A

Psychology of Night Lighting

The psychology of lighting can be subdivided into two general categories; lighting which helps one to perform intellectual tasks, and lighting which helps to achieve desirable emotional responses.

Intellectual Tasks:

In a sense, the assistance of night lighting for intellectual tasks is as necessary a function as is lighting to assist one in physical movement. Movement is aimless if we cannot see where we are, where we want to go, and choose an appropriate route to get there. Thus, another basic function of night lighting, and one which is essential, is to help to give order to the University at night. Lighting can be used to create visual identification of places, routes and destinations. Lighting also should assist in explaining these physical parts of the environment, and in differentiating between them by setting up hierarchies of relative importance between places, routes and destinations.

To accomplish these objectives, lighting can be used to mark or identify, to create visual focal points, to define, and to connect. Lighting can mark entrances to the University and to various spaces within each area. It can identify passages between buildings or between spaces. It can mark intersections of walkways or seats of activity. It can emphasize existing focal points within spaces such as site art. In addition, lighting can, by the relative numbers of fixtures and their placement, create a hierarchy of visual importance between these functions, and within each function. Lighting also must be employed to emphasize graphic signs for direction, information and orientation, even if this is accomplished by locating signs under lights, rather than by installing special sign lighting.

Lighting can be employed to create visual events on which to focus where none had existed. For example, a group of lights might be placed in the center of a particular space to distinguish that space in the night environment from some other space; or a particular building of a group of buildings might be floodlit to provide a terminus or focus at one end of a walkway. By varying lighting intensities, or numbers of fixtures, relative emphases can be placed on various foci. In addition to the practical gain from relative brightness emphasis, the visual picture is made subjectively richer and more satisfying.

Outdoor lighting can help to define various "ideas" in the landscape. It can bring shape and definition to a particular space which otherwise would be incomprehensible at night. It can, by the rhythm and location of fixtures show that a walkway really is a passage from here to there, and in the process show that here and there are linked together.

Emotional Tasks:

The emotional and aesthetic use of lighting in the night landscape environment are well known, but we have said that lighting no longer can be employed solely for these purposes. Lighting will either further aesthetic and emotional aims as a consequence of its functional purposes, or it will interfere with those aims. With careful planning and design, lighting can contribute to the aesthetic value of the University both at night and during the day, as well as perform its necessary practical functions. The physical appearance of the luminaire; the colour, shape and scale; the placement, sequences, and rhythms of location; the continuity of fixture types; and the appearance of the lighting quality: the brightness and color of the source; and the characteristics of the light pattern; all will evoke emotional and aesthetic response in the viewer.

These visual aspects of lighting and lighting instruments must be constructively employed to strengthen general landscape goals. For example, lighting can be used to help provide a sense of life, stimulation and vitality-or the opposite, a feeling of quiet. In a sense, these qualities follow naturally from innate human needs: lighting is not required if there are no people. We sense that where there is light there is life, or the potential for life. Lighting that spills over beyond areas that must be lighted, and light reflected from surfaces that must be lighted helps to light the whole night landscape and gives one a sense of the created environment, of foliage and buildings. Use of a full continuous spectrum source gives one a sense of the richness and natural quality of materials and also provides continuity with daytime perception. The scale and the rhythms of the lighting fixtures themselves can add a sure sense of scale to spaces, giving them character, and help to tell us not only that we are in a space, but what size of space it is.

By virtue of the physical needs of people for lighting, and the placement of lighting to meet those needs, the installation can speak eloquently. To the extent that human needs invite emotional response, lighting should suggest a unified view and a consistent approach to solutions. Lighting may be viewed as an integral strengthening of the grand design of its environment. The placement of groups of fixtures should be sympathetic and responsive to the specific environment with the result, at best, verging on poetry.

In addition to its potential for enhancing our sense of beauty, lighting can make us feel safe. Indeed, the psychological aspect of security may be the real reason for providing enough lighting for personal safety. Psychologically, lighted places suggest activity and safety. They imply that we will be able to see danger in time to do something about it and that others can see us if we are in trouble. They suggest to the criminals that they will be seen and possibly apprehended. Thus lighting should give us the feeling that we are safe from potential danger. If we can see that no one is in the area surrounding us, we feel safe. Lighting seen in this regard is lighting that reduces fear. It also intimidates the criminal, who is no longer able to operate "in the dark".

Appendix B

Vision: Basic Concepts

Luminance is equal to illuminance (incident light) times reflectance (reflectivity of the surface). In the Illuminating Engineering Society terminology, luminance is expressed in units of candelas per square metre (cd/m2). We seldom will use lux to describe incident illuminance. In reality, we see by photometric brightness units of luminance and not lux, or illuminance.

Day, night, dark vision:

Relating our three types of vision to units of measurement, we find that daytime or "photopic" vision is generally associated with eye adaptation to a luminance of at least 3 cd/m^2. Dark vision, or "scotopic" vision is associated with adaptation to a luminance less than 0.034 cd/m^2. Night vision, or "mesopic" vision, with luminance conditions between photopic and scotopic vision, is associated with adaptation to a luminance that is between roughly 3.4 and 0.034 cd/m^2.

What do these luminances mean in terms of designing a night environment for visual perception - assuming, of course, that to duplicate daylight, brightness is neither possible nor desirable?

Scotopic vision:

We are able to walk confidently by moonlight in a meadow when returning from fishing, enjoy the scenery and the stars, guided by the beacon effect of a glowing window in a farmhouse. Moonlight provides 0.2 lux of illuminance and perhaps 0.02 to .034 cd/m^2 of brightness under such conditions. Here we are using scotopic vision.

Mesopic vision:

When we reach the farmhouse we can read by candlelight or lamp light by holding the book in a favourable position with about 10 lux of illuminance and perhaps 2.7 cd/m^2 of brightness. Here we use mesopic vision.

We can again go outside, take another walk and return to the farmhouse with little adaptive difficulty; but we cannot take our book with us and read it without the candle. Therefore, optimum night lighting would seem to be attained somewhere between these two lighting levels. In fact, most human vision researchers agree that night vision will improve dramatically as the illumination level is increased from 0.2 lux (moonlight) to 10 lux, where vision that utilizes the "cones" of the eye begins to be dominant.

Importance of Colour:

While the photopic receptor system can readily perceive colours throughout the visible spectrum, peak sensitivity is in the yellow range. The scotopic system relies more on wave frequencies in the blue green range. Sources that are deficient in blue prevent the scotopic receptor "rods" from reaching the level of acuity of which they are capable. The scotopic system is also largely responsible for the detection of motion, and peripheral vision is almost entirely dependent on the 'rods'. Recent research also indicates that we are also reliant on this system even when the photopic "cone " receptors are in full use (i.e.. interior conditions). Overall, this means that blue deficient sources are particularly inappropriate for night lighting applications.

The control system in the human eye that is responsible for pupil size, (which in turn controls light intensity on the retina and depth of field focus) is also dependent on blue light. The eye gauges total light intensity at night using predominantly the blue portion of the spectrum as an indicator. While viewing a blue deficient sodium source at night we sense less radiant energy than is actually being emitted. As a result, pupil size becomes too large. The viewer is blinded by glare, and will experience an "aura" or "halo" around the source due to retina "over exposure". This in turn obscures all other less pronounced information in the field of vision. Also, visual acuity (or focus) is reduced for approximately 1/3 of the population who do not have proper corrective eyewear because when the pupil is too large, the depth of field of focus is reduced, thereby reducing the chance that the image will be properly focused on the viewer's retina.

It is proposed that exterior lighting levels should be designed for mesopic, or night vision and yet occasionally be brighter in selected areas to convey the appearance of brightness. Although the surfaces will seem bright, the sources will not cause a night vision adaptation problem. This is the best system to ensure enough visibility for personal safety.

Limits of brightness design:

The primary surfaces we light should have brightness of no less than 0.034 cd/m^2 (about the brightest of moonlight) and will rarely be greater than 3.4 cd/m^2 to keep within the bounds of mesopic vision. A few surfaces should exceed 7 to 17 cd/m^2 and these should have short transient viewing periods.

Where the design strays below 0.034 cd/m^2, as it will at considerable distances from luminaires, visibility potential will be reduced. These levels are appropriate to areas where there are no vital visual tasks and safety is not an issue. If the eye strays above 3.4 cd/m^2 for too long a duration, night vision adaptation will begin to be lost, and with this loss, an ability to see beyond the immediate location. In this circumstance, one's sense of security and comfort will be compromised. This problem occurs with overbright street lighting, which in fact reduces the ability to see into the shadows.

Maximum brightness:

We have used the moon as our reference source, and we will use it as a guide to the maximum brightness of luminaires to be used to achieve this night vision oriented lighting. The maximum photometric brightness of the moon is 2400 cd/m^2. This may be exceeded without losing our night vision adaptation only if the areas of higher luminance are kept at least 15 degrees off and above the usual line of sight. The principal luminaires to be used should have a brightness of less than 2400 cd/m^2 when viewed at less than 15 degrees above the line of sight. This may be exceeded occasionally.

Street lighting luminaires presently used in most applications can have excessive brightness. For this project, we propose using luminaires that are oriented to the pedestrian as well as to the automobile, and are much shorter than street-lighting poles. For effective night lighting, the brightness of the source is critical.

Visual tasks:

Do these low brightness levels provide illumination sufficient for the "tasks" of night movement, identification and general observation? As noted, one can easily walk across a meadow by moonlight, which has a luminance of 0.021 to 0.034 cd/m^2. Pragmatically, it has been observed that one can move safely around a rough construction site at night with incident illumination of from 0.2 to 0.1 lux, or approximately from 0.02 to 0.01 cd/m^2 ground brightness. At the lower end of this brightness range, movement can be problematic, while at the high end of the range, colors become perceptible.

Perception of brightness changes:

At low light levels, because the eye senses differences in intensity as a percentage of change, even a small absolute light level change is significant. A brightness change from 0.17 to 0.34 lux is a factor of 100% and would be noticeable. Thus, minor energy increases at low lighting levels can produce major changes in visual perception, while at higher levels, a much greater energy change is necessary to make a similarly meaningful visual change.

Visual efficiency vs. light levels:

Beyond a certain point, no increase in the quantity of light will improve task performance or increase safety in the environment. For various tasks, for example, the following results were observed: (from a 1970 report to the Illuminating Research Institute by Drs. R.M. Boynton and D.E. Boss) difficult tasks were performed to 95% accuracy in 43 lux. To achieve 98% accuracy required 1345 lux, while 99% accuracy necessitated 43,000 lux. We see from this that a maximum luminance level of about 2.7 cd/m^2, which corresponds to about 10 lux from an 80% reflective surface, will allow at least 95% accuracy in difficult reading tasks, provided other factors (glare, dark adaptability, contrast and movement) are properly controlled. The mesopic range allows a brightness of 3 cd/m^2, equivalent to 13.5 - 32 lux, or more, depending on surface reflectivity. The visual tasks to be performed outdoors are expected to be simple, such as large scale human figure discriminations and the recognition of clear, well designed graphics. Reading newspapers or writing letters are thought to be indoor activities.

Eye accommodation/adaptation:

The adaptation of the eyes to darkness is a principal reason for keeping brightness levels close to the Mesopic or night vision range. The adaptation of the eye to different levels of light and darkness is brought about by two functions. In the first place, the pupil of the eye increases in size as we go into a darkened area in order to admit more light to the eyes; it tends to contract in bright light, in order to limit the amount of light that enters the eye. This process takes several minutes and as we proceed from one condition of illumination to another, we may be partially blinded until this process is completed. Under such circumstances, the cones which are color sensitive lose much of their sensitivity. In the dark, our vision depends very largely on the rods, and color discrimination is limited. The time required for complete dark adaptation is usually 30 to 40 minutes. The reverse adaptation, from darkness to light, takes place partially in seconds, and is completed in a minute or two. Factors that affect visual discrimination, other than individual eye mechanism differences, include luminance contrast, time, luminance ratio, movement, colour, and glare.

Luminance contrast:

Luminance contrast refers to the difference in luminance of the features of the object being viewed, and in particular of the feature to be discriminated by contrast with its background. Within the University at night, this condition refers principally to the design and lighting of graphics and signage, such as the visibility of an arrow on a direction sign against the background of the sign.

Viewing time:

Within reasonable limits, the longer the viewing time, the greater is the ability to discriminate. This argues further for the acceptability of comparatively low night lighting levels for this project, especially in areas where movement is expected to be by foot.

Luminance ratio:

The luminance ratio is the ratio between the luminance of any two areas in the visual field, usually the area of primary visual attention and the surrounding area. To some extent, due to outdoor mesopic vision, the smaller this ratio, the greater is the ability to perceive one's total surroundings - except for objects perceived by contrast such as silhouetted figures or obstacles in a roadway.

Dynamic visual acuity:

Movement of the visual object or the observer, or both, brings into play a special type of visual acuity known as dynamic visual acuity or DVA. It is closely coupled with length of discrimination time discussed before. Such acuity generally deteriorates as a function of increased speed of movement. Obviously, more visual information can be taken in by a viewer on foot than one in an automobile.

Glare:

Glare is produced by brightness within the field of vision that is sufficiently greater than that to which eyes are adapted. Glare can cause annoyance, discomfort, or loss in visual performance and visibility. "Direct" glare is caused by light sources in the field of view. "Reflected" or specular glare is caused by reflections of high brightness from polished or glossy surfaces like building glass, metal, or wet pavement that are reflected toward the eye. The designer's objective is the creation of lighting conditions that provide adequate illumination/luminance levels while minimizing glare - except where controlled glare, as from bare filament lamps, is used for specific psychological advantage.

To minimize unwanted direct glare or contrast, low brightness sources and glare shields should be utilized. Such sources will increase the luminance of any area around the glare source to lower the luminance ratio.

Summary of Basic Visual Response Criteria:

The exterior lighting design for this project deals primarily with luminance, (the apparent brightness of surfaces or objects), rather than with illuminance, (the amount of light hitting a surface or an object), because of the true physical nature of visual perception. The design adjusts brightness, as far as practical, near the "night vision" luminance condition of from 0.034 to 3.4 cd/m^2, equivalent to from about 0.2 lux to as much as 30 lux. For some areas we may exceed these levels. Time of viewing will, however, be controlled.

Appendix C

Characteristics of Sources and Luminaires

Some of the aspects of artificial light sources that must be considered in their selection are "efficacy", life, color, spectrum, directionality of light emission and size. The choice or compromise among these factors should lead to conditions of maximum visibility at least cost.

Efficacy:

By efficacy, we mean the lumen output of light per watt of energy consumed. Sources range widely in this regard. Incandescent sources range from 10 to 25 lumens per watt. Fluorescent lamps usually produce between 60 and 80 lumens per watt. Induction lamps provide from 60 to 90 lumens per watt. High intensity discharge (HID) sources which include mercury vapour, metal halide, low and high pressure sodium lamps, vary from about 25 to more than 100 lumens per watt. Within these ranges, efficacy is a function of lamp type and total wattage. By conventional measurement techniques (i.e.. degree of radiant flux density), high pressure sodium delivers the most lumens per watt, with metal halide next and mercury vapour roughly half as efficient as H.P.S. (not counting ballast wattage.) These measurements determine the degree of photonic energy in the entire visible spectrum incident upon the test meter. As mentioned in Appendix B, the human scotopic sensor system relies heavily on the blue area of the spectrum for visual acuity, motion perception and peripheral vision, therefore sources like blue deficient H.P.S. do indeed deliver the most total radiant energy per watt but not the most useable energy. Recent studies vary on the exact degree of effect of blue on total visual ability, but several conversion factors have been forwarded for "meter" lumens per watt to "pupil" lumens per watt. Even the least favourable of these put metal halide on par or ahead of H.P.S. in terms of pupil efficacy. In general, for any source type, the larger the total wattage, the greater the efficacy and the greater the source brightness. Consequently, the efficacy of high wattage sources must be weighed against their potential for glare, color, emitting power, and resulting degradation of surrounding visibility. Too often, sources are selected entirely on the basis of their efficacy.

Life:

Life of sources is important both because of the cost of the lamp and costs associated with lamp replacement. The major cost of relamping is usually labour, not the lamp itself. Relative to lumen depreciation, and consistent with other requirements, lamps should be chosen for maximum life. "Lamp life" is rated at the point at which 50% of the lamps will still be burning, but group relamping should take place before this time. Rated lamp life of incandescent sources varies from 750 to 8,000 hours; exterior fluorescent lamps last about 10,000 hours, and HID from 1,500 to more than 24,000 hours. Compact fluorescent lamp life is 10,000 to 20,000 hrs., and inductive sources have lifespans reportedly in excess of 60,000 hrs. Relamping should be scheduled for the number of burning hours, which relate to a preselected percentage of initial lumen output. Many HID sources are needlessly bright, and overpowered lamps are sometimes used solely for their life cycle advantages over low wattage HID sources.

Colour:

The colour spectrum of light emitted from different sources varies widely. Sources may emit a light spectrum which is richer in some colours than in others, and which may be smoothly continuous or discontinuous between colours with little energy between "bursts" of specific colour energy. The ideal light is the white light of sunlight which we regard psychologically and physiologically as the norm.

Incandescent light has a continuous and broad spectrum which correlates most closely to human perception of all artificial sources to sunlight in the distribution and continuity of colours. The incandescent spectrum tends to be comparatively richer in red and yellow light but slightly deficient in blue and green light, when compared to sunlight.

HID sources vary greatly in colour output but typically have grossly discontinuous spectra that tend to concentrate light energy in narrow, intense bands of colour. When a spectrum of light includes components of blue, green and red light - and their relative intensities can vary significantly - the eye and brain integrate these colours into a perception of "white" light. But colour rendering of materials will be more or less uneven and the result will be perceived as "unnatural".

It should be noted that HID sources with the same Colour Rendering Index (CRI) do not necessarily exhibit the same colour, or tendency to enhance a particularly coloured object. The colour rendering index is an average of many spectral tests, and in no way indicates which areas of the spectrum that each source favours. Even two sources that the eye equates as the same colour temperature may exhibit different CRI's, with the more discontinuous "metamer" having the lower index rating.

Clear mercury vapour lamps produce light that is bluish-green and is flattering to foliage, but unflattering to people and reddish building materials. These lamps can be phosphor-coated to give more red output, but the coating effectively increases the source size to the dimensions of the outer glass lamp envelope, making optical control of the light emission more difficult and cumbersome. These lamps are now obsolete, and should not be considered for new installations.

Metal halide lamps are the most appropriate of the high output HID sources for exterior use in terms of colour. Their spectrum is rich in yellows, blues and greens, but includes enough red to produce an approximation of "white" light reminiscent of daylight. Metal halides are significantly better in providing a fuller spectrum metamer, so that people, the landscape and the full range of materials used in the design of the project will be seen in their truest hue. However, metal halide lamps exhibit a degree of "drift" from their specified colour temperature over time, particularly if left longer than the normal replacement period.

High pressure sodium lamps, which are employed to illuminate the streets in many cities, produce light which is yellow-orange, not even hinting at "white" - with almost no blue-green component. This light is relatively kind to people and reddish building materials, but turns the green of foliage to a dirty brown and makes landscape plantings appear to be dead or dying.

Fluorescent sources specifically for exterior use are not provided with the phosphor coatings to produce "warm" light. Recently, however, high output lamps that can be used in thermal enclosures are available in a variety of colour temperatures and high colour rendering indexes.

Compact fluorescent sources operate using the same principles as fluorescents. They have excellent colour rendition and temperature options, but are not used in cold-weather exterior applications without making accommodations for this factor in the fixture design. Lamps must be jacketed to maintain heat (hence lumen output), and must be thermostatically switched to remain lit below critical temperatures. The advantage of compact fluorescent is their relatively low lumen output, which is much more appropriate to non-blinding pedestrian scale fixtures and spacing.

Inductive sources are the newest on the market. Their colour and CRI, like the compact fluorescents, are of the same type as "T8" fluorescent lamps, yet they have no thermal constraints. Being new, the initial cost is high.

In terms of the illusion of "daylight white" light, and in colour rendering ability, incandescent sources are best, compact fluorescent, inductive, and high CRI fluorescents are next best, with metal halide following in the hierarchy.

Directionality:

For our purposes, all sources except fluorescent lamps emit light energy more or less evenly in a 360 degree sphere. Fluorescent lamps emit significantly greater energy perpendicular to their longitudinal axis than they do from their ends, or parallel to their longitudinal axis. This directional characteristic is important to the use of sources in fixtures intended to give 360 degree spherical dispersion, as frequently desired for landscape, street or building illumination.

Source Size:

The size of the source is of great importance where control of the directionality and control of light is sought by means of optical characteristics of the luminaire which encloses it. The larger the source, the more difficult is the problem of control, and the larger the fixture must be to effect control. For this reason, where great control and compact fixtures are required, clear incandescent lamps are appropriate because their filament sizes most nearly approximate an ideal "point" source. When the interior surface of a glass lamp is treated with phosphor or other coatings, the size of the source is increased in proportion to the dimensions of the globe, making control a larger-scaled operation. Fluorescent tubes are comparatively large in diameter and length. HID lamps have intermediate sized arc tubes that are amenable to control if phosphor coatings are not added to improve colour output. Lighting for large areas, such as streets and parking lots, require control to balance brightness or glare while directing adequate illumination for general area lighting.

Energy Cost/Conservation:

Energy conservation has become a significant issue in the design of large-scale projects, not only because of an energy shortage and higher energy costs, but also because of the public attitude toward energy use. This might be called the "energy ethic" of design. Projects such as this have the opportunity and the obligation to display an approach to energy conservation that, if emulated on a broad scale, would result in more value received, and less energy consumed.

The key is selecting efficient sources that produce the desired effect. For example, although fluorescent sources are more efficient than incandescent sources, they do not provide the sparkle, excitement, directional control and warmth of incandescent lamps and, thus, are not appropriate choices where such qualities are necessary. From this point of view, an incandescent or a metal halide lamp may be the most efficient source available to achieve the intended result.

Rather than concentrating on creating a design that merely uses a lower amount of energy, the lighting designers believe that the most important aspect of energy conservation is the elimination of energy waste. Lighting levels should be consistent with visual requirements, and should meet the established project criteria, not only minimize energy use. The illumination levels, moreover, should be no higher than what is necessary for safety, comfort and meeting the various design objectives.