NATIONAL ENDOWMENT FOR THE HUMANITIES

DIVISION OF PRESERVATION AND ACCESS

Narrative Section of a Successful Application

The attached document contains the grant narrative of a previously funded grant application. It is not intended to serve as a model, but to give you a sense of how a successful application may be crafted. Every successful application is different, and each applicant is urged to prepare a proposal that reflects its unique project and aspirations. Prospective applicants should consult the NEH Division of Preservation and Access application guidelines at http://www.neh.gov/divisions/preservation for instructions. Applicants are also strongly encouraged to consult with the NEH Division of Preservation and Access staff well before a grant deadline.

Note: The attachment only contains the grant narrative, not the entire funded application. In addition, certain portions may have been redacted to protect the privacy interests of an individual and/or to protect confidential commercial and financial information and/or to protect copyrighted materials.

Project Title: Integrating Risk Assessment for Pollutants into Energy-saving Strategies for Sustainable Environmental Management of Collection Storage Spaces

Institution: Rochester Institute of Technology

Project Director: Kelly McCauley Krish

Grant Program: Research and Development

I. SIGNIFICANCE TO THE HUMANITIES

For many years, the Image Permanence Institute (IPI) and other preservation research institutions have been advocating for environmental management strategies that achieve the best possible preservation environment with the greatest sustainability. "Energy benchmarking [to compare energy use across similar types of institutions] has revealed museums as intensive carbon emitters"[1]; and since it is estimated that mechanical systems account for approximately 30% of energy consumption in a building,[2] implementing mechanical system energy-saving strategies can have a significant impact on the carbon footprint of an institution. If collecting institutions across the nation are able to safely and effectively implement just one energy-saving strategy each, the savings would have a substantial cumulative effect on the museum sector as a whole. It is also something that many institutions will be legally required to do,[3] as cities and localities strive to meet carbon reduction goals. The proposed project's relation to climate change, financial impact, and preservation makes it both timely and urgent.

Additional challenges stemming from the Climate Crisis and COVID-19 pandemic are further increasing our need to better understand the effects of implementing these strategies which result in reduced air exchanges in collections spaces. Institutions in areas prone to wildfires, events that are increasing in frequency and intensity,[4] must often reduce or even block outside air for weeks during fire seasons to prevent smoke from permeating the building. A similar approach is often taken in areas undergoing construction to prevent fumes and particulates from getting into collection spaces, a less dramatic but widespread scenario. Many institutions also saw changes to their mechanical system operations when they closed due to the pandemic, and many of the strategies implemented focused on reduced air. A recent American Association of Museums newsletter included tips that recommended closing air dampers to save energy and costs during this period of institutional closings,[5] and ASHRAE's COVID-19 Building Readiness/Reopening Guidance recommends running mechanical systems on the minimum amount of outside air.[6] This project will inform new resources that provide research-based guidelines on how to operate under various scenarios.

The impact of this project is widespread. IPI has seen these strategies successfully implemented in small and large museums, libraries, and archives with diverse collections across the country, indicating that such solutions have applicability across a range of scenarios. Pollutants are pervasive, occurring in indoor and outdoor environments, and causing documented damage to nearly all forms of organic and inorganic materials. The development of a data collection and modeling procedure will enable institutions to balance risks from pollutants, allowing collections care professionals to make better informed decisions about mechanical system operations for collection spaces to enhance sustainability.

II. PRESERVATION AND ACCESS RESEARCH IMPACT

This project aims to provide a foundation to better balance and reduce risks associated with pollutants by developing and incorporating new, safer best practices for testing and implementing energy-saving environmental management strategies in collecting institutions. To date, there has been no preservation research to evaluate the relationships between temperature, RH, and pollutants in the context of sustainable

---

[1] Joyce S. Lee, "Earth Day during COVID-19: Green Tips for Closed Museums," April 22, 2020, https://www.aam-us.org/2020/04/22/earth-day-during-covid-19-green-tips-for-closed-museums/.
[2] Institute of Medicine, *Climate Change, the Indoor Environment, and Health* (Washington, DC: The National Academies Press, 2011) 210.
[3] "New York Museums Must Reduce Greenhouse Gas Emissions or Face Fines," *Artforum*, April 24, 2019, https://www.artforum.com/news/new-york-museums-must-reduce-greenhouse-gas-emissions-or-face-fines-79543.
[4] Institute of Medicine, *Climate Change, the Indoor Environment, and Health* (Washington, DC: The National Academies Press, 2011) 104.
[5] Joyce S. Lee, "Earth Day during COVID-19: Green Tips for Closed Museums," April 22, 2020, https://www.aam-us.org/2020/04/22/earth-day-during-covid-19-green-tips-for-closed-museums/.
[6] ASHRAE, "ASHRAE Offers COVID-19 Building Readiness/Reopening Guidance," accessed May 11, 2020, https://www.ashrae.org/technical-resources/building-readiness#restarting.

environmental management (see **Attachment 4: Bibliography** for literature review). The primary research question this project proposes to address is: to what degree do pollutant concentrations change at the room level in response to implementing energy-saving environmental management strategies?

In this proposal, *pollutant* is defined as any substance that has a detrimental effect on collections.[7] Numerous studies have identified specific outdoor- and indoor-generated pollutants that negatively affect collections, and new ones are added with regularity. This means that it is not feasible to monitor for all pollutants that could potentially cause damage in a single study; instead the focus will be on developing an approach that can be adapted by institutions to apply to any pollutant of concern.

As with light, damage from pollutants is a result of dose: concentration multiplied by time. When these two factors are not adequately or simultaneously considered, pollutants cause a wide range of deterioration to collections. The pollutants that will be monitored in this project (see **Table 1**) are confirmed to cause collection damage and have established *no* and *lowest observed adverse effect levels* (NOAEL and LOAEL)[8]. These levels are often much lower than those set for human health and safety, since collection materials often have greater sensitivities and also have no recuperative abilities.[9]

It is currently uncommon for pollutants to be regularly monitored in collecting institutions. A 2010 survey published by Prosek et al, suggests that only 3% of heritage sites in Europe and North America monitor air quality parameters other than temperature and relative humidity.[10] Instead of preventive monitoring, pollutant concentrations are typically measured in environments where damage has already occurred. That said, current guidelines, including PAS 198:2012 Specifications for Managing Environmental Conditions for Cultural Collections and the UNESCO World Heritage Periodic Reporting questionnaire, now recommend pollutant monitoring in recognition of the risks pollutants pose to collections.[11] This project will contribute to and advance these initiatives by integrating pollutant monitoring into sustainable environmental management.

Studies recognize air exchanges as a significant factor in determining pollutant levels as well as identifying it as an important component of sustainability management. Setting air exchange rates often depends on establishing the right balance between the introduction of outside air (and its corresponding pollutants) with dilution of already conditioned indoor air (and its generated pollutants). Outside air is also necessary to maintain positive pressurization of a space but bringing in outside air requires energy costs to condition it to the appropriate temperature and relative humidity. Mechanical operation representing the greatest potential for energy savings results in changes to air exchanges – either in rate (system shutdowns, fan speed adjustments) or nature (outside air reduction) – within the collection space, and the overall effect of these strategies on room-level pollutant concentrations is undocumented.

Previous research has looked at the influence of building-level factors, such as the building envelope, supply diffusers, and filters in the mechanical system. In 2016, the National Archives and Records Administration (NARA) estimated that the mechanical system in one of their buildings was costing approximately $1.5 million per year in electricity.[12] In an effort to reduce those energy costs, NARA tested the potential of shutting down redundant air handling units (AHUs) and reduced air exchange rates in collections storage

---

[7] Cecily M. Grzywacz, *Monitoring for Gaseous Pollutants in Museum Environments* (J. Paul Getty Trust, 2006), vii.
[8] Jean Tétreault, *Airborne Pollutants in Museums, Galleries, and Archives: Risk Assessment, Control Strategies, and Preservation Management* (Ottawa: Canadian Conservation Institute, 2003) 21.
[9] Elyse Canosa, "Strategies for Pollutant Monitoring in Museum Environments," (Swedish National Heritage Board, 2019) 7.
[10] Henoc Agbota et al, "Pollution monitoring at heritage sites in developing and emerging economies," *Studies in Conservation* 58, no. 2 (2013): 129.
[11] Ibid.
[12] Mark Ormsby, "Experiments with reducing energy use at the National Archives & Records Administration," paper presented at the Heritage Research to Conservation Practice conference, Birmingham, England, March 2016.

spaces in the building. The study found no significant difference in acetic acid and formaldehyde levels in the spaces after implementing changes. They then applied further pollutant monitoring to inform decisions about filtration on the AHUs. This work demonstrates how pollutant monitoring can be successfully integrated into institutions for sustainability purposes. This project significantly expands upon NARA's work by increasing the number of pollutants examined and the energy-saving strategies being implemented, and by creating a tool for institutions to optimize their operation for cost effectiveness and collection protection.

Table 1: Damage caused by representative pollutants[13,14,15]

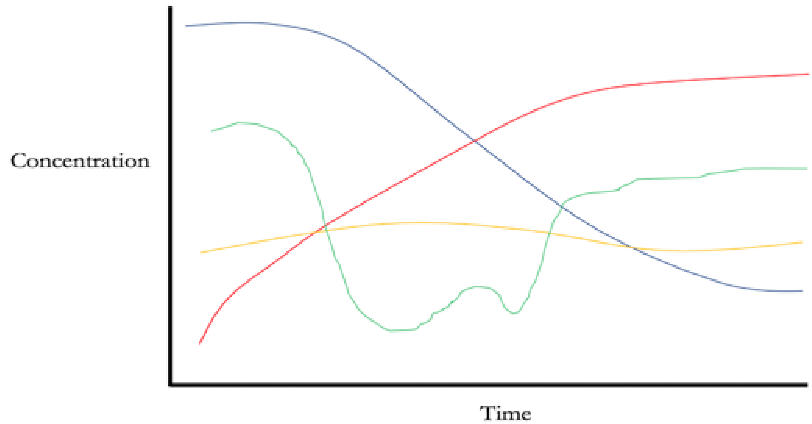
Categories of pollutants	Representative pollutant and their sources	Types of damage
Indoor-generated: **aldehydes and carboxylic acids**	**Acetic Acid (CH_3COOH)** • Materials including wood, paints, fabric, adhesives, sealants • Degradation of cellulose acetate materials • Microbiological contamination of air-conditioning filters	• Corrosion of glass and metals (particularly lead and copper alloys, but also zinc, cadmium, magnesium, iron, and silver) • Efflorescence on calcareous materials (including Byne's efflorescence on shells, but also on limestone and terra cotta surfaces) • Cellulose depolymerization (degrades paper)
Outdoor-generated: **oxidizing pollutants**	**Nitrogen Dioxide (NO_2)** • Reactions with combustion of fossil fuels from vehicles, industrial activities • Heavy equipment, heaters, generators that use combustion	• Fading of colorants, including dyed textile fibers, certain inks, organic pigments • Degradation of paper, fibers (including silk and wool) • Enhances effects of other pollutants
	Ozone (O_3) • Smog (secondary pollutant from combustion of fossil fuels) • Photocopiers • UV light sources • Some HVAC components	• Fading of colorants (especially ink-jet print dyes), attacks paint binders • Discoloration of photographic prints • Can affect plants, leather, parchment, animal skins • Embrittles fabrics, textiles, and cellulosic materials; cracking (ex. rubbers, plastics) • Corrosion of metals
Both outdoor- and indoor-generated: **sulfur gases, particulates, VOCs**	**Hydrogen sulfide (H_2S)** • outdoor: reactions with combustion of fossil fuels from vehicles, industrial activities; proximity to oceans, marshlands; forest fires • indoor: off-gassing of case materials (silks, wools, felts), adhesives	• Destroys plant tissue • Darkens pigments • Corrosion of metals • "Red rot" of leather and parchment
	Sulfur dioxide (SO_2) • outdoor: reactions with combustion of fossil fuels from vehicles, industrial activities • indoor: vulcanized rubber, gas-powered equipment	• Embrittles and weakens paper and textiles • "Red rot" of leather and parchment • Color change of pigments, fades dyestuffs • Corrosion of metals
	Particulates ($PM_{2.5}$) • outdoor: combustion, motor vehicle traffic (diesel fuel); construction activities • indoor: shedding from objects and people due to abrasion, vibration, and wear	• Discoloration and abrasion of surfaces • Accelerate deterioration by allowing formation of harmful compounds, trapping moisture, attracting insects, mold germination
	Total Volatile Organic Compounds (tVOCs) Varied: group classification for organic compounds that participate in photochemical reactions; used as an overall indicator of indoor air quality	

13 Cecily Grzywacz, *Monitoring for Gaseous Pollutants in Museum Environments* (Los Angeles, California: J. Paul Getty Trust, 2006), 98-103.
14 Jean Tétreault, *Airborne Pollutants in Museums, Galleries, and Archives: Risk Assessment, Control Strategies, and Preservation Management* (Ottawa: Canadian Conservation Institute, 2003) 8-9.
15 Elyse Canosa, "Strategies for Pollutant Monitoring in Museum Environments," (Swedish National Heritage Board, 2019) 10-19.

The current project will study pollutant levels by comparing concentrations prior to energy-saving mechanical system operation to those during energy-saving operations, to establish how pollutant levels change as a result of energy-saving strategies. Results will then be evaluated through a variety of means to assess whether these changes in levels represent risk to collections.

Anticipated results
This study will help further the field's understanding of pollutant concentrations at room level, and how the nature of air exchanges in both frequency and composition (indoor-outdoor ratio, or I/O) can be used effectively to balance risks and energy consumption. It is likely that pollutants generated outside will display a different pattern in response to implementation of energy-saving operations than those generated indoors. Several scenarios are possible, as illustrated by **Graph 1** below.

Graph 1: Examples of pollutant responses to energy-saving operations



For each pollutant, concentrations may remain roughly the same over time (yellow) if the implemented energy-saving strategies are short enough to have a negligible effect. However, concentrations could also increase (red), as might be the case if indoor-generated pollutants are not exhausted outside, or decrease over time (blue), in the case of fewer outdoor pollutants being introduced to the space. Finally, pollutants could demonstrate a more complicated pattern (green). Collecting the proposed data will allow us to understand and respond to each possible case as needed.

The project conclusions will be shared with the field as described in the Dissemination Plan (see **Appendix 10: Additional Documentation)**, with a primary project outcome being a data collection and modeling procedure to help institutions balance pollutant level changes while implementing energy-saving strategies. Adoption of results is expected to be strong (see **Appendix 9: Letters of Support**), since this applies to institutions with long-term sustainability goals (due to their locality's carbon emission targets, internal motivations, and/or budget limitations), as well as those looking at changes to their mechanical system operation that result in reduced air exchanges, as during planned construction, wildfires, or shutdowns during the COVID-19 pandemic. The research also has implications for other areas with reduced air exchanges, such as compact shelving and the trend towards passive buildings (which do not rely on mechanical systems to maintain conditions). Improving indoor air quality, and reducing cost of energy use and carbon footprint are current goals for many institutions, and one of the significant challenges facing the preservation field in light of the Climate Crisis and financial burdens.

III. PROJECT HISTORY, SCOPE, AND DURATION

History – IPI is a recognized leader in the field for best practices in managing sustainable long-term preservation environments. From 2010 to 2016, with support from the National Endowment for the Humanities (see **Appendix 6: History of Support**), IPI conducted multiple research projects to evaluate the effect of intentional temperature and RH changes on collection materials.[16] From 2014 to 2017, with support from the Institute of Museum and Library Services, IPI continued field experiments to further formalize a methodology for testing and implementing energy-saving strategies in collecting institutions and to create a written, online guide now used by professionals in collecting institutions to independently and successfully test energy-saving strategies in their collections environments. The project resulted in the publication, *IPI's Methodology for Implementing Sustainable Energy-saving Strategies for Collections Environments* (see **Appendix 10** for Outside Air Reduction excerpt). This electronic publication can be downloaded, printed, and accessed free-of-charge by cultural heritage professionals anywhere in the world. However, implementation of the methodologies has sometimes been confounded by concerns over the potential build-up of indoor pollutants. This research project seeks to address these unknowns through study of the actual impact of energy-saving strategies on pollutant levels.

In addition to temperature and RH investigations, IPI has a long history of research into the harmful effects of pollutants on various collection materials including paper, photographs, and modern digital hardcopy. Decay responses such as paper yellowing and embrittlement, photograph fading, and digital print cracking and bleed have been examined and the results published through a variety of conference proceedings and journals as well as on IPI's online resource the Digital Print Preservation Portal. In addition, the ability to slow pollutant-induced decay through low temperature storage, and enclosure materials and designs has also been studied.[17,18]

Scope – Field research inherently involves a large number of parameters, in this case including, but not limited to: local climate, building envelope, type and age of filtration, type and age of construction materials, type of collection materials, and airflow. It is not possible to account for the full range of variability in collection storage spaces. Therefore, this project will focus on the implementation of a methodology that has already been successfully used for temperature and relative humidity-based optimization. This will allow for the most widely applicable results.

In addition, there can be variations in temperature for storage areas, ranging from frozen, cold, cool, to room, and a range of relative humidity levels. Temperature and relative humidity play a role in the kinetics of pollutants; for example, it is known that low temperature slows the off-gassing of acetic acid. In order to minimize the impact of additional variables to the study, the focus of this project will be on storage spaces in the 50°-70°F range, the temperatures at which many (but not all) pollutants are more likely to cause deterioration (as compared to colder environments). Seasonal set points and system setbacks are two additional strategies that have demonstrated success in energy-savings and preservation gains that are not included in the proposed study because the changes relate to temperature and relative humidity settings, rather than air exchanges. However, these strategies could be investigated under a similar, future study.

Given the focus of this proposal on how pollutant concentrations respond to the implementation of energy-saving strategies, pollutants will only be examined at the room level; additional mitigation efforts will not be considered. For example, while sorbents and enclosures may be effective in managing pollutants at an object level, they do not address this initial research question and therefore will not be examined as part of this study. By first addressing how pollutants can be controlled in the macroenvironment, this project will inform

[16] Jean-Louis Bigourdan, "Methodologies for Sustainable HVAC Operation in Collection Environments" (final report to NEH: National Endowment for the Humanities, Division of Preservation and Access, NEH Grant #PR-50087-10, January 31, 2017).

[17] Daniel Burge, Nino Gordeladze, Douglas Nishimura, and Jean-Louis Bigourdan, "Mitigation of Pollution-Induced Deterioration of Digital Prints through Low-Temperature Storage," *Society for Imaging Science and Technology*: NIP29 and Digital Fabrication (2013).

[18] Daniel Burge and Andrew Lerwill, "Mitigation of Light-induced Damage on Modern Digital Prints: Photographs and Documents," *Society for Imaging Science and Technology*: NIP31 and Digital Fabrication (2015).

of the need for directed mitigation efforts, and add to the larger, overall picture of pollutants in the storage environment.

Duration – The project's scope and research objectives are entirely contained within a three-year timeframe starting in March 2021. The three-year program reflects the total time necessary to complete all phases of the project as described in detail in the work plan. Project activities are divided into three phases: 1) partner identification and site visits, 2) data collection and analysis, and 3) final evaluation and reporting. A detailed description of the experimental program and schedule of completion is provided in the work plan.

IV. METHODOLOGY

Research activities will be organized and led by IPI staff, who will facilitate the collaborative efforts of a multidisciplinary and multi-institutional project team for data collection, analysis, and reporting.

Experimental methodology – Traditionally, temperature and relative humidity (RH) levels have been the primary indicators of environmental risks to collections in storage environments because they are critical external forces influencing rates of chemical decay, as well as other types of deterioration including mold, metal corrosion, pest infestation, and mechanical damage. Implementation of energy-saving strategies in collections environments begins with environmental monitoring of temperature and relative humidity, ideally for at least one year to collect data covering seasonal variations. Once baseline data is collected, testing of individual energy-saving strategies for two-week periods informs their implementation over longer timeframes, even permanent use. An energy-saving strategy, under the current paradigm, would be considered successful if the temperature and RH data collected met the following criteria:

- temperature and RH fluctuations were not greater than those seen prior to testing the energy-saving strategy,
- changes in RH did not exceed the safe range for the collection type,
- temperature and RH did not rise significantly (more than 2°F or 5%RH) during the test, and
- there was no cumulative temperature or RH gain after successive shutdowns.[19]

Those criteria were established after two decades of environmental management research at IPI that focused on the impact of temperature and relative humidity. See **Table 2** which shows three current energy-saving strategies for mechanical system optimization that have proven successful across institutions small to large, within multiple collection types, and spanning the entirety of the United States.

Implementing mechanical system energy-saving strategies has proven effective in addressing institutional contributions to climate change as well as financial challenges. Doing so while maintaining or improving preservation quality requires a series of carefully defined, risk-managed steps that test each energy-saving strategy. While the appropriate final approach may be unique to each collection, space, and mechanical system, the strategies and IPI's implementation methodology have been found to be widely applicable, working in some combination for nearly all collecting institutions. This research will enhance institutional effectiveness whereby changes in room level pollutant concentrations, that may also pose a significant threat[20], can be comprehensively considered. This proposed project augments the prior research to be more inclusive of all critical factors.

Data capture – Continuous monitoring will be utilized to establish the close cause-effect relationship between pollutant levels, temperature and relative humidity, and other activities such as filter changes and system shutdowns.

---

[19] Image Permanence Institute, *IPI's Methodology for Implementing Sustainable Energy-Saving Strategies in Collections Environments* (Rochester, NY: 2017), 102.
[20] Nigel Blades, et al. "Guidelines on pollution control in heritage buildings," (London: Museum Association) 23.

Table 2: Impact of energy-saving strategies

<table>
<tr><th>Strategy</th><th>Approximate energy savings</th><th>Measured impact on preservation (temperature, %RH)</th><th>Possible impact on preservation (pollutants)</th></tr>
<tr><td>System shutdowns: mechanical system operation is completely suspended for a set period of time (generally 4-12 hours) and the collection spaces are allowed to passively maintain conditions</td><td>✓
Based on length of shutdown
Ex. 8 hour shutdown = 33% of operational costs eliminated</td><td>None
To meet criteria, temperature and relative humidity are maintained at pre-implementation levels</td><td rowspan="3">For all:
✓
Should decrease levels of outdoor-generated pollutants

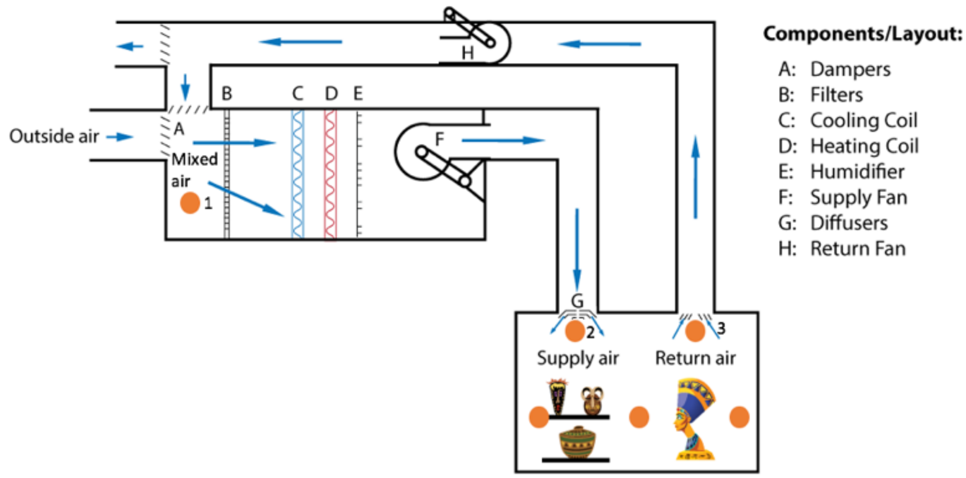
?
Concern that will lead to an accumulation of indoor-generated pollutants</td></tr>
<tr><td>Fan speed adjustments: fan speeds are reduced to save energy when the existing number of air exchanges is higher than required in a collection space</td><td>✓
Related to the affinity law
Ex. 50% reduction in fan speed = 87% reduction in horsepower lowering operational costs</td><td>None
Does not change temperature and relative humidity at mechanical system or in collection space</td></tr>
<tr><td>Outside air reduction: the percentage of outside air brought in is minimized to reduce the amount of work performed to cool, heat, dehumidify, or humidify it to the desired conditions; a higher percentage of return air is conditioned and re-supplied to spaces</td><td>✓
Dependent on the amount of outside air used and the difference between outside and inside conditions
Ex. Return air of 63°F to 60°F = 3°F of work; Outside air at 73°F to 60°F = 13°F of work
→ more than 4 times the amount of work for temperature control alone</td><td>✓
Often reducing the amount of outside air allows the mechanical system to maintain desired conditions more effectively, as it is not combating new moisture and heat loads</td></tr>
</table>

IAQ Guard will be used for continuous monitoring of pollutants at the following detection levels: 0-5 parts per million (ppm) with 10 parts per billion (ppb) resolution for NO_2; 0-5 ppm with 10 ppb resolution O_3, 0-10 ppm with 10 ppb resolution for H_2S; 0-20 ppm with 50 ppb resolution for SO_2; 0 to 500 $\mu g/m^3$ with 1 $\mu g/m^3$ $PM_{2.5}$; and 0-1000 ppm with a resolution of 0.2% of the measured value for VOCs. IAQ Guard is a series of sensors that connect wirelessly to a gateway node, which then uploads to the IAQ Guard remote dashboard. Data will be logged at 15 minute intervals and regularly downloaded.

Acetic acid will also be continuously monitored, with the ATI D-16 PortaSens III Gas Detector, with a +/-5% accuracy over a 0-100,000 ppb range. Acetic acid is one of the most common pollutants in collections storage environments and especially indicative of the off-gassing of collections. It is anticipated that continuous monitoring of this particular pollutant will be highly informative of the impact of energy-saving strategies on collections-generated pollutant levels.

The number of instruments needed is defined by the number of locations where changes to pollutant levels can occur, including one for each of the following within the mechanical system serving the collection storage space: 1) mixed air (before filters), 2) supply air, and 3) return air (see **Diagram 1**). This will allow for comparison between outdoor and indoor levels by measuring what the mechanical system is removing and what the collections are adding to the space in total. Another three monitoring locations within each institution will focus on the collections spaces themselves. Exact locations will be determined during site visits and modified during team meetings as needed in order to capture variations across the collection space.

Diagram 1: Proposed locations of pollutant dataloggers



Temperature and humidity dataloggers will also be deployed to verify that those conditions remain within the four temperature and humidity criteria described above. Existing institutional dataloggers will be maintained by each partner institution, with additional PEM2 and ACR TRH-1000 dataloggers used to supplement, including in the mechanical system, supply diffusers, and return vents to capture work being performed on the air. Both types of dataloggers have been used in numerous field projects by IPI staff. Data from the PEM2 is accurate to +/-1°F and 2%RH across its operating range, and data is downloadable by USB, allowing easy retrieval by partner institutions. The ACR TRH-1000 has a conformal coating, making it useful in high humidity locations such as outside air, cooling coil, and downstream of humidifiers; its sensor accuracy is +/-1°F and 4%RH.

Energy consumption of the mechanical equipment (air handlers and any directly connected chillers) at each cultural heritage institution will be measured by a Dent ELITEpro XC™ power datalogger. The power dataloggers will collect power and energy data in their on-board memory over the course of the project. The loggers will be connected to the institutions' WiFi networks and can be monitored remotely by GIS staff. Data may be remotely downloaded periodically. After testing is completed, the dataloggers will be returned to GIS where the power and energy data will be extracted for analysis.

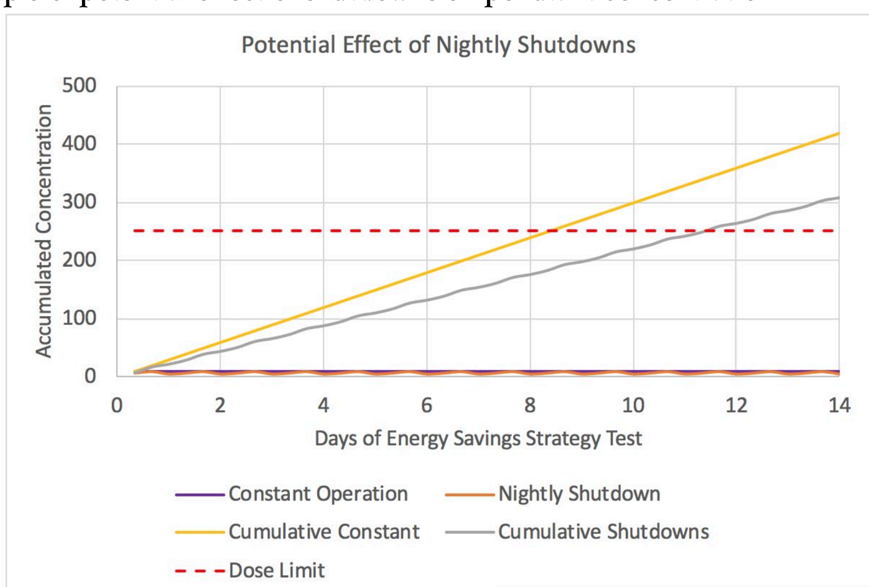
Standard calibration procedures for all equipment will be followed. IAQ Guard sensors have an auto-zero calibration algorithm that will be run monthly. ATI detectors will be recalibrated after one year of data collection. Partner institutions will be required to maintain calibration of their existing temp/RH dataloggers, while the PEM2 and ACR dataloggers will be calibrated prior to deployment in the spaces and will not require subsequent calibration in the course of the project. Partner institution staff will be trained in the placement, download, and analysis of data from continuous monitors; as well as the identification, testing, and modification of energy-saving strategies for mechanical system operation, so that they can be fully engaged and contribute to the success and outcomes of the project. In all phases of the project, work will be performed according to accepted professional standards and procedures and accomplished through collaboration of the multi-disciplinary project team.

Data collected from the monitors will be imported into Microsoft Excel to facilitate analysis of the datasets. Baseline data collected during the first year will be evaluated to determine selection and timing of energy-saving strategies to be tested. Modifications to monitor placement may be made as needed to ensure that understanding variations across the space is as complete as possible. Comparison will be made between indoor and outdoor levels of pollutants, and preventive maintenance on the system (such as replacing filters) will be noted, in order to estimate the effectiveness of the current system operation.

Data Analysis – The collected data from the project will lead to new practices to balance energy-saving strategies against the risks associated with the different types of pollutants, both outdoor and indoor. This data analysis approach will be developed into a data collection and modeling procedure for widespread use. For example, a possible result for an outdoor-generated pollutant can be illustrated in **Graph 2** below (note that this is only for explanation purposes and not based on an actual dataset). The graph shows what might occur while a two-week energy-saving strategy is tested; in this case, nightly shutdowns. The purple line represents the storage area's measured baseline pollutant concentration (at eight hour increments) when the mechanical system is run as normal. The orange line represents data points collected while measuring pollutant concentration when the system is shut down every night for eight hours, therefore excluding ingress of outdoor air. Due to nightly drops in pollutant levels followed by increases again during the day, the orange line is sinusoidal; however, it does somewhat approximate the baseline. It may appear that the threats to the collection are nearly the same.

However, just as with light, deterioration is not caused by a one-time event exceeding a prescribed limit, but through the accumulation of events over time, or dose. If an object is exposed to the near constant concentration represented in purple, over time the overall accumulated exposure by the pollutant builds and results in the yellow line. If the energy-saving strategies are implemented and ingress of the outdoor-generated pollutant is reduced as per the orange line, then the rate of accumulated dose will drop significantly over the test period resulting in the grey line. In this case, not only is energy being saved through the nightly shutdowns, but collection life is being extended through reduced accumulated pollutant exposure. Unfortunately, the opposite can occur where indoor pollutants increase during shutdowns. In that case, the indoor pollutant dose would rise. In one scenario, the life of the collection is being extended and in the other, the life is diminished, though in both cases energy use has been reduced. Understanding even minor changes to pollutant levels is therefore critical.

Graph 2: Example of potential effect of shutdowns on pollutant concentration



Each energy-saving strategy will first be evaluated according to previously-established criteria for temperature and relative humidity levels (see page 7) to establish that they are safe for the collections in terms of those parameters. The strategies will then also be re-evaluated with these new criteria for pollutant data:

- pollutant levels never increase to levels statistically higher than those seen prior to energy-saving implementation, and

- pollutant levels return to baseline levels consistently (i.e. the mechanical system is able to recover fully and remove any build-up).

These additional criteria will ensure that the preservation quality of the environment is never compromised in order to meet energy-saving goals, but also allow for natural variations that do not impact the long-term preservation of collection materials. The ability to meet these criteria during energy-efficient operation will be significant in determining success or the need for modification of energy-saving strategy implementations.

If the energy-saving strategy testing does not meet these criteria and discussion in team meetings suggests that modifications in timing, duration, or extent could improve the situation, additional two-week testing periods will be scheduled as possible within each season in order to identify optimal operation. If pollutant levels are found to change, the project team will use a variety of statistical methods to investigate the correlations between variables to inform how the strategy can be most effectively modified. Any changes will be correlated to potential collection risk.

Once an energy-saving strategy is deemed safe for a particular institution, data from the two-week test period can be extrapolated further into the future, creating a picture of additional gains in energy savings along with gains or losses in collection life over the long-term.

If the actual dose (pollutant concentration x time) needed to cause harm to the collection is known, then predictions regarding the life of the collection and the impact of energy use on that life can also be made. For example, if an object has a dose threshold of 250 ppb/time (red line), we can see that by implementing the energy-saving strategies consistently, the collection will reach this point after 30 time intervals, rather than only 25 intervals, representing a significant improvement in preservation as well as energy savings.

Finding dose thresholds is difficult at present. There are limits to existing research, with only certain materials having been studied under specific parameters. Reciprocity laws, which allow for projections to be made over a long period of time based on what happens over a short period of time, are not well established for pollutant effects on material types. Despite these limitations, this extrapolation method should prove a powerful demonstrator of the potential force that accumulation of pollutant exposure (like accumulated light exposure) can have on collections.

For this project, correlating the significance of the results to the risk of damage will be done with today's best available resources. Jean Tetreault, a Senior Conservation Scientist at the Canadian Conservation Institute, is a known leading expert in pollutant effects on cultural heritage and will assist with this part of the project. Additionally, while an individual threshold may not be established for all object types, categories of low, moderate, and high sensitivity can be developed based on existing research, in keeping with a risk assessment approach.[21] Finally, this project will be evaluating multiple pollutants. Using the above approaches to demonstrate effects, the risks created by each strategy can be ranked and ordered so that the worst offending pollutant and its source (outdoor or indoor) can be addressed, and subsequent steps can be taken to mitigate individual (or all) pollutants in order of their threat level.

Collections handling – No collection objects will be handled directly through this project; in the event that an object needs to be moved for data capture, only the appropriate institutional staff will do so.

Intellectual Property and Privacy – There are no intellectual property concerns, as results will be synthesized for reporting, exclusive of the instrumentation and software used. Partner institutions must agree that collected data and resulting analysis can be shared through the identified means of dissemination.

[21] Jean Tétreault, "Agent of Deterioration: Pollutants," Canadian Conservation Institute, last modified May 18, 2018, https://www.canada.ca/en/conservation-institute/services/agents-deterioration/pollutants.html.

V. WORK PLAN (see **Appendix 5: Work Plan** for further details)

Phase I: Partner identification and site visits (March 2021 - October 2021)

The project will begin with a call for applications for partner institutions. IPI will then select the three best suited and verify that energy-saving operations can be successfully implemented. The lead contact at each partner institution will supply initial documentation, including but not limited to: space layout, mechanical system design and operation, previous environmental data collected, and previous surveys/studies of the space (with attention to building envelope, environmental issues, and pollution levels). IPI will purchase all pollutant monitoring devices required for the project as outlined in the budget, and test their operation prior to project deployment.

Site visits will allow RIT staff and the outside consultants to meet with partner institutions, including representatives from collections and facilities departments. Each site visit will involve two days on location to review the current operation of the mechanical system serving the collection space to be monitored, identify appropriate monitoring locations for each type of pollutant monitoring device, and agree to a standard data collection protocol that all partner institutions feel adequately trained and prepared to conduct.

Phase II: Data collection and analysis (November 2021 - December 2023)

The purpose of Phase II is data collection and analysis. The first year will focus on collecting baseline data to account for natural variation in pollutant levels, temperature, and relative humidity across seasons. Staff at partner institutions will also record the occurrence of routine preventive maintenance such as filter changes and cleaning cooling coils, and other events that might impact data.

After a year's worth of baseline data collection, dates will be set to implement each of the energy-saving strategies. Throughout the course of the second year, IPI protocols will be followed to test each of the three energy-saving strategies selected for this project for a two-week period during multiple seasons. The project team will evaluate data for each strategy tested, discuss any issues encountered, and make modifications to the protocol as necessary. Using a combination of statistical methods, the project will discover and document any significant relationships between implementation of energy-saving strategies, temperature, relative humidity, and pollutants. Project consultants will apply statistical methods to establish correlations between variables as well as distinguish between baseline and energy-saving strategy data sets.

The project team of RIT/IPI and RIT/GIS staff, consultants, and collections and facilities staff at partner institutions will convene quarterly via online video conference calls throughout Phase II to analyze and discuss data and make work plan adjustments as necessary, depending on the responses of pollutant levels.

Phase III: Final evaluation and reporting (January 2024 - February 2024)

The purpose of this phase is to analyze the data collected in its entirety and initiate dissemination activities. As stated in the **Summary on page 1**, a primary outcome of the project will be a data collection and modeling procedure to help institutions reduce and balance pollutant level changes while implementing energy-saving strategies, based on their specific situation. The project conclusions will also be presented in a variety of other ways to ensure the broadest audience is reached, as described in the Dissemination Plan document included in **Appendix 10**.

VI. INSTITUTIONAL PROFILE AND PROJECT STAFF

The Image Permanence Institute (IPI) is a preservation research center in the College of Art and Design at Rochester Institute of Technology (RIT), dedicated to supporting the preservation of cultural heritage collections in libraries, archives, and museums around the world. IPI achieves this mission by maintaining an active preservation research program that informs and advances professional-level education and training activities, publications, consulting services, and the development of practical preservation resources and tools. IPI's extensive history of preservation environment research and preservation environmental management consulting, as well as laboratory-based pollution research, provide an excellent foundation for success.

IPI will collaborate with the Golisano Institute for Sustainability (GIS) at RIT to meet project goals. For more than 25 years, GIS has been a leading industrial sustainability research, development, and technology deployment organization with a mission to undertake world-class education and research in sustainability. GIS is part of the New York State Pollution Prevention Institute, a partnership with NYS to reduce toxic use, emissions, waste generation, and natural resource consumption through applied research, technology deployment, and information dissemination.

To accomplish project goals, field-based research activities will be organized and led by IPI staff, who will manage the collaborative efforts of the project team members including professionals from the preservation research, conservation, facilities management, indoor air quality, and sustainability fields. See **Appendix 3: Resumes** for further information on each individual's qualifications.

RIT/Image Permanence Institute (IPI) Staff:
Kelly Krish, Preventive Conservation Specialist and Principal Investigator, is an expert in preventive conservation and has consulted with a wide range of cultural institutions on collections assessments and the implementation of sustainable preservation environmental management programs. Ms. Krish has extensive experience managing collaborative projects with collection professionals, administrative personnel, and facilities managers. She will oversee the project and be responsible for developing and implementing the work plan, coordinating with project partners and participants, managing project activities, and ensuring that all deliverables are met. Ms. Krish will purchase equipment; arrange, participate in, and keep record of project meetings; and lead the project team in review and analysis of data. She will also be responsible for reporting to NEH and disseminating project information. It is estimated Ms. Krish will dedicate 30% of her time for three years to the project.

Christopher Cameron, Sustainable Preservation Specialist, is an experienced facility manager with Energy Service Company Certification in HVAC systems as well as Project Management Certification from the International Facility Management Association who has consulted with numerous collecting institutions on implementing sustainable environmental management programs. He will be responsible for documenting mechanical system operations and placing dataloggers at partner institutions, providing energy-saving strategy implementation recommendations, and assisting with data analysis and dissemination activities. It is estimated Mr. Cameron will dedicate 10% of his time for three years to the project.

Daniel Burge, Senior Research Scientist, has 30 years of preservation research experience, including serving as Principal Investigator for the digital print pollution research cited in the *History* section of this proposal. He will contribute to data interpretation, data analysis, model development, and project dissemination activities. Mr. Burge will visit the third partner location to contribute his expertise from previous pollutant research and gain perspective for data analysis and model development. It is estimated Mr. Burge will dedicate 5% of his time for three years to the project.

Lauren Parish, Web and Publications Manager, has expertise in graphic design, web development, and publication project management. She will be responsible for preparing publications and assisting with the project's dissemination plan. It is estimated Ms. Parish will dedicate 5% of her time in the third year to the project.

RIT/Golisano Institute of Sustainability (GIS) Staff:
Martin Schooping, Senior Project Manager, has 40 years of engineering and design experience. He currently conducts applied research in alternative energy and energy efficiency, assisting companies to identify energy saving opportunities. His responsibilities will include one visit to each partner institution gathering information and onsite measurements, and completing the baseline analysis process. He will participate in collaborative project calls to inform on relationships to energy use, documenting information, calculating and analyzing data, and reporting on findings. He will also provide input and documentation to inform

dissemination activities. Mr. Schooping will dedicate an average of 7% of his time to the project over three years.

Michael G. Thurston, Ph.D., Technical Director, leads the GIS research team in the areas of smart products and systems and life-cycle engineering. He will provide technical expertise and analysis review for the project. Dr. Thurston's will dedicate 1% of his time in the third year to project activities.

Consultants:
Dr. Philip Hopke, Professor in the Department of Public Health Sciences at the University of Rochester, has more than 40 years of experience in indoor air quality monitoring, and has both chaired and served as a participating member of professional committees including the National Research Council's, Board on Environmental Studies and Toxicology and the U.S. Environmental Protection Agency's Clean Air Scientific Advisory Committee. His responsibilities will include participation in site visits to two partner institutions to provide input on instrumentation locations and the development of protocols, and participation in data analysis, including chemometric modeling. He will also provide input as needed to inform dissemination activities. He is anticipated to spend about 76 hours of his time over three years.

Jean Tetreault, Senior Conservation Scientist, Canadian Conservation Institute, has 30 years of experience studying preventive conservation topics, including extensive experimental work on pollutant threshold limits for objects. He is lead author on pollutant guidelines for "Chapter 24: Museums, Galleries, Libraries and Archives" of the 2019 ASHRAE Application Handbook, and serves as a board member of the Indoor Air Pollution Working Group. He will serve in an advisory capacity for assessing the significance of any changes in pollutant levels for the collections, and development of the model. He is expected to spend approximately 30 hours of his time in the third year.

Partner Institution Staff:
In addition to the project team, upon reward of the grant, IPI will put out a call for applications for partner institutions. While various institutions have expressed interest in participating, it was determined that delaying selection until after the date of project award would be more desirable than selection at the present, given current circumstances surrounding COVID-19 that might exclude anyone due to difficulties in securing institutional commitment to projects at this time.

Three partner institutions will be selected from the applicants on the following basis: 1) the ability to provide access to a representative collections storage space with a dedicated mechanical system; 2) the ability to implement the energy-saving strategies, such as a Building Management System (BMS) for control and programming and a variable fan drive (VFD); and 3) a willingness and ability to participate in collaborative efforts, including a commitment of staff time and a record of effective communication. IPI is confident that these criteria can be met, but should applications be limited, IPI has a pool of partner institutions from previous energy-saving strategy implementation projects that can be utilized.

No funding is requested for staff effort or equipment for the partner institutions, and the project will be limited to storage spaces most suited to the project goals. Partner Institution Staff will be drawn from collection managers, conservators, conservation scientists, industrial hygienists, facility managers, and HVAC technicians. Each will bring the qualifications from their profession as well as a working knowledge of the history, needs, and performance of each institution's collection and facility. The duties and time commitment of the lead contact at each partner institution is expected to include participation in: onsite visits (2 days); logger placement, recording activities that could impact data (ex. filter changes), and data download (4 days); team meetings (8 days); and coordination of follow-up activities/implementation (4 days).

VII. EVALUATION AND SUSTAINABILITY

The project will be evaluated regularly through team meetings. On completion, the project's success will be first determined by the completeness of the stated work plan above and whether it reached its goal of accurately assessing the changes in pollutant levels during implementation of energy-saving strategies to reduce financial burdens on collecting institutions as well as their carbon footprints and impact on the Climate Crisis. However, the ultimate determinant of the project's success will be its acceptance by the field, through dissemination and the ongoing adoption and widespread use of the methodologies and tools. IPI has a strong track record of success in this regard, as demonstrated through post-project surveys, attendance at workshops and webinars, and use of products and services.

The project will be sustained into the future through publications, but also through regular sharing and application of the results. It is anticipated that, based on project results, the number of marker pollutants can be further reduced if similar patterns are observed across categories, and recommendations for more targeted, less expensive monitoring can be made to institutions. IPI will incorporate this knowledge into its own publications and sustainable preservation activities. The results will also be integrated into the content of the many educational events IPI participates in or hosts such as webinars, conferences, and workshops. IPI has a long history of perpetuating research nationally and internationally.

All data from continuous data monitors will be collected and stored in Comma Separated Values (CSV) files. The CSV format is an open standard maintained by the Internet Engineering Task Force (IETF) for use by anyone. Because it is an open standard, the data will be available for reading for many years after collection without relying on proprietary software. Data will be downloaded on a regular monthly basis from the electronic dataloggers to minimize loss risks and identify any unit issues in a timely manner. Auto-calibration checks will be performed monthly on the IAQ Guard, and ATI Porta-Sense devices will be sent in for recalibration at the end of one year of testing per manufacturer's instructions. This will be timed to occur between implementation of strategies so that each dataset is continuous during testing.

These files, along with any other generated documents (PDF or word processor documents, data spreadsheets, images, web files), will be uploaded by project team members to the IPI Dropbox account to allow for file sharing. In preparation for each quarterly team meeting, IPI will download all documents for storage on IPI's file storage cluster, which is maintained by the College of Art and Design's technology department. An automated process creates daily backups of all data, which is routinely verified. The collected data is protected by RIT access control standards, allowing only authorized users to read or modify it. The college has provisioned a large amount of space for file storage due to the file storage requirements of the College of Art and Design. There are no concerns about storage limits or data retention for this project.

Temperature and RH dataloggers, and one set of continuous pollution data monitors will be returned to IPI at the conclusion of the project, and will be utilized in future mechanical system optimization work (both federally-funded and otherwise).

CONCLUSION

This innovative project is expected to be "game-changing" for collecting institutions (through decreased financial burdens balanced with effective and safe preservation) as well as their local communities, the United States as a whole, and even globally (through decreased carbon footprint). This is the most advanced attempt to simultaneously manage storage environment energy expenditures for temperature and humidity control against the pernicious destructive forces that indoor and outdoor pollutants can inflict on our precious cultural heritage assets. The research project is strong in methodology, supported by expert collaborative partners and the field as a whole, and the dissemination program has been planned to ensure every institution will have ongoing access to these impactful new ideas.