NATIONAL ENDOWMENT FOR THE
Humanities

DIVISION OF PRESERVATION AND ACCESS

Narrative Section of a Successful Application

The attached document contains the grant narrative and selected portions 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 Preservation and Access Programs application guidelines at http://www.neh.gov/grants/guidelines/PARD.html for instructions. Applicants are also strongly encouraged to consult with the NEH Division of Preservation and Access Programs staff well before a grant deadline.

Note: The attachment only contains the grant narrative and selected portions, 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: Methodologies for Sustainable HVAC Operation in Collection Environments

Institution: Rochester Institute of Technology

Project Director: Jean-Louis Bigourdan

Grant Program: Preservation and Access Research and Development

SIGNIFICANCE

This project is a research and development effort to investigate the best methods to ensure that library, archives, and museum collections are not harmed by short-term environmental fluctuations made in the name of reducing energy costs and institutional carbon footprints. Like it or not, almost every institutional facilities manager is being asked or directed to bring down operating costs for heating, ventilating, and air conditioning (HVAC) systems. The spaces where collections of books, photographs, manuscripts, audio-visual materials and other artifacts that form the basis of humanities scholarship reside are often the most tempting targets of cost-cutting efforts, because they offer the greatest potential for savings. Fully temperature- and humidity-conditioned spaces consume, on average, about $4 worth of fuel energy per square foot per year. (The $4 figure is based on calculations performed by Peter Herzog, a nationally known energy efficiency expert who is a consultant to this project.)

Given the amount of partially or fully conditioned space in American institutions, the dollar amounts expended on fuel energy alone are enormous. It makes perfect sense for facilities managers to look for ways to reduce that fiscal burden and demonstrate progress toward institutional sustainability goals. A number of university campuses have announced ambitious targets of net "zero carbon" within a decade, so the pressure to operate energy-hungry HVAC systems in new ways is likely to grow in coming years from both the cost and climate neutrality points of view.

Redesigning buildings and installing more efficient systems is not practical in the near and medium term for most institutions. One immediately accessible approach to reducing energy use is to turn existing systems down or off during unoccupied hours at night and on weekends. Not only are collection storage spaces relatively large energy consumers, they tend to be unoccupied for a large portion of the week, typically 45% to 65% of the total time. Although institutional mechanical systems are much more complex than home furnaces—and there are many possible ways to address energy use reduction in big systems—the simple idea of lowering temperature settings (or raising them, in summer) or slowing fans, or even shutting parts of the system down at night and on weekends is direct and compelling to many facilities managers. To save energy with existing equipment, one must turn things down or off at some point. "Setbacks" are familiar to every homeowner who operates a furnace in a climate with a cold winter. Indeed, setbacks are already common practice for some libraries and archives.

The problem, and also the fact that forms the need for the proposed research, is that at present neither facilities managers nor collection care specialists know how to evaluate the impact of short-term, intentional fluctuations on the preservation of collections. Disturbances induced in the climate surrounding collections in the name of energy saving or sustainability might be harmful or beneficial—we don't know. How far can the envelope of "safe" conditions be pushed before real damage is done? What are the tradeoffs between risks to collections and achieving cost savings that save jobs and keep institutions fiscally sound and environmentally responsible? What methods should be used to assess risks, provide feedback to facilities managers, and document that stewardship of collections is not sacrificed?

For a number of reasons, a methodology to answer these questions does not already exist. Preservation research has long focused on defining the ideal environment for materials and collections, in the belief that institutions should provide the most benign conditions possible. The ideal articulated to generations of preservation professionals usually involved year-round constancy and tight tolerances for temperature and humidity. (Never mind that this ideal was seldom achieved in actual practice.) The prevailing view among collection care staff is that fluctuations are harmful and should be avoided. In the last few decades new research has been done by the Image Permanence Institute (IPI), the Canadian Conservation Institute, the Library of Congress (LOC), and the Smithsonian's Museum Conservation Institute that is transforming approaches to environmental management in preservation. Studies on the nature of deterioration processes have led to wider tolerances for humidity control and less emphasis on constant temperature. The field is in transition from static to dynamic approaches that depend on knowledge of the

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physics and chemistry of deterioration to assess risks that might arise from changes in temperature and relative humidity (RH) over time.

This transition, and the laboratory data that underpin management methods for dynamic conditions, are still incomplete. Very little research has been done on some of the most important questions that arise in judging the impact of short-term events such as night and weekend setbacks. These questions can be simply stated: When room conditions change, when do collections “feel” (experience in full) the change? How big a temperature change causes damage to typical humanities collection materials? How big a humidity change causes damage? When do seasonal differences matter in determining the safe limits for nightly or weekend setbacks?

To state these broad questions and to describe the need for a practical method to evaluate and manage them in real-life institutions is fairly simple, but the research to address them is not. The heart of this project is to take a few of the most important kinds of material configurations found in humanities collections and subject them to an extensive series of laboratory experiments to simulate what would happen when settings are adjusted for periods of a few hours up to two days. Sensors will track the temperature and moisture content inside the objects and provide a great deal of empirical data which will be of practical use. Not every possible scenario of fluctuations can be simulated, so another important part of the research is to construct mathematical models based on both theory and experiment to estimate what would be “felt” by the objects in any imaginable pattern of fluctuations in room conditions. Field experiments in a real library in which setbacks are occurring will produce data on what the collections are experiencing. This data will be compared to laboratory data and predictions from the models. Finally, IPI will publish a “field guide” explaining research results in plain language and giving, as far as possible, a usable method for monitoring room environments and estimating the impact of short-term fluctuations.

The impact of this research will potentially be felt by any institution that possesses materials similar to those studied in the project. They will be able to more confidently design and evaluate protocols for energy saving and sustainability improvements, balancing stewardship of collections with fiscal realities and global environmental responsibility.

BACKGROUND OF APPLICANT

IPI ORGANIZATIONAL PROFILE

IPI is a university-based, non-profit research laboratory founded in 1985 as a department of the College of Imaging Arts and Sciences at Rochester Institute of Technology, in Rochester, New York. Devoted to scientific research in preservation technology, IPI updated its mission statement in 2009 to guide current and future activities:

> The Image Permanence Institute will be a recognized world leader in the development and deployment of sustainable practices for the preservation of images and cultural property. IPI will do this through a balanced program of research, education, products, and services that meet the needs of individuals, companies, and institutions.

IPI’s original focus was the preservation of photography, microfilm, cinema, and other forms of recorded information. The laboratory remains the world leader in preservation technology for imaging media collections. In the last decade, IPI has broadened its research activities to include a wide range of materials found in cultural institutions, with a focus on the role of environment in preservation management.

IPI has been recognized with awards and honors including a Technical Achievement Award from the Academy of Motion Picture Arts and Sciences (1998), the Fuji Gold Medal from the Society of Motion Picture and Television engineers (1998), and the Preservation Publication Award from the Society of American Archivists (1999).

A more detailed organizational profile can be found in Appendix 1.

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IPI'S CONTRIBUTIONS TO PRESERVATION RESEARCH

IPI has conducted extensive research on the stability of information-recording media (e.g., paper, film, microfilm, magnetic tape, digital hard-copy); studied the effects of temperature, humidity, light, and pollutants on imaging materials; contributed to the development of ISO standards; disseminated research findings through publications, technical conferences, and seminars; developed A-D Strips, a diagnostic tool for assessing acetate-based collections materials; and conducted numerous surveys for large institutions. IPI is often sought out for its expertise in developing preservation strategies. During the past 15 years, IPI has focused on developing new approaches for optimizing storage environments for libraries, archives, and museum collections.

IPI's ability to address the practical needs that challenge collection managers, preservation administrators, and conservators is widely recognized in the field. Through its contributions to film preservation IPI has proven an ability to identify critical preservation issues, conduct extensive laboratory research, articulate important findings, and provide easy-to-use collection management tools that over time have become invaluable resources to the field of preservation. For archivists, A-D Strips are a quick and easy way to manage the preservation of film collections. The *IPI Storage Guide for Acetate Film*,[1] the *Storage Guide for Color Photographic Materials*,[2] and the *IPI Media Storage Quick Reference*[3] address the importance of proper storage for acetate-based materials, color dyes, and mixed collections, respectively. These publications were designed as instructional, plain-language, management tools, conveying essential information to those working in the field. The field guide planned for the proposed project, like its precursors, will communicate valuable research findings in a "ready-to-use" format.

IPI'S CONTRIBUTIONS TO STORAGE ENVIRONMENT EVALUATION AND MANAGEMENT

Since 1994, IPI's efforts have focused more and more on the creation of new preservation strategies for optimizing collection environments in libraries, archives, and museums. This concentration of effort is strongly supported by numerous studies concluding that proper environment is the single most important factor in preventing or delaying damage to collection materials due to the four most common categories of decay: natural aging, mechanical damage, biological decay, and metal corrosion. IPI's extensive laboratory research has demonstrated that the stability of information-recording media is strongly dependent upon temperature and humidity storage conditions, but it has also made clear that storage temperature and RH don't convey the whole picture. It is difficult to answer the question of how *good* or *bad* a given storage environment is by examining temperature and humidity records alone. To enable collection managers to not only monitor the climate conditions in their storage areas, but ultimately to quantify the decay in their collections, IPI developed four *preservation metrics*. These metrics are complex algorithms designed to transform measured temperature and RH data into quantitative measures of the collection decay risk, including natural aging or chemical change of organic objects, environmentally-induced dimensional change and mechanical damage, the potential for biological decay or mold risk, and moisture-induced corrosion. They are described in more detail in Appendix 2.

These preservation metrics are unique assets in the system IPI has developed for monitoring, analyzing, and optimizing storage environments. The system includes a new temperature and RH logger (PEM2®) designed for cultural institutions; computer software for temperature and RH data analysis (Climate Notebook®); and, most recently, a web-based application for viewing, storing, and analyzing environmental data (PEMdata.com). These tools have enabled IPI to develop new approaches and procedures that already have enhanced the way in which numerous institutions in the U.S. and abroad approach collection environment management. The preservation metrics have proved their value in

[1] J. M. Reilly, *IPI Storage Guide for Acetate Film*, Image Permanence Institute, Rochester Institute of Technology, Rochester, NY, 1993.
[2] J. M. Reilly, *Storage Guide for Color Photographic Materials*, University of the State of New York, New York State Library, Albany, NY, 1998.
[3] P. Z. Adelstein, *IPI Media Storage Quick Reference*, Image Permanence Institute, Rochester Institute of Technology, Rochester, NY, 2004.

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practice in such diverse institutions as the LOC, the Museum of Fine Arts, Boston, and the National Museum of Denmark, Copenhagen.

This project is part of IPI's broader investigation of sustainable HVAC operations. IPI has applied to the Institute of Museum and Library Services (IMLS) for funding support for research into institutional energy savings. These two projects are complementary but fundamentally distinct. The project proposed here is based primarily on laboratory experimentation and HVAC setting adjustments, while the IMLS project will be an on-site exploration of the effects of HVAC shutdowns.

IPI'S TECHNICAL INFRASTRUCTURE CAPABILITY

IPI has the necessary infrastructure and equipment to conduct the proposed research. The lab possesses a number of programmable temperature- and humidity-controlled chambers of various sizes that will be needed for simulating a wide range of environments. IPI's PEM2®, the new electronic temperature and humidity logger, will be used during the laboratory investigation and the field experiment. Each PEM2 used for this study will be calibrated at IPI using a five-point NIST-traceable calibration procedure. Laboratory testing will be done in the climate-controlled chambers currently available at IPI:

- A walk-in temperature- and-humidity controlled chamber capable of accommodating a large number of collection materials and large housings such as a metal flat-file cabinet. This chamber can provide consistent RH control from 10% to 80% at elevated and low temperatures down to 10°C (50°F). This equipment will be used to moisture-condition and test collection objects at various temperature and RH conditions.
- Two new programmable low-RH temperature- and humidity-controlled chambers able to maintain a range of RH set points between 15% and 80% at 10°C.

No major equipment costs will be included in the project proposal. Most of the research will be conducted with existing IPI equipment, as reflected in the budget.

HISTORY, SCOPE, AND DURATION

HISTORY

Earlier Research on Collection Environments

The proposed research is an outgrowth of IPI's current activities involving the optimization of storage environments and of previous IPI research projects dealing with the effect of changing temperature and RH conditions on library and archives materials. Recommendations for storage temperature and RH levels have been periodically re-examined following the latest advancements in preservation science. Two main approaches have been taken by researchers. The first approach has focused on defining a suitable temperature and humidity range for collection materials.[4,5,6,7] The second approach has been an attempt to revisit temperature and humidity flat-lines.[8,9] At the same time, the buffering role of microclimates has been given increasing attention. A number of initiatives began to investigate the relationship between

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[4] G. Thomson, *The Museum Environment*, 2nd ed., Butterworth-Heinemann, 1986.
[5] D. Erhardt and M. Mecklenburg, "Relative Humidity Re-Examined," (Paper delivered at Preventive Conservation Practice, Theory and Research, IIC Congress, Ottawa, September 1994), 32-37.
[6] S. Michalski, "Relative Humidity and Temperature Guidelines: What's Happening?," *CCI Newsletter*, No. 14 (1994): 6-8.
[7] M. H. McCormick-Goodhart, "The Allowable Temperature and Relative Humidity Range for the Safe Use and Storage of Photographic Materials,"*Journal of the Society of Archivists*, Vol. 17, No. 1 (1996), 7-21.
[8] D. Erhardt, M. F. Mecklenburg, C. S. Tumosa, and M. H. McCormick-Goodhart, "The Determination of Allowable RH Fluctuations," *WAAC Newsletter*, Vol. 17, No. 1 (1995), 19-23.
[9] Ch. S. Tumosa, M. F. Mecklenburg, D. Erhardt, and M. H. McCormick-Goodhart, "A Discussion of Research on the Effects of Temperature and Relative Humidity on Museum Objects," *WAAC Newsletter*, Vol. 18, No. 3 (1996), 19-20.

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macro- and microenvironments in a variety of situations.[10,11,12,13] In the 1990s, advanced studies in material behavior underscored the importance of the physical response of various organic collection materials to changes in temperature and RH and developed computerized modeling of stress for paintings and photographs.[14] Thermal and moisture equilibration rates for specific materials such as magnetic tapes, photographic film, photographic prints, and other collection materials have been evaluated to various degrees.[15,16,17]

These past studies underlined the importance of the dynamic relationship between the storage environment (the microenvironment) and the space in which a collection artifact is kept (the microenvironment). Relative to the proposed research, these earlier studies support the idea that as long as a collection object is not in equilibrium with ambient temperature and RH conditions, it is ultimately the object's microclimate that governs its stability. In other words, if the object is not thermally equilibrated, its temperature can be higher or lower than the current storage temperature; if the object has not reached full moisture equilibrium, its moisture content may be higher or lower that it would be when in equilibrium with the current room RH level. Such observations, made by evaluating thermal and moisture equilibration rates of various materials, lead us to assume that adverse storage temperatures and RH levels may not adversely affect a collection when these conditions are temporary. Thus, it is critically important to know how fast collections materials reach equilibrium with ambient conditions. In the context of developing new sustainable HVAC strategies, documenting the moisture-buffering and thermal-insulation capabilities of various storage housings and configurations is critically important. IPI has conducted two NEH-funded studies exploring these questions, one dealing primarily with the use of microclimates in preserving film materials, the other studying the effect of changing environments on library and archives materials. Findings from these studies relevant to this grant application are briefly discussed below. The proposed research is seen as a continuation of these earlier projects, but with the explicit goal of understanding short-term fluctuations.

Field experimentation has played a significant role in IPI research on collection environments over the past decade. From 1998 to 2001, IPI, the LOC, and the New York Public Library (NYPL) worked on *Optimization—Collection Life and Energy Costs*. Funded by the Mellon Foundation, the project involved measuring and evaluating HVAC systems, making improvements to the preservation quality of storage conditions, and identifying actions that could lower operating costs. LOC has contracted with IPI since 2001 to continue the project through a series of *Environmental Monitoring Initiative and Mitigation Planning* projects. NYPL received funding from NEH to continue similar work from 2007 to 2009.

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[10] S. Weintraub, *Report on the Environmental Performance of Solander Boxes*, unpublished report (October, 1987).
[11] N. Kamba, "Performance of Wooden Storage Cases in Regulation of Relative Humidity Change," (Paper delivered at Preventive Conservation Practice, Theory and Research, IIC Congress, Ottawa, September 1994), 181-184.
[12] K. Toishi and T. Gotoh, "A Note on the Movement of Moisture between the Components in a Sealed Package," Studies in Conservation, Vol. 33, No. 2 (1994), 265-271.
[13] A. E. Bülow, D. S. Watt, and B. J. Colston, "Microenvironments within Glass-fronted Book Cases: A Study Comparing Environmental Changes within Books and Interactions with Local Environments," *Paper Restaurierung*, Vol. 4, No. 3 (2003), 23-31.
[14] M. F. Mecklenburg, M. McCormick-Goodhart, and C. S. Tumosa, "Investigation into the Deterioration of Paintings and Photographs Using Computerized Modeling of Stress Development," *JAIC*, Vol. 33 (1994), 153-170.
[15] M. Vos, "Heat and Moisture Diffusion in Magnetic Tape Packs," *IEEE Transactions on Magnetics*, Vol. 30, No. 2 (1994), 237-242.
[16] J.-L. Bigourdan, P. Z. Adelstein, and J. M. Reilly, "Moisture and Temperature Equilibration: Behavior and Practical Significance in Photographic Film Preservation," *La Conservation: Une Science en Evolution Bilans et Perspectives*, *Actes des troisièmes journées internationales d'études de l'ARSAG,* Avril 1997, 154-164.
[17] J.-L. Bigourdan, J. M. Reilly, and K. A. Santoro, *Effects of Fluctuating Environments on Library and Archives Materials*, Final Report to National Endowment for the Humanities, Division of Preservation and Access, NEH Grant #PA-23159-98, February 15, 2003.

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Elements of the optimization approach include an understanding of the outdoor climate and the role that the building and its mechanical systems play in shaping the environment that collection experience. The optimization approach to analyzing mechanical systems involves the development of a holistic view of system capabilities and an orientation toward making existing systems function as well as they can.

IPI's Research in Photographic Film Microenvironments

From 1994 to 1996, IPI was engaged in research[18] that addressed the role of enclosures and the use of microenvironmental approaches to film preservation. The investigation evaluated the effectiveness of various housing situations and the efficiency of using adsorbents such as molecular sieves for controlling vinegar syndrome. The study concluded that control of the macroenvironment offers greater potential benefit for film stability than the microenvironments evaluated in the study.[19, 20] During this project, thermal equilibration and moisture conditioning rates were investigated in an effort to address practical considerations connected with the recommended use of low storage temperature.[21] In this context, data on the relationship between temperature, RH, and film moisture content were developed. This part of the research led to further investigation and helped in developing safe handling practices for film kept in cold storage.[22]

Film Temperature and Moisture Equilibration Rate

During the above research the behavior of film rolls exposed to temperature and RH changes was studied. Thermal equilibration was investigated by subjecting film (rolls and sheet film stacks) to a one-time temperature change. Film core temperature was monitor using thermocouples. The same basic approach was used to document the rate of moisture conditioning of film rolls. Results indicated that thermal equilibration was mostly controlled by the mass of film materials and that the type of enclosure (plastic, cardboard, or metal) had no measurable effect in altering the equilibration rate. The reverse situation was observed when considering the rate of moisture conditioning. Data for film indicated that enclosures, to various degrees, act as moisture barriers, contributing to the control of the moisture equilibration process. Results also indicated that the rate of thermal equilibration is much faster (just hours) than that of moisture equilibration (weeks or months). These preliminary experiments demonstrated that film artifacts, depending on their format, mass, and enclosure, will respond to temperature and humidity changes at various rates. The duration of the thermal or humidity modifications determines whether these objects "feel" the changes. For now, it can be said that the more slowly a material equilibrates, the less likely it will be that it will experience the effect of short-term environmental fluctuations.

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[18] J.-L. Bigourdan and J. M. Reilly, *Environment and Enclosures in Film Preservation*, Final Report to the Office of Preservation, National Endowment for the Humanities, Grant #PS 20802-94, September 15, 1997.

[19] J.-L. Bigourdan, P. Z. Adelstein, and J. M. Reilly, "Use of Microenvironments for the Preservation of Cellulose Triacetate Photographic Film," *Journal of Imaging Technology*, Vol. 42, No. 2, March/April 1998: 155-162.

[20] J.-L. Bigourdan and J. M. Reilly, "Effectiveness of Storage Conditions in Controlling the Vinegar Syndrome: Preservation Strategies for Acetate Base Motion-Picture Film Collections," JTS, Image and Sound Archiving and Access: the Challenges of the 3rd Millennium, January 20-22, 2000. Paris, CNC May 2000: 14-34.

[21] P. Z. Adelstein, J.-L. Bigourdan, and J. M. Reilly, "Moisture Relationships of Photographic Film," *J. of American Institute for Conservation*, Vol. 36 (1997), 193-206.

[22] J.-L. Bigourdan, P. Z. Adelstein, and J. M. Reilly, "Moisture and Temperature Equilibration: Behavior and Practical Significance in Photographic Film Preservation," *La Conservation: Une Science en Evolution Bilans et Perspectives, Actes des troisièmes journées internationales d'études de l'ARSAG*, Paris 21-25 avril 1997, 154-164.

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Effect of Temperature and RH Cycling on Microenvironments

IPI conducted an investigation of the effect of temperature and humidity cycling on the microclimate within an enclosure containing paper materials. In this investigation, a drop-front cardboard box containing a stack of cardboard mat boards was pre-conditioned to room conditions and then exposed to daily temperature cycling (between 15°C and 25°C) while the ambient RH was maintained at 50%. A temperature and RH logger was used to monitor the microenvironment inside the box, and a second logger was embedded at the core of the stack of cardboard mats. Figure 1 illustrates the impact of temperature cycling on the microenvironment. Thermal equilibration was reached rapidly. Temperature cycling, however, caused unexpected RH changes both inside the box and within the cardboard stack. Increased temperature caused an increase in RH, rather than the reverse, which would be expected in the microenvironment. This indicates that an increase in temperature "forced" the hygroscopic cardboard mats to release a small quantity of moisture, which led to an RH increase in the enclosure. The opposite behavior is observed in the subsequent portion of the cycle when the temperature is lowered. Also of interest are the observations that little happened in the middle of the stack and that after about 12 hours both the materials and the microenvironment were in equilibrium.

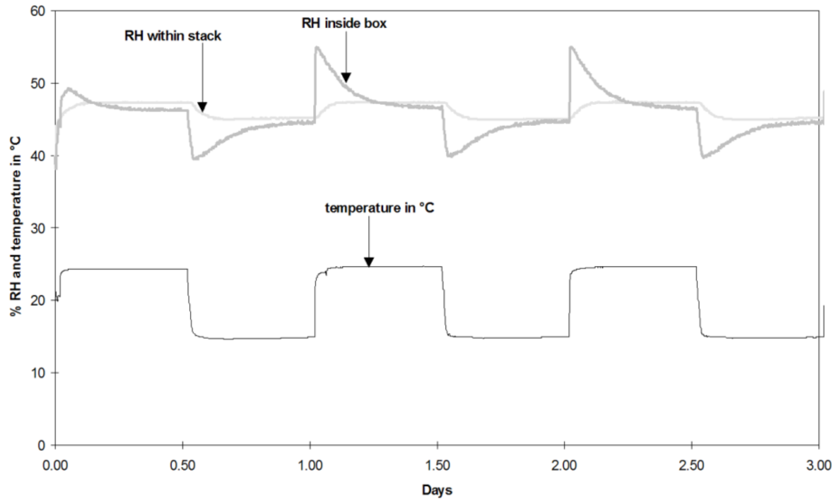

Figure 1. Impact of daily temperature cycling on the microenvironment inside a cardboard box containing matboard mounts.

The objective of the proposed project is to expand on this type of experimentation and to study a larger body of collection materials and real-life situations. It is believed that the thermal mass of large collections, as well as their arrangement and the types housing used, may considerably alter the way collection items feel short-term temperature adjustments of various magnitude and duration.

Seasonal Humidity Drift

Seasonal humidity drifts can significantly affect storage conditions. Environment evaluations done across the U.S. indicated that seasonal change in collection environments is common. Although the study of the effect of short-term RH changes for a book on a library shelf indicated that the RH measured at the core of the book remained steady despite ambient RH cycling (see Figure 2), the book is affected by gradual seasonal RH change, as shown in Figure 3. The data in Figure 3 were collected by inserting an RH sensor

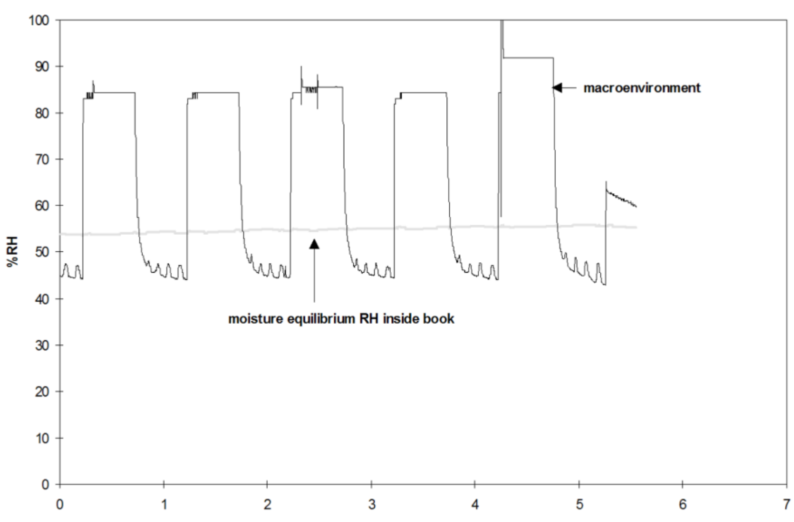

Figure 2. Effect of daily 60%±20% RH cycling on the core of a book at 21°C.

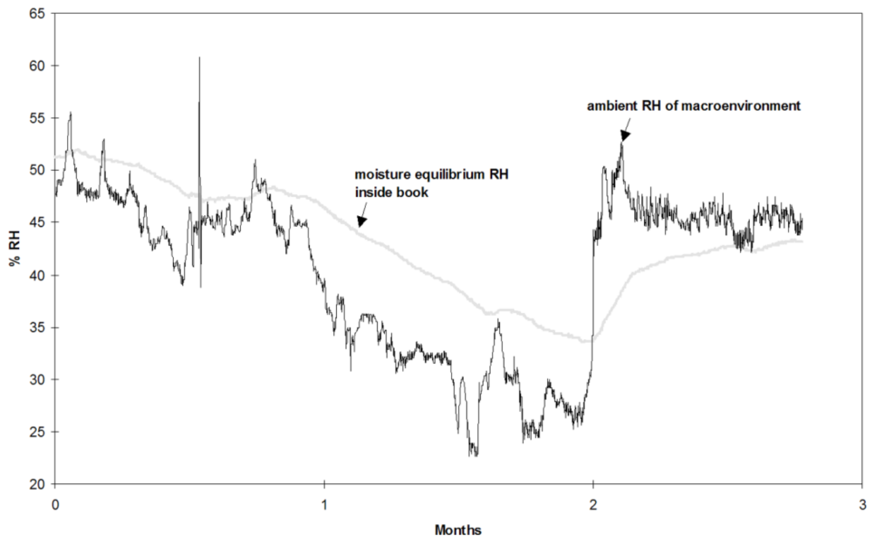

Figure 3. RH inside and outside a book during a three-month period at room conditions (IPI library).

inside the book and by monitoring the ambient RH in the library. The slow moisture diffusion rate causes conditions at the center of the book to lag behind the conditions outside the book, but eventually equilibrium is reached. It all depends on how sustained the seasonal changes are. Ultimately seasonal changes may have the greatest impact on collection stability. The effect of RH changes on the microclimates inside housings and at the core of collection materials is mostly dependent upon the humidity profile over time and the characteristic of the collections. One objective of the proposed study is to develop empirical data that will enable the modeling of the behavior of common library and archives materials.

IPI's Research on the Effect of Fluctuating Environments on Library and Archives Materials
From 1998 to 2000 IPI conducted an NEH- and IMLS-funded research project[23] that explored the effect of changing temperature and RH levels on library and archives materials. The study quantified the responses of motion-picture films, still roll films, sheet films, microfilms, magnetic tapes, books, and paper in various housings when exposed to humidity changes at different temperatures. The research data shed new light on the dynamic interaction between objects and their environment. The project provided unique data on the effect of cycling temperature and RH on the stability of paper and triacetate film base.

Effect of Temperature and RH Cycling on Natural Aging
One important aspect of this study was to investigate the possibility that the temperature and humidity transitions in cycling environments cause extra decay in paper and film supports. Within the framework of this study, the rates of decay observed under cycling RH and cycling temperature offered no evidence that transition from one RH to another or from one temperature to another causes a new mechanism of deterioration or accelerates degradation more than would be expected by current thermodynamic models.

Results obtained for various paper materials[24] and acetate film[25] validated IPI's preservation metric for evaluating the risk for natural aging and confirmed the value of TWPI in informing storage decisions that do not neglect unexpected chemical degradation caused by temperature and RH transitions. The proposed research will introduce *both temperature and RH changes in the collection environments*; this is a critically important difference from IPI's earlier research.

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[23] J.-L. Bigourdan, J. M. Reilly, and K. A. Santoro, *Effects of Fluctuating Environments on Library and Archives Materials*, Final Report to National Endowment for the Humanities, Division of Preservation and Access, NEH Grant #PA-23159-98, February 15, 2003.
[24] J.-L. Bigourdan and J. M. Reilly, "Effects of Fluctuating Environments on Paper Materials—Stability and Practical Significance for Preservation," *Preservation in the Digital Age, 4th ARSAG International Symposium*, Paris, May 27-30 2002: 180-192.
[25] J.-L. Bigourdan, "Film Storage Studies—Recent Findings," *Preserve—Then Show, 60th Anniversary Seminar of Danish Film Institute/Film Archive*, Copenhagen, Denmark, November 11-13, 2001: 40-51.

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Rate of Moisture Conditioning for a Variety of Materials and Enclosures
This research focused on determining the rate of moisture equilibration for film, photographs, paper, books, and magnetic tape in a variety of formats and housing situations. Table I in Appendix 3 lists the wide range of materials studied in this project and shows a wide range of observed material behavior. Table II in Appendix 3 is a summary of the results; the response of the materials to a one-time humidity change are categorized as "fast," "medium," or "slow," based on the time needed to achieve 50% equilibration.[26] The rate of moisture equilibration being relatively slow, it was expected that short-term RH transitions would generally have a limited effect, while seasonal transitions over several months would be felt by the collection materials. Also, this study investigated the effect of temperature on the rate of moisture equilibration. Very little data has been developed on thermal equilibration in real-life situations. This earlier work provides a solid knowledge base from which IPI can move forward with the research proposed here.

SCOPE
This project is national in scope and impact; results will be applicable in any region, in any type of institution, and to any type of HVAC system. The information gained from the laboratory study and field experiment will increase our understanding of the behavior of typical library and archives materials.

While museums hold important humanities collections, museum objects will not be included in this study. This research will focus on paper-based materials, because they comprise the largest portion of humanities collections.

Knowing to what extent short-term temperature transitions are felt by materials in real-life storage situations will benefit libraries and archives both with and without HVAC systems. They will gain knowledge that will inform their future storage decisions and encourage them to consider more sustainable preservation strategies, and they will better understand the moisture-buffering and thermal-insulation properties of different housings and storage arrangements and be able to choose the most beneficial housing system for their collections. Institutions without HVAC systems will be better informed prior to investing in such equipment.

The laboratory research and field experiment will provide guidance to librarians, archivists, and HVAC operations managers in implementing intentional short-term temperature and/or RH setbacks during unoccupied hours and evaluating the possibility of applying seasonal HVAC settings.

Through computer modeling, the research will re-evaluate current methods of assessing the impact of changing environments on collection materials and will develop new algorithms that will reflect real-life storage situations. It is believed that these mathematically tested models will help to predict how beneficial or detrimental to the stability of the materials given temperature and RH profiles may be. Such models will have practical value in helping institutions identify opportunities for developing a more sustainable storage management approach.

Research findings and methodology will be made available online. A print publication will be created in the form of a field guide or handbook that will describe a step-by-step practical approach to reduction of energy consumption through the implementation of nightly, weekend, or seasonal HVAC setting changes.

The impact of the research will be lasting and will not be limited by the present fiscal crisis. This research, if successful, has the potential to reduce the financial stress on libraries and archives, large or small, and to provide new opportunities to strengthen humanities studies.

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[26]J.-L. Bigourdan, J. M. Reilly, and K. A. Santoro, *Effects of Fluctuating Environments on Library and Archives Materials*, Final Report to National Endowment for the Humanities, Division of Preservation and Access, NEH Grant #PA-23159-98, February 15, 2003.

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Duration

The duration of this research will be three years. Project activities will be divided into four groups: (1) laboratory research, (2) a field experiment, (3) data analysis and modeling, and (4) creation of a plain-language publication. A detailed schedule for completion and description of the project's activities are included in the work plan.

METHODOLOGY AND STANDARDS

IPI will design and conduct the laboratory test program using experimental protocols developed in earlier IPI research. The experimental program described in the work plan will be implemented according to the timetable in Appendix 4. IPI will follow standard calibration procedures for all needed equipment. Temperature- and humidity-controlled chambers will be calibrated using a NIST-certified Vaisala HMI41 indicator and HMP46 probe. Temperature and humidity values will be monitored using two high-precision loggers: IPI's PEM2 and the Spectrum logger (SP-2000-20R) from Veriteq.

The PEM2 is calibrated using a 5-point calibration profile that takes the monitor from 20% to 80% RH. A scheme of rising and falling RH levels (20% to 50% to 80% to 50% to 30% to 50% to 70%) allows observation of hysteresis characteristics of each humidity sensor. The calibration chamber is the Thunder Scientific 2500 Two-Pressure Humidity Generator. This apparatus produces known humidity values using the principle of the "two-pressure" generator developed by the National Institute of Standards and Technology (NIST). This system is capable of continuously supplying accurately known humidity values for instrument calibration. The device itself is sent to the Thunder Scientific facility to be calibrated in compliance with ISO/IEC 17025. IPI works hard to insure that each PEM2 is as accurate as possible. The PEM2's stated humidity accuracy is ± 2% RH, but no PEM2 leaves IPI unless it reaches ± 1% calibration values.

Veriteq's SP-2000-20R Precision Temperature and Relative Humidity data logger has stated humidity accuracy to ± 2% RH, and to ± 0.15°C. It has three-point humidity calibration: 11% RH, 45% RH, and 80% RH.

Project Partners and Advisors

IPI will conduct the field study in partnership with RIT Libraries. The project will benefit from the involvement of Chandra McKenzie, Assistant Provost and Director, RIT Libraries, and Witold Bujak, Sustainability Manager, RIT Facilities Management Services. Ms. McKenzie will provide guidance from the standpoint of her responsibility toward the preservation of humanities collections. Mr. Bujak will be instrumental in investigating the intricacy of sustainable HVAC operation management and implementing the field study.

Peter Herzog of Herzog/Wheeler & Associates will consult on the project from the point of view of an energy savings expert. His expertise in energy management process design, technical analysis of energy-consuming processes and systems, and energy conservation planning will be extremely valuable (see Herzog/Wheeler & Associates organizational profile, Appendix 5).

In a project that seeks to develop new methodologies or best practices, it is important to consult with professionals with expertise on the subject. Because this project deals with environmental conditions for library and archives collections, mechanisms of deterioration of collection materials, and methodologies for responsible HVAC operations management, it should have input from scientists, collections administrators, preservation specialists, and HVAC systems specialists. Accordingly, an advisory committee has been formed for this project. Together with IPI staff, RIT Libraries, and Peter Herzog, the advisory committee will bring needed perspectives to the project. Committee members will be unpaid and will not meet face to face, but they will receive copies of all reports to NEH and will consult with the project coordinator by e-mail and telephone. The advisory committee will receive a draft of the project's publications: the *IPI Field Guide: Methodologies for Sustainable HVAC Operation in Collection Environments*, to be developed in the third year of the project, and technical papers to be written on the project's completion. Letters of commitment are attached in Appendix 6.

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Members of the advisory committee are:

Paula De Stefano
Barbara Goldsmith Curator for Preservation
New York University
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Collections and Research Services
70 Washington Square South
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Dr. Eric F. Hansen, Ph. D.
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The Library of Congress
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Shannon Zachary
Head, Preservation and Conservation
University Library
The University of Michigan
3202 Buhr Building, 837 Greene St.
Ann Arbor, Michigan 48104

The role of the advisory committee will be to provide guidance during the research, to review and critique the publication during its development, and to provide insights into the practicality, benefits, and drawbacks of new recommended practices.

WORK PLAN

Project activities will be divided into four groups. The first group will focus on laboratory research and will produce data on the rate at which temperature and RH changes propagate into the microenvironments and into the core of typical library and archives materials. The second group will be a field investigation carried out in partnership with the RIT Libraries and will involve the implementation of short-term changes to HVAC settings during unoccupied hours, for the purpose of studying the rate at which temperature and RH changes propagate through the collections. The third group will focus on data analysis and modeling for the purpose of developing and testing mathematical models that will then be integrated into a methodology for implementing sustainable HVAC operations. The fourth group will focus on the dissemination of project findings through a field guide for librarians, archivists, and HVAC administrators. The four groups of activities will take three years, as shown in the timetable.

ACTIVITY GROUP I: LABORATORY RESEARCH

The goal of the laboratory experiments is to study the behavior of typical material configurations when subjected to both short-term and sustained temperature and/or humidity changes. Typical real-life housing situations will be simulated and effects will be monitored at the surface and at the core of the materials using electronic temperature sensors.

Phase A ─ Preparation (3 months)
The first three months of the project will be devoted to preparation for the laboratory testing program and the field experiment. These activities are related and will be carried out during the same period. Phase A will involve final design of the experimental program, purchase of necessary materials and housings, purchase of electronic temperature and humidity sensors, assembly of test samples, and calibration of the temperature and humidity chambers.

Phase B─ Effect of Short-Term Temperature Setbacks at Constant Dew Point (9 Months)
Purpose
To determine the impact of short-term temperature changes without RH control on selected materials in various housings.

Introduction
It is important to determine the impact of any intentional short-term HVAC temperature changes at the surface and the core of collection materials before such changes are implemented. The experiment will

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provide information on the rate of thermal equilibration of the materials and will determine to what extent temperature changes of 6 to 60 hours will be felt by the objects. Results of laboratory tests will be augmented by those of the field investigation. Phase B will investigate the effect at constant dew point, i.e., at constant absolute humidity. This experiment simulates a situation in which the thermostat setting is altered and no moisture is added to or removed from the air. Assuming that the storage area is a closed space, the ambient RH will be determined partly by the temperature adjustment and partly by the behavior of the hygroscopic materials present in the space. While lowering temperature induces higher humidity levels, significant quantities of hygroscopic materials (e.g., books on shelves) may buffer some of these humidity changes. Such interactions are at the core of this research. Results from these experiments will inform us regarding the dynamic relationship existing between the microenvironment, the microenvironment surrounding the objects, and the objects themselves.

Materials
For this research, IPI will focus on typical paper-based library and archives materials stored in several types of housing. The following eight configurations will be included in the research:

- Books on a shelf
- Manuscripts in an archival document box
- Maps in a metal flat-file cabinet
- Prints and photographs in an archival drop-front box
- Prints and photographs in a museum case
- Mounted prints and photographs in an archival drop-front box
- Mounted prints and photographs in a museum case
- Paper stacks in an office file cabinet

Experimental
The configurations listed above will be assembled and equipped with electronic temperature and RH sensors. One data logger will be embedded in the center of the test material (e.g., a hard-cover book, a stack of paper, a stack of mounted prints). A second will be placed close to the outer surface of the object inside its enclosure (e.g., box, museum case, flat-file cabinet). Each logger will be equipped with an extension cable so that data can be downloaded without having to open the enclosure or disturb the object.

Once supplies for all configurations are acquired, they will be moisture-conditioned to initial RH levels in a room-size temperature- and humidity-controlled chamber. After all materials reach moisture equilibrium, the eight configurations will be assembled in the same chamber.

A number of different possible storage situations will be studied in Phase B; they will include a variety of initial temperature and RH levels, temperature setbacks of different magnitudes, and temperature setbacks of different durations.

The test samples will be moisture-conditioned at 20°C to 60%, 50%, 40%, and 30% RH, to correspond to a series of real-life environments and levels of material moisture content. Once moisture equilibration has been reached for each RH level, the temperature of the chamber will be set back to the temperatures shown in Table I. At this point, the RH level in the chamber will be set to maintain the same dew point throughout the test.

Table I: Test conditions for Phase B.

Initial Temp.	**20°C**			
Initial RH	**60%**	**50%**	**40%**	**30%**
Dew Point	**12**	**9**	**6**	**2**
Test temperature(in °C)	18	18	18	18
	16	16	16	16
	—	14	14	14
	—	—	12	12
	—	—	—	10

To study the effects of temperature setbacks during an institution's unoccupied hours, IPI will test setbacks for periods of 6, 12, and 60 hours. Phase B will implement actual weekly HVAC profiles (for example, six-hour nightly setbacks and 60-hour weekend setbacks).

Property Measurement
Temperature and RH data collected by electronic data loggers in the chamber, in the various enclosures, and in the center of the materials will be analyzed. Each test condition will provide a series of temperature and RH data sets that will show the behavior of the materials studied.

Equipment and Supplies
A temperature- and RH-controlled chamber large enough to accommodate test materials stored in a flat-file cabinet and a filing cabinet is required for initial conditioning and testing. IPI has such equipment, and it will be used for this part of the project.

A total of twenty temperature and RH loggers will be used for this phase of the project. Thirteen PEM2 loggers will be used to monitor the room's macroclimate and twelve microclimates. A small logger is needed to monitor conditions in the tight space at the center of a test material; therefore, seven new Spectrum loggers will be purchased.

Duration
Depending upon the progress of the research, Phase B might include 42 relatively short experiments and a small series of four-week experiments to investigate the effect of repeated temperature and RH cycling. The final experimental program will be adapted based upon initial findings. The expected duration for Phase B is nine months.

Phase C─ Effect of Short-Term Temperature Setbacks at Constant RH (6 Months)
Purpose
To determine the impact of short-term temperature changes at constant RH on selected materials in various housings.

Introduction
The effect of short-term temperature reductions with RH maintained at the initial value will be studied in this phase. This scenario will simulate turning down the thermostat while dehumidification/humidification systems maintain a steady RH level. Lowering the temperature will demand more dehumidification of the space. In this scenario, as long as the HVAC system is able to cope with the increase in RH, high RH levels should not occur. Phase C will provide information on the effects of short-term temperature changes on microclimates and on the moisture content of materials.

Materials
For this part of the research, IPI will study six material configurations. The large configurations (flat-file cabinet and filing cabinet) will not be included for practical reasons. It is believed that this will not reduce the significance of the work. The six material/enclosure combinations are listed below:

- Books on a shelf
- Manuscripts in an archival document box
- Prints and photographs in an archival drop-front box
- Prints and photographs in a museum case
- Mounted prints and photographs in an archival drop-front box
- Mounted prints and photographs in a museum case

Experimental
The six configurations listed above will be assembled and equipped with electronic temperature and RH sensors as described for Phase B. One data logger will be embedded in the center of the materials (e.g., hard-cover book, stack of paper, stack of mounted prints) and a second will be placed close to the outer surface of the object inside its enclosure (e.g., box, museum case). As in Phase B, each logger will be

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equipped with an extension cable for data download.

All six configurations will be moisture-conditioned at 20°C to 60%, 50%, 40%, and 30% RH in a temperature- and humidity-controlled chamber. Once all materials have reached moisture equilibrium, the configurations will be exposed to a series of short-term temperature changes while the RH is maintained at the initial level.

In this phase a series of initial temperature and RH conditions will be used and temperatures will be reduced from 20°C through a range of temperatures down to 10°C (see Table II).

Table II: Test conditions for Phase C.

Initial Temp.	**20°C**			
RH	**60%**	**50%**	**40%**	**30%**
Test temperature(in °C)	18	18	18	18
	16	16	16	16
	—	14	14	14
	—	—	12	12
	—	—	—	10

To study the effects of temperature setbacks at constant RH during an institution's unoccupied hours, IPI will test setbacks for periods of 6, 12, and 60 hours.

Property Measurement
Temperature and RH data collected by electronic data loggers in the chamber, in the various enclosures, and in the center of the materials will be analyzed. Each test condition will provide a series of temperature and RH data sets that will inform the behavior of the materials studied.

Equipment and Supplies
Two temperature- and humidity-controlled chambers capable of maintaining low RH are required for conditioning and testing. IPI has two such chambers that will be used for this phase. The materials, enclosures, and loggers purchased for Phase B will be used for Phase C.

Duration
As in Phase B, preliminary planning for Phase C includes a number of tests. Because Phase C will require shorter pre-test conditioning time, this phase will not take longer than six months.

Phase D ─ Study of the Effect of Seasonal RH Settings (15 Months)
Purpose
To investigate the impact of seasonal RH settings on microclimates and material moisture content.

Introduction
Extensive monitoring of temperature and RH conditions in storage spaces around the U.S. indicates that outdoor conditions strongly influence the quality of storage as well as the associated costs. Although different local climates pose different challenges for institutions trying to maintain proper temperature and RH levels throughout the seasons, in general, summers are hot and humid, and winters are cold and dry. Seasonal cycles will affect the collection environment to various degrees, depending on the properties of the building envelope, the amount of fresh air introduced into the storage area, and the capacity and condition of the HVAC system. These cycles are commonly characterized by high humidity during the summer and low humidity during the winter. Many HVAC systems are taxed by seasonal high or low RH; if the system can deal with these swings, it is at a significant energy cost. What if collection materials do not, in fact, feel these observed humidity changes, or feel them only slightly? The goal of Phase D is to scientifically document the impact of higher RH settings on library and archives materials and their microclimates over a period of months.

Materials
This part of the research will include the same eight material/housing configurations studied in Phase B:

- Books on a shelf
- Manuscripts in an archival document box
- Maps in a metal flat-file cabinet
- Prints and photographs in an archival drop-front box
- Prints and photographs in a museum case
- Mounted prints and photographs in an archival drop-front box
- Mounted prints and photographs in a museum case
- Paper stacks in an office file cabinet

Experimental
Materials and housings will be moisture-conditioned at 20°C, 50% RH in a temperature- and RH-controlled chamber. After full moisture equilibration, the eight configurations will be assembled and equipped with electronic loggers. The test samples will then be exposed to a one-time RH change at 20°C for a period of three months. The experiments in this phase will investigate the rate of moisture equilibration at 20°C from 50% RH to a series of higher and lower RH levels. Table III shows the RH settings chosen. The objective is to document to what extent the rate of moisture equilibration of common material/housing combinations can intrinsically postpone the impact of low or high storage RH levels.

Table III: RH test conditions for Phase D. Test will be conducted at 20°C.

Initial RH	50%			
Higher RH settings	60%	70%	80%	–
Lower RH settings	40%	30%	20%	15%

Property Measurement
Temperature and humidity loggers placed in the chamber and inside the test samples will monitor the moisture equilibration process. Temperature and RH data sets from this phase will describe the buffering behavior of the test samples, an this hard data will enable the creation of moisture equilibration models.

Equipment and supplies
The same equipment and supplies used in Phase B will be used in Phase D. These include a room-size climate-controlled chamber, materials and supplies for the eight test samples, thirteen PEM2 loggers, and seven Spectrum loggers. The climate chamber is part of IPI's existing equipment. The twenty temperature and humidity loggers are included in the budget. Two additional low humidity climate-controlled chambers, also available at IPI, will be used to study smaller test samples.

Duration
The design of Phase D includes seven RH test conditions. Each RH setting will be maintained for a period of three months. Because of time constraints and dimensional limitations, the behavior of large configurations (i.e., maps in a metal flat-file cabinet, and paper stacks in an office file cabinet will not be studied for 60%, 40%, and 15% RH settings. Phase D testing is expected to take 12 months. Additional time will be needed for preparation and moisture conditioning prior to testing. The total duration of Phase D will be 15 months. The work will be started before the completion of Phase C.

ACTIVITY GROUP II: FIELD EXPERIMENT
IPI will partner with RIT Libraries to conduct a field study to investigate the impact of short-term HVAC setting changes. This will provide a unique way to evaluate how rapidly temperature and humidity changes will propagate throughout collections and determine the extent to which short-term adjustments are felt by collection materials. This investigation will focus first on determining the effect of incremental overnight and weekend temperature setbacks on a series of microclimates in the libraries. These real-life experiments will be conducted during both seasonal transition periods. The second part of the field study will be a one-year evaluation of the long-term impact of a predetermined dynamic profile for HVAC settings on collection stability. IPI preservation metrics will be used to conduct a thorough risk assessment of the library collections.

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The field experiment will be conducted by IPI in partnership with Chandra McKenzie, Assistant Provost and Director, RIT, and Witold Bujak, Sustainability Manager, Facilities Management Services, RIT. This partnership presents a unique research opportunity, combining the perspectives of a libraries director, a facilities and sustainability manager, and preservation scientists. The field research will also involve Peter Herzog, whose background is in HVAC systems analysis and performance verification.

Phase A ─ Preparation (3 Months)
IPI will work with RIT Libraries to:

- Form a work team
- Document the nature and size of the collections
- Document and specifically describe all storage spaces
- Document the HVAC systems in place
- Gather and analyze recent environmental data from the selected storage sites
- Document the occupancy schedule for the selected storage sites

IPI will assemble a series of test samples that will be shelved throughout the collections. These samples will be equipped with temperature and RH loggers to monitor the microclimates surrounding the test samples and the moisture content in the center of the samples. This approach will be identical to the methodology used during the laboratory research. The six following material/housing combinations will be included in the field experiment:

- Books on a shelf
- Manuscripts in an archival document box
- Prints and photographs in an archival drop-front box
- Prints and photographs in a museum case
- Mounted prints and photographs in an archival drop-front box
- Mounted prints and photographs in a museum case

IPI will prepare two identical sets of test configurations.

Based on the information gathered in the first step, IPI and the RIT Libraries will develop the final experimental program. A precise time table will be developed for implementing short-term temperature changes. Incremental temperature setbacks will be planned for nights and weekends. Documentation and the experimental program will be reviewed by Peter Herzog prior to implementation.

Phase B─ Evaluation of Short-Term HVAC Temperature Setbacks (6 Months)
Purpose
To investigate the impact of short-term overnight and weekend temperature setbacks on library and archives collections.

Introduction
The impact of short-term temperature changes on collections will depend on how fast thermal and moisture transfer propagate through the collection materials. Phase B will provide scientific data on the real impact of repeated temperature changes over time. Temperature change will also induce moisture transfer, which will be evaluated. Field experiment results will complement laboratory results, but, most importantly, they will also provide an evaluation of the impact the thermal mass of a large collection of materials. In that sense, the value of the field research goes beyond what can be achieved by studying the behavior of a single object in a climate chamber or the evaluation of an empty space. It will be a unique opportunity to explore the dynamic relationship between the HVAC system, the storage microenvironment, a series of microenvironments, and the moisture content of collection materials.

Experimental
RIT Libraries microenvironments, certain microenvironments in the library storage areas, and a series of shelved test samples will be monitored and the data will be analyzed.

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The RIT Libraries building is home to the Wallace Library, the Cary Graphic Arts Collection, and the RIT Archives. This part of the research will be conducted in the Wallace Library, where the collections are stored on four floors with public access. Temperature and RH conditions will be monitored at four points on each floor, for a total of 16 monitoring points.

A series of microenvironments identified in Phase A will be monitored in the library. Configurations comparable to those studied in the laboratory will be sought (e.g., maps in a flat-file cabinet, prints and photographs in various housings). New configurations will also be identified and monitored.

Two identical sets of the six material/housing combinations prepared in Phase A will be deployed throughout the collections. These configurations will be monitored for the rates of temperature and humidity equilibration within enclosures and at the core of the materials.

Test Conditions
The development of the final test program will be based on the information gathered in Phase A. The changes in temperature settings will be determined after a thorough examination of the HVAC systems in place. The goal of the study is to implement incremental temperature setbacks during unoccupied hours. An example of a testing sequence that will be studied is reported in Table IV. Over the course of the project, a series of temperature setting profiles will be studied. Profiles will be repeated, as shown in the table. The magnitude of the temperature changes will be determined based on the simultaneous monitoring and analysis of temperature and RH data.

Table IV: Example of HVAC temperature setback testing.

	Temperature	% RH	HVAC Settings
Week 1	20°C	50	Normal HVAC settings
Week 2	20°C	50	
Week 3	18°C	50	2°C setback overnight 2°C setbacks during the weekend
Week 4	18°C	50	
Week 5	20°C	50	Normal HVAC settings
Week 6	20°C	50	
Week 7	16°C	50	4°C setback overnight 4°C setbacks during the weekend
Week 8	16°C	50	

Property Measurement
Forty monitoring points will be set up on the four library floors. Temperature and RH data will be monitored using PEM2 and Spectrum loggers placed in the storage areas, in selected microclimates, and in the center of the test samples. This monitoring project will generate a large number of data files, which will be compared and analyzed using PEMdata, IPI's web-based application (www. pemdata.org). PEMdata will make it possible to store all temperature and RH data sets on a secure server.

Duration
Phase B is expected to take six months. Data gathered during this phase will be used in the design of the one-year field experiment.

Phase C─ One-Year Field Experiment (12 Months) Following 3 Months Initial Preparation
Purpose
To evaluate the impact of a dynamic approach to HVAC operations management on collection stability.

Introduction
This phase will offer a unique opportunity to quantify the effect of sustainable HVAC operations on collection stability. During the year a dynamic approach to HVAC system management will be implemented. The modalities of that approach will be based on the research results developed in the previous phases of the project. These findings will determine how much room there really is for adjustments to the HVAC settings, based on *to what extent* and *when* collection materials experience significant temperature and/or moisture-content changes. The experiment will be an opportunity to create an HVAC management profile geared toward energy savings. The profile will be determined with simple

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principles in mind: i.e., less heating when it is cold outside, less cooling when it is hot outside, less added moisture when it is dry outside, and less moisture removal when it is humid outside. Optimizing the need for heating, cooling, humidification and dehumidification without compromising collection stability represents the main objective of the research.

Experimental
Based on the results of the previous phases, short-term changes to HVAC settings will be applied during unoccupied hours, and seasonal HVAC settings may be applied over the course of one year. IPI, Chandra McKenzie, Witold Bujak, and Peter Herzog will agree on the methodology and HVAC management program to be tested for the year. IPI and facilities management will share responsibility for implementing the management plan. IPI will be responsible for the placement of the loggers and test samples, collecting the temperature and RH data, and data analysis. Because this is applied research, new circumstances and unexpected events may call for adaptations to the initial plan.

Property Measurement and Analysis
Forty monitoring points will be set up throughout the four library floors. Temperature and RH data will be monitored using PEM2 and Spectrum loggers placed in the storage areas, in selected microclimates, and in the center of the test samples. The impact of this approach will be quantified using PEMdata. The data sets will also be used to test the mathematic models to be developed during the data analysis and modeling stage of the research.

Duration
The testing in Phase C will take 12 months. This will not include preparation and the development of the initial HVAC management profile, which will take an estimated three months.

ACTIVITY GROUP III: DATA ANALYSIS AND MODELING
The laboratory research and field experiment will provide a wealth of basic scientific knowledge regarding the behavior of selected collection materials and circumstances. Each temperature and RH data set will provide significant information for individual materials and housing situations. An effort will be made to present the information in the most comprehensive and conclusive way for librarians, archivists, and HVAC administrators. Another goal is to develop a suite of mathematically tested models. The value of models that describe temperature and moisture equilibration to environmental changes is that many scenarios can be mathematically tested rather than actually implemented. Such models will make it possible to simulate temperature and RH changes and predict the overall impact of a particular HVAC setting profile on collections. Ultimately, these algorithms could become part of the risk assessment methodology based on IPI's preservation metrics.

Modeling Temperature Equilibration Data
Data from this project will be modeled to allow the information to be more generally applied. The commonly required data, such as temperature change, have already been modeled. The temperature of objects tends to change fairly quickly, and this will probably be the largest observed effect of changing the storage environment for short periods of time. The rate of temperature change will depend on the volume of the object, its density, its heat capacity (the amount of heat energy required to change the temperature of a unit mass of the object one degree), and its thermal conductivity. Some of these factors depend on the object's form and others on characteristics of the object's material. In the 17th century, Sir Isaac Newton measured and modeled the rate of temperature change in a warm body that is cooling down. The assumption is that a warm object (perhaps a bowl of soup) is put into a room that is at some temperature that doesn't change during the course of the experiment. The equation tells us that the rate of change of temperature is proportional to the difference in temperature between the room and the object. Newton's law applies to the object as a whole or to the core temperature of the object. The more complex Fourier's general heat conduction equation, which describes the temperature at any given point in the object at any time, is not needed in this case; Newton's law is satisfactory, as was demonstrated during earlier experimentation at IPI. (See Appendix 7.)

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Modeling Moisture Equilibration Data
The rate at which organic materials come to moisture equilibrium with the environment is determined by diffusion and can be described by Fick's law of diffusion. Temperature and moisture equilibration are physically described by the random movement of molecules either resulting in collisions, as with temperature, or resulting in a net movement of material (water) for humidity. The fundamental characteristic of this process is that the direction of the "next step" is independent of any of the previous "steps." Equations of the same form therefore can model either temperature or moisture equilibration, although the rate constants for the two processes are quite different.

Using temperature and moisture equilibration data from an earlier project, IPI has tested the feasibility of developing models that describe a variety of collection materials and housing circumstances. IPI will pursue that approach in this project, foreseeing a new methodology for sustainable HVAC operations that will benefit from the modeling of temperature and humidity equilibration data.

ACTIVITY GROUP IV: CREATION OF A PLAIN-LANGUAGE PUBLICATION
The last nine months of the project will be devoted to the creation of a print publication, tentatively titled *IPI Field Guide: Methodologies for Sustainable HVAC Operation in Collection Environments*. This guide will present the methodology developed during the research. Incorporating empirical data and models developed during the project that describe the reactions of paper-based materials in their various housings to nightly and weekend temperature setbacks and sustained humidity changes, this publication will detail practical ways to implement nightly, weekend, and seasonal HVAC setting adjustments with the goal of reducing energy consumption without risk to collections. The intended audience for the guide includes collection care, facilities, and administrative staffs in libraries and archives. Users will be able to determine, through an easy selection process, a range of appropriate HVAC setting adjustments for a given institution or storage location. The step-by-step methodology will likely be presented as a series of questions, such as: What types of paper-based materials do you have in your collections? What types of housings do you use? When are storage areas not occupied by staff or the public? How would you characterize your environment over a one-year period? Facilities managers and collection care specialists can use the guide in developing their own approach to the management of HVAC operations.

The nine-month period will be divided into three segments. The first four months will be devoted to design and content development. At the end of this period the advisory committee and Peter Herzog will receive a draft of the guide for review. Editing and further development will follow, and a second draft will go to the advisory committee and Peter Herzog. Final editing will be done during the last two months, after which the guide will go to press.

STAFF

Jean-Louis Bigourdan, IPI Research Scientist, has responsibility for all aspects of the project. He will lead the design and implementation of laboratory and field research and coordinate, organize, and document all project activities. He will spend 45% of his time on the project and will be responsible for reporting to NEH, disseminating project results, and developing the publication. Since 1994, Mr. Bigourdan has conducted several NEH-funded projects related to media stability. He has studied the role of enclosures and microenvironments in film preservation and the effect of changing environments on library and archives materials. His findings have led to the redefinition of storage strategies for preserving film. He has published extensively on the topic of film stability and has presented IPI research results at conferences, symposiums, and workshops in the U.S. and abroad. He has conducted collection surveys, developed storage strategies for institutions, and consulted on the implementation of low-temperature storage. He led the NEH-funded project *Effects of Fluctuating Environments on Library and Archives Materials,* which provides information critical to the proposed project.

James M. Reilly, Director, Image Permanence Institute, will act as research advisor, spending 15% of his time on the project. He will contribute to the design of the field experiment and development of the methodologies. Mr. Reilly has designed, executed, and directed preservation research activities since 1978. He is well known for his research on the effects of temperature and humidity on library, archives

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and museum collections, deterioration of 19th-century photographic prints, environmental monitoring and control, management of film archives, and the major causes of image deterioration. Mr. Reilly led the development of the Preservation Environment Monitor®, Climate Notebook® software for environmental analysis, the PEM2, *PEMdata.com*®, and *MyClimateData.com*. He is a consultant to numerous museums and government agencies. He has written and lectured extensively on preservation issues, and in 1998 he received a Technical Achievement Award from the Academy of Motion Picture Arts and Sciences.

Douglas Nishimura, IPI Research Scientist, is well known in the field of preservation as a technical authority on the chemistry of deterioration. He was instrumental in the creation of the metrics used in Climate Notebook® software and for the development of the *IPI Storage Guide for Acetate Film* and *The Storage Guide for Color Photographic Materials*. He will spend 15% of his time on this project, focusing on data analysis and modeling. He will be instrumental in developing mathematically tested models that will reflect the behavior of materials exposed to a variety of temperature and RH conditions. His extensive experience in teaching and presenting will be beneficial during publication development and dissemination of project information.

Kristin Smith, IPI Project Associate, joined IPI as an intern and was hired to assist with IPI projects related to environmental preservation. Ms. Smith will give 15% of her time to facilitate field testing, assist with the design and implementation of the field study, and contribute to field guide content. She is a key member of IPI's environmental team and assists with presentations to the field, product development, outreach, and technical support.

Lisa Cerra, IPI Business Manager, will devote 5% of her time to this project. Ms. Cerra is responsible for financial management of grants and contracts, budget preparation and oversight, and financial reporting and forecasting. Ms. Cerra also supports principal investigators and ensures compliance with sponsor and institute guidelines.

Lauren Parish, IPI Web Designer, will spend 15% of her time on this project, primarily during the 3rd year. Joining IPI in 2008, Ms. Parish has designed and produced various print publications and worked on new design initiatives, including research project websites, web-based software, and IPI site redesign.

Peter Herzog, Consultant, Herzog/Wheeler & Associates, will provide guidance on design and planning of the field experiment during the 1st year. During the 2nd and 3rd years, he will assist with the field experiment, contribute to the development of practical methodologies, and review the draft of the field guide. He will consult via email and telephone, devoting 12 days to the project over 3 years. Mr. Herzog is an architect, engineer, author, and teacher with a long, distinguished career in energy management process design, technical analysis of energy-consuming processes and systems, troubleshooting, and energy conservation planning. His background in HVAC systems analysis and performance verification has played a major role in his work with IPI on optimization and preservation environment monitoring and analysis projects.

DISSEMINATION

IPI will produce a final report on this project, which will be available on its web site. IPI will also create a plain-language print publication in the form of a field guide for librarians, archivists, and HVAC operation administrators. It will describe a step-by-step practical approach to reduction of energy consumption through the implementation of nightly, weekend, and seasonal HVAC setbacks. This portable reference for users will contain essential information and provide a methodology to achieve energy savings, meet the needs of the collections, and determine the range of possible HVAC setbacks. Research findings will determine the final content of the publication, which will be similar in nature to *IPI Media Storage Quick Reference* in Appendix 8 and likewise will be made available online as a free download and in print form (sold on a cost-recovery basis).

Research findings will also be made available in technical papers, at conference presentations, symposiums, IPI's e-newsletters, workshops, and other professional venues.

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