

# **A DECISION-SUPPORT FRAMEWORK FOR THE DESIGN AND APPLICATION OF RADIANT COOLING SYSTEMS**

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Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State  
University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

In

Architecture and Design Research

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Blacksburg, VA

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Mandates, Decision Mapping

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## **A. Informed consent for participants**

### **VIRGINIA POLYTECHNIC AND STATE UNIVERSITY Informed Consent for Participants in Research Projects Involving Human Subjects**

Title of Project: A Decision-Support Framework for the Design and Application of Radiant Cooling Systems

Primary Investigator: Prof. James R. Jones

Co-Investigator: Shouib N. Ma'bdeh

#### **I. Purpose of this Research**

Creating a sense of place through a comfortable indoor condition is a main goal of the architectural design process. Thermal comfort is an important component of this condition. To achieve thermally comfortable environments mechanical systems such as radiant cooling (RC) could be used. RC systems have potential benefit of lower energy consumption when compared to other common heating, ventilating and air-conditioning systems. Decisions related to the use of architectural systems such as these should be considered in the early stages of design to maximize the building performance through systems integration.

Radiant cooling systems have many issues and related variables. Architects, HVAC system engineers, and decision-makers have to understand these issues and variables and their impact on the other building performance mandates. Through this understanding, these professionals can better evaluate tradeoffs to reach the desired solution of the design problem. Unfortunately, in the United States few architects have experience with RC systems which limits the application of these systems.

Through a series of case studies and interviews with experienced professionals, the anticipated findings of this study is to capture and structure knowledge related to how decisions are made concerning radiant cooling systems. Through this knowledge capturing procedure, the relevant design performance mandates, barriers and constraints, and potential advantages and benefits of radiant cooling systems will be determined and mapped to a decision-support framework. This framework will be graphically presented which may later be translated to a decision-support software package which could then be developed as a radiant cooling system design assistance tool for architects and HVAC engineers.

#### **II. Procedures**

Unstructured (open ended) interviews will be conducted by the investigator in person or over the phone, either at Virginia Tech's College of Architecture and Urban Studies or in the office of the interviewee at a mutually agreeable time. These interviews will be prefaced by web-based survey tools accessed by interviewees at Survey.vt.edu, which will give interviewees the opportunity to review the questions and prepare responses. The interviews will be recorded using a digital voice recorder. Interviews will last between one-half and one hour. A follow-up interview or interviews may be requested of the

interviewee. The interviewee has complete power to grant or deny this request. No more than three (3) one-hour interview sessions will be requested from any individual.

### **III. Risks**

There is a minimal risk that in the process of relating their design experiences, some interviewees may be reminded of unpleasant or adversarial project conditions that may lead to difficult emotions or reactions. The investigator agrees to refrain from asking any leading questions that seek to deliberately evoke a potentially damaging negative reaction. The participant has complete freedom to stop the interview or withdraw from the study at any point. Each participant will have full access to the transcript of his or her interview as well as the opportunity to provide feedback to the investigator.

### **IV. Benefits**

No promise or guarantees of benefits are offered from the research group to any of the participants. However, the framework generated in part from the outcome of these interviews is expected to be of benefit to the larger design community, and to be of particular and significant interest to architects and engineers involved in spaces with Radiant Cooling systems.

### **V. Extent of Anonymity and Confidentiality**

All information collected from all participants will be confidential. All interviews will be recorded with a digital voice recorder. Transcriptions of voice data will be performed by the investigator. Voice data and transcriptions of interviews, and responses to web-based survey tools, will be stored in a secure location by the investigator. A coding system will be used to label web-based surveys and interviews. These materials will only be accessible to the investigator and his advisor.

Voice data, transcriptions and web-based survey responses will be destroyed when research involving these items is deemed complete by the research group. The investigator will be forced to break confidentiality if any abuse incidents are known or strongly suspected or if the participant is believed to be a threat to himself or herself or others.

In certain cases, due to the relatively small size of the radiant cooling systems, it may be possible for the reader of the final dissertation or papers generated there from to deduce the identity of the interviewee based on his or her responses to questions. This is an unavoidable outcome of research in the design field, where the identity of the designers of buildings is generally considered to be public knowledge. By agreeing to participate in this study, the interviewee consents to accept the risk of this possibility. The investigator agrees to not deliberately divulge the identity of the interviewee without his or her express prior written consent.

### **VI. Compensation**

The participants will receive no compensation for their participation in this study. If members of the research group determine that the participant should seek counseling or medical treatment, a list of local services will be provided.

## VII. Freedom to Withdraw

Participants will have full freedom to stop the interview or withdraw from the study at any point. Participants are free not to answer any interview questions that they choose. There may be situations where the investigator may determine that a participant should not continue to be involved in the study.

## VIII. Approval of Research

This research project **has been** approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University. IRB Approval Date: (to be mentioned after the approval later). IRB Approval Expiration Date: (to be mentioned after the approval later)

## IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. To access web-based survey tools and participates in a one-half to one hour recorded interview, either in person or over the telephone.
2. To provide feedback to the research group as needed.

## X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

Date \_\_\_\_\_

\_\_\_\_\_  
Subject Signature

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Dr. James R. Jones (540)231-7647 / [wolverine@vt.edu](mailto:wolverine@vt.edu)  
Principle Investigator Telephone / e-mail

Shouib Ma'bdeh (540)808-5853 / [mabdehsn@vt.edu](mailto:mabdehsn@vt.edu)  
Co-Investigator Telephone / e-mail

David M. Moore (540)231-4991/ [moored@vt.edu](mailto:moored@vt.edu)  
Associate Vice President for Research Compliance, Telephone/e-mail  
Office of Research Compliance, Virginia Tech

## **B. Recruitment Letter**

### **VIRGINIA POLYTECHNIC AND STATE UNIVERSITY**

#### **Recruitment Letter**

Title of Project: A Decision-Support Framework for the Design and Application of  
Radiant Cooling Systems

Primary Investigator: Prof. James R. Jones

Co-Investigator: Shouib N. Ma'bdeh

Dear ...,

My name is Jim Jones and I am a Professor of Architecture and Director of the Ph.D. Program for Design Research, here in the College of Architecture and Urban Studies, Virginia Tech. We are currently initiating a research project that seeks to look at the boundaries between architecture and engineering, particularly as these boundaries relate to Radiant Cooling (RC) systems. Our goal through this research it to develop a better understanding for how architects and engineers make decisions with regard to these systems and from this, develop a decision-support framework that maps the decision-making process from the architect's perspective. The Ph.D. student candidate working with me on this, Shouib Ma'bdeh, has identified a few recently constructed projects that might serve as case studies for this investigation. In particular it appears that the **(PROJECT NAME)** may serve as a case study for our work. I was hoping that you might talk with Shouib about this project and participate in the questionnaire and interview he developed. Please let me know if you might be willing to help us in this effort and if we could follow up with a phone conversation?

Thank you.

Jim Jones Ph.D.

Director – Ph.D. Program for Design Research

Director – Center for High Performance Environments

College of Architecture and Urban Studies

Virginia Tech, 540-231-7647

## C. Approval Letter



VirginiaTech

Office of Research Compliance  
Institutional Review Board  
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Website: [www.irb.vt.edu](http://www.irb.vt.edu)

### MEMORANDUM

**DATE:** June 13, 2011

**TO:** James R. Jones, Shouib Nouh Ma'bdeh

**FROM:** Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

**PROTOCOL TITLE:** A Decision-Support Framework for the Design and Application of Radiant Cooling Systems

**IRB NUMBER:** 11-252

Effective June 10, 2011, the Virginia Tech IRB Chair, Dr. David M. Moore, approved the amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at <http://www.irb.vt.edu/pages/responsibilities.htm> (please review before the commencement of your research).

### PROTOCOL INFORMATION:

Approved as: **Expedited, under 45 CFR 46.110 category(ies) 6, 7**

Protocol Approval Date: **3/15/2011**

Protocol Expiration Date: **3/14/2012**

Continuing Review Due Date\*: **2/29/2012**

\*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

### FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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## **D. Appendix A: Interview Questions**

### ***Group no. 1: Introductory questions***

To establish a background about the respondent, the role he/she played in implementing the RC system, the RC system type he/she used, and the system's endogenous variables.

- a) In general, what is your experience with radiant systems?
- b) What is the nature of your experience with RC systems?
- c) How many projects using RC systems have you been involved with?
  - i. Can you explain the building type of these projects?
  - ii. How does the building type influence the decision to use a RC system?
  - iii. What types of RC systems do you have experience with? (ceiling systems, floor systems)
  - iv. How does the building type influence the selection of one RC system type over another?
- d) What factors lead to RC systems being initially considered?
  - i. What were the differences in characteristics between the RC system and other systems that led you to consider RC?
- e) Focusing only on the RC system, what makes a RC system differ from one to another?
  - i. Does the RC system type influence the decision-making process? If so, how?
  - ii. The following variables could be described as RC system endogenous variables: System cooling capacity, system surface temperature, system control, and system physical properties (such as dimensions of the RC system, finishing color of the cooled surfaces, locations and finish materials of the cooled surfaces).
    - i. Would you like to add more variables?
    - ii. Which one of these concerns you the most? Why?
    - iii. What are the variables affecting the RC system cooling capacity?
    - iv. What are the variables affecting the system radiant temperature limits?
    - v. How may the RC system control affect the implementation decision?
    - vi. How may the system physical properties affect the implementation decision?

- f) In general, what are the common barriers and constraints to implementing RC systems?
  - i. How do you decide on if the barriers/constraints can be overcome and to continue with the RC system?
  - ii. How do you address them?

**Group no. 2: Design process**

Identify the factors affecting the design process, exogenous variables, endogenous variables, and the limitations/constraints the designer may face.

- a) Could you please describe briefly the process you go through when implementing a RC system in your project?
  - i. How do you decide on whether to consider a RC system?
  - ii. How do you decide the type of the RC system?
- b) Once the decision is made to consider a RC system, in the early stages of the design, what are the factors you must be considered? For example is the climate a factor in deciding to implement a RC system? What other factors must be considered?
  - i. Do these factors vary among projects, locations... and if so, how?
  - ii. How do you address these factors?
  - iii. For each of these factors, how do you evaluate performance?
    - a. What tools do you use to evaluate performance?
    - b. What is your level of confidence in these assessment procedures and tools?
  - iv. The following variables could be described as RC system exogenous variables: designer's and client's goals and preferences, building codes and standards such as ASHRAE 55 and ASHRAE 621 and ASHRAE 90.1, climate (outdoor environment), space function, space characteristics, construction system type, additional system in the space, and the ventilation strategy.
    - a. Would you like to add or omit any to this list?
    - b. Which of these variables are relevant when deciding to implement a RC system?
  - v. How do you see codes and standards govern the use and implementation of RC systems?

- a. Do these codes limit the implementation process? If yes, can you name the code and explain how it limits the implementing process?
- vi. How does climate affect the use of RC systems?
  - a. What concern you the most about the climate variables?
  - b. How do you deal with it?
- vii. Space function affects the cooling loads, how do you deal with this?
  - a. Each space has its own characteristics such as geometry, window placement and finish material: how do these characteristics affect the decision to use a RC system?
  - b. How does the space height affect the decision to use a RC system?
  - c. How does the glazing area affect the decision to use a RC system?
- viii. How does the construction system type affect the decision to implement a RC system in the space/building?
- ix. How does the use of other systems inside the space affect the use and implementation of the RC system?
- x. When using a RC system you have to make a decision about the ventilation strategy you will implement: how is this decision made?
  - a. How are these two systems related or affecting each other?

**Group no. 3: Relationships with thermal comfort and IAQ**

To study the direct relationship between the RC systems and thermal comfort and IAQ. To extract rules of thumb, recommendations, and solutions.

- a) In general, when you are designing a space, what you are trying to achieve in that space? What kind of environment you are trying to create?
  - i. How do you evaluate these achievements?
  - ii. How do you evaluate the space's environment?
- b) Richard Rush mentioned in his book six interior building performance mandates: Thermal performance, IAQ performance, Acoustical performance, Visual performance, and spatial performance,
  - i. Would you like to add any other mandates?

- ii. When installing a RC system in the building, which of these performance mandates are you trying to address?
- c) How will thermal performance affect the decisions to implement a RC system?
- d) How will implementing a RC system in the space affect thermal performance?
  - i. Which of the following variables of thermal comfort will be affected: Operative temperature (which is the combination of mean radiant temperature and air temperature), Relative humidity, air speed, temperature variation with time?
  - ii. What are the concerns for thermal comfort when implementing a RC system?
  - iii. Will installing a RC system cause any kind of local thermal discomfort?
    - a. ASHRAE categorized local thermal discomfort to radiant asymmetry, draft, vertical air temperature differences, and floor surface temperature, which of these will be affected?
    - xi. How do you evaluate and decide on issues associated with the RC system?
- c) How will IAQ performance affect the decisions to implement a RC system?
- d) How will implementing a RC system in the space affect the IAQ performance?

***Group no. 4: Relationships with other Building Performance Mandates (BPMs)***

To study the relationship between the RC system and the other BPM. To extract rules of thumb, recommendations, and solutions.

- a) Do you think installing a RC system in the space will affect the other building performance mandates? Which ones specifically?
- b) How will acoustical performance affect the decisions to implement a RC system?
  - i. How will implementing a RC system in the space affect its acoustical performance?
- e) How will visual performance affect the decisions to implement a RC system?
  - i. How will implementing a RC system in the space affect its visual performance?
- f) How will thermal performance affect the decisions to implement a RC system?
  - i. How will implementing a RC system in the space affect its spatial performance?

***Group no. 5: Conclusion***

- a) Based on your design experience, do you have any recommendations for architects when implementing a RC system?
- b) Would you like to add any additional information, comments, or clarification on any of the previous questions?
- c) Are you willing to see the final product of this research, “the decision support framework”, and comment on it?