TC 1.5 Computer Applications
Research Subcommittee Meeting Minutes
ASHRAE Winter Meeting, San Francisco, CA
Sunday, January 18, 1997

1. Call to Order/Introductions

The meeting was called to order at 7:00 p.m. All present introduced themselves.

2. 966-RP PMS Report

Brian Kammers, PMS Chair, reported that the contractor's progress was satisfactory. Duane Barrett was appointed to replace Rich Linton on the PMS.

3. 1017-TRP PMS Report

Jim Watt, PMS Chair, reported that ten proposals had been received for the project and reviewed and evaluated by the PMS members prior to the meeting. The PMS had met earlier that same day upon selected a contractor to recommend to the full TC (during executive session) on Monday evening.

4. Proposed Research

No new research projects were presented for consideration by the subcommittee chairs. The Emerging Applications subcommittee chair, Rob Briggs, asked if anyone would volunteer to write a work statement for the priority 3 one-pager entitled "Development and Implementation of an Electronic Method for Interactive Commenting of Research, Technical and Symposium Papers and Peer Approval of Research Project Documents." No one volunteered.

4. Discussion/Review of Work Statements and One-Pagers

Dave Branson's work statement, WS-1032, "Identification and Computer-Based Preservation of Building Design and Commissioning Information" had been submitted for a TC letter ballot following the annual meeting in June 1997. The work statement was approved by the TC for submission to the RAC for consideration. The RAC considered the work statement but returned it to the TC for revision in November. The comments contained in the cover letter accompanying the returned work statement were not specific and provided little guidance to the author in his efforts to revise the work statement.

Dave Branson revised the work statement prior to the meeting and provided those in attendance with copies for their review. (See Enclosure 1). The Chair requested that the members review the modified work statement prior to Monday's full TC meeting and be prepared to vote as to whether the revised document should be resubmitted to the ASHRAE RAC for consideration. The Chair noted that the one-pager for this work statement had received a "priority" rating from RAC and that its potential was considerable.

The Chair reported that Walter Grondzik's work statement entitled "A Demonstration Multimedia Database for Examining and Comparing HVAC Design Alternatives" had also been submitted by letter ballot to the TC following the annual meeting. This work statement was not approved by the TC. The Chair indicated that he had not spoken with Walter prior to the meeting and would attempt to contact him before the full TC to share the members' concerns and to determine if he would be willing to revise the work statement. (The Chair was not successful in speaking to Walter Grondzik prior to the meeting but will contact him prior to the next meeting.)

5. Research Topic Prioritization

The TC research plan now consists of four one-pagers (#2-5).

6. New Business

Les Norford, TC 4.7 presented a "high-risk" work statement to the committee for their consideration. (See Enclosure 2). TC 4.7 requested that TC 1.5 consider co-sponsorship of this work. The Chair asked the members to review the work statement and be prepared to vote on TC 4.7's request at the TC meeting on Monday evening.

7. Adjournment

The meeting was adjourned at 8:00 p.m.

WORK STATEMENT
from

<u>Technical Committee 1.5, Computer Applications</u>

TITLE:

Identification and Preservation of Building Design Information for Use in Commissioning and Operations

BACKGROUND:

Many HVAC & R systems and components do not perform in practice as well as intended at the design stage. Formal building commissioning is of growing interest to building owners concerned with ensuring that building systems and components function in accordance with design intent. One of the barriers to wide spread adoption of commissioning is the cost associated with the development of detailed design documentation, test plans, and test results. Another aspect of this barrier is lack of standardization in managing information about HVAC & R designs. The development of standard guidelines to preserve HVAC & R design information will facilitate the development of standard commissioning data and serve as the starting point for recording results from commissioning. These data, in turn, are critical for ensuring the HVAC & R systems operate in an optimal, cost-effective manner. The development of standard procedures for recording HVAC & R design data will help building owners and operators to receive complete, structured, reliable data and information documenting the design intent, equipment characteristics, and overall HVAC & R performance objectives such as indoor environmental criteria and energy-use targets.

A related aspect to the problem of building component performance when compared to design intent is that many organizations within the HVAC & R industry dedicate significant fiscal time and resources to the transfer of information from one automated tool to another. Collaborative efforts to define standards for exchanging HVAC & R data among these tools are underway within the US and abroad. These efforts will benefit from a careful analysis of current practice and emerging structured methods to record HVAC & R data for commissioning and operations, and are of widespread interest to ASHRAE members. The entire HVAC & R industry can benefit from greater use of automated information management technology for recording design data. Such technology will become more robust and useful to the design community and commissioning authorities if common data structures are developed, allowing information to be shared among multiple computer-based tools.

JUSTIFICATION:

The vast amount of information generated in the design process is poorly organized and often unavailable. The design begins with general overall HVAC & R objectives, while more detailed information is developed as specific products are selected. Computer models are developed for equipment sizing and comparison of alternative scenarios, and to convey characteristics of integrated building systems. Estimates of equipment costs, energy use, and operations and maintenance are generated, but rarely carefully archived for later reference. Typically the majority of information is not preserved for use by commissioning authorities or facilities managers in later phases of ongoing operations. Standardized collection and preservation of design information will greatly facilitate commissioning and subsequent operations. The development of an entire set of standards for defining and archiving all critical HVAC & R design data for commissioning, and in similar fashion, pertinent commissioning data for building operations, is a large task. However, developing information management standards for two common HVAC & R systems will provide a useful reference and starting point for ASHRAE members interested in proving commissioning services and monitoring building mechanical system performance.

OBJECTIVES:

1. Identify building mechanical system design and sequence of operation information required for use in verifying performance as part of commissioning and ongoing operations, for two types of systems:

a. Variable air volume, air handling and distribution systems;
b. Chilled water system with multiple chillers.

2. Characterize the generic features of this information and create a data schema suitable for use in a computer-based tool.

3. Develop a paper-based method of recording the system design and sequence of operations information required for functional testing, for the two systems specified in (1).

SCOPE:

The project will be divided into six (6) phases as follows:

1. Identify Related Studies and Research: The Contractor shall conduct a search to identify other projects complementary to the development of methods and procedures related to the collection, storage, transmission and use of engineering design data at later stages of the building life cycle in the HVAC & R industry. This shall include an evaluation of existing standards, guidelines and current research, including those references listed in this work statement. The Contractor shall determine the applicability of these methods and procedures to this project domain.

2. Identify Pertinent Data for Collection and Preservation: The Contractor shall identify information specific to a) variable air volume air handling and distribution systems, and b) chilled water systems with multiple chillers, as they pertain to operations. This shall include engineering design data, equipment performance characteristics, sequence of operation, building operating schedules, and other related data.

3. Develop Generalized Methods and Procedures: The Contractor shall develop standardized generic methods and procedures, applicable to manual or automated means, for identification, collection and transmission of data pertaining to building mechanical systems. The Contractor shall make in-development submittals of those methods and procedures to the PMS prior to each progress conference.

4. Evaluate Methods for Data Collection: The Contractor shall explore authoring and other software tools that are currently available to implement methods and procedures developed in this project.

5. Validate Methods and Procedures: The Contractor shall apply the methods and procedures developed in-contract to two example scenarios described below to demonstrate capture, storage and transmission of pertinent information among modeling tools commonly used in the building construction industry (e.g., CAD, energy analysis, etc.):

   a. Variable air volume, air handling and distribution systems;
   b. Chilled water system with multiple chillers.

6. Generate Final Report: A Final Report shall be generated which documents the development of project deliverables and validation of methods and procedures, including examples.

Please note that ASHRAE retains all intellectual rights and any copyrights for any guidelines or software developed in this project. Licenses for software purchased as part of the project will either be registered as owned by ASHRAE or transferred to ASHRAE at the conclusion of the project.

DELIVERABLES:

The Contractor shall provide the following items as deliverables for this research project:

1. Detailed methods and procedures shall be developed which define the types and amount of information to be collected during the engineering design and commissioning phases of the building system life-cycle. They shall

provide a method for preservation of information such that it can easily be made available for use by automated tools that simulate building operations and project associated costs.

2. The Contractor shall provide two (2) independent examples of the building information collection/retrieval/reuse process, using data that represents a wide variety of building system characteristics. Example systems shall be of the following types:

   a. Variable air volume, air handling and distribution systems;
   b. Chilled water system with multiple chillers.

3. The examples shall demonstrate the application of these developed methods and procedures in both paper-based and automated formats. In addition, they shall illustrate portability of data between numerous computer tools that simulate various phases of the building HVAC & R systems life-cycle.

4. Monthly progress teleconferences shall be conducted, and shall be initiated by the Chair of the Project Monitoring Subcommittee (PMS). The Contractor shall prepare meeting minutes and provide a copy by email to each member of the PMS by the day following the conclusion of the teleconference.

5. Progress and Financial Reports shall be made to ASHRAE through its Manager of Research at quarterly intervals - specifically on or before each January 1, April 1, June 1 and October 1 of the contract period.

6. The Principal Investigator shall report in person to ASHRAE Technical Committee (TC) 1.5 at the Annual and Winter Society Meetings, and answer such questions regarding the research as may arise.

7. A Final Report shall be prepared and submitted to the Manager of Research by the end of the contract period covering complete details of all research carried out on the project. Six (6) draft copies of the Methods and Procedures and the Final Report shall be furnished for review by the PMS.

   Following approval by the PMS and TC 1.5, final copies of the Final Report and the Methods and Procedures will be furnished as follows:

   - An Executive Summary suitable for wide distribution to the industry and to the public;
   - Six (6) bound copies;
   - One unbound copy, printed on one side only, suitable for reproduction;
   - Four (4) copies on 3½"diskette media – two (2) in ASCII format and two (2) in Microsoft Word 6.0 for Windows format.

8. A Technical Paper shall be submitted in a form suitable for presentation at a Society meeting. The paper shall conform to the Society's "Submitting Manuscripts for ASHRAE Transactions" which may be obtained from the Special Publications Section. Additionally, a Technical Article suitable for publication in the ASHRAE JOURNAL may be requested by the Society. This is considered a voluntary submission and not a deliverable.

All papers or articles submitted for inclusion in any ASHRAE publication shall be made through the Manager of Research and not to the publication's editor.

LEVEL OF EFFORT:

This project is estimated to take no more than one year to complete. The level of effort is estimated to be:

Experience Level	Person-months
Principal Investigator	4
Mechanical Engineer	4
Application Developer	2

The estimated total cost is $85,000.

OTHER INFORMATION FOR BIDDERS:

Bidders will be evaluated on the following criteria:

- The bidder's understanding of the Work Statement as revealed in the proposal.
- The bidder's familiarity with, experience in using, and involvement in developing methods and procedures related to data transfer between computer tools of unlike functionality within the building construction industry, and particularly the HVAC & R sector of that industry.
- The bidder's familiarity with, experience in using, and involvement in developing guidelines related to collection, storage, and transmission of data, e.g., CAD database management, database schema integration, etc..
- The bidder's familiarity with the use of interoperability protocols in building construction engineering design.
- The bidder's familiarity with the use of computer tools for simulation of building systems operations and life-cycle costing.
- The bidder's experience in developing software products.

REFERENCES:

1995 ASHRAE Handbook HVAC Applications, Chapters 32-39 Building Operation and Maintenance.
1997 ASHRAE Handbook Fundamentals, chapters 23-28 Load and Energy Calculations.
ASHRAE Guideline 1, Guideline for Commissioning of HVAC Systems.
ANSI/ASHRAE Standard 105, Standard Methods of Measuring and Expressing Building Energy Performance.
Industry Foundation Classes - Release 1.5 Specifications, International Alliance for Interoperability, 1998.
Federal Energy Conservation Incorporated, Model Commissioning Specification and Guidebook.
Draft ASTM Standard, Managing and Organizing Building Data.

CO-SPONSORS:

ASHRAE TC 1.5 Computer Applications
ASHRAE TC 9.9 Building Commissioning

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WORK STATEMENT
FROM
TC 4.7 ENERGY CALCULATIONS

CO-SPONSORED BY TC 1.5, TC 4.6

ADVANCED CONCEPTS

TITLE

Building System Design Synthesis and Optimization

BACKGROUND

Design of buildings that minimize their impact on the global environment while meeting the needs of the occupants for a high quality indoor environment requires that both the envelope and the mechanical systems be well matched to the particular characteristics of climate, site, utility rate structure, occupancy etc. In many cases, designers do not attempt this matching, either because they do not have the necessary skills or because their fees do not permit investigation of alternatives to a limited number of conventional systems. One approach to this problem is to develop computer-based tools that can assist designers by automatically generating and comparing alternative design solutions.

Traditional building simulation methodologies allow building systems to be modeled either as prescribed systems, as in BLAST, DOE-2 etc., or as user-described systems, as in HVACSIM+, TRNSYS etc. In each case, the configuration of the system is determined before the simulation is run and cannot be changed 'on the fly' during the run. The user can optimize a particular system design by varying particular parameters and re-running the simulation, and can then choose between designs involving different system configurations by comparing the results of runs with different (optimized) system configurations. In programs such as BLAST and DOE-2, the user is restricted to the configurations that have been implemented by the developer, which naturally tended to be conventional systems for conventional buildings. In those programs, such as HVACSIM+ and TRNSYS, that have the flexibility to allow the user, rather than the developer, to specify the system configuration, the process of actually specifying the configuration is time consuming and error-prone and is also limited by the ability of the user to generate alternative, feasible, configurations. A highly desirable advance would be for alternative configurations to be generated automatically.

Some programs, e.g. TRNSYS, can perform parametric variations automatically. Automatic configuration generation and variation, together with automatic parameter variation, could then be combined with a suitable search technique to synthesize an optimal design. The resulting optimization problem may, in general, be categorized as a mixed-integer nonlinear programming (MINLP) problem, containing integer variables to define a configuration and size components and continuous variables to represent component model parameters. Problem constraints can include lower and upper parameter bounds as well as bounds on operational variables such as temperatures, humidities and flow rates.

Similar optimization problems associated with synthesizing optimal configurations of heat exchangers, distillation columns and chemical reactors are the subject of extensive research reported in the chemical engineering technical literature ([1] for example). Commercial software products that determine an optimal configuration of chemical process components are already available.

A number of minimization algorithms have been applied to different classes of synthesis problems. Some use numerically computed gradients to advance toward a minimum while others search for the minimum using only computations of the objective function. Methods which use gradients in the solution of problems with continuous variables and a continuous objective function (e.g. sequential quadratic programming) may be combined with integer programming solution methods to solve MINLP type problems. Other methods such as simulated annealing and genetic algorithms sample the objective function surface and approach a region "most likely" to contain the global minimum according to some stochastic or heuristic rule. These algorithms have the advantage of being able to escape local minima but use relatively large amounts of computational time [2,3].

The application area for the 'proof of concept' prototype goal oriented simulation program to be developed in this project is secondary HVAC systems. This application area has been selected because there is a wide variety of systems to meet building thermal loads and because several comprehensive libraries of models of secondary system components have already been developed [4,5,6,7].

JUSTIFICATION

Current simulation programs are mainly used to confirm performance and optimize sizing and operational parameters once the basic design decisions have been made. Simulation would be able to play a much more significant role in design if simulation programs were set up also to help designers in the early stages of design. In particular, the ability to generate and investigate a wide range of system configurations would allow novel and innovative system configurations to be synthesized and assessed much more easily and efficiently, leading to system configurations that are better matched to the particular requirements of each design.

OBJECTIVE

Develop methods for the synthesis of optimal configurations of HVAC systems. Demonstrate a prototype program that implements these methodologies to synthesize optimal configurations of secondary HVAC systems.

SCOPE

The main elements of a prototype optimal system synthesis program are:

a) A *configuration generator*. A configuration consists of a set of components (fans, coils etc.) and a set of connections between the components. The possible connections are limited by the need for compatibility of type (e.g. connect air to air, not air to water) and compatibility of direction (i.e. connect inlets to outlets not inlets to inlets).

b) An automatic *editor* for the selected simulation program(s) that will generate input files corresponding to the different designs produced by the configuration generator.

c) A *component-based simulation program*, together with a set of models that predict the quantities necessary to evaluate the cost functions of interest (e.g. first cost, life cycle cost). Currently available component libraries contain models that will predict energy and environmental performance. Meaningful design optimization also requires a prediction of first cost (i.e. purchase cost plus installation cost). For each class of component (e.g. coils, fans) the first cost can be expected to be a fairly simple function of size and it should be possible to extend current models to predict approximate first cost without significant difficulty.

d) An *optimization program* suitable for minimizing or maximizing a user defined objective with respect to a set of integer and continuous variables along with constraints. Functionally, at each iteration, the optimization routine will output a set of variable values. The editor will then create an input file for the simulation program from the variable set. The simulation program will run, predicting costs or other values used in the objective function. The user specified scalar objective function will be calculated and the resulting value returned to the optimization routine.

e) A *run-time supervisor* that can use one or more minimization techniques in order to optimize the design.

The tasks involved in developing a prototype building system synthesis program for HVAC secondary systems are:

1. Produce an inventory of existing design alternatives for secondary systems, itemizing the components used and the ways in which they can be connected to each other and to components and sources/sinks outside the boundaries of the system. Define a set of pseudo-components (e.g. sources of ambient air, chilled water) that will be used to impose boundary conditions on the simulation. Select a limited set of configurations to be used in testing the configuration generator, as discussed below.

2. Review component-based simulation programs and select suitable program(s) and component models for target application.

3. Extend component models to include an approximate estimate of first cost. A simple cost model is sufficient for the 'proof of concept' goal-oriented simulation to be developed here, but the implementation should allow for more accurate and realistic cost models to be added in later versions.

4. Develop configuration generator: group component model inputs and outputs into 'links' of pre-defined type (e.g. moist air, water refrigerant) consisting of pre-defined variables (e.g. a moist air stream can be defined by its temperature, humidity ratio, mass flow rate and, if relevant to the calculations, pressure). Develop a method that allows a wide variety of physically realizable HVAC secondary system configurations to be generated automatically. Consider possible ways in which the number of configurations can be limited, e.g. elimination of redundant components, setting a (user-defined) threshold on system complexity. Implement the configuration generator in such a way that the criteria for eliminating particular configurations can be changed easily by the user.

5. Test the configuration generator by verifying (a) that it can generate all of the test set of configurations referred to in (1) above, and (b) that the constraint functions serve to disallow impossible or prohibited configurations.

6. Develop an editor or editors that will generate input files for the simulation program(s). The components and their connections will be defined by the configuration generator. The boundary conditions will be determined by the design brief and the initial values and feasible ranges of the parameters will be determined from expert knowledge, e.g. rules of thumb. The editor must account for the following:

   a) Generation of initial values and feasible ranges for the parameters. One possibility that should be investigated is the automation of the psychrometric analysis methods used in conventional system sizing.

   b) Automatic generation of a control strategy for each configuration. One possibility would be to perform an on-line optimization at each time step to generate the optimal operating point, since a system model is necessarily available. If this proves too difficult, the more restricted objective of optimizing for design conditions could still be addressed as a limited proof of concept.

   c) Characterization of each configuration by a set of variables (such as coil UA) that define the search space for the optimizer.

7. Review optimization methods and select one or more methods for implementation. The selection criteria should reflect the nature of the design problem and should include the ability to deal with local minima, constraints and

a combination of discrete and continuous variables. (Various parameters relating to system sizing are discrete, e.g. available coil size, in addition to the discrete nature of alternative system configurations.)

8. Implement the selected optimization method(s) in a software environment that allows the simulation program(s), together with the appropriate input files, to be called in order to evaluate the value of the selected cost function for different parameter values.

9. Develop a set of design briefs for use as test problems for the goal-oriented simulation. These should differ in complexity and include cases where the optimal design can be established analytically and others where there are several design configurations that are close to the optimum. Use an exhaustive search technique to identify the global minimum, and all the local minima, within an appropriate, explicitly defined region of the design space.

10. Test the prototype optimum system synthesis program using the test problems developed in (9) and, where possible, modify the approach and the software to improve its performance.

11. Assess the overall performance of the prototype and the technical viability of the approach. If appropriate, make recommendations for further work:

    a) how the approach could be further developed generically;

    b) how the prototype implementation could be made more robust;

    c) how the approach could be implemented in other application areas (e.g. primary systems);

    d) how the practical utility of the approach could be assessed, e.g. by trials involving practicing designers.

INTERACTION WITH PROJECT MONITORING SUBCOMMITTEE

It is necessary that the contractor interact closely with the project monitoring subcommittee. The contractor will be required to make the following submittals for Project Monitoring Subcommittee (PMSC) approval:

1. Choice of component-based simulation program(s) and available component models (Task 2).

2. A viable design for a configuration generator that will produce configurations of interest while eliminating to the maximum extent possible configurations that an expert would consider to be unrealizable or otherwise of no interest (Task 4).

3. The configurations used to test the configuration generator (Task 1) and the results of the tests (Task 5).

4. A working version of editor that generates input for the simulation program from system defined by the configuration generator (Task 6).

5. Choice of optimization program. If at all possible, the program should be an existing, well documented and tested approach for which executable code is available (Task 7).

6. An initial test problem to be optimized.

    a) Choice of an appropriate problem (Task 9). For example, the objective may be to select an optimal system that meets the annual heating/cooling loads and ventilation requirements for four different zones. To focus effort on system configuration and evaluation, pre-calculated loads should serve as boundary conditions for system and plant components, much as is done in common building energy simulation programs. The scope of the problem should be limited to one for which all results for all possible configurations can be calculated within reasonable time/computational constraints.

b) A set of possible components that will be available to the configuration generator to meet the requirements of the initial test problem.

c) A demonstration of the program's ability to find the optimal solution to the test problem, with comparative results for all possible configurations (Task 10).

7. A list of three test problems of increased scope. For example, the problems could include more zones and a broader list of components available to the configuration generator. The intent should be to probe the optimal solution to a problem of increased dimension, large enough that all possible configurations can not be simulated in any reasonable amount of time (Tasks 9 and 10).

DELIVERABLES

a. Progress and Financial Reports shall be made to the Society through its Manager of Research at quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

b. The Principal Investigator shall report in person to the TC at the annual and winter meetings, and answer such questions regarding the research as may arise.

c. A Final Report shall be prepared and submitted to the Manager of Research by the end of the contract period covering complete details of all research carried out on the project. The final report shall include all developed computer code, in both fully commented source and executable versions, and thorough documentation of program input and output variables and assumptions underlying the program. Unless otherwise specified, six draft copies of the final report shall be furnished for review by the Project Monitoring Subcommittee (PMS).

Following approval by the PMS and the TC, final copies of the final report will be furnished as follows:

- An Executive Summary suitable for wide distribution to the industry and to the public.
- Six bound copies.
- One unbound copy, printed on one side only, suitable for reproduction.
- Two copies on diskette(s), one in ASCII format and one in Microsoft Word 6.0.

a. One or more Technical Paper(s) shall be submitted in a form suitable for presentation at a Society meeting. The Paper(s) shall conform to the Society's "Submitting Manuscripts for ASHRAE Transactions" which may be obtained from the Special Publications Section.

b. All papers or articles submitted for inclusion in any ASHRAE publication shall be made through the Manager of Research and not to the publication's editor.

A Technical Article suitable for publication in the *ASHRAE JOURNAL* may be requested by the Society. This is considered a voluntary submission and not a deliverable.

LEVEL OF EFFORT

It is estimated that the project will require 42 person months of effort with the total project to be completed within an 36 month time period, based on an estimate of 6 person-months of the Principal Investigator and 36 person months of a research assistant. The expected cost is $175,000. The projected time and cost reflect the scope of work and the need for a sustained effort by researchers with appropriate skills. The contractor is expected to identify personnel and their commitment to the project, with an emphasis on continuity.

OTHER INFORMATION FOR BIDDERS

The successful bidder will demonstrate:

1. Familiarity and experience with suitable optimization methods and their implementation;

2. Familiarity and experience with HVAC modeling and simulation;

3. Experience with writing and testing computer code to be used by others.

Bidders should also explain their approach to the design of the configuration generator.

REFERENCES

1. Diwekar, U. M., I. E. Grossmann, and E. S. Rubin. An MINLP Process Synthesizer for a Sequential Modular Simulator, *Ind. Eng. Chem. Res*., 31, 1992.

2. Kirkpatrick, S., C. Gelatt, M. Vecchi. Optimization by Simulated Annealing. *Science*. 220 (4598), 1973.

3. Wright, J. A., "HVAC Optimisation Studies: Sizing by Genetic Algorithm", *Building Services Engineering Research and Technology*, 17(1), 1996

4. ASHRAE 629-RP, "Preparation of a Toolkit for Secondary HVAC System Energy Calculations", Final Report.

5. Klein, S. A., Beckman, W. A. and Duffie, J. A., "TRNSYS - a transient simulation program", *ASHRAE Trans*, 82, Pt 2, 1976.

6. Park, C., Clarke, D. R. and Kelly, G. E., An overview of HVACSIM+, a dynamic building/HVAC/control systems simulation program", *Proceedings 1st. Annual Building Energy Simulation Conference*, Seattle, WA, 1985.

7. ASHRAE 825-RP, "A Standard Simulation Testbed for the Evaluation of Control Algorithms and Strategies", Final Report, 1997.

AUTHORS:

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