Cooling the Data Center: Design of a Mechanical Controls Owner Project Requirements (OPR) Template

Stefan A. Robila
Department of Computer Science
Montclair State University
Montclair, USA
robilas@mail.montclair.edu

David Grant
Oak Ridge National Laboratory
Oak Ridge, USA
grantdr@ornl.gov

Chris DePrater
Lawrence Livermore
National Laboratory
Livermore, USA
deprater1@llnl.gov

Vali Sorell
Microsoft
Charlotte, USA
herbert.sorell@microsoft.com

Terry L. Rodgers
JLL
Concord, USA
TerryLee.Rodgers@am.jll.com

David Martinez
Sandia National Laboratory
Sandia, USA
davmart@sandia.gov

Shlomo Novotny
Chilldyne
San Diego, USA
shlomo.novotny@chilldyne.com

***Abstract*— As the power demands of supercomputers continue to grow, so do the demands of the mechanical cooling systems that support the infrastructure and building in which the supercomputers reside. Planning for the cooling systems and their mechanical controls are an intrinsic part of any new supercomputer installation. To support the design and commissioning of the mechanical control systems, the Energy Efficient High Performance Computing Working Group (EE HPC WG) Cooling Controls is developing a template for an OPR (Owner Project Requirements) document. The design of the template, while pursued by a small team, leveraged the expertise of the broad membership of the EE HPC WG through surveys and feedback sessions. As a result, the OPR template includes not only a suggested structure, and a checklist of topics that a site might consider including in the document, but also many real-world examples of how the topics were addressed in previous projects. Finally, the Mechanical Controls OPR template is being developed in parallel with other templates focused on other aspects of a supercomputer installation. These templates are intended to improve the efficiency and comprehensiveness of the programming (pre-design) phase of project execution and provide the engineering and design team with better clarity of the facility infrastructure capabilities, expandability, and performance requirements. The intended result is improved construction documents (Basis-of-Design, drawings and specifications) that support the project goals and objectives including reliability, resiliency, and energy efficiency expectations of the HPC facility.**

Keywords*— *cooling systems, commissioning, data centers, energy efficiency, high performance computing, mechanical controls

I. Introduction

As supercomputers' performance continues to increase, so does the energy loads and associated cost required to operate them. Since the vast majority of the energy consumed is converted into heat, the cooling loads have also grown proportionally. Improvements in the computational efficiency and increased system density, coupled with new cooling technologies have partially offset the increase in energy consumption and associated costs [1]. To sustain such improvements, data center cooling strategies must be designed concurrently with the engineering and design of the HPC systems for optimal heat removal [2]. Appropriate monitoring and control of the cooling systems has been shown to be key in achieving improved energy efficiency [3].

This co-design process is valuable for all aspects of the data center; in particular for mechanical controls of the cooling systems due to the unique power profile characteristics and respective cooling demands associated with HPC systems and the need to support both the HPC infrastructure and building(s) in which the supercomputers reside. As refresh rates for supercomputers can be on the order of 3 years, the upgrade and/or expansion of the mechanical cooling may also follow a similar cycle.

In large facilities, interdisciplinary collaboration for the co-design of both compute and cooling of data centers resulted in significant improvements in energy efficiency [4]. In searching for better approaches for design of efficient cooling, software engineering techniques were also employed [5]. In other cases, algorithmic innovation such as computational fluid dynamics (CFD) analysis was described in designing solutions for the cooling topologies and associated controls [6]. Such approaches provide objective, data-driven engineering evaluation of potential cooling control strategies and strengthen the cooling system controls design in meeting the HPC requirements.

Mechanical cooling control systems are often over-looked during the pre-design process. The controls systems are considered second tier priority or are simply not properly

2168-9253/21/$31.00 ©2021 IEEE
DOI 10.1109/Cluster48925.2021.00085

addressed due to other constraints or the lack of understanding of the unique cooling load profile characteristics associated with HPC systems. This can result in reduced mechanical cooling efficiency, suboptimum operator interfaces, compromised functionality, and increased operating costs. It can also lead to decreased reliability and resiliency of the cooling system and inability to accommodate future cooling needs and expandability/upgrades as the HPC facility evolves. Finally, it can result in lower productivity for the facility and operations managers as they work with the contractors to try and re-design these control systems on-the-fly during construction, or worse yet, after the site goes into operation and the inadequacies become apparent.

Recognizing the need to support the co-design process, in 2020-2021, the Energy Efficient HPC Working Group (EE HPC WG) Cooling Controls Team shifted its focus from examining and documenting case studies of cooling controls implementations, to investigating the development of a design guideline for cooling controls. In preliminary work that analyzed case studies and through meeting discussions, the Team identified weakness in the cooling controls design process that could be addressed. The Team concluded that there is a need to provide to the cooling controls designers an explanation of the ideas, concepts and criteria that are important to the owner and which are desired to be tracked throughout design and construction.

II. OWNER'S PROJECT REQUIREMENTS (OPR)

The Owner's Project Requirements (OPR) is defined as "a written document that details the functional requirements of a project and the expectations of how it will be used and operated." [7] OPRs have been developed for a multitude of fields and have become an essential component in the commissioning of buildings as a structured approach to ensure that what is considered important from the owner's perspective is properly addressed throughout all the stages of the project. The OPR is typically developed in the pre-design phase of a project. Information about the proposed facility's purpose, goals, objectives and overarching requirements are gathered from all stakeholders and users, compiled into the OPR document, and communicated to the designers to provide direction on the development of the project Basis-of-Design (BOD) and subsequent construction documents. It also establishes the foundation for objective acceptance criteria that the commissioning provider can cite when accepting or rejecting project services and deliverables.

The OPR forms the basis from which all design, construction, acceptance, and operational decisions are made. The OPR can be modified by the owner/stakeholders during the design process as the owner's objectives and criteria are refined. The use of OPR's in commissioning data centers is well documented [8], [9], however, given the complexity and unique requirements of HPC cooling systems, OPRs focused on HPC deployments are needed. The primary stakeholders for the cooling controls OPR are the operations and facility managers at HPC sites who are responsible for mechanical cooling control systems. The primary users of the OPR are the architects and engineers (A&E) who provide engineering and design services for HPC site mechanical cooling control systems.

III. TEMPLATE DESIGN PROCESS

The Energy Efficient High Performance Computing Working Group consists of approximately 800 members from 20 different countries. While membership is open to all interested parties, it includes many data center professionals with expertise in national data center facilities such as the ones managed by the Department of Energy or other federal agencies, together with others representing industry, academic institutions, or international organizations [10]. A key priority of the Group is to develop and disseminate best practices for energy efficiency in HPC facilities and equipment. Through regular meetings and through community polling, the Group identifies high value activities that are relevant to its constituency.

The Group's activities are also spearheaded by content Teams that target specific aspects of the energy efficiency of the data centers, some focused on the computing systems, while others focused on the infrastructure. Within the infrastructure area, a team focused on Controls generated a list of data elements required for dynamic, integrated cooling controls, as well as collected and discussed information on use cases [11]. As part of the process, the Team also identified the need for improved specifications of the cooling controls and better integration of their design within the overall cooling design. Team also concluded that such integration will be more successful if the specifications are organized as an OPR template and started the work on its design.

The Team held regular weekly meetings throughout the 2020-2021. Starting with a sample OPR [12] and using ASHRAE commissioning guidelines [13], the Team built the structure of the template and then proceeded with refining each component. An initial draft was generated in Spring 2021 and shared with the Group. Feedback was collected through meetings as well as through a survey. The survey included questions on the structure and content of the sections noted above.

Fig. 3 displays the survey-based feedback for the topics of the Key Owner's Project Requirements ("*Assess each checklist item as to whether it should be included in this high-level section- the Key Owner's Project Requirements.*"). Overall, the template structure was evaluated to work well. Furthermore, suggestions for additional topics were received and incorporated.

The survey also included questions on the value of the OPR template ("*Overall, how would you rate the value to you of an OPR Guideline for improving HPC data center mechanical control systems?*"). The respondents were overwhelmingly in agreement that such template would be a valuable addition to the data center design toolkit (see Fig. 4).

IV. PROPOSED MECHANICAL COOLING CONTROLS OPR TEMPLATE

While an OPR is created and updated specifically for a project, an OPR template provides the needed guidance for facility and operations managers to make sure that the mechanical cooling control systems are well designed 'up-front' in the process of installing a new supercomputer. By presenting a checklist of topics and design parameters, the OPR template will assist the design team in writing the OPR for the mechanical controls systems supporting data centers or high-performance computing (HPC) facilities.

The OPR template serves two functions: 1) it provides an outline for writing a mechanical cooling control system OPR and 2) it provides a checklist of questions that help prompt what information might complete the text contained within the sections of that outline. The proposed template suggests eight sections for the document that should be created and documented as part of an OPR for mechanical cooling control systems:

1. key owner's project requirements
2. general project description and background
3. objectives
4. functional uses
5. budget considerations and limitations
6. performance criteria
7. commissioning
8. service and maintenance

These sections can be reduced or expanded as needed for specific projects. For each category, a detailed list of topics is suggested. As example, the list of topics proposed to be potentially covered under the Key Owner's Project Requirements is:

- The owner holds the pen for the OPR. The commissioning provider in collaboration with the architects and engineers should help create and update this OPR. They are to communicate its contents to other team members and contractors during the creation of the BOD. The BOD is owned by the architects and engineers and must be informed by the OPR.
- Commissioning- The Controls Contractor shall provide support to the commissioning agent throughout the project. Commissioning needs to be considered at the start of the controls system design. 100% of point-to-point testing required by controls contractor and 10-20% random sampling to be evaluated by the commissioning agent. Includes functional testing, load bank testing, integrated system testing.
- Proposed project and operational budgets (CAP-Ex and OP-Ex or TCO) and timeline/schedule
- Must comply with defined thermal envelope and/or water classification for the data center. This should reference any owner or industry standards, guidelines, or site-specific requirements.
- New systems must adhere to those operational practices already in place with existing infrastructure or be approved as exceptions. Those systems should have the same look and feel (graphical interfaces) and the data should be compatible for all operational data analytic purposes, e.g., GUI, diagnostics. This applies to security and documentation features as well.
- Security, including cyber security- The system designed and built shall incorporate best practices and standards for security. This includes the full-service life; from early design through end-of-life.
- Physical control to access to the hardware (e.g.- lockable panels, switches.)
- Describe the existing level of operational availability and define to what extent new systems are to hold to that level of availability.
- Ensure new and/or existing-to-remain hardware and software are not at their end of life and will not be obsolete in the near term. Also, make sure that products are not in beta testing, have been fully validated, and will remain supported by the vendor/manufacturer over the expected lifespan.
- Alarm escalation, nomenclature, and method of communication strategies.
- Training- Training manuals are to be produced and training session(s) provided to all operations staff.
- Documentation- All documentation must be provided to support design, construction and testing, integration with other components, operation, service and maintenance.
- Enhance existing building controls if they are inadequate.
- Seamlessly integrate with existing building controls (e.g. – HPC Systems, existing Building Automation System (BAS), Data Center Infrastructure Management (DCIM), electrical power monitoring systems (EPMS)). network, sensors, and sequences of operation.
- Controls Vendor Service Response (spare parts, warranty, duration, response time)
- Align with existing standards (e.g., asset naming, electrical mechanical standards)
- Communications Protocols should be an open protocol such as Redfish and BACNET/SC.

In addition, for each subtopic, specific examples are provided (see Figs. 1 and 2 for examples of a Key Owner's Project Requirements topic). These examples draw from the Team's expertise, the case studies, or feedback from the broader EE HPC WG community.

New systems must adhere to those operational practices already in place with existing infrastructure. Same look and feel (graphical interfaces). Data for all operational data analytic purposes: e.g., GUI, diagnostics. This applies to security and documentation features as well.
[e.g. - For any new system or function that is added to an existing one, a user must not have to re-learn how to interact with the GUI. It should be a seamless transition.]
[e.g. - Scenario. With the implementation of the new control system, the energy data for pumps wasn't carried through to the DCIM system.]

Fig. 1. Key Owner's Project Requirements - Examples/suggestions for the operational practices topic

Serviceability and Maintainability- All equipment must be maintainable in order to achieve a certain level of availability. Serviceability is the ease with which equipment can be maintained.
[e.g.- There must be a separation of high and low control voltages. This is done for the safety of troubleshooting. If there is a problem at 3AM, we can troubleshoot the systems without dressing out in the proper protective equipment or having a second person or getting hurt.]
[e.g.- Controllers and Sensors must be placed in accessible locations and visible from the floor level. Pressure gauges that are located on pipes 2 meters above the floor are facing up are very difficult to read.]

Fig. 2. Key Owner's Project Requirements - Examples/suggestions for the scalability and maintanability topic

V. DISCUSSION

The OPR template directly addresses brownfield and not greenfield sites because an upgrade at an existing site and for an existing building is a much more common occurrence for HPC. However, the information contained in the template would also be valuable in these situations as many aspects would be common to all such projects. Furthermore, it does not address future HPC system architectural changes that might affect the HPC building and infrastructure (quantum computing or cloud computing, for example).

The feedback received was incorporated in the OPR template revisions. In addition, work continues to identify relevant examples for each of the topics (especially for the functional uses). This whitepaper highlights work on a OPR template (described in section III. Proposed Mechanical Cooling Controls OPR Template) that is still being developed. The complete document is expected to be made available through the EE HPC WG website and disseminated through presentations at professional meetings.

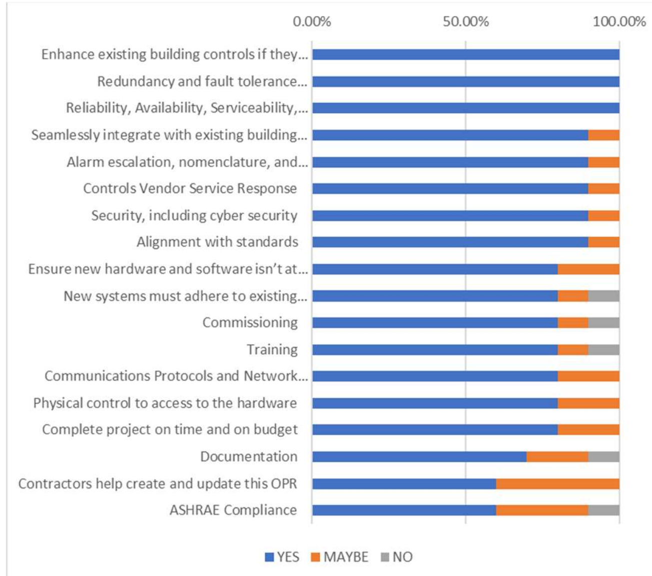

Fig. 3. Survey based feedback on wheteher the proposed topics are relevant to the Key Owner's Project Requirements

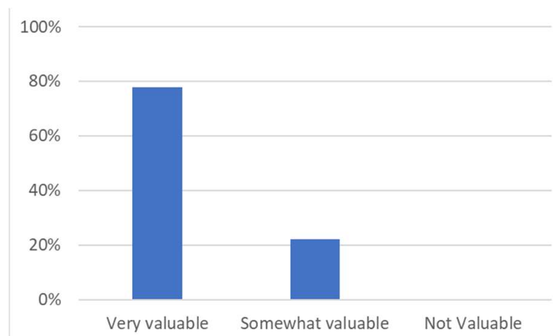

Fig. 4. Survey based feedback on the value of the OPR template

ACKNOWLEDGMENTS

The authors would like to acknowledge the Team from the Energy Efficient HPC Working Group Cooling Controls and for spearheading the idea. Additional thanks to all members of the EE HPC WG that have provided feedback on the OPR design, both through surveys and direct communication. This work was supported by, and used the resources of, the Oak Ridge Leadership Computing Facility, located in the National Center for Computational Sciences at ORNL, which is managed by UT Battelle, LLC for the U.S. DOE (under the contract No. DE-AC05-00OR22725).

REFERENCES

[1] A. Shehabi *et al.*, "United states data center energy usage report," 2016.

[2] L. A. Parnell, D. W. Demetriou, and E. Y. Zhang, "Combining cooling technology and facility design to improve HPC data center energy efficiency," in *2016 15th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, 2016, pp. 417–425.

[3] N. Bourassa *et al.*, "Operational data analytics: Optimizing the national energy research scientific computing center cooling systems," in

Proceedings of the 48th International Conference on Parallel Processing: Workshops, 2019, pp. 1–7.
[4] N. Bourassa, "LBNL's High Performance Computing Center: Continuously Improving Energy and Water Management," *ASHRAE Journal*, vol. 62, no. 12, pp. 30–36, 2020.
[5] L. Bortot, W. Nardelli, and P. Seto, "Data Centers are a software development challenge," in *48th Annual International Conference on Parallel Processing*, 2019, pp. 1–5.
[6] L. Bortot, W. Nardelli, and P. Seto, "Multi source cooling control algorithm," in *2019 IEEE/ACM Industry/University Joint International Workshop on Data-center Automation, Analytics, and Control (DAAC)*, 2019, pp. 25–30.
[7] D. McFarlane, "Owner's project requirements," *ASHRAE Journal*, vol. 55, no. 8, pp. 32–38, 2013.
[8] E. P. Rafter and P. E. CxAP, "The Data Center Tier Performance Standards and Their Importance to the Owner's Project Requirements," in *National Conference on Building Commissioning: May*, 2007, vol. 2, p. 4.
[9] J. Prisco *et al.*, "Investigative Report on Electrical Commissioning in HPC Data Centers," in *2020 IEEE International Conference on Cluster Computing (CLUSTER)*, 2020, pp. 519–522.
[10] "Energy Efficient High Performance Computing Working Group." https://eehpcwg.llnl.gov/index.html (accessed Jun. 17, 2021).
[11] "Energy Efficient HPC Working Group - Controls Team." https://eehpcwg.llnl.gov/infra_ctrls.html (accessed Jun. 17, 2021).
[12] ASHRAE, "Draft Owner's Project Requirements - ASHRAE Headquarters." Jan. 03, 2019. Accessed: Jun. 17, 2021. [Online]. Available: https://www.ashrae.org/File%20Library/About/New%20HQ/ASHRAE-OPR-attachment-to-Design-Services-RFP-signed.pdf
[13] ASHRAE, *Guideline 0-2019 -- The Commissioning Process*. ASHRAE, 2019.
[14] ASHRAE, *Design Considerations for Datacom Equipment Centers, 2nd Ed*. ASHRAE 2009