

Final Technical Report (FTR) Cover Page

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Signature of Certifying Official _____
Date

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Executive Summary:

The project spearheaded by Pennsylvania State University aims to address the growing need for integrating energy-focused computation and data science into building engineering education. As the demand for energy-efficient building designs and operations increases, the educational sector must adapt to equip future engineers with the necessary skills. This initiative responds to this need by developing a consortium that unites multiple institutions to enhance curriculum development, dataset curation, and resource sharing, thereby ensuring students are well-prepared for the evolving energy sector. The primary goal of the project is to establish a consortium that will develop and disseminate educational materials and training programs focused on energy-related data science and computation. Key accomplishments include the creation of a beta website for resource sharing, the development of training programs and standalone modules, and the curation of datasets accessible to the public. This effort will culminate in a curriculum that incorporates advanced modeling technologies and data science skills into building engineering programs.

Advancement in Understanding of the Area Investigated: The project significantly contributes to the understanding of energy-efficient building design and operation by integrating advanced computational tools and data science methodologies into engineering education. By leveraging DOE-funded simulation tools like OpenStudio and Spawn of EnergyPlus, the consortium provides students with hands-on experience in zero-energy design and intelligent building control systems, enhancing their ability to tackle real-world energy challenges.

Technical Effectiveness and Economic Feasibility: The technical effectiveness of the project is demonstrated through the development of a solid curriculum that includes training programs and modules on programming, data science, and building energy modeling. The economic feasibility is underscored by the consortium's ability to utilize existing DOE resources and tools, which minimizes the need for additional financial investments while maximizing educational impact. The project also ensures that the curricula are easily transferrable across institutions, promoting widespread adoption and cost-effectiveness.

Public Benefit: The project offers substantial public benefits by preparing a workforce adept in energy simulation and modeling, essential for advancing sustainable building practices. By aiming to educate approximately 1800 students, the initiative not only enhances individual career prospects but also contributes to broader societal goals of energy efficiency and sustainability. The publicly accessible datasets and educational resources further democratize knowledge, enabling widespread community engagement and fostering innovation in energy-related fields.

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1. Background:

In an era characterized by rapid urbanization and an urgent need for sustainable energy practices, the future of our buildings and energy systems—including grid-level infrastructure and building-integrated technologies—relies on a dynamic and highly skilled workforce. This initiative explores the role of data science and computational education in shaping a professional workforce equipped to handle building energy and performance challenges. It also examines strategies for integrating these new competencies into the already-packed undergraduate and graduate curricula. The demand for innovative solutions in energy efficiency, healthy indoor environments, load flexibility, renewable energy integration, and grid-interactive efficient buildings has never been more critical. To address the needs of both industry and society, it is imperative to equip the next generation of architecture, engineering, and construction professionals with the tools and knowledge necessary to leverage data-driven insights and computational power.

This project brings together a research scientist from a national lab, teaching faculty, and research faculty from both large state institutions and small private institutions. Together, they are developing open-access undergraduate and graduate curricula focused on building energy and performance, integrated with data science and computational skills. By utilizing this diverse group, the project aims to highlight the transformative potential of cross-disciplinary education and issue a call to action for other educators committed to fostering the future workforce in buildings and energy systems.

The current landscape of engineering graduate and undergraduate offerings reflects an evolving yet challenging environment for integrating building energy education (Hong et al, 2018). Most architectural engineering programs include courses related to buildings, building performance, and energy efficiency. However, these courses often have a limited scope due to the demands of an already busy curriculum. While core courses such as thermodynamics and HVAC systems design are staples in undergraduate architectural engineering programs, a noticeable gap exists in the incorporation of data science, building energy modeling, and computation.

Some programs attempt to bridge this gap by offering elective courses that address these competencies. These electives often include computational elements, particularly energy modeling, but there remains a critical need to infuse data science more thoroughly into engineering programs. The challenge is compounded by the diverse backgrounds of students and the varying structures of programs. Although some curricula include a programming course to satisfy ABET requirements, this knowledge is not consistently integrated into subsequent courses. As a result, students may struggle with even basic software tools like Excel when tasked with analyzing building energy data. This limitation underscores the necessity for a gradual transition in curricula to incorporate additional data science competencies without overwhelming the existing structure.

In discussing the pros and cons of computer science courses for building energy engineering students, it is essential to acknowledge our bias as engineering educators.

A significant limitation is the separation of specialized disciplines within energy education, which often results in siloed knowledge and limited exposure to cross-disciplinary perspectives. This fragmentation can impede graduates from addressing real-world energy challenges, which demand holistic solutions. While engineering students may have some exposure to computer science courses, prerequisites and the need for additional deficiency courses can limit their deeper engagement with computer science concepts.

The potential benefits and drawbacks of offering a specific energy data analytics course are noteworthy (Snyder, 2021). Integrating data science and computation into existing curricula is challenging due to the packed nature of these programs, which leaves little room for new courses unless energy data analytics can be incorporated into existing courses. This approach raises the question of how faculty can gain sufficient understanding of data science to integrate it effectively into their courses (Losi et al, 2022). The rapid advancements in data science and computation necessitate ongoing faculty development to keep pace with these changes.

Despite these challenges, there are success stories of students who have benefited from contextualized education in energy and computing. By incorporating data science and computation, students from various disciplines have secured positions and made significant contributions to the emerging and essential field of building analytics. These success stories highlight the positive impact that integrated, interdisciplinary education can have on students' career trajectories and the broader field of building energy efficiency.

2. Project Objectives:

2.1 Impact on National Goals:

The Educational Consortium for Energy-related Data Science & Computation in Building Engineering Programs significantly contributed to national clean energy goals and economic benefits for the U.S. by cultivating a workforce skilled in energy efficiency and advanced building technologies. By integrating cutting-edge computational tools and data science into building engineering education, the project aligned with the Department of Energy's objectives to enhance energy efficiency and promote sustainable building practices. This initiative prepared approximately 1,800 students to enter the workforce with industry-relevant skills, thereby supporting the transition to a clean energy economy. The consortium's efforts to disseminate educational resources nationwide facilitated the widespread adoption of energy-efficient technologies, contributing to reduced energy consumption and emissions in the building sector.

2.2 Project Goals and Expected Outcomes:

The primary goal of the project was to establish a multi-institutional consortium that developed and shared educational resources focused on energy-related data science and computation in building engineering curricula. Key outcomes included the creation of a beta website with accessible datasets and training materials, the development of four

training programs, and the preparation of students for energy simulation and modeling careers. By the end of the project, the consortium had at least 1800 students complete the curriculum, with implementation across four external institutions. These outcomes enhanced the skills of the future workforce, supporting national energy efficiency goals and economic growth.

2.3 Significance, Innovation, and Fundamental Advances:

The project's significance lay in its innovative approach to integrating energy-focused computation and data science into building engineering education. By leveraging DOE-funded simulation tools and real-world datasets, the consortium provided students with practical experience in zero-energy design and intelligent building control systems. This initiative addressed key competency gaps identified by the DOE, such as energy modeling, smart technology integration, and cybersecurity. The project's fundamental advances included the development of a scalable and transferable curriculum that equipped students with the skills needed to drive energy efficiency and sustainability in the building industry. The consortium's collaborative model fostered innovation and ensured that educational resources were accessible to a diverse range of institutions, promoting equity and inclusion in energy education.

2.4 Summary of Tasks and Milestones

The project was structured into two budget periods, each with specific tasks and milestones:

2.4.1 Budget Period 1: Development and Piloting

- **Task 1: Consortium Kickoff Meeting**
 - **Description:** Conducted a kickoff meeting to establish project goals, roles, and agreements among consortium members.
 - **Outcome:** Successfully held the meeting with full participation, setting a strong foundation for collaboration.
- **Task 2: Alpha Website Development**
 - **Description:** Developed an operational alpha website for resource sharing and accessibility.
 - **Outcome:** The website was completed, featuring project objectives, datasets, educational materials, and a Q&A forum. Accessibility was verified using Web Content Accessibility Guidelines.
- **Task 3: Initial Dataset Curation**
 - **Description:** Curated and uploaded initial datasets with metadata and explanatory text.
 - **Outcome:** Two initial datasets were successfully uploaded to the website, meeting quality standards.
- **Task 4: Survey Creation**

- **Description:** Created surveys for students and professors to evaluate curriculum efficacy.
- **Outcome:** Surveys were developed and deployed, collecting valuable feedback for curriculum improvement.
- **Task 5: Initial Training Program Development and Pilot**
 - **Description:** Developed and piloted two training programs and ten modules.
 - **Outcome:** Training programs and modules were implemented and incorporated feedback for refinement.
- **Task 6: Full Dataset Expansion**
 - **Description:** Expanded the number of datasets available on the website.
 - **Outcome:** Successfully uploaded eight additional datasets, exceeding the target.
- **Milestones for Budget Period 1:**
 - **Completion of Alpha Website:** The website was operational and accessible, meeting all initial requirements.
 - **Initial Datasets:** Curated and uploaded, providing foundational data for educational use.
 - **Initial Training Programs:** Developed and piloted, demonstrating effective curriculum delivery.

2.4.2 Budget Period 2: Multi-Institution Program Deployment

- **Task 7: Translation Surveys Implementation**
 - **Description:** Developed and deployed surveys to assess content transferability between institutions.
 - **Outcome:** Surveys were successfully implemented, capturing insights into the effectiveness of content translation.
- **Task 8: Full Training Programs Deployment**
 - **Description:** Deployed training programs and modules across partner institutions.
 - **Outcome:** All training programs were fully implemented, reaching over 1800 students across multiple institutions.
- **Task 9: Train-the-Trainer Documents Development**
 - **Description:** Developed train-the-trainer documents and best practices.
 - **Outcome:** Documents were completed, including self-reflection materials, best practices, and a recorded webinar.
- **Task 10: Implementation Feedback Collection**

- **Description:** Collected evaluation and feedback from program implementation.
- **Outcome:** Feedback from instructors and students was collected and used to enhance educational materials.
- **Task 11: Beta Website Development**
 - **Description:** Updated the website to beta version, incorporating feedback and additional resources.
 - **Outcome:** The beta website was completed, featuring enhanced functionality and additional datasets.
- **Task 12: Project Sustainability and Scaling**
 - **Description:** Developed a sustainability plan to ensure continued use and scaling of project resources.
 - **Outcome:** A sustainability plan was drafted, outlining strategies for ongoing support and dissemination.
- **Milestones for Budget Period 2:**
 - **Completion of Beta Website:** The website was updated with additional datasets and resources, ensuring continued accessibility and usability.
 - **Full Training Programs and Modules:** Deployed across multiple institutions, meeting educational and quality standards.
 - **Train-the-Trainer Documentation:** Developed to support the effective transfer of educational materials between institutions.

Go/No-Go Decision Points

- **Decision Point 1 (End of Budget Period 1):** Evaluated progress, including the completion of 20% of training programs and modules, and assessed curriculum quality. Successfully met all criteria, allowing the project to proceed to the next phase.
- **Decision Point 2 (End of Budget Period 2):** Evaluated the beta website, educational materials, and train-the-trainer documentation, ensuring alignment with project goals and quality standards. All objectives were met, confirming the project's success and readiness for scaling.

3. Project Results and Discussion

3.1 Project Tasks and Milestone Comparison

3.1.1 Budget Period 1: Development and Piloting

Task 1: Consortium Kickoff Meeting

- **Anticipated Outcome:** Conduct a consortium-wide kickoff meeting to establish project goals, roles, and agreements.

- **Realized Outcome:** Successfully held the consortium kickoff meeting with all members present, both virtually and physically. Meeting minutes documented the discussions and agreements reached.

Task 2: Alpha Website Development

- **Anticipated Outcome:** Develop an operational alpha website with functionality and accessibility.
- **Realized Outcome:** Completed the alpha website, which included pages for project objectives, datasets, educational materials, and a Q&A forum. Accessibility was verified using Web Content Accessibility Guidelines.
 - **Milestone M2:** "The website is operational with functionality and accessibility. PSU will provide a live demo to DOE."
 - **Verification:** The alpha website was demonstrated to the DOE, meeting all accessibility and functionality criteria.

Task 3: Initial Datasets Curation

- **Anticipated Outcome:** Upload initial datasets with metadata and explanatory text.
- **Realized Outcome:** Successfully curated and uploaded two initial datasets. Feedback was collected and used to ensure data quality.
 - **Milestone M3:** "Existing Datasets have been uploaded to the website. PSU will provide the link to the data pages."
 - **Verification:** Links to the datasets were provided to DOE, meeting the milestone requirements.

Task 4: Survey Development

- **Anticipated Outcome:** Generate two surveys for students and professors to evaluate curriculum efficacy.
- **Realized Outcome:** Developed and deployed surveys with at least ten questions each. Data was collected and stored securely.
 - **Milestone M4:** "Two surveys will be generated: one for students and a second for professors as part of the consortium. Provide a copy of each survey to DOE."

Task 5: Initial Training Program Development and Pilot

- **Anticipated Outcome:** Develop and pilot two training programs and ten modules.
- **Realized Outcome:** Two training programs and ten modules were developed and piloted, reaching 165 students. Feedback was incorporated to improve content.
 - **Milestone M5:** "All of the training programs and modules presented in Task 5 will be on the website. DOE and the project team will verify the organization and navigability."
 - **Verification:** Links to program and module pages were provided to DOE, and organization and navigability were verified.

Task 6: Full Datasets Expansion

- **Anticipated Outcome:** Expand the number of datasets available on the website.

- **Realized Outcome:** Successfully curated and uploaded additional datasets, exceeding initial targets.

Go/No-Go Decision Point 1:

- **Anticipated Outcome:** Evaluate progress, including the completion of 20% of training programs and modules.
- **Realized Outcome:** Exceeded the 20% completion requirement, with significant progress in program and module development. Survey feedback indicated high curriculum quality.

3.1.2 Budget Period 2: Multi-Institution Program Deployment

Task 7: Translation Surveys Implementation

- **Anticipated Outcome:** Develop and deploy translation surveys to assess content transferability.
- **Realized Outcome:** Translation surveys were developed and deployed, capturing feedback on content transferability between institutions.
 - **Milestone M7:** "Two translation surveys generated: one for students taking part in coursework based off the training program and a second for professors. Provide a copy of each survey to DOE."

Task 8: Full Training Programs Deployment

- **Anticipated Outcome:** Fully deploy training programs and modules across partner institutions.
- **Realized Outcome:** Successfully deployed all training programs and modules, reaching over 1800 students across multiple institutions.
 - **Milestone M8:** "All training programs and training modules will be complete and uploaded to the website. PSU will provide a live demo to DOE."

Task 9: Train-the-Trainer Documents Development

- **Anticipated Outcome:** Develop train-the-trainer documents and best practices.
- **Realized Outcome:** Train-the-trainer documents were developed, including self-reflection materials and best practices.
 - **Milestone M9:** "Train-the-trainer documents on website. Summary feedback from reviewing personnel and link to the webpage provided to DOE."

Task 10: Implementation Feedback Collection

- **Anticipated Outcome:** Collect evaluation and feedback from program implementation.
- **Realized Outcome:** Feedback was collected from over 50% of participating instructors and 10% of students, informing further improvements.
 - **Milestone M10:** "Feedback from a minimum 10% of the students, and from 50% of the other instructors at other universities adapting and teaching either programs or individual modules in their full semester courses will be used to update materials as needed and incorporate them into the website."

Task 11: Beta Website Development

- **Anticipated Outcome:** Update the website to beta version, incorporating feedback and additional resources.
- **Realized Outcome:** The beta website was completed, featuring enhanced functionality and additional datasets.

Task 12: Project Sustainability and Scaling

- **Anticipated Outcome:** Develop a sustainability plan to ensure continued use and scaling of project resources.
- **Realized Outcome:** A sustainability plan was drafted, outlining strategies for ongoing support and dissemination.

Go/No-Go Decision Point 2:

- **Anticipated Outcome:** Evaluate the beta website, educational materials, and train-the-trainer documentation.
- **Realized Outcome:** Successfully evaluated and updated the beta website and materials, ensuring alignment with project goals and quality standards.

3.2 Project Tasks and Milestone Comparison

The project utilized a combination of curriculum development, dataset curation, and feedback collection methodologies. The alpha and beta websites were developed using web development best practices, ensuring accessibility and ease of use. Data quality was assessed using established metrics, and curriculum quality was evaluated based on feedback from surveys and stakeholder reviews. The project team maintained regular communication through biweekly meetings and utilized project management tools to track progress and address any challenges. Supporting documentation, including survey results, feedback summaries, and links to the educational materials and datasets, is available upon request. This documentation provides detailed evidence of the successful completion of project milestones and objectives.

4. Significant Accomplishments and Conclusions:

4.1 Outcomes:

4.1.1 Positive Outcomes:

4.1.1.1 Establishment of a Multi-Institutional Consortium: The successful formation of a consortium that included nine universities and one national laboratory was a key achievement, as it enabled the pooling of resources, expertise, and best practices, significantly enhancing the project's reach and impact. These partners included:

- The Pennsylvania State University (PSU)
- Missouri University of Science & Technology (MST)

- National Renewable Energy Laboratory (NREL)
- Illinois Institute of Technology (IIT)
- George Mason University (GMU)
- Oklahoma State University (OSU)
- University of New Mexico (UNM)
- The University of Texas at Austin (UT)
- The University of Miami (UM)
- Tennessee State University (TSU)

This collaboration facilitated the development and dissemination of innovative educational materials, reaching over 1800 students and preparing them for careers in energy simulation and modeling.

4.1.1.2 Comprehensive Curriculum Development: The creation of full training programs and standalone modules provided students with practical experience in energy-related data science and computational tools, marking a significant achievement. These educational resources were integrated into building engineering curricula across multiple institutions. This curriculum addressed key competency gaps in the industry, equipping students with the skills necessary for advancing energy efficiency and sustainability in the building sector. Below is an overview of the training programs available:

REVIT: This program consists of 4 lessons and 4 files, providing an in-depth exploration of Revit modeling for buildings. Students learn about creating building information models (BIM), modeling building elements, adding annotations and dimensions, and generating construction documentation.

Acoustics: With 8 lessons and 11 files, this program helps students understand how acoustics impacts building performance and teaches them to design buildings that meet desired acoustic outcomes.

Energy Conservation in Buildings: This extensive course contains 20 lessons and 17 files, focusing on sustainability in design. Students learn to calculate building heating and cooling loads, develop skills in sustainable building design using LEED codes and ASHRAE standards, and gain experience in project design and energy analysis using computer-based energy simulation methods.

Load and Energy Use Simulations for Buildings: Comprising 21 lessons and 61 files, this course provides fundamental knowledge and understanding of methods and computational tools used in predicting and determining energy use of whole buildings and important subsystems.

HVAC: This program offers 6 lessons and 8 files of standalone training modules for instruction in Heating, Ventilation, and Air Conditioning.

Daylighting: With 5 lessons and 6 files, this collection focuses on the principles and practices of building daylighting, including strategies for optimizing natural light

in buildings, the impacts of daylight on human health and well-being, and the role of daylighting in sustainable design.

Building Energy Conservation Techniques: This course consists of 20 lessons and 21 files, aiming to enable students to analyze energy consumption patterns in buildings.

Parametric Modeling: Featuring 20 lessons and 56 files, this course provides students with fundamental knowledge of parametric thinking, visual programming, and data management for applications in architectural engineering

Heating and Cooling Loads: This collection of 4 lessons and 8 files covers the fundamental principles and calculations involved in determining heating and cooling loads in buildings, including heat transfer, load calculation methods, psychrometrics, and HVAC system design.

Building Information Modeling: With 20 lessons and 37 files, this course aims to provide students with fundamental knowledge of BIM/BEM applications throughout a project's lifecycle, focusing on data management and developing skills for data extraction, analysis, and visualization for multi-disciplinary requirements.

Intro to Programming and Computation for Architectural Engineers: This course, consisting of 20 lessons and 46 files, provides students with fundamental knowledge of programming and data science applicable to a broad set of problems in architectural engineering.

4.1.1.3 Development of an Accessible Educational Platform: The alpha and beta websites provided a centralized platform for educational resources, including datasets, and training materials which was a significant accomplishment. The website provides access to various datasets intended for training engineering students in energy-related topics. The datasets encompass a range of simulations and analyses aimed at understanding energy use in both commercial and residential buildings across the United States. The End Use Load Profiles for Commercial Buildings dataset includes baseline 15-minute data simulations of hundreds of thousands of commercial buildings, representing the current condition of the US building stock. It also includes a version with heat pump RTUs (Rooftop Units) added, allowing for a comparative analysis of energy use before and after this modification. Additionally, this dataset provides annual data for commercial buildings with various energy-saving measures applied, enabling detailed analysis of potential energy savings. Similarly, the End Use Load Profiles for Residential Buildings dataset offers baseline 15-minute data simulations of residential buildings, along with a version showing the impact of adding heat pump RTUs. It also includes annual data for residential buildings with different energy-saving measures applied. Other datasets include the Bar Typical Secondary School, an OpenStudio Analysis focusing on the parametric analysis of envelope form and characteristics for secondary schools, and the National Solar Radiation Database, which provides a collection of meteorological and

solar irradiance data. The PV Data dataset consists of information from experimental and commercial public PV sites. Additionally, the Educational Surveys dataset includes a collection of surveys used throughout the project to gather educational data. The Building Type Characteristics in Selected Public Use Microdata Areas (PUMAs) dataset offers detailed information on building type, size, and vintage mix across nine metro areas, with data sourced primarily from the American Community Survey. Lastly, the Teach the Teacher dataset comprises worksheets designed for instructors, aimed at enhancing teaching practices and promoting inclusivity in education.

The document titled "Teach the Teacher" is an educational resource designed to assist educators in recognizing and addressing biases in their teaching practices, specifically within the context of teaching data science and computational tools for building energy topics. It aims to promote inclusivity and equity in the classroom by providing educators with tools and strategies for self-reflection and critical examination of their teaching methods. The document begins with a preface that acknowledges the inherent biases all educators bring into the classroom. It emphasizes the importance of recognizing these biases to create more inclusive and equitable learning environments. The preface clarifies that the worksheets are framed with the assumption of bias as a starting point, encouraging educators to proactively engage in self-reflection and critical examination of their teaching practices. The goal is to empower educators with the tools and strategies needed to mitigate biases and promote inclusivity and equity. The document includes three worksheets, each designed to guide educators through different aspects of bias recognition and mitigation.

Worksheet 1: Recognizing and Mitigating Biases in Teaching Computational Science for Building Energy Topics aims to help educators reflect on their own biases and their impact on teaching computational science. The worksheet is structured in two parts. Part 1 focuses on identifying personal biases, stereotypes, and assumptions about students, encouraging educators to consider how these factors might influence their teaching methods and interactions. Part 2 provides strategies for mitigating these biases, offering guidance on how to make teaching more inclusive and how to engage in meaningful self-reflection. The worksheet includes references to the Implicit Association Test (IAT) as a tool for raising awareness of implicit biases, and it cites an article by the National Education Association that discusses effective teaching frameworks, providing educators with additional resources for developing their teaching practices.

Worksheet 2: Exploring Bias and Equity in Teaching Data Science for Building Energy: Scenarios and Reflections encourages self-reflection and critical thinking regarding potential biases and challenges in teaching data science and computation. The worksheet presents various scenarios that explore biases in teaching, such as balancing sustainability values, encouraging participation among students, and developing equitable assessment strategies. Through these scenarios, educators are prompted to consider the complexities of teaching data science, emphasizing the importance of promoting equity and the need for ongoing reflection and adaptation of teaching practices. This worksheet serves as a tool for

educators to examine their teaching environments and make adjustments to foster a more inclusive atmosphere.

Worksheet 3: Enhancing Inclusivity and Equity in Individual Lessons guides educators in critically examining and improving individual lessons to promote inclusivity and equity. The worksheet is divided into three parts. Part 1 focuses on identifying potential biases in learning objectives, instructional materials, and assessment methods. Part 2 suggests strategies for improving lesson content, supporting diverse learning styles, promoting engagement, and ensuring assessment equity. Part 3 encourages reflection and action, prompting educators to continuously improve lessons and evaluate the effectiveness of changes made. The key takeaways highlight the importance of lesson-specific improvements, adaptation of content to accommodate diverse student backgrounds, and ongoing reflection to create an inclusive learning environment. This worksheet provides a structured approach for educators to enhance their teaching practices and ensure that all students have equal opportunities to succeed.

4.1.2 Negative Outcomes:

4.1.2.1 Challenges in Dataset Curation: Curating and uploading datasets proved more challenging than anticipated due to data quality issues and the need for extensive metadata documentation, which was a significant hurdle. Although all targeted datasets were eventually uploaded, the process required additional time and resources, which delayed some aspects of the project.

4.1.2.2 Variability in Institutional Adoption: While the curriculum was successfully implemented at several institutions, some encountered difficulties integrating the new materials due to existing course structures and faculty resistance, which was a significant challenge. This variability highlighted the need for more holistic train-the-trainer documentation and support systems to facilitate smoother transitions.

4.2 Challenges and Lessons Learned

4.2.1 Data Quality and Integration: Ensuring the quality and relevance of datasets for educational use was a significant challenge, as initial datasets required extensive cleaning and documentation to be effectively integrated into training programs. The lesson learned is that future projects should allocate more time and resources for data preparation and consider establishing partnerships with data providers early in the project timeline to streamline this process.

4.2.2 Institutional Resistance to Change: Some institutions were hesitant to adopt new curricula due to entrenched teaching methods and curricular structures, presenting a significant challenge. The lesson learned is that providing train-the-trainer materials and ongoing support is important. Engaging faculty early in the development process and highlighting the benefits of new educational approaches can help mitigate resistance.

4.2.3 Technical and Logistical Hurdles: Developing and maintaining a user-friendly and accessible website required overcoming technical challenges, including ensuring compliance with accessibility standards. The lesson learned is that investing in skilled web development and accessibility expertise from the outset can prevent delays and ensure the platform meets user needs.

5. Path Forward:

Future research and development efforts will focus on enhancing and expanding the existing curriculum to include emerging topics in energy-related data science and computational tools. This will involve updating training materials to reflect the latest advancements in technology and industry practices, such as integrating artificial intelligence and machine learning applications in energy management. There are plans to develop advanced modules that dive deeper into specialized areas such as smart grid technology, renewable energy integration, and advanced building simulation techniques. These modules will aim to provide students with cutting-edge knowledge and skills that are directly applicable to current industry needs. Establishing partnerships with industry leaders will be a key focus to ensure that the curriculum remains relevant and aligned with real-world applications. These collaborations could involve joint research projects, internships, and guest lectures, providing students with valuable industry insights and experience.

The educational platform developed during the project can be further enhanced and marketed as an open-access resource for educational institutions worldwide. This would involve promoting the platform through academic conferences, workshops, and online channels to increase its visibility and adoption. The consortium could pursue collaborative research initiatives with other academic and research institutions to further explore and develop innovative educational methodologies and technologies. The next steps in research and development should focus on integrating emerging technologies such as the Internet of Things (IoT) and blockchain into the curriculum. These technologies have the potential to revolutionize energy management and efficiency, and their inclusion in the curriculum would prepare students for future industry challenges. Collecting and analyzing feedback from students, faculty, and industry partners will be important for refining the curriculum. This iterative process will ensure that the educational materials remain relevant and effective. Additionally, exploring the use of virtual and augmented reality in educational settings could provide immersive learning experiences for students, particularly in demonstrating complex energy systems and simulations.

Ensuring the continued quality and accessibility of datasets remains a technical risk. Maintaining up-to-date and relevant data will require ongoing partnerships with data providers and investment in data management infrastructure. Some institutions may continue to resist adopting new curricula due to entrenched teaching methods. Overcoming this barrier will require ongoing engagement with faculty and demonstrating the tangible benefits of the updated curriculum. Scaling the educational platform to accommodate a larger user base could present technical challenges. Ensuring the platform's infrastructure can support increased traffic and user interactions will be essential for successful commercialization. Securing funding and resources for continued

research and development could be a barrier. Pursuing grants, partnerships, and other funding opportunities will be necessary to advance the technology and expand its reach. By addressing these challenges and pursuing the outlined R&D steps, the project can continue to evolve and contribute significantly to the field of energy-related data science and computational education.

6. Products:

Website: <https://sites.psu.edu/benefit/>

7. Project Team and Roles:

Participant	Institution	Role / Contribution
Dr. Rebecca Napolitano	The Pennsylvania State University	As the Principal Investigator, Rebecca Napolitano was responsible for overseeing the overall management of the project, coordinating consortium activities, and contributing to the development of one of the training programs focused on computational and data science in architectural engineering.
Dr. David Goldwasser	NREL	David Goldwasser provided essential datasets for the project and assisted in curriculum development. His role included offering guidance on using energy modeling tools and best practices for teaching energy-related data science.
Dr. Zufen Wang	Tennessee State University	Dr. Wang focused on incorporating smart building controls into the curriculum. She contributed to the creation of training modules that addressed the integration of these technologies in building energy management.
Dr. Mohammad Heidarinejad	Illinois Institute of Technology	Heidarinejad was involved in developing training modules related to building energy modeling and efficiency. His expertise in energy analysis and simulation was important for ensuring the curriculum met industry standards.
Dr. Greg Pavlak	The Pennsylvania State University	Pavlak developed training programs and modules related to data analytics and simulation for energy grids and mechanical systems. He played a significant role in ensuring that the educational materials were aligned with current industry practices.
Dr. Nathan Brown	The Pennsylvania State University	Brown was responsible for developing modules on parametric design and

		optimization. His work helped students learn how to apply computational tools to improve energy efficiency and sustainability in building design.
Dr. Yuqing Hu	The Pennsylvania State University	Hu contributed to the curriculum by focusing on Building Information Modeling (BIM) and Building Energy Modeling (BEM). She helped integrate these technologies into the training programs to enhance students' understanding of energy efficiency in buildings.
Dr. Ryan Solnosky	The Pennsylvania State University	Solnosky focused on computer modeling and provided expertise in developing educational materials that incorporated these techniques into the curriculum, enhancing students' practical skills.
Dr. Gang Wang	University of Miami	Wang contributed to the project by developing modules related to sensors and HVAC systems. His work ensured that students gained hands-on experience with technologies critical to building energy management.
Dr. Stuart Baur	Missouri University of Science and Technology	Baur worked on modules related to solar energy and energy modeling. He helped integrate renewable energy concepts into the curriculum, broadening students' understanding of sustainable energy solutions.
Dr. Fernando Moreu	University of New Mexico	Moreu was responsible for adapting and implementing training modules at his institution. He provided feedback on the translation process and helped refine the materials for broader use.
Dr. David Lattanzi	George Mason University	Lattanzi contributed by implementing the curriculum and providing insights into digital twins and life-cycle management, enriching the educational content with advanced engineering concepts.
Dr. Kahled Mansy	Oklahoma State University	Mansy focused on sustainable architecture and helped adapt the curriculum to include these principles. His contributions ensured that the materials were relevant to architectural education.
Dr. Atila Novoselac	University of Texas at Austin	Novoselac played a role in implementing the curriculum and offering feedback on building energy analysis. His expertise helped ensure

		the training programs were applicable to real-world scenarios.
Jonathan Broyles	The Pennsylvania State University	Facilitated generation of curriculum as well as instruction.
Borna Farnod	The Pennsylvania State University	Facilitated generation of curriculum as well as instruction.
Joe Kallas	The Pennsylvania State University	Facilitated generation of curriculum as well as instruction.
Saanchi Kaushal	The Pennsylvania State University	Facilitated generation of curriculum as well as instruction.
Daniele Melo Santos Paulino	The Pennsylvania State University	Facilitated generation of curriculum as well as instruction.
Muhammad Rakeh Saleem	The Pennsylvania State University	Facilitated generation of curriculum as well as instruction.

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