GRANT AGREEMENT

RIVERSIDE PUBLIC UTILITIES
ENERGY INNOVATIONS GRANT PROGRAM

(Coordinated Energy Management in Net Zero Buildings)

THIS AGREEMENT is made and entered into this _____ day of ______________, 2016 by and between the CITY OF RIVERSIDE, a California charter city and municipal corporation ("City"), through its Department of Public Utilities ("RPU"), and THE REGENTS OF THE UNIVERSITY OF CALIFORNIA, ON BEHALF OF ITS RIVERSIDE CAMPUS, a California non-profit corporation ("Recipient"), with reference to the following:

RECITALS

WHEREAS, California Public Utilities Code ("Code") Section 385 provides that a local publicly-owned utility shall establish a non-bypassable, usage-based charge on local distribution service to fund investments by the utility and other parties in (1) cost-effective, demand-side, management services to promote energy-efficiency and energy conservation; (2) new investment in renewable energy resources and technologies consistent with existing statutes and regulations which promote those resources and technologies; (3) research, development, and demonstration programs for public interest to advance science or technology which is not adequately provided by competitive and regulated markets; and (4) services provided for low-income electricity customers, including but not limited to, targeted energy efficiency and rate discounts; and

WHEREAS, RPU has funds available pursuant to the requirements of Code Section 385 for the purpose of providing financial funding to its public and private post-secondary educational institution electric customers, whose primary activities are within the city limits of Riverside, for the purpose of promoting the development and demonstration of energy-efficiency, energy conservation, and investment in the advancement of renewable energy resource technology hereinafter referred to as the Energy Innovations Grant Program (the "Program"); and

WHEREAS, Recipient has submitted its Application and Proposal to RPU requesting funding from RPU's 2016-2017 Program, as set forth in Code Section 385 (the "Proposal"); and

WHEREAS, following screening by the RPU Program Committee and recommendation by the Board of Public Utilities and the City Council of the City of Riverside ("City Council"), the

"Coordinated Energy Management in Net Zero Buildings" project ("Grant Project") was selected for funding.

NOW, THEREFORE, in consideration of the mutual covenants herein set forth and the mutual benefits to be derived therefrom, the City and Recipient mutually agree as follows:

1. Grant Award. City hereby allocates to Recipient the amount of $100,000 (the "Grant") for development and implementation of Recipient's Grant Project, for the purpose and subject to the terms hereinafter set forth. The Grant funds ("Grant Funds") will be paid from available RPU Program funds for the fiscal year 2016-2017.

2. Scope of Services. The Grant Funds shall be used in furtherance of the purposes set forth in Code Section 385 to develop and implement the Grant Project as more fully set forth in Recipient's Proposal attached hereto as Exhibit "A" and incorporated herein by this reference.

3. Independent Contractor.

a. Recipient is a California corporation and an electric customer whose primary activities are within the city limits of Riverside. All acts of Recipient and all others acting on behalf of Recipient relating to the performance of this Agreement shall be performed as independent contractors and not as agents, officers, or employees of City. Recipient, by virtue of this Agreement, has no authority to bind or incur any obligation on behalf of City. Recipient has no authority or responsibility to exercise any rights or power vested in City. No agent, officer, or employee of City is to be considered an employee of Recipient. It is understood by both Recipient and City that this Agreement shall not under any circumstances be construed or considered to create an employer-employee relationship or a joint venture.

b. Recipient is, and at all times during the term of this Agreement shall represent and conduct itself as, an independent contractor and not as an employee of City.

c. Recipient shall design, develop, and implement the Grant Project in its entirety. Recipient shall be responsible to City only for the requirements and results specified in the Proposal and, except as expressly provided in this Agreement, shall not be subjected to City's control with respect to determination of the Grant Project, selection of materials or the methods for completion. However, Recipient agrees to be responsible to City for all of the foregoing with respect to the Proposal and description of the Grant Project under this Agreement.

d. If necessary, Recipient has the responsibility for employing other persons or firms at its sole cost to assist Recipient in fulfilling the terms and obligations under this Agreement.

e. If, in the performance of this Agreement, any third persons are employed by Recipient, such persons shall be entirely and exclusively under the direction, supervision, and control of Recipient. All terms of employment including hours, wages, working conditions, discipline, hiring, and discharging or any other term of employment or requirements of law shall be determined by Recipient.

f. It is understood and agreed that as an independent contractor and not an employee of City, neither Recipient nor Recipient's assigned personnel shall have any entitlement as a City employee, right to act on behalf of the City in any capacity whatsoever as an agent, or ability to bind the City to any obligation whatsoever.

g. It is further understood and agreed that Recipient must issue W-2 or other tax forms as required by law for income and employment tax purposes for all of Recipient's assigned personnel under the terms of this Agreement.

h. As an independent contractor, Recipient hereby indemnifies and holds City harmless from any and all claims that may be made against City based upon any contention by any third party that an employer-employee relationship exists by reason of this Agreement.

4. <u>Effective Date and Funding of Grant</u>.

a. This Agreement shall commence upon the date of its execution ("Effective Date") and shall terminate twelve (12) months from the date of Grant Project Initiation, as defined in Section 4.b ("Termination Date"), unless extended pursuant to Section 4.c or Section 6.

b. City shall provide Recipient the Grant Funds in three installments in accordance to the Milestone Schedule below. Recipient must achieve each Milestone Deliverable on or prior to the corresponding Milestone Date to be eligible for funding:

Milestone Due Dates	Milestone Deliverables	Grant Funds
1st Update report due end of 6th month	**<u>Grant Project Initiation</u>:** Submit to City a Certification of Project Initiation **Milestone 1** (1st month – 6 months) Modeling and design of online energy management algorithm for net-zero mixed-use building	$50,000
2nd Update report due end of 9th month	**Milestone 2** (7th month – 9 months) Development of simulation platform for evaluating the proposed energy management algorithm	$25,000
Final report due end of 12th month	**Milestone 3** (10th month – 12months) Evaluation results and project final report	$25,000

c. If Recipient fails to achieve any one Milestone by the applicable Milestone Date therefor, Recipient shall immediately notify City of such failure and may request a Cure Period of up to thirty (30) days to achieve the missed Milestone. The requested Cure Period must be approved by City, and such approval shall not be unreasonably withheld, delayed or conditioned. For the avoidance of doubts, each Milestone Date in the Milestone Schedule may be extended by a maximum of thirty (30) days, and without prejudice to City's rights to terminate this Agreement under Section 20, all Milestone Dates subsequent to the missed Milestone Date as well as the Termination Date of this Agreement shall be extended accordingly on a day-to-day basis, *provided* that in no event shall the Termination Date of this Agreement be later than September 1, 2017.

d. The Grant Funds check will be issued to Recipient as named in Exhibit "A."

e. City reserves the right, in its discretion, to award a portion of the requested Grant Funds.

5. <u>Performance</u>.

a. Recipient shall perform in accordance to the Milestone Schedule in Section 4.b. Failure to promptly commence work and/or diligently pursue such work to completion may be grounds for termination of this Agreement.

b. Recipient shall be responsible to begin, proceed with, and complete the Grant Project according to the Milestone Schedule in Section 4.b and quarterly tasks completion deadline as set forth in the Project Timeline included in the Proposal.

c. For the Term of this Agreement, Recipient shall make its facility available for City's inspection of the Grant Project any time upon City's request.

d. If Recipient fails to meet a Milestone listed in the Milestone Schedule in Section 4.b by the end of the requested Cure Period, City may, at its sole discretion, terminate this Agreement pursuant to Section 19.a. In the event of such termination, Recipient agrees to return all previously released Grant Funds back to City within five (5) days of receipt of City's written termination notice.

e. Releasing of Grant Funds for the following Milestones will depend on Recipient meeting certain performance criteria detailed in Performance Standards attached hereto as Exhibit "D" and incorporated herein by this reference:

i) Grant Project Completion

ii) Quarterly Report I

iii) Quarterly Report II

iv) Final Report

6. Extension. This Agreement may be extended from time to time, with mutual consent from both Parties, by quarterly increments following the completion of Quarterly Report II, *provided,* such extension shall be agreed upon, along with new Milestones for the duration of the extension, sixty (60) days prior to the original Termination Date.

7. Project Budget.

a. Recipient hereby certifies and agrees that the Grant Funds it receives shall be used entirely as set forth in the Project Budget attached hereto as Exhibit "B" and incorporated herein by this reference ("Budget").

b. The Grant Funds represents the City's total contribution to the Grant Project.

c. Recipient agrees that any amounts required to complete the Grant Project over and above the Grant Funds will be paid by Recipient.

d. Recipient agrees funds over and above the Grant are available so as not to delay completion of the Grant Project due to insufficient Project funding.

e. Recipient agrees to keep within the Budget, and any variations from the Budget will be reported to RPU.

f. Recipient agrees to pay for all costs necessary to operate and maintain the Grant Project for the term of this Agreement.

g. Recipient agrees to pay for all costs necessary to operate and maintain the Grant Project for the term of this Agreement.

8. Use of Grant.

a. The Grant Funds shall be used exclusively for costs of the Grant Project as set forth in the Proposal and the Budget.

b. Grant Funds shall not be used for any other purpose, including within limitation:

(i) As security or to guarantee payments for any non-Program obligations, nor as loans for non-Program activities; or

(ii) To pay for entertainment, meals, or gifts.

9. Intellectual Property Provisions. Recipient and RPU agree that all patents, software and copyrightable material shall be subject to the Intellectual Property Provisions attached hereto as Exhibit "C" and incorporated herein by this reference.

10. No Assignment or Transfer of Grant Funds. The Grant Funds are personal to Recipient, based upon the unique qualification of Recipient set forth in the Proposal and are for the purpose of accomplishing the goals set forth in the Proposal. Recipient shall not assign any right or obligation under this Agreement, and any such purported Assignment shall be void *ab initio*.

11. Transfer of Project Equipment.

a. For any Grant Proposal that provides for the development, purchase, or installation of equipment paid for in whole or in part by Grant Funds:

(i) Recipient shall install and operate the equipment only at Recipient's business location within City's utility service territory; and

(ii) Recipient shall not remove or transfer any equipment developed, purchased, or installed, in whole or in part, with Grant Funds within five (5) years of the Effective Date, without the express written consent of City. City reserves the right to withhold such consent.

b. Recipient agrees that if it removes or transfers such equipment without City's consent as required herein, Recipient shall reimburse City the costs of equipment purchased, developed, or installed by Grant funding, proportionately as follows:

(i) Transfer or removal within first year from Effective Date—100%

(ii) Transfer or removal within second year from Effective Date—80%

(iii) Transfer or removal within third year from Effective Date—60%

(iv) Transfer or removal within fourth year from Effective Date—40%

(v) Transfer or removal within fifth year from Effective Date—20%

12. Final Report. Recipient shall prepare and submit to City a final report on or prior to the Termination Date. The final report shall include: title page, introduction and background, project objectives, project performance (including results of energy-savings monitoring), project expenses (including receipts) and project time line, conclusions, and recommendations.

13. Interim Grant Project Changes. Recipient shall promptly notify City in writing of any and all proposed Grant Project changes. Grant Project changes must be pre-approved by RPU and must be consistent with the purpose and scope of the Grant Project. A detailed description of Grant Project changes and impacts to the project schedule and/or Budget must be provided to RPU and approved prior to any changes to all or art of the Grant Project.

14. Program Monitoring.

a. Recipient shall maintain financial, programmatic, statistical, and other supporting records of the Grant Project feasibility study, design, development, installation, implementation, purchase of equipment, and energy-saving results. In addition, Recipient shall prepare and maintain the following records and reports to assist City in maintaining its record keeping requirements:

(i) Documentation of Grant Project expenses;

(ii) Documentation of energy use and energy cost-saving information, including a comparison of Recipient's energy consumption prior to implementation of the Grant Project, future estimated energy consumption, and estimated energy cost savings over a one-year period and a five-year period, as well as documentation of developmental concepts promoting energy conservation;

(iii) Quarterly progress reports on Grant Project deadlines as defined in Proposal; and

(iv) Any other related records and reports as City shall require from time to time.

b. Failure to keep and provide such records and reports may result in demand for return of Grant Funds to City.

15. Audits.

a. The Recipient's records in connection with the Grant Project shall be open to inspection and audit by an authorized City representative.

b. Said records shall be retained for no less than three (3) years after completion of the Grant Project.

c. Records which relate to (i) complaints, claims, administrative proceedings, or litigation arising out of the performance of this Agreement or (ii) costs and expenses of this Agreement to which City or any other governmental agency takes exception, shall be retained beyond the three (3) years until resolution or disposition of such appeals, litigation claims, or exceptions.

16. Taxes and License. Recipient understands and agrees that City has no obligation to pay or withhold state or federal taxes or to provide workers' compensation or unemployment insurance. Recipient, as an independent contractor, shall be responsible for any and all taxes that apply to it as an employer.

17. Publicity. The City acknowledges that the name "University of California" is the property of the State of California and that City's use of the name "University of California" must also comply with section 92000 of the California Education Code. Recipient agrees to cooperate with the City in publicizing, advertising, or otherwise promoting the Program or Grant Project in accordance with the California Education Code section 92000.

18. General Compliance with Laws. Recipient shall keep fully informed of federal, state, and local laws and regulations which in any manner affect the performance of services by Recipient pursuant to this Agreement and shall at all times observe and comply with all such laws and regulations.

19. Non-Discrimination. Except as provided in Section 12940 of the California Government Code, during Recipient's performance of this Agreement, Recipient shall not discriminate on the grounds of race, religious creed, color, national origin, ancestry, age, physical disability, mental disability, medical condition including the medical condition of Acquired Immune Deficiency Syndrome (AIDS) or any condition related thereto, marital status, sex or sexual

orientation, genetic information, gender, gender identity, or gender expression, in the selection and retention of employees and subcontractors and the procurement of materials and equipment. Contractor shall also comply with the requirements of the Americans with Disabilities Act in the performance of the Agreement.

20. Termination.

a. In the event of a substantial failure of performance by Recipient, City may terminate this Agreement upon a ten (10) day written notice to Recipient. The ten-day notice period shall be used by both parties in an attempt to negotiate resolution of disputes and remedy any breach.

b. In the event of a material breach of this Agreement by Recipient, City may terminate this Agreement and Recipient agrees to refund the Grant Funds to City within five (5) days of receipt of the City's written notice of such termination. Recipient agrees that any of the following, individually or collectively, shall be conclusively deemed a material breach or breaches of the Agreement:

(i) Recipient's fraudulent misrepresentation as to Recipient's use of the Grant Funds or as to any material matter in the Grant application and Proposal;

(ii) Delay in beginning, development, or completion of the Grant Project without written approval of extensions by RPU's General Manager; or

(iii) Substantial changes in the Grant Project or use of Grant Funds.

20. Contract Administration. A designee of City will be appointed in writing by City's Public Utilities General Manager to administer this Agreement on behalf of City and shall be referred to herein as Contract Administrator.

21. Certifications. Recipient certifies to City that Recipient will select equipment or products on the basis of Recipient's own investigation including without limitation as to the effectiveness, merchantability, and fitness of the equipment or products for the Grant Project and that Recipient has not relied on any statement by City or an agent of City in making such selection.

22. Amendments. This Agreement may be modified or amended only by a written agreement executed by the City and Recipient.

23. Venue. Any action at law or in equity brought by either of the parties hereto for the purpose of enforcing a right or rights provided for by this Agreement shall be tried in a court of

competent jurisdiction in the County of Riverside, State of California, and the parties hereby waive all provisions of law providing for a change of venue in such proceedings to any other county.

24. Notices. Service of any notices, bills, invoices, or other documents required or permitted under this Agreement shall be sufficient if sent by one party to the other by United States mail, first class postage prepaid and addressed as follows:

City of Riverside	Recipient
City of Riverside Department of Public Utilities 3750 University Avenue Riverside, CA 92501 Attention: Lynn Scott Account Manager/Producer	University of California, Riverside Office of Research and Economic Development 200 University Office Building Riverside, CA 92521-0217 Attn: Tim LeFort Principal Sponsored Programs Officer

Either party may change such address by giving notice to the other party in writing herein.

25. Assignment. It is mutually understood and agreed that this Agreement shall not be assigned to any third party by either City or Recipient.

26. Severability. Each provision, term, condition, covenant, and/or restriction, in whole and in part, in this Agreement shall be considered severable. In the event any provision, term, condition, covenant, and/or restriction in this Agreement is declared, in whole and/or in part, invalid, unconstitutional, or void for any reason, such provision or part thereof shall be severed from this Agreement and shall not effect any other provision, term, condition, covenant, and/or restriction of this Agreement, and the remainder of the Agreement shall continue in full force and effect.

27. Authority. The individuals executing this Agreement and the instruments referenced herein on behalf of Recipient each certifies that they have the legal power, right, and actual authority to bind Recipient to the terms and conditions hereof and thereof.

28. Entire Agreement. This Agreement constitutes the final, complete, and exclusive statement of the terms of the agreement between the parties pertaining to the subject matter of this Agreement and supersedes all prior and contemporaneous understandings or agreements of the parties. Neither party has been induced to enter into this Agreement by, and neither party is relying on, any representation or warranty outside those expressly set forth in this Agreement.

29. Exhibits. The following exhibits attached hereto are incorporated herein to this Agreement by this reference:

Exhibit "A" – Recipient's Proposal

Exhibit "B" – Project Budget

Exhibit "C" – Intellectual Property Provisions

Exhibit "D" – Performance Standards

(Signatures on Following Page)

IN WITNESS WHEREOF City and Recipient have caused this Agreement to be duly executed on the day and year first above written.

CITY OF RIVERSIDE, a California charter city and municipal corporation, through its Department of Public Utilities

By: ______________________
City Manager

Attest: ______________________
City Clerk

Approved as to Form:

By: Susan Wilson
Assistant City Attorney

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA, ON BEHALF OF ITS RIVERSIDE CAMPUS, a California non-profit corporation

By: ______________________
Tim LeFort

Its: Principal Sponsored Programs Officer

By: ______________________

Its: ______________________

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EXHIBIT "A"

Recipient's Proposal

Coordinated Energy Management in Net-Zero Mixed-Use Buildings

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Executive Summary

As typical complex facilities, both datacenters and buildings are energy-intensive and have received a significant amount of attention to optimize energy efficiency in the past. The majority of datacenters are physically located within *mixed-use buildings* that include both datacenter operation and a significant space for other non-datacenter usage (e.g., office). Nonetheless, the existing efforts on datacenter energy efficiency have dominantly centered around *dedicated* datacenter, which by itself is a stand-alone building where all the spaces and supporting infrastructure (e.g., cooling, electrical) are directly associated with datacenter. On the other hand, the vast literature on building energy efficiency has been focused on non-datacenter load (e.g., office HVAC— heating, ventilating, and air conditioning), while treating datacenters as "miscellaneous" loads and ignoring the high scheduling flexibilities associated with datacenter workloads. Consequently, such isolated/uncoordinated energy management fails to jointly manage datacenters and non-datacenter functionalities in mixed-use buildings, thereby resulting in many undesired outcomes (e.g., high peak demand).

This project proposes a new coordinated approach to optimize energy consumption for cost saving in mixed-use buildings that have both datacenter operation and other non-datacenter usage as an integrated cyber-physical system. Specifically, we aim at studying the following question: **how to minimize the building's energy cost while satisfying "net-zero"?** "Net-zero" is an important goal that many buildings, including mixed-use buildings with datacenter operation, are increasingly seeking, as mandated by government regulations and/or in pursuit green certifications (e.g., LEED) which bring tax/zoning benefits.

The key idea in this project is to holistically manage datacenter loads and non-datacenter loads in concert with each other, which have their own dynamics (e.g., computing load dynamics and temperature dynamics). By doing so, the mixed-use building can effectively reduce the building-level peak power demand and also maximizing the utilization of on-site renewables (if any), thus reducing the energy bill and achieving "net zero". Towards this end, we propose a coordinated *software-based* online energy management approach, with a salient feature being that it optimizes the energy consumption decisions without foreseeing the far future information. Our new algorithm can be **integrated with the existing building energy management system (BEMS) as an add-on control module without any infrastructure upgrades, climate/location requirement or heavy capital investment.**

This project benefits numerous mixed-use buildings served by the Riverside Public Utilities (RPU) which can improve energy efficiency and reduce energy cost by integrating our control module without infrastructure upgrade or capital investment. Note that dedicated datacenters or buildings can also benefit from this project, as they are special cases of mixed-use buildings (i.e., with a single use rather than mixed uses). Further, RPU can also better manage the peak power usage across the region by installing the developed automated energy management system for load-side management while minimizing the inconveniences caused to mixed-use building customers due to temporary energy shedding. Last but not least, this project is an integral component of the UCR's commitment to sustainability, benefiting the university in sustainability education and research.

Background and Objective

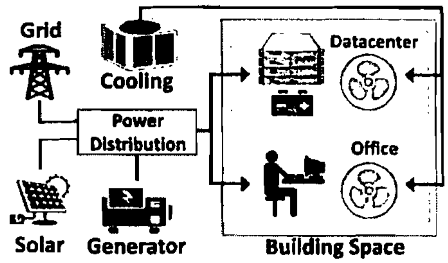


Figure 1: Illustration of a mixed-use building with datacenter and office.

Commercial and institutional buildings account for 18% energy usage in the United States. Most buildings include a combination of multiple distinct uses, such as computing, office, lab, industrial, among others. Although the results in this project also apply to dedicated buildings or datacenters (which are both special cases of mixed-use buildings), for generality, we explicitly focus on mixed-use building that includes datacenter operation as well as a *significant* space for *non-datacenter* functions. Typically, the large non-datacenter space in a mixed-use building is for office, which we consider as the default function unless otherwise stated. Throughout the proposal where applicable, "mixed-use building" is sometimes used to refer to our concentrated type of mixed-use building that has datacenter operation. In such a mixed-use building as illustrated in Fig. 1, datacenter shares the building space and main electrical power supply with the office operation. Typically, servers have dedicated back-up power infrastructure (e.g., uninterrupted power supply, or UPS) for emergency. In some buildings, datacenter may also share cooling system (e.g., chiller and cooling tower) with the office [40]. Note that datacenters in a mixed-use building can be of various types, ranging from state-of-the-art *commercial* datacenter (e.g., Equinix [10]) to scientific computing cluster and to small-/medium-size server rooms.

Mixed-use building with datacenter operation is a critical segment of building industry and very common in practice, but it is much less studied than dedicated datacenters and other types of mixed-use buildings (e.g., those combining residential and commercial functions [3]). According to a report by Green Grid [40], "the majority of datacenters are within mixed-use facilities" (mixed-use buildings). For example, there are over 1,400 colocation datacenters in the U.S., most of which reside in mixed-use buildings [7]. Another recent study [32] shows that mega-scale dedicated datacenters only take up around 4% of the total datacenter energy consumption, whereas the remaining **96%** goes to other datacenters (e.g., scientific computing cluster, colocation, server room) that are mostly located in mixed-use buildings. Thus, considering the fact that datacenters altogether consume over 2% of global electricity [23] and datacenter load may take up 50% of a building's overall energy [4], it is estimated that the combined energy usage by mixed-use buildings with datacenter operation has already taken up 4% or more of the worldwide electricity consumption, with a projected *quick growth* to over 6% by 2020 [32]. Furthermore, many mixed-use buildings are located in populated metropolitan areas (like California) with high energy demand and cost [7], thus placing an urgent pressure on optimizing their energy management.

State of the Art and Limitations. Energy management, both for datacenters and for buildings, has received a lot of attention in the past. For optimizing datacenter energy efficiency, many resource management approaches have been proposed and also implemented in real systems. These approaches include, but are not limited to, dynamically turning on/off servers for "energy proportionality" [24, 51], geographic load balancing to exploit location diversities for cost saving [52], carbon footprint minimization [12], as well as brown energy reduction [13, 57], cooling-aware scheduling [29], and joint management of servers and energy storage devices (e.g., battery, employees' electrical vehicle) [16, 17, 43]. These studies, however, focus on energy management for dedicated datacenters (e.g., Google), while isolating the significant amount of non-datacenter loads that co-exist in mixed-use buildings.

Likewise, for decades, researchers have developed numerous strategies to model, manage and control the energy consumption for sustainability and/or reducing peak demand in different types of buildings [3]. Recent work includes energy management by taking into account both the energy demand and the thermal comfort of the occupants [9, 18, 39]. Other common techniques for building energy management include lighting power reduction, global thermostat setpoint setback control, supply air temperature adjustment, pre-cooling, and discharging energy storage device (e.g., battery) [19, 42, 47, 49, 53]. However, the prior studies for (mixed-use) buildings treat datacenter loads as "miscellaneous" without judiciously exploring their high scheduling flexibilities (e.g., some datacenter workloads can be deferred and/or even geographically routed to other sites [25, 26]).

Nonetheless, the existing numerous studies treat datacenter and non-datacenter loads separately, although these two types of loads often physically reside together in mixed-use buildings and share the main electrical power line (sometimes as well as cooling). Consequently, *they result in uncoordinated energy management that leads to undesired outcomes such as high peak power demand.*

Research Objective. Recognizing the critical importance of mixed-use building, we propose an interdisciplinary approach that requires expertise from both datacenter (PI Ren) and building (co-PI Zhu) research communities: judiciously manages the energy consumption by datacenter and non-datacenter parts in a mixed-use building as an integrated cyber-physical system. Specifically, we aim at studying the following question: **how to minimize the building's energy cost while satisfying "net-zero"?** Buildings, including mixed-use buildings with datacenter operation, are increasingly seeking "net-zero" (long-term grid energy usage is capped, i.e., energy capping, or completely offset by renewable energy credit/budget), as mandated by government regulations and/or in pursuit green certifications (e.g., LEED) which bring tax/zoning benefits. Further, based on the datacenter's electricity usage and its fraction in a building's total energy, it is estimated that the U.S. mixed-use buildings with datacenter operation altogether spent over 20 billion dollars on their electricity bills in 2013. Thus, it has become an undeniably pressing issue to optimize energy management in mixed-use buildings for cost saving while achieving "net-zero".

We now highlight why we need to judiciously coordinate energy management in mixed-use buildings. Fig. 2 illustrates an example of coordinated energy management to "flatten" the total energy usage in a mixed-use building for taming peak demand charge, where "delay sensitive/tolerant" are two major types of datacenter traffic and ESD represents energy storage device (e.g., battery). Note that combining the existing approaches in a naive manner without careful coordination results in many inefficiency problems and undesirable outcomes. To see this point, let us consider the following example.

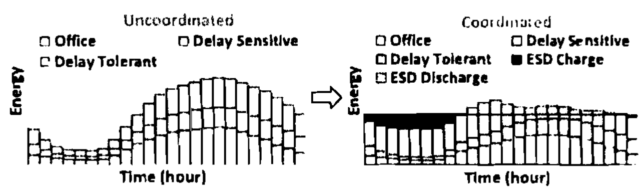


Figure 2: Illustration of coordinated energy management in a mixed-use building.

Example #1: High peak power demand charge. As a large electricity customer, mixed-use building is charged by power utilities not only based on energy consumption, but also based on peak power demand during a billing cycle (e.g., the maximum power consumption measured over each 15-minute interval). Peak power demand charge is widely existing in all the U.S. states, and may even take up over 40% of the total electricity bill. Nonetheless, without judiciously managing both datacenter and non-datacenter loads to avoid peaking their energy usage at the same time, mixed-use building may still have an unnecessarily high aggregate peak power demand, incurring a high electricity cost.

Example #2: "Deviating from the renewables". State-of-the-art buildings, including mixed-use buildings, have on-site renewable energy (e.g., produced from solar), which is green but intermittent and costly to store at a large scale. Naturally, to maximize the utilization of renewables and reduce carbon footprint, it is desirable to "follow the renewables". However, datacenter load and non-datacenter load (e.g., office cooling) altogether share the limited renewables and, without coordinating their consumption, the overall energy usage of a mixed-use building may not follow the renewables.

Challenge and Proposed Solution. While coordinated energy management is critical for mixed-use buildings as demonstrated through the above examples, it presents new challenges. In particular, for "net-zero", the long-term energy usage *shared* by both datacenter and non-datacenter loads needs to be capped or offset by renewables [35, 41], but this is challenged by the highly-dynamic environment with large uncertainties/unknowns (e.g., datacenter's dynamic traffic, office occupancy, weather, among others). That is, coordinated energy management decisions must be made online without possibly foreseeing the complete future information. Further, datacenter and HVAC loads have distinct system dynamics (e.g., computing load dynamics and temperature dynamics) that require different modeling and optimization techniques. Last but not least, optimizing the energy management for net-zero mixed-use buildings must take into account the constraint that datacenter workload performance and human comfort in mixed-use buildings cannot be compromised.

Building upon the PIs' interdisciplinary expertise (i.e., datacenter and building energy management), we propose a new online coordinated energy management algorithm which can minimize the mixed-use building's energy cost while successfully meeting its net-zero goal without foreseeing the far future. More specifically, we use an online approach based on model predictive control (MPC) and Lyapunov technique. Originally proposed for establishing control system stability, Lyapunov technique was recently extended to achieve long-term queueing stability in networks, with a salient feature being that it does not require future information when making control decisions. Here, for meeting "net-zero", we can treat the actual energy usage in each time slot as "job arrivals" to a virtual energy deficit queue, and view the desired energy usage as "job departures". Thus, if the virtual queue can be pushed to zero at the end, then the long-term energy consumption is capped below the desired target for net-zero.

Our *software-based* online energy management approach can be integrated with the existing building energy management system (BEMS) as an add-on control module without any infrastructure upgrades, climate/location requirement or heavy capital investment. In other words, it leverages the existing control knobs (e.g., datacenter load management and HVAC temperature setpoint) that are already available in mixed-use buildings and holistically optimizes the control of these knobs for cost saving and "net-zero". It benefits numerous mixed-use buildings served by the Riverside Public Utilities (RPU) which can improve energy efficiency and reduce energy cost by integrating our control module without infrastructure upgrade or capital investment. Note that dedicated datacenters or buildings can also benefit from this project, as they are special cases of mixed-use buildings (i.e., with a single use rather than mixed uses). Further, RPU can also better manage the peak power usage across the region by installing the developed automated energy management system for load-side management while minimizing the inconveniences caused to mixed-use building customers due to temporary energy shedding. Last but not least, this project is an integral component of the UCR's commitment to sustainability, benefiting the university in sustainability education and research.

Prior Research

The project naturally interconnects and builds upon expertise from both datacenter (PI Ren) and building (co-PI Zhu) communities. PI Ren's prior research has been focused on power-aware computing and datacenters, including net-zero capacity provisioning and VM resource allocation [22, 28, 35]. PI Ren also has expertise in network economics and mechanism design with applications to networking [36, 37], cloud computing systems [38], and datacenter demand response [5, 56]. Co-PI Zhu has extensive experience in building energy management and simulation and HVAC control [27, 47, 48, 49, 50, 54, 55]. More recently, PI Ren and co-PI Zhu have begun to investigate co-managing datacenter and HVAC loads in mixed-use buildings, and the initial evaluation under realistic settings [46] demonstrates that it can significantly reduce the total footprint (e.g., by over 10%) compared to state-of-the-art cost-minimizing solutions that do not coordinate the energy consumption by both datacenter and non-datacenter functions in mixed-use buildings. With complementary expertise suited to the project, PI Ren and co-PI Zhu will focus on the coordination of datacenter and non-datacenter loads in mixed-use buildings—reducing operating costs subject to "net-zero" — and jointly lead the efforts to perform the research.

Next, we summarize in detail the PIs' recent research most relevant to this project.

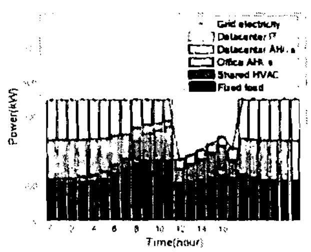
PIs' Joint Research on Mixed-Use Buildings [46]. In our recent research, we have begun to investigate co-managing datacenter and HVAC loads for reducing the energy cost in mixed-use buildings. In particular, we overcome the limitations that existing studies have only focused either buildings or datacenters separately, while these two types of loads are often co-located in mixed-use buildings. Further, they have their own unique dynamics determined by IT workload arrivals and scheduling decisions and require a different and also much richer set of control knobs (e.g., servers turned on/off, workload deferment). The shared HVAC components (e.g., chillers) between datacenter rooms and office rooms also present new challenges in modeling and co-management. Furthermore, the two types of loads typically share the limited on-site renewable energy supplies. Without coordinating their consumption, the overall energy usage may not be able to effectively follow the availability of renewables and leverage it for energy cost reduction.

In view of the critically important but little-investigated mixed-use buildings with datacenters, we extend the building energy management literature by uniquely incorporating and leveraging the large yet flexible datacenter loads that offer new cost saving opportunities. We propose a novel energy management approach that schedules the energy demands of datacenter and non-datacenter operations in a coordinated fashion. More specifically, *the main contributions of our work* are as follows. First, we model the major physical and cyber components in mixed-use buildings, e.g., room thermal dynamics, HVAC operation and energy demand for both datacenter and office rooms, and datacenter workload and energy consumption. These models set the foundation for our co-scheduling approach. Second, we develop a model predictive control (MPC) based formulation for co-scheduling datacenter and HVAC loads, with the consideration of intermittent renewables and battery storage, to minimize total energy cost while satisfying requirements on temperature, ventilation and datacenter workload deadlines. The formulation can also be extended for minimizing carbon footprint, an important environmental objective, and evaluating its trade-off with energy cost. Third, we demonstrate the effectiveness of our co-scheduling approach through real-world trace-based simulations, showing that our approach may provide up to 10%-13% reduction in energy cost when compared with a separate baseline scheduling policy and is also effective in reducing carbon footprint.

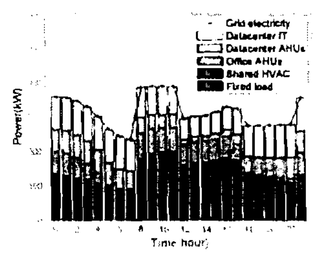
Below, we show the details of our evaluation results on a simulation platform modeling a large mixed-use building with datacenters. Our grid electricity price profile is a practical time-of-use tariff to bill business customers. Based on Tesla's PowerWall battery storage system, the depreciation cost p_b of battery installed in the mixed-use building is set to $0.09\$/KW$, and its round-trip efficiency is set to 92%. The battery capacity is set to $300KWh$, and its state of charge thresholds are 20% and 80% of its capacity, respectively. The maximum amount of charging/discharging energy in one hour is set to 25% of its capacity. The peak solar power supply during the day time is set to 50% of the building's average power demand. The solar power is proportional to the solar radiation.

In the following experiments, we compare our co-scheduling approach with a baseline approach where datacenter load and office room HVAC are scheduled separately using MPC to reduce energy cost. All experiments are simulated for one month to take into account of the monthly peak demand charge.

Effectiveness of Co-Scheduling without Renewables and Battery: First, we conduct experiments to evaluate the effectiveness of our co-scheduling formulation, without considering renewables and battery storage. The initial value of the peak energy consumption within a time interval is set to $350KWh$ based on the analysis of simulation data (in practice, it could be based on historical data). In the baseline approach, this value is proportionally reduced based on the demands of datacenter operation and of office room HVAC control.



(a) Co-scheduling



(b) Baseline

Figure 3: Comparison between co-scheduling and baseline

Fig. 3 shows the energy consumption comparison between co-scheduling and baseline approaches on a weekday. Various energy demand types are represented with different colors, including datacenter IT operations, datacenter AHUs, office room AHUs, shared HAVC (chiller, water pump, cooling tower), and fixed load. The red curve shows the total grid electricity usage. From the figure, we can see that our co-scheduling approach is much more effective in reducing the energy consumption during peak hours from 12:00 to 17:00 and in reducing peak demand. In contrast, the baseline separate scheduling approach has a much higher energy consumption during peak hours and also higher peak demand, due to the lack of coordination between datacenter load scheduling and office room HVAC control.

Table 1 shows the comparison of monthly energy cost between co-scheduling and baseline approaches, including energy consumption cost and peak demand charge. *We can see that the co-scheduling approach significantly reduces the total cost and is able to achieve a 13.3% cost reduction overall.*

Table 1: Costs of co-scheduling and baseline approaches, including consumption cost and peak demand charge (in $)

Co-scheduling			Baseline			% reduction
Cons.	Peak	Total	Cons.	Peak	Total	
32344	5730	38074	37507	6387	43893	13.3

Effectiveness of Co-Scheduling with both Renewables and Battery Storage: We also conduct experiments to compare co-scheduling and baseline approaches with solar energy supply (peak supply at $150KW$) and battery storage system ($300KWh$ capacity). For the baseline approach, the battery capacity is proportionally allocated to datacenter and office rooms based on their demands.

Experimental results show that our co-scheduling approach again is more effective than the baseline approach, with a 11.2% *monthly energy cost reduction.* Compared with the co-scheduling case with solar but without battery, an additional 3.8% cost reduction can be achieved.

Summary: In our recent work [46], we have proposed a novel energy management approach that schedules the energy demands of datacenter and non-datacenter operations in a coordinated fashion. We model the major physical and cyber components in mixed-use buildings, e.g., room thermal dynamics, HVAC operation and energy demand for both datacenter and office rooms, and datacenter workload and energy consumption. These models set the foundation for our co-scheduling approach. We develop a MPC based formulation for co-scheduling datacenter and HVAC loads, with the consideration of intermittent renewables and battery storage, to minimize total energy cost while satisfying requirements on temperature, ventilation and datacenter workload deadlines. We also demonstrate the effectiveness of our co-scheduling approach through real-world trace-based simulations, showing that our approach may provide up to 10%-13% reduction in energy cost when compared with a separate baseline scheduling policy and is also effective in reducing carbon footprint.

While our prior research has successfully demonstrated the compelling advantage of coordinating datacenter and non-datacenter loads in mixed-use buildings for reducing energy cost, it does not consider the important goal of "net-zero". In many parts of the world (especially California), buildings, including mixed-use buildings, are increasingly seeking net-zero, as mandated by government regulations [2, 31] and/or in pursuit green certifications (e.g., LEED [45]) which bring tax/zoning benefits. Keeping this important goal in mind, we plan to extend our prior research to address "net-zero" in mixed-use buildings by developing a new online coordinated energy management approach that can be integrated with the existing building energy management system (BEMS) as an add-on control module without any infrastructure upgrades, climate/location requirement or heavy capital investment.

Research Plan

Building upon our prior research, we plan to study *"how to minimize the building's energy cost while satisfying 'net-zero'?"*. Towards this end, we develop a new online coordinated energy management approach that can be integrated with the existing building energy management system (BEMS) as an add-on control module without any infrastructure upgrades, climate/location requirement or heavy capital investment. Next, we present the details of our proposed research.

Modelling of Mixed-Use Building: Based on Fig. 4 that presents the overview of a mixed-use building that we focus on in this project, we briefly present models for both datacenter and non-datacenter loads. We consider a discrete-time model by equally dividing the total time period of interest (e.g., one month) into K time slots indexed by $t = 0, 1, \cdots, K-1$, each having a duration T_d (e.g., 15 minutes) that matches the timescale of updating energy management decisions.

Datacenter. As validated by real system measurements [11, 24], the datacenter IT energy consumption can be expressed in terms of the utilization: $e_{dc}^{IT}(t) = e_s(t) + e_d(t) * u(t)$, where $e_s(t)$ and $e_d(t)$ are the static and dynamic energy (depending on the number of active servers), respectively, and $u(t) \in [0,1]$ is the datacenter server utilization decided by the datacenter scheduler at time t. There are two types of datacenter workloads: delay-sensitive (e.g., user-facing web service request) and delay-tolerant (e.g., back-end data analytics), whose traffic arrivals are quantified in terms of the server utilization (i.e., the amount of server resources normalized by the datacenter capacity) as $\lambda_a(t)$ and $\lambda_b(t)$, respectively. Denote the amount of delay-sensitive and delay-tolerant workloads processed at time t as $u_a(t)$ and $u_b(t)$, respectively. Then, we have $u_a(t) = \lambda_a(t)$ (for delay sensitivity), and $\sum_{t=0}^{K-1} u_b(t) \geq \sum_{t=0}^{K-1} \lambda_b(t)$ (for delay-tolerant workload queue stability). Note that as in our prior research [35], we can also extend the current model to account for delay-tolerant workload's deadline constraint and server-level resource management (e.g., how many workloads are allocated to each server).

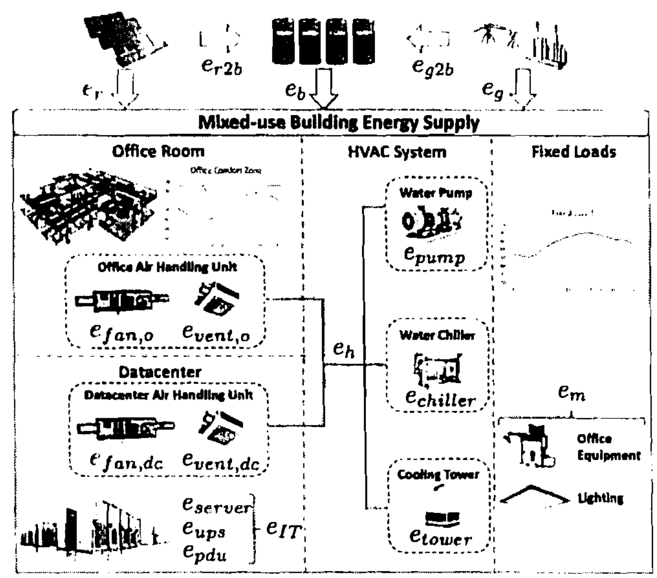


Figure 4: Overview of mixed-use building.

Non-datacenter. Our model for characterizing non-datacenter (cooling/heating) load is as follows. At any time instant t, the transient heat balance of inside zone air is (each room is a zone):

$$C_z \frac{dT_z}{dt} = \sum \dot{Q}_i(t) + \sum \dot{Q}_e(t) + \sum \dot{Q}_{inf}(t) - \sum \Delta \dot{Q}_s(t) \tag{1}$$

where $C_z = \rho_a C_p C_T$, C_p is zone air specific heat, ρ_a is zone air density, C_T is sensible heat capacity multiplier, and T_z is the zone air average temperature. $\sum \dot{Q}_i(t)$ is the internal heat, and the heat to be removed/supplied by HVAC is $\sum \Delta \dot{Q}_s(t)$. The term $\sum \Delta \dot{Q}_{inf}(t)$ is the heat transfer due to infiltration of outside air. $\sum \dot{Q}_e$ includes the net heat into the building through walls and windows by conduction, which depends on the physical wall's thermal conductivity and thickness. All heat transfer modes on the outside wall of the building depend on building's physical design, and vary with outside air conditions (temperature, humidity, and wind speed). $\sum \dot{Q}_e$ can be determined by the following heat balance equation on the outside wall: $\dot{Q}_{asol}(t) + \dot{Q}_{LWR}(t) + \dot{Q}_{conv}(t) - \dot{Q}_{\epsilon} = 0$, where $\dot{Q}_{asol}(t)$ is the absorbed direct and diffuse solar (short wavelength) radiation heat, $\dot{Q}_{LWR}(t)$ is the net long wavelength (thermal) radiation heat with the air and surroundings, and $\dot{Q}_{conv}(t)$ is the convective heat due to outside air. The above equation (1) can be solved by finite difference method. Then, the office load $u_o(t)$ during time slot t is determined based on the net energy entering or leaving the zones.

HVAC system. As illustrated in Fig. 5, the HVAC system in a mixed-use building includes several subcomponents, like chiller, air handler, and other supporting components (e.g., water pump). In general, the total cooling system energy increases with the cooling load (mainly datacenter server energy and office load in our project), which we model as $e_{cool}(t) = f_{cool}(e_{dc}^{IT}(t) + u_o(t))$. The specific form of $f_{cool}(\cdot)$ is system-dependent, but it can usually be approximated as an affline or quadratic function [6, 33, 44, 49].

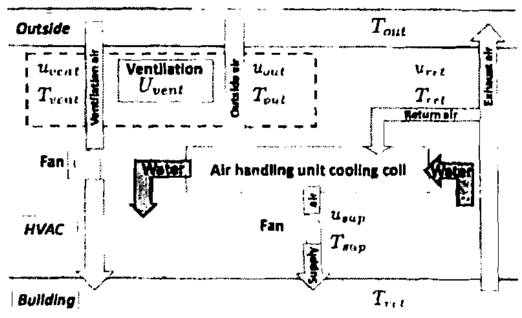


Figure 5: Air flow demand and supply in air handling units

Renewables. As the cost of solar panel continuously decreases, more and more buildings are installing onsite solar panels. We denote the available solar energy at time t by $e_{renewable}(t)$.

ESD discharging/charging. Energy storage device (ESD, e.g., battery and electrical vehicles if applicable) is emerging as an effective tool to shave the peak demand. We denote the ESD energy available at time t as $b(t)$ and the amount of charged energy by $e_{ESD}(t)$, whose negative value means "discharging". Note that $b(t)$ and $e_{ESD}(t)$ can be vectors, each element representing one individual ESD.

Others. Other loads in a mixed-use building include lighting, power distribution loss, among others. Instead of delving into the model details, we denote $e_{others}(t)$ as their aggregate load.

Problem Formulation: Based on the above model, we can write the total grid (net) energy usage at time t as $e(t) = e_{dc}(t) + e_{cool}(t) + e_{ESD}(t) - e_{renewable}(t) + e_{others}(t)$, where, for notation convenience, each parameter represents the total energy usage for that component (e.g., $e_{ESD}(t)$ is the total battery charging energy, although there may exist multiple battery devices). There are various notions of "net-zero", and we adopt a common practice: the long-term electricity usage is capped or offset by renewables (e.g., in the form of renewable energy credits) [8, 15, 35]. For example, the monthly grid energy consumption is capped by the monthly renewable energy credit/budget R. Following this notion, we formulate the cost-minimization problem (**P-1**) as

$$\text{CoMin}: \quad \min \left[\sum_{t=0}^{K-1} p(t) \cdot e(t) + p_d \cdot \max_{t=0,\cdots,K-1} \frac{e(t)}{T_d} \right], \tag{2}$$

subject to: **(C1)** $\sum_{t=0}^{K-1} e(t) \leq R$, i.e., "net-zero" constraint; **(C2)** delay constraint datacenter workloads; **(C3)** thermal comfort constraint; **(C4)** ESD constraint (e.g., charging/discharging rate, remaining energy); and **(C5)** cooling capacity constraint, among others. In the optimization objective (2), the first term is the energy charge and the second term is the peak demand charge. Some utilities also charge different peak demands, e.g., daily peak and nightly peak [1], which can be captured with minor modification to our formulation (as in our research for datacenter cost minimization [21]). The decisions at the beginning of each time slot include: server on/off in

Algorithm 1 Online coordinated energy management

1: At the beginning of time t, predict the T-step future information (e.g., workload arrivals, office load, among others) based on model dynamics and regression technique (for, e.g., renewables and datacenter's future workloads).
2: Minimize "$\sum_{\tau=t}^{t+T-1}[V\cdot p(\tau)\cdot e(\tau)+q_e(\tau)\cdot e(\tau)-q_b(\tau)\cdot u_b(\tau)]$" based on the predicted T-step future information.
3: Apply the optimized energy management decisions for time t.
4: At the end of time t, update the energy deficit queue following (3) and the real job queue for datacenter's delay-tolerant workloads based on scheduling decisions.

datacenter, how many delay-tolerant workloads are processed, ESD charging/discharging, and air mass flow rate in office/datacenter subject to respective loads.

Challenge: It is very challenging to optimize the coordinated energy management for minimizing mixed-use building's electricity cost, because it requires offline future information (e.g., datacenter's dynamic workloads, office's time-varying loads, among others). To see this point, we note that the peak power demand is determined as $\max_{t=0,\cdots,K-1}\frac{e(t)}{T_d}$, where $\frac{e(t)}{T_d}$ is the power usage during time t, and hence, the peak power demand is unknown until the end of total timescale. Further, the desired "net-zero" constraint $\sum_{t=0}^{K-1}e(t)\leq R$ couples all the energy usage over time. In practice, however, only short-term future information (e.g., a few hours) can be relatively accurately predicted, whereas the long-term (monthly in our problem) information is not available in advance.

Online Coordinated Energy Management: To address the lack of complete future information needed to solve **P-1**, we propose an online solution based on model predictive control (MPC) and Lyapunov technique [30]. Originally proposed for establishing control system stability, Lyapunov technique was recently extended to achieve long-term queueing stability in networks [30], with a salient feature being that it does not require future information when making control decisions. Here, for "net-zero", we can treat the grid energy usage in each time slot as "job arrivals" to a virtual energy queue, and view the desired usage as "job departures". Thus, if the virtual queue can be pushed to zero at the end, then the long-term grid energy usage is capped below the target R (i.e., the amount of renewable energy credit/budget). Specifically, we replace the net-zero constraint with an energy deficit queue that evolves as follows

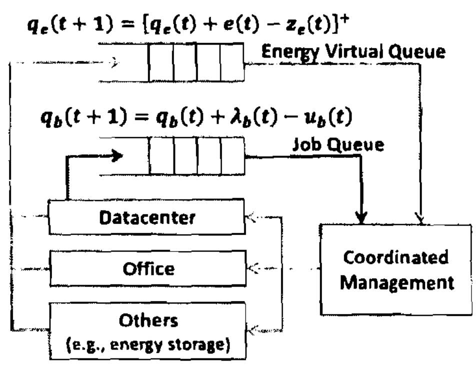


Figure 6: Illustration of online energy management.

$$q_e(t+1)=\{q_e(t)+e(t)-z_e(t)\}^+, \tag{3}$$

where $q_e(t)$ is the energy deficit queue length, and $z_e(t)$ is the reference energy usage satisfying $\sum_{t=0}^{K-1}z_e(t)=R$. The real job queue for datacenter's delay-tolerant workloads evolves as $q_b(t+1)=q_b(t)+\lambda_b(t)-u_b(t)$. Our algorithm is described in Algorithm 1.

Algorithm Discussion: As shown in Algorithm 1 and illustrated in Fig. 6, the additional term "$q_e(t)\cdot e(t)-q_b(t)\cdot u_b(t)$" serves as a feedback mechanism to give weights on "net-zero" constraint and average queueing delay for delay-tolerant workloads: if the electricity usage exceeds the reference usage (e.g., $q_e(t)$ is positive), then the building manager will consider reducing more energy (via turning off unused servers [24]) for achieving net-zero; on the other hand, if there is a long queue backlog (i.e., $q_b(t)$ is large), then we will schedule more delay-tolerant workloads by increasing $u_b(t)$ for reducing queueing delay. Note that we will also keep track of the building-level power usage: if the new power usage is expected to exceed the currently-tracked peak, then the building will reduce more energy (e.g., defer more datacenter workloads and discharge ESD if applicable) to tame the peak demand charge. Finally, a trade-off parameter in our online solution is V, which governs the cost-delay/"net-zero" tradeoff: when V becomes larger, our online solution (Algorithm 1) tends to minimize the cost, while giving relatively less attention to "net-zero" and/or the datacenter deferrable workload's queueing delay, and vice versa. Dynamically tuning V for a desired value is available in the literature [20].

Research Tasks. Next, based on the proposed methodology presented above, we list the specific research tasks to complete this project.

Task 1: Modeling and Algorithm Design. We will first further refine our models to capture different components (e.g., datacenters, HVAC, battery) based on actual measurement in mixed-use buildings located in Riverside County. A representative example of mixed-use building is the Winston Chung Hall (WCH) in UC Riverside with multiple datacenter rooms. WCH is also the building where the PIs' home department is located, and hence it allows easy access to and monitoring of the energy usage information. Then, based on the new models, we will design our algorithms based on the methodology presented above.

Task 2: Extension to Multiple Mixed-Use Buildings. Our above model and formulation focus on scheduling data center workloads and HVAC loads in a single mixed-use building. In practice, large organizations and campuses often have multiple mixed-use buildings with datacenter operation, each having their own spatial diversities (e.g., renewable energy availability). Thus, the flexibility in scheduling datacenter workloads geographically across multiple sites (called geographic load balancing, or GLB) [26, 34] opens up opportunities to explore such spatial diversities. Thus, we extend our model from a single mixed-use building to multiple mixed-use buildings, and study joint coordinated energy management across multiple mixed-use buildings for reducing the total energy cost and achieving "net-zero".

Task 3: System Development and Evaluation. Towards making a real impact, we provide system support to automate the proposed online resource management approach for cost saving in "net-zero" mixed-use buildings. Our software module provide new application program interfaces (APIs) that can be integrated with the existing building energy management module. Our module includes an online coordinated optimizer that judiciously manages the energy consumption by datacenter, office, and other loads (e.g., ESD).

We first use a simulation platform to evaluate the effectiveness of our solution. We use the whole building energy simulation (BES), *EnergyPlus*, to evaluate the overall energy performance of Through the whole BES, we will be able to determine the building's total energy consumption in various timescales, from every few minutes to a yearly basis. To obtain the server energy model, we construct a scaled-down server cluster composed of 14 PowerEdge servers. Each of the servers has a 6-core Intel Xeon E-26XX Processor (210-ABVP) and 32G RAM. The power consumption of each server is measured with a WattsUp Pro power meter. We run real-world workload record traces, provided by Google for public access [14], as datacenter workload for evaluations. The power model obtained based on the scaled-down system will be further scaled and calibrated using publicly-available sources (e.g., datacenter-level power characterization). Then, we will integrate the datacenter simulation model/parameters with the whole building to evaluate our proposed energy management strategies for mixed-use building.

Besides lab-based simulations and prototypes, we also seek collaboration with building managers in Riverside County and leverage their first-hand experiences to steer our research. As this

Table 2: Project Timeline.

Timeline	Research Plan
1-4 months	Modeling and design of online coordinated energy management based on real load measurement in mixed-use buildings
5-6 months	Extending online coordinated energy management from a single mixed-use buildings to multiple mixed-use buildings
7-12 months	Developing an energy management software module to implement our proposed algorithm and evaluating it based on simulation platform and testbed

project proceeds, a pilot implementation of our research incorporating timely feedback from building managers will be explored.

Project Timeline. With complementary expertise in power-aware computing, datacenters and buildings, the PIs have formed a coherent collaboration while working at UC Riverside. Throughout the project, the PIs will engage in weekly meetings to discuss the project activities. Graduate students will also join the meetings for brainstorming and addressing inter-task dependencies. The specific project time over a one-year period is shown in Table 2.

Budget Proposal

Project Title: Coordinated Energy Management in Net-Zero Mixed-Use Buildings
Sponsor: Riverside Public Utilities
Principal Investigator: ShaoleiRen / Assistant Professor
Department: Electrical and Computer Engineering
Institution: University of California, Riverside
Period of Performance: 7/1/16-6/30/17

	No. of people	Salaries	Benefits	Total
A. Senior Personnel	2			$9,016
Principal Investigator: ShaoleiRen / Assistant Professor		$4,000	$508	
Qi Zhu (co-PI) / Assistant Professor		$4,000	$508	
B. Other Personnel (salaried and non-salaried)				$48,587
Graduate Student TBN, 11.76 months	2	$46,862	$1,725	
C. Fringe Benefits	Included above			
D. Permanent Equipment				$0
None				
E. Travel				
Domestic				$4,000
Foreign				$0
F. Other Direct Costs				
Materials/supplies				$2,912
Publication costs				$0
G. Subcontract				$0
None				
TOTAL DIRECT COST				$64,515
TOTAL INDIRECT COST				$35,485
GRAND TOTAL, 1 YEAR				**$100,000**

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Biographical Sketch

List of Researchers

Principal Investigator: Shaolei Ren, Assistant Professor of Electrical and Computer Engineering, UC Riverside

Co-Principal Investigator: Qi Zhu, Assistant Professor of Electrical and Computer Engineering, UC Riverside

Shaolei Ren
Assistant Professor
Department of Electrical and Computer Engineering
University of California, Riverside
Homepage: `http://www.ece.ucr.edu/~sren/`

Professional Preparation

- **Tsinghua University**, Beijing, China — **B.E.** & 2006
  Electronics Engineering
- **Hong Kong University of Science and Technology**, Hong Kong — **M.Phil.** & 2008
  Electronic and Computer Engineering
- **University of California, Los Angeles**, California, United States — **Ph.D.** & 2012
  Electrical Engineering

Appointment

- **University of California, Riverside**, Riverside, CA — 07/2015 Present
  Assistant Professor in Department of Electrical and Computer Engineering
  Cooperating Faculty in Department of Computer Science and Engineering

- **Florida International University**, Miami, FL — 08/2012 06/2015
  Assistant Professor in School of Computing and Information Sciences

Products

Most Relevant Products

1. N. H. Tran, C. Pham, S. Ren, and C.-S. Hong, "Coordinated Energy Management for Emergency Demand Response in Mixed-Use Buildings," The Workshop on Next Generation of Green ICT and 5G Networking (**GreeNets**), 2015.
2. N. Chen, X. Ren, S. Ren, and A. Wierman, "Greening Multi-Tenant Data Center Demand Response," *The International Symposium on Computer Performance, Modeling, Measurements and Evaluation* (**IFIP WG7.3 Performance**), 2015.
3. M. A. Islam, X. Ren, S. Ren, A. Wierman, and X. Wang, "A Market Approach for Handling Power Emergencies in Multi-Tenant Data Center," *IEEE International Symposium on High Performance Computer Architecture* (**HPCA**), 2016 (accepted).
4. M. A. Islam, H. Mahmud, S. Ren, and X. Wang, "Paying to Save: Reducing Cost of Colocation Data Center via Rewards," *IEEE International Symposium on High Performance Computer Architecture* (**HPCA**), 2015.
5. S. Ren and Y. He, "COCA: Online Resource Management for Cost Minimization and Carbon Neutrality in Data Centers," *International Conference for High Performance Computing, Networking, Storage, and Analysis* (**SC**), 2013.

Other Significant Products

1. J.-M. Yun, Y. He, S. Elnikety, and S. Ren, "Optimal Aggregation Policy for Reducing Tail Latency of Web Search," *ACM SIG on Information Retrieval* (**SIGIR**), 2015.
2. L. Zhang, Z. Li, C. Wu, and S. Ren, "Online Electricity Cost Saving Algorithms for Co-Location Data Centers," **IEEE Journals of Selected Areas in Communications**, vol. pp, no. 99, 2015. (Earlier version appeared at **SIGMETRICS 2015**)

3. M. A. Islam. H. Mahmud, S. Ren and G. Quan, "Online Energy Budgeting for Cost Minimization in Virtualized Data Center," **IEEE Transactions on Services Computing**. vol. pp. no. 99. 2015. (Earlier version appeared at **MASCOTS** 2013)
4. M. Polverini.A. Cianfrani, S. Ren, and A. V. Vasilakos, "Thermal-Aware Scheduling of Batch Jobs in Geographically Distributed Data Centers," **IEEE Transactions on Cloud Computing**. vol. 2, no. 1, pp. 71-84, 2014. (Earlier version appeared at **ICDCS** 2012)
5. B.-G. Kim, S. Ren, M. van der Schaar, and J.-W. Lee, "Bidirectional Energy Trading and Residential Load Scheduling with Electric Vehicles in the Smart Grid," **IEEE Journals of Selected Areas in Communications**, vol. 31, no. 7, pp. 1219-1234, July 2013. (Earlier version appeared at **INFOCOM 2013**)

Synergistic Activities

- **Selected Awards**
  NSF CAREER, 2015; **Best Paper Award** in *International Workshop on Feedback Computing*, 2013; **Best Paper Award** in *IEEE International Conf. on Communications*, 2009.
- **Recent Press**
  "*How Can Supercomputers Survive a Drought?*" by ACM TechNews, Communications of the ACM, etc.; "*COCA Targets Datacenter Costs, Carbon Neutrality*" by HPCwire; "*5 Reasons the Thirst for Water Technology Will Grow in 2014*" by GreenBiz; TMM'14 paper on "resource allocation for stream mining" featured by *IEEE ComSoc Technology News*, Feb. 2014.
- **Course Development**
  Special Topics on Sustainable Computing (UCR), Cyber Sustainability (TCN-5710, FIU). Management of Datacenter Systems (CAP-4783, FIU)
- **Selected Recent TPC Services**
  IWQoS'16, ICDCS'16, ACM ICS'15, IEEE Cloud'15, ICAC'15
- **Invited Reviewer for Selected IEEE/ACM Journals**
  ACM Computing Surveys, IEEE Transactions on Parallel and Distributed Systems, IEEE Transactions on Cloud Computing, IEEE/ACM Transactions on Networking, IEEE Transactions on Mobile Computing, IEEE Journal of Selected Areas in Communications, IEEE Journal of Selected Topics in Signal Processing. IEEE Transactions on Signal Processing, IEEE Transactions on Wireless Communications, IEEE Transactions on Multimedia

Collaborators & Other Affiliations

Collaborators and Co-Editors (16 in total): Choong Seon Hong (KHU), Antonio Cianfrani (La Sapienza), Sameh Elnikety (Microsoft Research). Zhu Han (Houston), Yuxiong He (Microsoft Research). Zongpeng Li (UCalgary), Kathryn McKinley (Microsoft Research), Gang Quan (FIU), Shangping Ren (IIT), Mihaela van der Schaar (UCLA). Muhammad Z. Shakir (Caleton), Nguyen H. Tran (KHU), Athanasios V. Vasilakos (Lulea U.ofT), Xiaorui Wang (OSU), Adam Wierman (Caltech). Chuan Wu (HKU),

Graduate and Postdoctoral Advisors (2 in total): Prof. Khaled Ben Letaief (HKUST). Prof. Mihaela van der Schaar (UCLA)

Thesis Advisor and Postgraduate-Scholar Sponsor (4 in total): Kishwar Ahmed (FIU). Atiqul Islam (UCR). Hasan Mahmud (FIU). Qing Wang (FIU)

BIOGRAPHICAL SKETCH

Qi Zhu

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Professional Preparation

Tsinghua University	CS	B.E., 2003	Beijing, China
University of California, Berkeley	EECS	Ph.D., 2008	Berkeley, CA, U.S.A.

Appointments

Assistant Professor Department of Electrical and Computer Engineering	August 2011 – present University of California, Riverside
Research Scientist Strategic CAD Laboratories	October 2008 – August 2011 Intel Corporation

Products

Five publications most relevant to the proposed project

1. Tianshu Wei, Qi Zhu and Nanpeng Yu, "Proactive Demand Participation of Smart Buildings in Smart Grid", *to appear in the IEEE Transactions on Computers (TC)*, 2015.
2. Tianshu Wei, Bowen Zheng, Qi Zhu and Shiyan Hu, "Security Analysis of Proactive Participation of Smart Buildings in Smart Grid", *34th IEEE/ACM International Conference on Computer-Aided Design (ICCAD'15)*, Austin, TX, November, 2015.
3. Tiansong Cui, Shuang Chen, Yanzhi Wang, Shahin Nazarian, Qi Zhu and Massoud Pedram, "Optimal Control of PEVs for Energy Cost Minimization and Frequency Regulation in the Smart Grid Accounting for Battery State-of-Health Degradation", *52nd ACM/IEEE Design Automation Conference (DAC'15)*, San Francisco, CA, June, 2015.
4. Tianshu Wei, Qi Zhu and Mehdi Maasoumy, "Co-scheduling of HVAC Control, EV Charging and Battery Usage for Building Energy Efficiency", *33rd IEEE/ACM International Conference on Computer-Aided Design (ICCAD'14)*, San Jose, CA, November, 2014.
5. Tianshu Wei, Taeyoung Kim, Sangyoung Park, Qi Zhu, Sheldon X.-D. Tan, Naehyuck Chang, Sadrul Ula and Mehdi Maasoumy, "Battery Management and Application for Energy-Efficient Buildings", *51st IEEE/ACM Design Automation Conference (DAC'14)*, San Francisco, CA, June, 2014.

Five other publications

6. Mehdi Maasoumy, Qi Zhu, Cheng Li, Forrest Meggers and Alberto Sangiovanni-Vincentelli, "Codesign of Control Algorithm and Embedded Platform for HVAC Systems", *4th IEEE/ACM International Conference on Cyber-Physical Systems (ICCPS'13)*, Philadelphia, April, 2013. (Best Paper Award)
7. Yang Yang, Qi Zhu, Mehdi Maasoumy and Alberto Sangiovanni-Vincentelli, "Development of Building Automation and Control Systems", *IEEE Design and Test of Computers, Special Issue on Green Buildings*, Vol. 29, No. 4, pp. 45-55, August, 2012.
8. Yang Yang, Alessandro Pinto, Alberto Sangiovanni-Vincentelli and Qi Zhu, "A Design Flow for Building Automation and Control Systems", *31st IEEE Real-Time Systems Symposium (RTSS'10)*, San Diego, CA, December, 2010.

9. Abhijit Davare, Qi Zhu, Marco Di Natale, Claudio Pinello, Sri Kanajan and Alberto Sangiovanni-Vincentelli, "Period Optimization for Hard Real-time Distributed Automotive Systems", *44th IEEE/ACM Design Automation Conference (DAC'07)*, San Diego, CA, June, 2007. (Best Paper Award)
10. Qi Zhu, Nathan Kitchen, Andreas Kuehlmann and Alberto Sangiovanni-Vincentelli, "SAT Sweeping with Local Observability Don't-Cares", *43rd IEEE/ACM Design Automation Conference (DAC'06)*, San Francisco, CA, July, 2006. (Best Paper Award)

Synergistic Activities

- *Technical Program Committee member*
  IEEE/ACM International Conference on Computer-Aided Design (ICCAD) 2013, 2014, 2015
  IEEE International Conference on Embedded Software and Systems (ICESS) 2015 (Subcom. chair)
  IEEE/ACM International Conference on Hardware/Software Codesign and System Synthesis 2015
  IEEE/ACM Design Automation Conference (DAC) 2012, 2013, 2014
  IEEE/ACM Asia and South Pacific Design Automation Conference (ASP-DAC) 2015, 2016
  IEEE International Symposium on Industrial Embedded Systems (SIES) 2013, 2014, 2015
  IEEE International Conference on Emerging Technology & Factory Automation (ETFA) 2013, 2014
  IEEE/ACM International Conference on Formal Methods and Models for Codesign 2012, 2013
  IEEE Real-time and Embedded Technology and Applications Symposium (RTAS) 2012
  IEEE International Conference on Parallel and Distributed Systems (ICPADS) 2012
  IEEE International Symposium on VLSI Design, Automation and Test 2010 – 2013
- *Member and CPS Software Sub-Committee Chair* of the IEEE Technical Committee on Cybernetics for Cyber-Physical Systems (CCPS)
- *Session Chair* at DAC 2014, ICCAD 2013 and MemoCODE 2012.
- *Invited speaker* at the IEEE Council for Electronic Design Automation (CEDA) Distinguished Speaker Series, 2008.
- *Best Paper Awards:* ICCPS 2013 (one best paper out of 103 submissions), DAC 2007 (2 out of 712), DAC 2006 (2 out of 865).

Collaborators & Other Affiliations

Collaborators (29)

Felice Balarin (Cadence), Laxmi Bhuyan (UC Riverside), Naeyuck Chang (Korea Advanced Institute of Science and Technology), Abhijit Davare (Intel), Douglas Densmore (Boston University), Rajiv Gupta (UC Riverside), Sandeep Gupta (USC), Marco Di Natale (Scuola S. Anna), Edward Lee (UC Berkeley), Wenchao Li (SRI International), Chung-Wei Lin (Toyota), Xue Liu (McGill University), Mehdi Maasoumy (C3 Energy), Forrest Meggers (Singapore-ETH Centre), Massoud Pedram (USC), Fabio Pasqualetti (UC Riverside), Roberto Passerone (University of Trento), Alberto Sangiovanni-Vincentelli (UC Berkeley), Natarajan Shankar (SRI International), Yiyu Shi (University of Notre Dame), Alena Simalatsar (EPFL), Sheldon Tan (UC Riverside), Stavros Tripakis (UC Berkeley), Sadrul Ula (UC Riverside), Yanzhi Wang (Syracuse University), Jinjun Xiong (IBM), Yang Yang (Google), Nanpeng Yu (UC Riverside), Haibo Zeng (Virginia Tech).

Graduate advisor

Alberto Sangiovanni-Vincentelli, Professor, EECS Department, University of California, Berkeley

Dissertation committee

Alberto Sangiovanni-Vincentelli, Professor, EECS Department, University of California, Berkeley
Jan Rabaey, Professor, EECS Department, University of California, Berkeley
Phil Kaminsky, Professor, Department of IEOR, University of California, Berkeley

Total number of graduate students advised (7): Peng Deng, Bowen Zheng, Tianshu Wei, Kenneth O'Neal, Shu Zhang, Shuyue Lan, Hengyi Liang.

Total number of post-doc scholars sponsored (0).

EXHIBIT "B"

Project Budget

Budget Proposal

Project Title: Coordinated Energy Management in Net-Zero Mixed-Use Buildings
Sponsor: Riverside Public Utilities
Principal Investigator: ShaoleiRen / Assistant Professor
Department: Electrical and Computer Engineering
Institution: University of California, Riverside
Period of Performance: 7/1/16-6/30/17

	No. of people	Salaries	Benefits	Total
A. Senior Personnel	2			$9,016
Principal Investigator: ShaoleiRen / Assistant Professor		$4,000	$508	
Qi Zhu (co-PI) / Assistant Professor		$4,000	$508	
B. Other Personnel (salaried and non-salaried)				$48,587
Graduate Student TBN, 11.76 months	2	$46,862	$1,725	
C. Fringe Benefits	Included above			
D. Permanent Equipment				$0
None				
E. Travel				
Domestic				$4,000
Foreign				$0
F. Other Direct Costs				
Materials/supplies				$2,912
Publication costs				$0
G. Subcontract				$0
None				
TOTAL DIRECT COST				$64,515
TOTAL INDIRECT COST				$35,485
GRAND TOTAL, 1 YEAR				**$100,000**

EXHIBIT "C"

Intellectual Property Provisions

INTELLECTUAL PROPERTY PROVISIONS

(1) Recipient Rights, Responsibilities, and Indemnity

a. Patent rights for inventions conceived and first actually reduced to practice in performance of this Grant, whether actually patented or unpatented, will be the property of the Recipient whose employees or researchers are inventors of such inventions pursuant to U.S. Patent law. The Recipient shall grant a non-exclusive, non-commercial license to any patented invention to the sponsor, the City of Riverside. Recipients must obtain Agreements to effectuate the government use license with all persons or entities, except for the U.S. Department of Energy (DOE), obtaining ownership interest in such patent rights. Upon the perfecting of a patent application for subject inventions, Recipient will fill out and sign a Uniform Commercial Code (UCC.1) Financing Statement that documents the City of Riverside's use license.

The Recipient will disclose to the City of Riverside on a confidential basis all inventions, software, and copyrightable material that was first conceived or first actually reduced to practice in performance of this Grant.

Recipient and all persons and/or entities obtaining an ownership interest in invention(s) shall include within the specification of any United States patent application, and any patent issuing thereon covering a Subject Invention, the following statement:

"This invention was made with support from the City of Riverside. The City of Riverside has certain rights to this invention."

b. All software and copyrightable material first produced under this Grant shall be the property of the Recipient. The Recipient shall grant a non-exclusive, non-commercial license to any such software or copyrightable material to the sponsor, the City of Riverside.

c. Recipient shall provide the City of Riverside with a copy of all technical, generated, and deliverable data produced under this Agreement. Recipient does not have to copy and submit data the City has identified as being unusable for City purposes. For instance, some data may not warrant routine copying and shipping because the raw data is too disaggregated or voluminous for practical application. Recipient shall retain such data at the Recipient's facility for inspection, review, and possible copying by the City.

d. To the extent permitted by law, Recipient will defend and indemnify the City of Riverside from and against any claim, lawsuit, or other proceeding, loss, cost, liability, or expense (including court costs and reasonable fees of attorneys and other professionals) to the extent arising out of any third party claim solely arising out of the negligent act(s) or omission(s) by the Recipient, its employees, or agents, in connection with intellectual property claims against either deliverables or the Recipient's performance under this Agreement.

e. In no event will the City of Riverside be liable for any special, incidental, or consequential damages based on breach of warranty, breach of contract, negligence, strict tort, or any other legal theory for the disclosure of Recipient's confidential information, even if the City of Riverside has been advised of the possibility of such damage. Damages that the City of Riverside will not be responsible for include, but are not limited to, loss of profit; loss of savings or revenue; loss of goodwill; loss of use of the product or any associated equipment; cost of capital; cost of any substitute equipment, facilities, or services; downtime; the claims of third parties including customers; and injury to property.

(2) City of Riverside Rights and Responsibilities

a. For all inventions that were first conceived and first actually reduced to practice in the performance of this Grant, the City of Riverside retains a no-cost, nonexclusive, nontransferable, irrevocable, perpetual, royalty-free, paid-up worldwide nonexclusive license to use or have practiced such rights for or on behalf of the City of Riverside for governmental purposes to the degree that is consistent with Federal law. The City retains the right to file a Uniform Commercial Code (UCC.1) Financing Statement on all subject inventions that are patented in order to document the City of Riverside's right to use such items for governmental purposes. Previously documented (whether patented or unpatented under the patent laws of the United States of America or any foreign country) inventions are exempt from this provision.

b. For software first developed in performance of this Grant, the Recipient shall grant the City of Riverside-a royalty-free, no-cost, nonexclusive, irrevocable, nontransferable, world-wide, perpetual license to produce and use for governmental purposes.

c. For copyrightable material first produced in performance of this Grant, the Recipient shall grant the City of Riverside a royalty-free, no-cost, nonexclusive, irrevocable, nontransferable, worldwide, perpetual license to produce translate, publish, use and dispose of, and to authorize others to produce, translate, publish, use and dispose of all copyrightable material.

d. The City of Riverside shall not purposefully enter into competition with Recipient's Licensee or take affirmative actions intended to effectively destroy the commercial market where a Licensee has introduced a Licensed Product.

e. Data provided to the City of Riverside by Recipient, which data the City has not already agreed to keep confidential and which Recipient seeks to have designated as confidential, or is the subject of a pending application for confidential designation, shall not be disclosed by the City except as provided in Title 20 CCR, Sections 2506 and 2507 (or as they may be amended), unless disclosure is ordered by a court of competent jurisdiction.

f. It is the City of Riverside's intent to use and release project results such as deliverables and data in a manner calculated to further the intent of California Public Utilities Code, Section 385, while protecting proprietary or patentable interests of the parties. Therefore, the City agrees not to disclose confidential data or the contents of reports containing data considered by Recipient as confidential, without first providing a copy of the disclosure document for review and comment by Recipient. Recipient shall have no less than ten (10) working days for review and comment and, if appropriate, to make an application for confidential designation on some or all of the data. The City of Riverside shall consider the comments of Recipient and use professional judgment in revising the report, information or data accordingly.

EXHIBIT "D"

Performance Standards

In accordance to Section 4.b and Section 5.e in the Agreement, Recipient must meet certain Performance Standards applicable to each of the following Milestones before City releases the corresponding Grant Fund installment:

A. Grant Project Completion Submit Final Report and certify that software-based online resource management approach optimizes the energy consumption decisions without foreseeing the far future information.

B. Quarterly Report I Due by the last day of the 6th month of the contract. Report on building energy models based on measurement from the CE-CERT (Center for Environmental Research & Technology) or other applicable buildings. Failure to deliver report on measurements will be deemed as non-performance and may be subject to reduced Grant Fund payments based on the following schedule:

90 – 100% Accuracy = 100% Grant Fund Release
80 – 89% Accuracy = 90%
70 – 79% Accuracy = 75%
60 – 69% Accuracy = 50%
50 – 59% Accuracy = 30%
< 50% Accuracy = 0%

C. Quarterly Report II Due by the last day of the 9th month of the contract. Development of a simulation platform for evaluating the proposed energy management algorithm. Failure to deliver simulation platform will be deemed non-performance and may be subject to reduced Grant Fund Payments based on the following schedule:

90 – 100% Accuracy = 100% Grant Fund Release
80 – 89% Accuracy = 90%
70 – 79% Accuracy = 75%
60 – 69% Accuracy = 50%
50 – 59% Accuracy = 30%
< 50% Accuracy = 0%