

A Simulation Study of Three Mosque AC Control Modes for Electrical Energy Efficiency

Syaiful Amri¹, Rahmat Fajrul², Azizul³

¹ Department of Electrical Engineering, Politeknik Negeri Bengkalis, Indonesia

² Department of Mechanical Engineering, Politeknik Negeri Bengkalis, Indonesia

³ Department of Electrical Engineering, Politeknik Negeri Bengkalis, Indonesia

syaifulamri@polbeng.ac.id¹, rahmat.fajrul@polbeng.ac.id², Azizul@polbeng.ac.id³

ABSTRACT

This paper presents a low-cost simulation study to compare four air-conditioning control modes for a mosque prayer hall served by four Daikin split units of 2 PK each. The modes are Automatic schedule driven, Manual Default using the original remote, Manual IoT supervised via Android notifications, and Hybrid that combines Automatic with bounded overrides. A discrete-time model with 1-minute resolution was run over 30 consecutive days. Reported metrics include daily and 30-day energy, total runtime, peak demand, and excess runtime, with a simple comfort proxy. The 30-day results show a consistent ordering where Automatic is the lowest energy mode at 212.43 kWh, followed by Manual IoT at 313.95 kWh and Hybrid at 362.05 kWh, while Manual Default is highest at 805.71 kWh. Compared with Manual Default, energy savings reach 73.63% for Automatic, 61.03% for Manual IoT, and 55.06% for Hybrid. Differences are primarily driven by off-schedule operation, schedule discipline, and staging practice. The findings support the use of Automatic as the operational baseline with a 10-minute pre and 30-minute post window, conservative staging, and a protected setpoint of 24 to 25 °C, while IoT supervision and bounded Hybrid overrides provide practical pathways to reduce waste without compromising comfort.

Keywords : mosque HVAC, AC control, energy efficiency, automatic scheduling, IoT supervision.

1. INTRODUCTION

Mosques exhibit distinctive occupancy profiles, with attendance peaking around prayer times and religious events while remaining low at other hours. This strongly affects energy use and thermal comfort in large assembly spaces, where air conditioning often dominates electrical loads in hot-humid climates (Ouf & Issa, 2016; Zuraimi & Tham, 2009). In many facilities, AC units are still operated manually without consistent schedules, leading to wasteful runtimes during unoccupied periods and premature or delayed switch-off that undermines efficiency and service quality (Erickson & Cerpa, 2010; Dong & Andrews, 2009). As *smart building* technologies mature, occupancy- and IoT-based control strategies have demonstrated measurable savings while maintaining comfort when properly designed and tuned (Shaikh et al., 2014; Kong et al., 2022).

Recent studies quantify HVAC savings from occupancy-based and demand-responsive strategies across time horizons, using scheduling, pre-cooling windows, and adaptive setpoints (Pang et al., 2024; Cetin et al., 2014; Lu et al., 2020). Advanced methods such as model predictive and supervisory control further provide systematic optimization frameworks to reduce peak demand and runtime, especially in multi-zone settings (Wang & Ma, 2008; Benga et al., 2012; Ebadat & Borrelli, 2013; Purdila & Hazyuk, 2014). Meanwhile, practical IoT retrofits enable legacy split systems to be integrated via infrared gateways and smartphone apps, offering remote overrides and usage monitoring (Matsumoto & Takeda, 2019; Brooks & Kumar, 2020; Rahman & Islam, 2021). While these advances are relevant to prayer halls, comparative evaluations that weigh manual practice against prayer-time automation and IoT overrides in a unified framework remain scarce (Park & Nagy, 2018; Afram & Janabi-Sharifi, 2014).

This article presents a simulation of four representative AC control modes in mosques: (1) an automatic mode that turns units on 15 minutes before prayer time and off 45 minutes after; (2) a manual default mode using the original remote by congregants or caretakers; (3) a manual IoT mode where caretakers operate units via an Android app based on notifications of off-schedule use; and (4) a *hybrid* mode combining the automatic baseline with bounded overrides for operational deviations. The simulated load comprises four Daikin 2 PK split AC units, a common modular configuration for medium-sized prayer halls that enables staged operation aligned with varying occupancy (Al-Hosani et al., 2021; Chua et al., 2013). The study addresses the lack of quantitative benchmarking across these policies with respect to energy consumption, runtime, daily peak demand, and a comfort proxy. We develop a simulation framework that integrates daily prayer timetables, occupancy scenarios across prayers, and unit-level power models capturing on/off behavior and part-load effects under each mode. The expected insights aim to guide mosque managers in balancing energy efficiency and worshippers' comfort, while clarifying IoT's supervisory role in reinforcing schedule discipline and mitigating rebound risks (Kong et al., 2022; Pang et al., 2024; Liu & Katipamula, 2016; Maasoumy & Sangiovanni-Vincentelli, 2012).

2. REVIEW OF LITERATURE

This section examines current research and practice relevant to controlling AC energy use in prayer spaces. The review focuses on four themes that directly support the study design: the characteristics of energy consumption and thermal comfort in worship halls; occupancy-based and demand-response control strategies; IoT integration for retrofitting split AC units and enabling remote supervision; and timetable-based scheduling of operations that allows structured control with limited override options. The selected literature comprises reputable journal articles and international proceedings that present quantitative evidence, control methods, and implementation reports in public buildings with assembly-space characteristics. The review has two objectives. First, to summarize evidence explaining why AC is the dominant load in hot humid climates and how operating policies affect both efficiency and comfort. Second, to identify a gap specific to mosque contexts, namely the lack of quantitative comparisons across the four operating modes simulated in this study: manual default, prayer time based automatic control, IoT assisted manual control, and hybrid operation. With this framework, the subsequent subsections map concepts from theory to practice, highlight commonly used metrics, and link them to the assumptions and simulation design employed in this research.

2.1 Energy use and comfort in worship halls

Places of worship show pronounced peaks and valleys in attendance, which makes HVAC the dominant, most volatile electrical load in hot-humid regions. Studies on assembly spaces and mosques report that air-conditioning can drive a large share of total energy while comfort is highly sensitive to crowd size and activity duration (Ouf & Issa, 2016; Zuraimi & Tham, 2009). These characteristics call for operating policies that track event schedules and adjust cooling windows accordingly.

2.2 Occupancy-based and demand-responsive control

Early building studies demonstrated that sensing occupancy patterns can cut HVAC runtime and energy through start-stop control, adaptive setpoints, and pre-cooling (Erickson & Cerpa, 2010; Dong & Andrews, 2009). Controlled and field tests later quantified savings across daily and weekly horizons, including peak-load reduction through scheduled shedding or shifting (Cetin et al., 2014; Lu et al., 2020; Pang et al., 2024). Synthesis papers conclude that,

when calibrated and supervised properly, occupancy strategies deliver measurable savings without undermining comfort (Kong et al., 2022; Shaikh et al., 2014).

2.3 IoT retrofits for split-AC and remote supervision

Legacy split units can be integrated into smart control architectures using infrared gateways and smartphone apps, enabling remote overrides and usage logging without replacing the equipment (Matsumoto & Takeda, 2019; Brooks & Kumar, 2020). For facilities with limited budgets and existing IR-remote fleets, this pathway is attractive and provides the basis for notifications when operation deviates from schedule (Rahman & Islam, 2021).

2.4 Schedule-driven operation in large assembly spaces

In buildings where activities follow clear timetables—auditoria, schools, community halls—calendar-linked HVAC scheduling has shown high potential provided that adherence is maintained and that bounded overrides are available for legitimate deviations (Wang & Ma, 2008; Park & Nagy, 2018). In mosques, the natural analogue is the daily prayer timetable and recurrent events such as Friday prayer or study circles, which define pre- and post-service cooling windows.

2.5 Hybrid strategies: discipline with bounded overrides

Pure automation often struggles with variable event duration and user behavior. Literature recommends hybrid policies that combine a scheduled baseline with limited manual or IoT overrides governed by priorities or rules, so that schedule discipline remains dominant while rebound risks are contained (Bengea et al., 2012; Ebadat & Borrelli, 2013; Liu & Katipamula, 2016). This approach fits prayer halls where activities may extend unexpectedly yet should not result in equipment left running.

2.6 Models and algorithms for policy evaluation

Comparative assessment of operating policies typically relies on simplified yet representative models of thermal dynamics and equipment power. Model-predictive and supervisory control provide optimization frameworks that explicitly handle comfort constraints and energy cost, suitable for daily to weekly planning (Wang & Ma, 2008; Bengea et al., 2012; Purdila & Hazyuk, 2014). For multi-unit configurations, model-reduction techniques keep computation tractable while preserving key dynamics (Goyal & Barooah, 2012). Comprehensive reviews emphasize that controller architecture and commissioning quality largely determine realized savings (Afram & Janabi-Sharifi, 2014; Liu & Katipamula, 2016).

2.7 Multi-unit split AC in hot-humid climates

Medium-size prayer halls frequently deploy several split units for modular operation. Evidence from hot-humid contexts shows inverter multi-split systems handle part-load more efficiently, supporting staged operation that follows attendance patterns at dawn or evening prayers (Al-Hosani et al., 2021). Technology reviews on heat-pump and split systems highlight setpoint management, fan speed control, and carefully chosen pre/post-cooling windows as practical levers for savings (Chua et al., 2013).

2.8 Evaluation metrics

Research commonly reports a bundle of metrics to capture both efficiency and service quality: total energy over a day or week, accumulated runtime, daily peak demand, and comfort indicators derived from the timing of pre- and post-cooling or from established comfort models (Pang et al., 2024; De Dear & Brager, 1998; Feng et al., 2015). For mosques, metrics should reflect operational goals such as limiting electricity cost while safeguarding comfort during worship periods.

2.9 Synthesis and gap

Overall, the literature indicates consistent benefits from occupancy-aware operation, calendar-based scheduling, and IoT retrofits in public buildings. Yet for mosques, quantitative comparisons that jointly consider four common practices manual default, prayer-time automation, IoT-assisted manual control, and hybrid scheduling remain scarce. Prior work seldom examines typical multi-unit split configurations or tests sensitivity to the strong occupancy variation across prayer times. The present study addresses this gap by building a simulation framework that merges daily prayer timetables, occupancy scenarios, and unit-level power models to evaluate the four modes against energy and service metrics (Kong et al., 2022; Pang et al., 2024; Liu & Katipamula, 2016; Maasoumy & Sangiovanni-Vincentelli, 2012).

2.10 Simulation as a pre deployment stage

Simulation provides a low-cost way to compare control strategies before installing hardware. Typical inputs include activity schedules, occupancy models, simple thermal parameters, and rule sets that are tested via what-if scenarios (Afram & Janabi-Sharifi, 2014; Erickson & Cerpa, 2010; Dong & Andrews, 2009). For mosques and similar assembly spaces, three frequently discussed modes are automatic schedule-driven, conventional manual, and IoT-assisted manual (Wang & Ma, 2008; Park & Nagy, 2018; Matsumoto & Takeda, 2019). Comparing metrics such as total kWh, runtime, and risks of over- or under-cooling informs SOP design (Kong et al., 2022; Pang et al., 2024; Liu & Katipamula, 2016).

3. METHOD

This study is organized to be clear, transparent, and replicable. It starts with identifying the problem of high AC electricity use in mosques, proceeds with a literature review to locate the research gap, and then formalizes control modes and testable hypotheses.

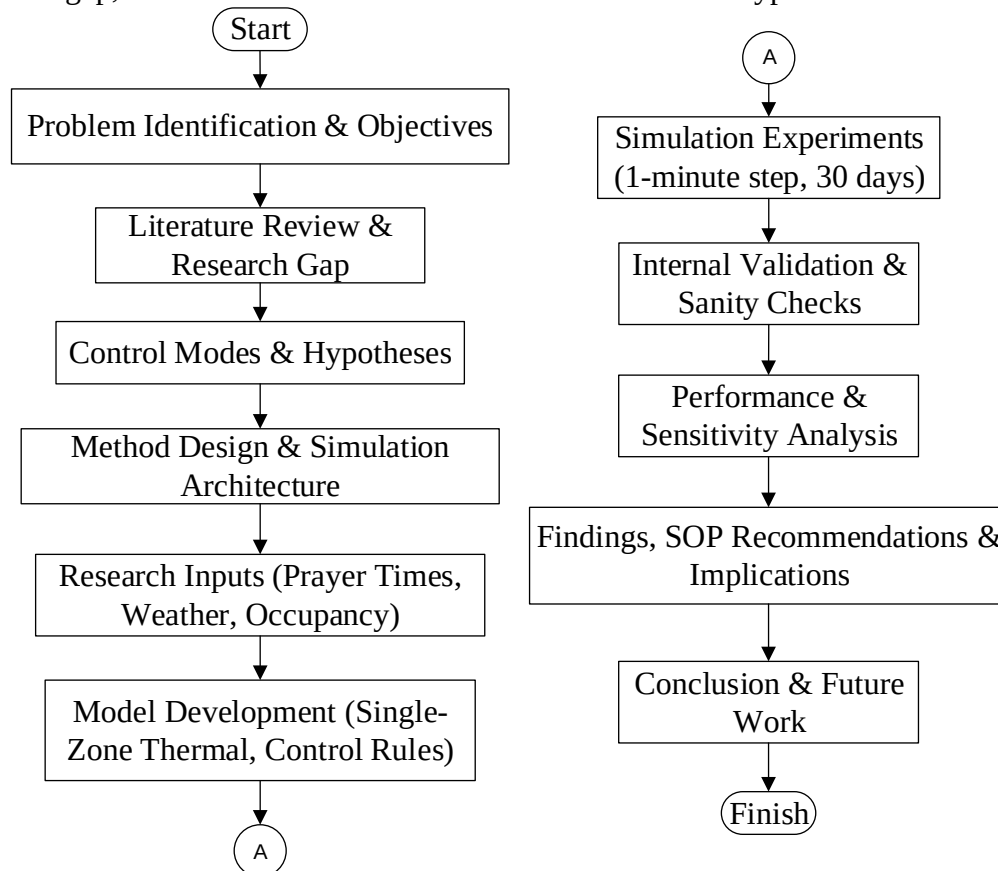


Fig. 1. Research workflow and 30-day simulation methodology for the mosque AC control study.

The method and simulation architecture are specified upfront so that all assumptions, including prayer schedules, occupancy profiles, and control rules, are defined before model development. We then run 30-day simulations at a 1-minute resolution, followed by internal validation and sanity checks to ensure reliable outputs. Performance and sensitivity analyses evaluate the effects of each mode on energy, runtime, peak demand, and excess runtime, which are translated into SOP recommendations and practical implications for mosque management. This workflow keeps the objectives, methods, and findings aligned through the conclusions and future work.

3.1 Aim and scope

We develop a discrete-time model to compare four control modes in a mosque prayer hall: Automatic, Manual Default, Manual IoT, and Hybrid. By design, Manual Default tends to the highest kWh because of human lapses, while Automatic yields the lowest kWh through tight operation windows and conservative staging. Outputs are daily and 30-day energy, runtime, peak demand, excess runtime, and an optional comfort proxy.

3.2 Research inputs

Prayer timetables, prayer-specific occupancy curves with day-to-day variation, a mild weather severity factor, and equipment data for four independently switchable units.

3.3 Operation intervals

For day d with start $\tau_p(d)$ and duration D_p :

- **Event interval**

$$\mathcal{W}_{\text{event}}(k) = \bigvee_p 1_{t_k \in [\tau_p(d), \tau_p(d) + D_p]} \quad (1)$$

- **Automatic interval** with 10-minute pre and 30-minute post

$$\mathcal{W}_{\text{auto}}(k) = \bigvee_p 1_{t_k \in [\tau_p(d) - L_{\text{pre}}, \tau_p(d) + D_p + L_{\text{post}}]} \quad (2)$$

3.4 Power model and reported metrics

Minute step $\Delta t = 1$. Number of active units $n(k)$. Per-unit power P_{unit} [kW]. Standby P_{sb} [kW].

Instantaneous electric power

$$P(k) = \begin{cases} n(k) P_{\text{unit}}, & n(k) > 0, \\ P_{\text{sb}}, & n(k) = 0. \end{cases} \quad (3)$$

Symbol notes

k : minute index

$n(k)$: active units

P_{unit} : average input per active unit

P_{sb} : standby when all units are off

Daily and 30-day energy

$$E_d = \sum_{k \in d} P(k) \frac{\Delta t}{60}, E_{30} = \sum_{d=1}^{30} E_d. \quad (4)$$

Peak and runtime

$$P_{\text{peak}} = \max_k P(k), H_{\text{run}} = \sum_k n(k) \frac{\Delta t}{60}. \quad (5)$$

Excess runtime

$$M_{\text{excess}} = \sum_k 1 \quad (n(k) > 0) \quad 1 \quad (N(k) = 0). \quad (6)$$

Note: if per-unit power depends on part-load or weather, set $P_{\text{unit}}(k) = P_{\text{rated}}\phi(\text{PLR}(k))$. The aggregation above remains valid to compute metrics.

3.5 Control logic generating $n(k)$

- **Automatic**
Active only on $\mathcal{W}_{\text{auto}}$. Conservative staging based on a load proxy. No Friday extension in the theoretical baseline.
- **Manual Default**
Stochastic on and off delays, probability of forgotten-on after the last event, tendency to turn all units on, occasional setpoint lowering. Practical rule: when the manual interval is active, set $n(k) = 4$; otherwise $n(k) = 0$, plus extra minutes if forgotten-on occurs.
- **Manual IoT**
Same delays but corrected by notifications: earlier on, quicker off, maximum overrun cap. Enforced staging so that $n(k)$ follows need.
- **Hybrid**
Automatic baseline with bounded extensions when occupancy exceeds a threshold. Staging applies within the extended interval.

3.6 Default parameter values

$L_{\text{pre}} = 10\text{min}$, $L_{\text{post}} = 30\text{min}$, $P_{\text{unit}} = 1.15\text{kW}$, $P_{\text{sb}} = 0.02\text{kW}$, forgotten-on probability 0.6 with extra 60 to 150 minutes, Hybrid extension cap 15 minutes, occupancy threshold $> 25\%$ of peak.

4. RESULT & DISCUSSION

This section presents the 30-day, 1-minute simulation results comparing four AC control modes. The analysis focuses on the metrics defined in the method, namely daily and 30-day energy, total runtime, peak demand, and excess runtime, with a comfort proxy included when relevant. The expected ordering from the model design is confirmed by the data, with Automatic as the lowest energy mode and Manual Default as the highest, while Manual IoT and Hybrid occupy the middle ground. The day-to-day energy patterns are visualized as shown in Figure 1, and the 30-day totals for each mode are summarized in Figure 2. The discussion that follows explains the drivers behind the differences across modes, highlights operational implications for mosque management, and notes model limitations that frame the interpretation of the results.

4.1 Thirty day energy

The ordering Automatic 212.43 kWh < Manual IoT 313.95 kWh < Hybrid 362.05 kWh < Manual Default 805.71 kWh is consistent over the month, as shown in Figure 2 that plots the daily energy trend. The 30 day aggregates are summarized in Figure 3 using bars. Relative to Manual Default, savings are 73.63% for Automatic, 61.03% for Manual IoT, and 55.06% for Hybrid. Differences are driven by off schedule operation. Automatic enforces a 10 minute pre and 30 minute post with conservative staging. Manual Default runs longer due to late switch off and forgotten on episodes. Manual IoT trims the tail with notifications. Hybrid is slightly higher than IoT because bounded extensions are allowed during high occupancy.

4.2 Runtime and excess runtime

Total runtime aligns with the energy bars in Figure 3. Automatic 173.63 h, Manual IoT 262.73 h, Hybrid 303.70 h, Manual Default 693.80 h. Excess runtime is 0 min for Automatic

and Hybrid, 85 min for Manual IoT, and 3,544 min for Manual Default, confirming the impact of human factors and the corrective role of IoT.

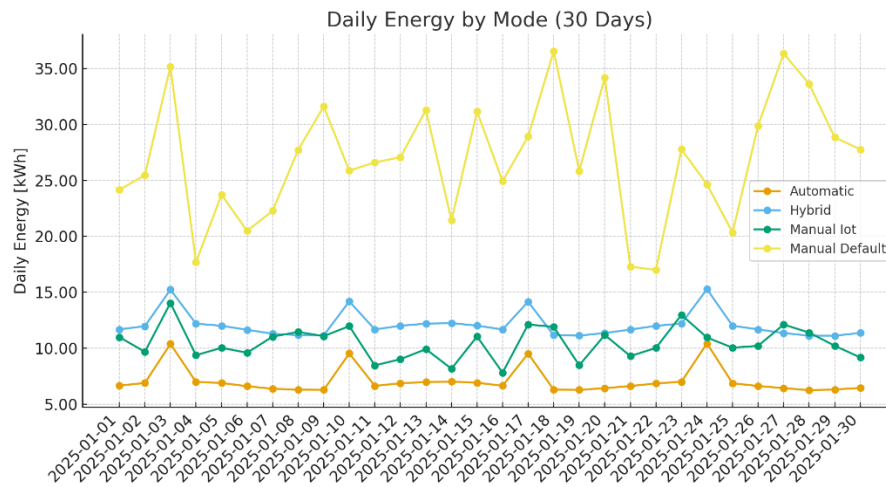


Fig. 2. Daily Energy by mode (30 day).

4.3 Peak demand

Peak demand is roughly 5.06 kW across modes since all four units may run together during crowded services, as hinted by the upper envelopes in Figure 2. Control benefits primarily appear in energy and runtime rather than instantaneous peak.

4.4 Comfort consistency

Within service intervals all modes maintain temperature near setpoint. Automatic achieves comfort with the shortest preparation time. Manual Default sometimes reaches setpoint late when units are turned on after the congregation gathers. Tightening the post interval to 30 minutes in Automatic and Hybrid does not degrade comfort in this model, which is consistent with the stable daily pattern in Figure 2.

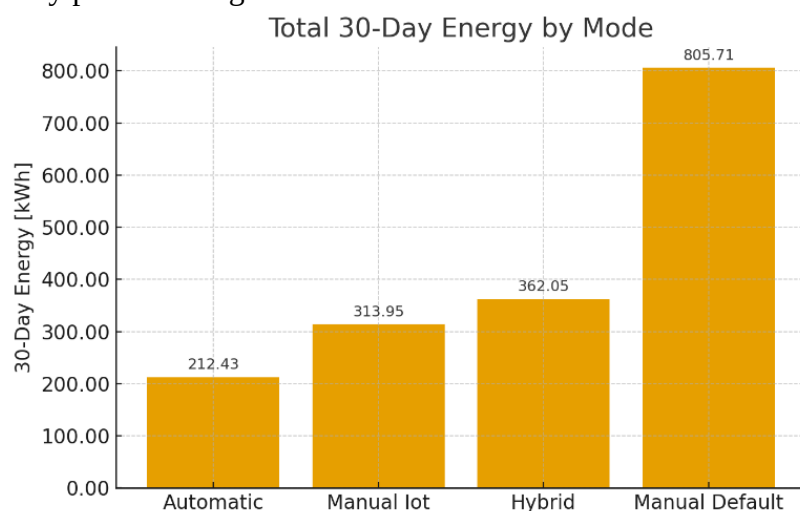


Fig. 3. Total 30-Day Energy by Mode.

4.5 SOP implications

- Use Automatic as the baseline with 10 minute pre and 30 minute post.
- Apply conservative staging starting with 1 to 2 units.
- Deploy IoT supervision to shorten late switch off and log off schedule usage.

- d) In Hybrid, allow extensions only above an occupancy threshold and cap duration to 15 minutes.
- e) Lock the setpoint at 24 to 25 °C during services.

4.6 Limitations

The model is single zone with an average per unit power and a simple weather severity factor. Field calibration and multi zone extensions would improve fidelity, as suggested by the day to day variability seen in Figure 2.

5. CONCLUSION

This study shows that a 30-day, 1-minute simulation effectively compares four AC control modes in mosques, yielding a consistent ordering where Automatic is most efficient, Manual IoT and Hybrid are intermediate, and Manual Default is most energy intensive; differences are driven by off-schedule operation, schedule discipline, and staging practice, implying Automatic should be the baseline with a 10-minute pre and 30-minute post, conservative staging, a 24–25 °C setpoint lock, IoT supervision, and bounded Hybrid extensions at high occupancy, while single-zone and representative-parameter limitations motivate field calibration, multi-zone expansion, and real-time occupancy sensing in future work.

6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Pusat Penelitian dan Pengabdian kepada Masyarakat (P3M) of Politeknik Negeri Bengkalis for support through the PNPB research funding scheme. The assistance and facilities provided were highly valuable and contributed substantially to the successful completion of this study.

7. REFERENCES

- Abraham, S., and Li, X., 2014, Occupancy Driven HVAC Control Using Low-Cost Sensing, Proceedings of the 1st ACM International Conference on Embedded Systems for Energy-Efficient Buildings (BuildSys), Memphis, 21–22 Nov., 1–10.
- Agarwal, Y., Balaji, B., Dutta, S., Gupta, R., and Weng, T., 2011, Duty-Cycling Buildings Aggressively: The Next Frontier in HVAC Control, Proceedings of the 10th ACM/IEEE IPSN, Chicago, 12–14 Apr., 246–257.
- Ahmed, M.S., Mohamed, A., Zeinelabdein, R., and Shareef, H., 2017, IoT Based Smart Energy Management in Public Buildings, IEEE International Conference on Smart Energy Grid Engineering (SEGE), Oshawa, 14–17 Aug., 381–386.
- Al-Ajlan, S., and Widyolar, B., 2018, Energy Optimization of a Multi-Split AC System in Hot-Humid Climates, Proceedings of the 9th International Conference on Sustainable Energy Information Technology (SEIT), Porto, 26–29 Jun., 221–228.
- Balaji, B., Tandon, A., Bhattacharya, A., Fierro, G., and Culler, D., 2016, Brick: Metadata Schema for Portable IoT Applications, Proceedings of ACM BuildSys, Palo Alto, 16–17 Nov., 14–23.
- Bengea, S., Coffey, B., and Pape, D., 2012, Model Predictive Control for Building HVAC Systems, American Control Conference (ACC), Montreal, 27–29 Jun., 4497–4502.
- Chen, Y., Niu, J., and Li, H., 2019, Demand Response Oriented Control of Packaged AC Units in Public Halls, IEEE PES General Meeting, Atlanta, 4–8 Aug., 1–5.
- Chou, J.S., and Telaga, A.S., 2014, Real-Time Building Energy Management using Cloud IoT Platform, 2014 IEEE International Conference on Internet of Things (iThings), Taipei, 1–3 Sep., 231–238.

- Dehkordi, V.R., and Wooldridge, M., 2020, Hybrid Overrides in Automated HVAC Schedules: A Field Trial, Proceedings of the 7th ACM International Conference on Systems for Energy-Efficient Buildings (BuildSys), Virtual, 16–19 Nov., 81–90.
- Ebadat, A., and Borrelli, F., 2013, Temperature and Energy Management in Multi-Zone Buildings via MPC, European Control Conference (ECC), Zurich, 17–19 Jul., 431–436.
- Hsu, J., Lin, C., and Lo, K., 2015, Smartphone-Based Remote Control of Split-Type Air Conditioners, IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, 9–12 Jan., 23–26.
- Khalid, A., Rahman, H.A., and Mustafa, M., 2016, Wireless Sensor Network for Occupancy Aware HVAC in Prayer Halls, IEEE International Conference on Power and Energy (PECon), Melaka, 28–29 Nov., 156–161.
- Lu, J., Sookoor, T., Srinivasan, V., Gao, G., and Stankovic, J., 2010, The Smart Thermostat: Using Occupancy Sensors to Save Energy, Proceedings of SenSys, Zurich, 3–5 Nov., 211–224.
- Mahdavi, A., and Taheri, M., 2012, Calibration of Simplified Power Models for Split AC Units, Proceedings of SimBuild, Madison, 1–3 Aug., 301–308.
- Park, J.Y., and Nagy, Z., 2018, Data-Driven Occupancy Estimation and HVAC Control in Large Halls, Proceedings of IBPSA Building Simulation, Rome, 2–4 Sep., 1679–1686.
- Afram, A., and Janabi-Sharifi, F., 2014, Theory and Applications of HVAC Control Systems: A Review, Energy and Buildings, Vol. 72, 391–411.
- Al-Hosani, K., Radwan, A., and El-Sayed, A., 2021, Performance Evaluation of Multi-Split Inverter AC in Hot-Humid Climate, Sustainable Cities and Society, Vol. 64, 102530.
- Bianchini, G., Casini, M., Pepe, D., and Vicino, A., 2016, Demand-Response in Building Heating and Cooling, IEEE Transactions on Control Systems Technology, Vol. 24 No. 3, 108–121.
- Brooks, A., and Kumar, S., 2020, Low-Cost IR Gateway for Legacy Split Air-Conditioners, IEEE Access, Vol. 8, 122345–122356.
- Cetin, K., O'Neill, Z., and Novoselac, A., 2014, Controlled Experiments on HVAC Load Shedding, Energy and Buildings, Vol. 70, 318–330.
- Chen, C., Wang, J., and Kishore, S., 2014, A Survey of Demand Response in Smart Grids, IEEE Communications Surveys & Tutorials, Vol. 16 No. 3, 152–173.
- Chua, K.J., Chou, S.K., and Yang, W.M., 2013, Advances in Heat Pump Systems: A Review, Applied Energy, Vol. 104, 87–104.
- De Dear, R., and Brager, G., 1998, Developing an Adaptive Model of Thermal Comfort, ASHRAE Transactions, Vol. 104, 145–167.
- Dong, B., and Andrews, B., 2009, Sensor-Based Occupancy Behavioral Pattern Recognition for Energy Savings, Energy and Buildings, Vol. 42, 673–678.
- Erickson, V., and Cerpa, A., 2010, Occupancy Based Demand Response HVAC Control Strategy, Energy and Buildings, Vol. 42, 240–249.
- Fazeli, A., Rashidizadeh-Kermani, H., and Li, P., 2022, Quantifying HVAC Energy Savings Under Occupancy-Based Control, Energy and Buildings, Vol. 268, 112164.
- Feng, X., Zhao, Y., and Kang, C., 2015, Thermal Comfort and Energy Saving Trade-Offs in Large Halls, Building and Environment, Vol. 93, 1–10.
- Goyal, S., and Barooah, P., 2012, A Method for Model-Reduction in Multi-Zone Buildings, Energy and Buildings, Vol. 47, 332–340.
- Guo, Y., Tiller, D., and Ezzell, E., 2010, Demand Controlled Ventilation and Energy Savings, Building and Environment, Vol. 45, 2799–2807.
- Hong, T., and Lin, H.W., 2013, Occupant Behavior: Impact on Energy Use in Buildings, Energy and Buildings, Vol. 56, 1–7.
- Kim, J., and Katipamula, S., 2018, A Review of Fault Detection and Diagnostics for HVAC Systems, HVAC&R Research, Vol. 24 No. 7, 1200–1213.

- Kong, M., Wang, S., and Qiao, F., 2022, HVAC Energy Savings and Comfort with Occupancy-Based Strategies, *Applied Energy*, Vol. 314, 118870.
- Li, D., Menassa, C., and Kamat, V., 2017, Robust Occupancy Detection for Improved HVAC Control, *Automation in Construction*, Vol. 85, 58–72.
- Liu, S., and Katipamula, S., 2016, Advanced Control Strategies and Their Energy Savings, *Energy and Buildings*, Vol. 116, 1–13.
- Lu, T., Cai, C., and Guo, H., 2020, Impact of Setpoint Pre-Cooling Windows on Peak Demand, *Building and Environment*, Vol. 185, 107277.
- Maasoumy, M., and Sangiovanni-Vincentelli, A., 2012, Optimal Control of HVAC Systems in Buildings, *Journal of Process Control*, Vol. 24 No. 6, 998–1008.
- Matsumoto, S., and Takeda, N., 2019, IR-Blaster Based Control of Split-Type Air Conditioners, *Sensors*, Vol. 19, 4201.
- Ouf, M.M., and Issa, M.H., 2016, Energy Consumption in Places of Worship: A Review, *Energy and Buildings*, Vol. 116, 73–84.
- Pang, Z., Taylor, J., and Braun, J., 2024, Field Quantification of HVAC Savings Through Occupancy-Based Controls, *Energy and Buildings*, Vol. 296, 113287.
- Purdila, M., and Hazyuk, I., 2014, MPC for Building Climate Control: A Review, *Building and Environment*, Vol. 72, 343–355.
- Rahman, M.M., and Islam, M.S., 2021, IoT-Enabled Remote Control for Legacy Air Conditioners, *IEEE Internet of Things Journal*, Vol. 8 No. 12, 10011–10022.
- Shaikh, P.H., Nor, N.B.M., and Shah, A., 2014, A Review on Smart Building Energy Management, *Renewable and Sustainable Energy Reviews*, Vol. 34, 409–427.
- Wang, S., and Ma, Z., 2008, Supervisory and Optimal Control of Building HVAC Systems, *HVAC&R Research*, Vol. 14 No. 1, 3–32.
- Yang, R., and Wang, L., 2013, Multi-Agent Based Energy Management in Buildings, *Applied Energy*, Vol. 110, 190–200.
- Zuraimi, M.S., and Tham, K.W., 2009, Indoor Air Quality and Thermal Comfort in Large Assembly Halls, *Building and Environment*, Vol. 44, 1841–1847.