
# IN$^2$ Final Report

**TO:** Software Motor Company, Wells Fargo IN$^2$ Board of Directors, Wells Fargo Corporate Properties Group

**FROM:** NREL

**IN$^2$ Company Name:** Software Motor Company

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## 1. Technology Description

It is estimated that 38.4% of the total U.S. electrical energy consumption is used to run motors.[1] Annually, 45 billion kWh are used by 1-10 horsepower motors, alone. Even a small increase in motor efficiency could greatly reduce energy consumption. Software Motor Company (SMC) has developed a patented High Rotor-Pole Switched Reluctance Motor (HRSRM) system that can achieve up to 95% peak motor efficiency and maintain similarly high levels of performance over a wide range of operating speeds. From the beginning, SMC has focused on retrofit applications for heating, ventilating, and air-conditioning (HVAC) systems including commercial rooftop units (RTUs). Its 1-10 horsepower product line is well-positioned to replace most commercial RTU supply fan motors.

SMC reports that its motor peak and part-load efficiencies are superior to induction motors and electronically commutated motors, which are the most common RTU motors. As a requirement for HRSRMs, SMC has developed a motor controller with the ability to operate a single motor, whose operation can be coordinated with up to nine motors using a master controller known as a supervisor. In addition, the built-in input/output (I/O) terminals and logic engines in these controllers and supervisors can be used to coordinate or control other systems such as the functions of an HVAC RTU. The company has not yet taken advantage of its controller and supervisor platform to provide additional energy savings value in RTU retrofit applications. For this reason, SMC decided to use the National Renewable Energy Laboratory's (NREL's) expertise in advanced HVAC control to develop control strategies so it could provide both inherently highly efficient motors and advanced control strategies.

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[1] J. Douglas and G. McCoy, 2014 *Premium Efficiency Motor Selection and Application Guide: A Handbook for Industry*. (Advanced Manufacturing Office: U.S. Department of Energy, 2014, DOE/G0-102014-4107).

## 2. Project Description

NREL evaluated the performance of SMC's HRSRM in RTU applications. The project consisted of the following main tasks:

- **Task 1**. Investigated the capability of SMC's motor system and performed literature research on advanced control strategies for RTUs. The primary objective for Task 1 was to explore experimentation designs that could effectively capture the performance and key energy efficiency attributes of the SMC motor system. Through a robust ideation process, potential baseline and energy efficiency centric control strategies were identified. This process was recorded in a report delivered to SMC before Task 2 began.
- **Task 2**. Assessed the feasibility and operability of selected control strategies using laboratory settings. Task 2 focused on experimental validation of control schemes for two baselines, and seven distinct control strategies. It is important to note that even the baseline strategies are recognized as advanced rooftop control strategies in the field. However, for clarity, they are referred to as baseline, while the unique control strategies are referred to as the advanced control strategies. The key questions for each subtask were:
    1. Feasibility: Was the SMC motor system capable of running the control strategy?
    2. Operability: Did the control strategy operate as intended?

Laboratory experiments were designed to stack each new control strategy on top of the previous one. Such integration provided a platform for assessing the cumulative and interactive impacts of various control schemes. During the initial stages of the project, NREL and SMC agreed upon four areas of advanced control that would be the most impactful for customers. These four key subtasks were:

- **Demand Control Ventilation (DCV)**

    DCV adjusts the amount of outdoor air required for ventilating the building based on a real-time count of occupants in the building. DCV saves energy because the designed outdoor air ventilation is typically determined based on an estimated number of occupants per zone, which can be much higher than the actual number of people within that zone.
- **Integrated Economizer Control (IEC)**

    IEC interlocks the economizer operation with mechanical cooling. This allows lower temperature outdoor air to contribute as much cooling benefit as ambient conditions permit, while the compressor operates simultaneously to satisfy the difference in meeting the cooling load. Depending on the mechanical cooling controls, under these conditions, the compressor can consume less power and operate more efficiently.
- **Matching the RTU Capacity with Cooling Loads (Match Capacity)**

    Building cooling loads are affected by many factors, including weather, internal loads, heat transfer through the building envelope, and infiltration, to name a few. Accurately matching the cooling output of the RTU with the fluctuating cooling load can result in significant reduction of compressor and supply fan power and, ultimately, energy savings over time.
- **Sensor Augmentation (Add. Sensors)**

    The final subtask intended to determine what additional benefits could be created with the use of additional sensors. For this subtask, the additional sensor was a relative humidity sensor in the zone. This would potentially create savings by preventing dehumidification of the building air when it was not needed.

- **Task 3**. This task was developed to pave the path for commercialization of the SMC technology by spreading awareness of this project within pertinent industry channels.

## Methodology

The overall methodology involved the assessment of control strategies developed under Task 2 on a 5-year-old, 10-ton RTU within the controlled environment of NREL's HVAC laboratory, which can replicate various climatic conditions. The supply fan motor of the RTU was replaced with the SMC system as shown in Figure 1.

*Figure 1. (Left) Legacy motor and (right) SMC motor installed in a 10-ton RTU.*

The RTU was then instrumented to analyze its cooling capacity and power consumption. The baseline and unique control algorithms were developed in collaboration with SMC and uploaded onto the SMC controller and inverter. Figure 2 depicts the test order and complexity of the experimented control strategies. As shown, the first subtask was DCV followed by IEC, matching capacity, and finally the use of additional sensors. With the exception of DCV, the control strategies for each subtask also included control strategies developed in the previous subtask. For example, all IEC control strategies were capable of running DCV control, as well. Sensor augmentation (Add. Sensors) was the final subtask and hence the most complex strategy; it incorporated DCV, IEC, and even matching capacity subtask control strategies.

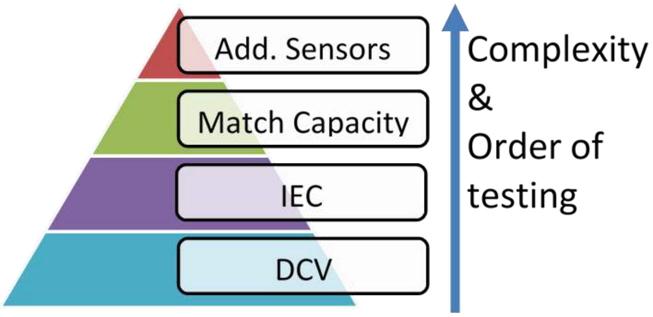


*Figure 2. Illustration of the order of test and complexity of subtasks.*

## Findings

NREL researched codes, standards, and literature affecting commercial buildings. This literature research influenced the direction NREL took with the unique control strategies. Additionally, SMC hardware, software, and I/O characteristics were closely studied to determine the type and feasibility of RTU subsystem controls. As an example, the SMC controller has sufficient I/O and programming capabilities to perform exact tracking of the RTU's supply air temperature. This information was summarized in a report sent to SMC before beginning laboratory testing in Task 2.

Throughout the project, the NREL team partnered with SMC to address several technical challenges that emerged. For example, NREL discovered an I/O voltage output issue caused by a bug in a new firmware release for controllers and supervisors that affected the scaling factor for the output voltage. This issue was fixed with a subsequent firmware update. Another issue suggested communication problems between the controller and supervisor, but was actually found to be caused by an out-of-date version of the SMC PC application and resolved with a software update. Additionally, SMC provided a cellular router in order to collect diagnostic information from the test system which sped up issue tracking and resolution. NREL discovered a lag issue in debugging mode where displays of inputs and outputs from the supervisor were interrupted. Further investigation led to the realization that continuous read/writes could create a backlog of identical commands and was corrected by enforcing time-based operating cycles.

The outcomes of experimentations for all subtasks are summarized in Table 1. The SMC system was capable of operating with all control strategies developed during the project.

One of the key advantages of the SMC system is its variable fan speed operation. As shown in Table 1, the baseline control strategies did not take full advantage of this feature and instead staged the fan speed based on the thermostat inputs. All advanced control strategies operated with fully variable fan speed, limited by user-defined minimum and maximum fan speed constants.

Furthermore, all advanced strategies controlled the supply air temperature. This type of control delivers better zone humidity control and provides a lever to adjust RTU power consumption as a function of supply air temperature.

*Table 1. Results of IN² project with SMC to develop control strategies for RTUs.*

| Subtask | Control Strategy | Did the SMC system work? | Did the control strategy operate as intended? | Fan Operation | Supply Air Temperature Control | Control Objectives |
|---|---|---|---|---|---|---|
| DCV | Baseline | Yes | Yes | Staged | None | Basic DCV control |
| | CS1 | Yes | Yes | Fully variable | Yes | More advanced DCV control |
| | CS2 | Yes | Yes | Fully variable | Yes | More advanced DCV control + two stage RTU control |
| IEC | Baseline | Yes | Yes | Staged | None | Basic DCV + IEC control |
| | CS1 | Yes | Yes | Fully variable | Yes | Delay compressor operation |
| Match Capacity | Baseline | Yes | Yes | Fixed | None | Basic DCV + IEC control |
| | CS1 | Yes | Yes | Fully variable | Yes | Maximized sensible cooling |
| | CS2 | Yes | Yes | Fully variable | Yes | Pre-cooling |
| Add. Sensors | Baseline | Yes | Yes | Staged | None | Basic DCV + IEC control |
| | CS1 | Yes | Yes | Fully variable | Yes | Automated turn on/off of Match Capacity CS1 |
| | CS2 | Yes | Yes | Fully variable | Yes | Automated adjustment of supply air temperature setpoint |

More specific results for each subtask (feasibility and operability) are also recorded in Table 1. As mentioned previously, the main goal of this project was to assess the presence or absence of feasibility and operability. Therefore, further experimentation will be required to ascertain the energy efficiency facets of these control strategies. NREL plans to present the findings of this IN² project in the upcoming 2019 ASHRAE winter meeting, as well as participate in the Wells Fargo exit webinar. NREL and SMC also intend to apply for follow-on IN² work and to create a published report that details the new control strategies and their potential to further advance the controls market for commercial RTUs.