FINAL REPORT

Cannabis Production ISP

Rhode Island Energy

Date: November 3, 2022

Table of contents

List of figures

No table of figures entries found.

List of tables

List of acronyms used in this report

AHU	air handling unit
BMS	building management system
CCC	Cannabis Control Commission
DX	direct expansion
HID	high-intensity discharge
HPS	high-pressure sodium
HVAC	heating, ventilation, and air conditioning
ISP	industry standard practice
LED	light-emitting diode
M&V	measurement and verification
MA	Massachusetts
ML	metal halide
PA	program administrator
PAR	photosynthetically active radiation
PPFD	photosynthetic photon flux density
QA	quality assurance
RI	Rhode Island
VRF	variable refrigerant flow

Executive Summary

The purpose of this study was to define industry standard practice (ISP) in Rhode Island for the cannabis industry end-uses including horticultural lighting, lighting controls, cultivation area HVAC, HVAC controls, and dehumidification, using high-rigor methods including interviews of service providers who have operated in the state. DNV carried out the industry standard practice (ISP) study for indoor cannabis cultivation in Rhode Island. At the time of the study, the cannabis industry in RI was limited to the medical market, though a law was recently passed to expand to the recreational market and most vendors foresee changes to design practices, as capital investment in cannabis facilities will likely increase. The study focused on tiered cultivation, where cannabis is grown in vertical racks, as utility experience in RI has noted a high percentage of tiered grows. Tiered cultivation presents additional questions related to lighting and HVAC systems due to the density of lighting and plants and the proximity of the horticultural fixtures to the plant canopy. The DNV team leveraged a recently completed MA cannabis baseline ISP study, as it contains recent secondary research on national and MA cannabis practices and was used to compare practices in RI. Secondary research specific to RI was also conducted to assess the existing market size, the current state of legislation toward an adult-use market, and whether there is any consideration for energy standards as in MA.

Methodology and Approach

The findings presented in this report are based on interviews of a random selection of **five** service providers active in Rhode Island out of a population of 13.

- **Three** of the five participants also completed surveys for the MA cannabis ISP study.
- The service providers are mostly **engineers and consultants** who have worked on at least one licensed facility in Rhode Island.
- Most have experience in **other jurisdictions**, including Massachusetts.

The team developed **interview guides** to cover each broad category of interest and to methodically review the design choices and motivations behind key decisions for all areas of interest. The interview guide sections were:

- Familiarity with Cannabis Technology
- Horticultural Lighting
- Mechanical Systems and Dehumidification
- HVAC Controls
- Program Influence
- General Questions

For this study, the decision was made to focus on the population of service providers, as their insight would be on a broader market scale than that of cultivators themselves. Service providers consist of all supporting vendor and consulting professionals that assist in the design and construction of a cannabis facility.

The approach to this study consisted of the following stages:

Sample design → **In-depth interviews** → **Analysis** → **Reporting**

Horticultural Lighting Results

Some market actors indicated facilities may install different options per cultivation area. Responses like this can be seen for areas such as flower, where facilities typically either install LED lighting or double-ended high-pressure sodium (HPS). This was a response shared by each market actor that handles lighting in some way.

Technology		Flower	Vegetation	Clone/Seedling	Mother
LED		50% (n=2)	87.5% (n=3.5)	87.5% (n=3.5)	75% (n=3)
HID	Single-ended HPS	0%	0%	0%	0%
	Double-ended HPS	50% (n=2)	0%	0%	12.5% (n=0.5)
	Ceramic Metal halide	0%	0%	0%	0%
	Metal halide	0%	0%	0%	0%
Fluorescent	T5	0%	12.5% (n=0.5)	12.5% (n=0.5)	12.5% (n=0.5)

For lighting controls, most respondents said that simple strategies deploying timers are typically used for the different cultivation areas, otherwise, sites perform manual switching. If dimming is installed, it is primarily to reduce shock on plants when going between phases, especially in dual-use rooms when the room changes to a different phase of growth.

HVAC Results

The responses to the questions on HVAC ISP were consistent and primarily revolved around packaged and split direct expansion (DX) systems. Percentages represent the total number of times survey respondents indicated they had experience with a given technology.

System Type		Percent of Responses
Mini-splits		10% (n=0.5)
Chiller	Electric	30% (n=1.5)
	Gas fired	0%
DX units		60% (n=3)
Water source heat pumps		0%
VRF		0%

Dehumidification

Dehumidification is key for indoor cultivation facilities. For primary dehumidification, respondents used:

20% (n=1) DX units	80% (n=4) portable units

Controls

The primary HVAC control devices are programmable thermostats and humidistats. Some respondents indicated experience with a centralized BMS, but this is rare, as smaller RI facilities do not have the capital to install and maintain these systems.

Conclusions

While the study was able to identify ISP for some systems and end uses, for many others, no ISP was identified. Therefore, site-specific baselines for energy efficiency projects are appropriate.

Horticultural lighting: Lighting designs in Rhode Island typically revolve around set PPFD targets by the owner. Lighting ISPs by stage of growth are:

- **Flower/bloom:** 830-watt mixed LED and HPS technology (1,000-watt double-ended HPS or 660-watt LED), with a target PPFD of 900 and a photoperiod of 12 hours.
- **Vegetative:** 400-watt LED, with a target PPFD of 450 and a photoperiod of 18 hours.
- **Clone/seedling:** 200-watt LED, with a target PPFD of 200 and a photoperiod of 24 hours.
- **Mother:** 350-watt LED, with a target PPFD of 600 and a photoperiod of 18 hours.

Environmental conditioning: The sizing of HVAC systems should be based on the anticipated sensible and latent loads for the facility using site-specific load calculations. There are both a substantial sensible load from the horticultural lights and large latent loads from the transpiration of plants, which releases moisture that must be removed from the space to maintain environmental targets. Managing these loads contributes to high cooling and dehumidification use. **The team found direct expansion systems to be the ISP for all facility sizes.**

Recommendations

Recommendation 1: Use identified ISP for baseline. The team recommends the use of the ISP practices identified in this study by implementors as the baselines for projects and by evaluators when evaluating those projects. For all systems and equipment where an ISP was not identified, a site-specific baseline should be used.

Recommendation 2: Future research. During the writing of this report, Rhode Island legislators legalized recreational cannabis for adult use. Most market actors who participated in the survey effort indicated that Rhode Island practices are typically not as sophisticated as other jurisdictions given the low capital invested for the smaller facilities. However, they expect this to change now that recreational use is legalized. As capital increases for these facilities, owners may pursue more sophisticated options for systems and controls. It is likely the cannabis landscape in RI will evolve over the coming years. The PA should consider revisiting this study later to research the adapting landscape and adjust ever-evolving ISP.

2 INTRODUCTION

The DNV team carried out the industry standard practice (ISP) study for indoor cannabis cultivation in Rhode Island. The study's overall objective was to define ISP in Rhode Island (RI) for the cannabis industry for technologies such as horticultural lighting, lighting controls, cultivation area HVAC, HVAC controls, and dehumidification using high-rigor methods including interviews of service providers who have operated in RI. At the time of the study, the cannabis industry in RI was limited to the medical market, though a law was recently passed to expand to the recreational market at the end of the survey task. Though this doesn't impact the project, most vendors foresee changes to design practices as capital will likely increase for the market and for horticultural projects.

The recently completed Massachusetts (MA) ISP study determined that the unique lighting power density requirements specified by Cannabis Control Commission (CCC) regulations in place in MA have impacted the standard practice for horticultural lighting there. Unlike MA, RI does not have energy efficiency requirements for cannabis facilities or a governing body such as the CCC, and as of the timing of this study, RI was only a market for medical cannabis. Therefore, the conclusions of the MA ISP study are not applicable to RI, due to the different regulatory environments. Instead, the DNV team leveraged the recently completed MA cannabis baseline ISP study as it contains recent secondary research on national and MA cannabis facility construction practices and was used to compare practices in RI. Secondary research specific to RI was conducted to assess the existing market size, the current state of legislation toward an adult-use market, and whether there is any consideration for energy standards as in MA. The study placed focus on tiered cultivation, where cannabis is grown in vertical racks, as utility experience in RI has noted a high percentage of tiered grows compared to MA. Tiered cultivation presents additional questions related to lighting and HVAC systems due to the higher density of lighting and plants and the proximity of the horticultural fixtures to the plant canopy.

For this study, the baseline or ISP is defined as "the equipment or practice specific to the application or sector that is commonly installed absent program intervention." While this report identifies several ISPs, cannabis facility designs have proven highly variable. In accordance with the Massachusetts Commercial/Industrial Baseline Framework, which Rhode Island generally follows,[1] implementors and future evaluators are permitted to make use of project-specific baselines for ISP systems when "…particular circumstances render standard practice irrelevant, and evidence is provided to justify [a project specific baseline]."[2]

The DNV team conducted five interviews with RI service providers serving the indoor cannabis market. Some of the interviewed service providers also participated in the MA study and were able to provide a comparison in opinions. The interviews were structured in a similar fashion to the MA study to assess practices for equipment such as horticultural lighting designs per growth area (e.g., flowering, vegetative, seeding), HVAC system types and controls including dehumidification, and PPFD values at the canopy.

2.1 Study background

Medical cannabis use was legalized in Rhode Island in 2006, and there are currently 64 licensed cultivators.[3] Rhode Island is currently expanding the number of compassion center licenses and just passed legislation allowing for full adult-use legalization in May 2022.[4]

[1] http://ma-eeac.org/wordpress/wp-content/uploads/MA-Commercial-and-Industrial-Baseline-Framework.pdf
[2] Ibid.
[3] https://dbr.ri.gov/divisions/medicalmarijuana/approvals.php
[4] http://webserver.rilin.state.ri.us/BillText/BillText22/SenateText22/S2430.pdf

As mentioned before, the main difference between MA and RI implementation practices stems from the regulation of minimum standards adopted in MA by the CCC. Since RI does not have a regulating body such as the CCC, vendors have more freedom designing buildings to owner-specific targets, such as PPFD to maximize crop yield.

2.2 Research objectives

The primary objective of this study was to define standard practice in indoor cannabis cultivation in Rhode Island using high-rigor methods and considering processes and equipment related to the cultivation and preparation of medical cannabis, including horticultural lighting, lighting controls, cultivation area HVAC, and HVAC controls. The team researched the following systems:

Horticultural lighting – Horticultural lighting is the primary process in indoor cultivation facilities. Horticultural lighting technologies include high-pressure sodium, metal halide, ceramic metal halide, fluorescent, and LED fixture types. Fixture types and run hours vary by growth phase. Baseline lighting technology, density, and run hours will be investigated for the following stages of growth:

- Seedlings/clones
- Mother plants
- Vegetative growth
- Flower/bloom

The study also reviewed lighting control systems and strategies, as well as systems and controls in tiered cultivation spaces.

Environmental conditioning – Maintaining proper environmental conditions is critical to the productivity of a cannabis facility and to act as a primary line of defense against biological contamination such as powdery mildew. There are substantial sensible heat loads from the horticultural lights and large latent loads from the transpiration of the plants. Most of the irrigation water introduced to the plants is released into the room's atmosphere through transpiration. That moisture must be removed from the space to maintain environmental targets. Managing these sensible and latent loads contributes to high cooling and dehumidification energy use. Based on our experience, most facilities attempt to introduce as little outdoor air as possible to limit the introduction of possible contaminants and to mitigate odors leaving the facility. The result is that mechanical cooling and dehumidification is relied on for all meaningful space conditioning. The team researched baseline systems for cooling, dehumidification, heating, and ventilation systems as well as operating parameters (temperature, relative humidity, CO_2 enrichment) for the various stages of growth for the following systems:

- Cooling
  - Chiller-based systems: air- and water-cooled electric- and engine-driven
  - DX-based systems: RTUs, mini-splits, and VRF
- Dehumidification
  - Portable (e.g., Quest dehumidifier)
  - Dedicated (e.g., wrap-around heat recovery coils or desiccant wheel AHUs)
  - Integrated (e.g., GrowAire systems)
- Re-heat as part of traditional mechanical dehumidification
- Heating
- Control systems and sequencing
- Ventilation

- Energy recovery

- Environmental targets (temperature, relative humidity, CO_2) for:
  - Clones/seedling rooms
  - Mother rooms
  - Vegetative growth rooms
  - Flower/bloom rooms

HVAC and dehumidification control systems and strategies were also be researched.

The DNV team anticipated variance in systems based on other characteristics such as years in operation, facility size, and retrofitted facilities vs. new construction. Additional details are provided in Section 3.

2.3 Methods

The findings presented in this report are based on interviews of a random selection of five service providers active in Rhode Island out of a population of 13, where three of the five participants also completed surveys for the MA cannabis ISP study. The service providers are mostly engineers and consultants who have worked on at least one licensed facility in Rhode Island, and most have experience in other jurisdictions, including Massachusetts.

While the effort initially intended to include a survey of cultivators, the DNV, PA, and consultant team concluded that insight from service providers who work on the broader market would be more beneficial than from cultivators who would only be able to provide insight into their facility.

2.4 Project roles and responsibilities

Table 2-1 describes the roles and responsibilities of project team members. These roles and responsibilities were developed from Table 1-1 in the MA C&I Contract Management Plan, this project's scope of work, and other documents that are part of the DNV management system.

Table 2-1. Project roles and responsibilities

Title	Roles and responsibilities
Project Manager **Cameron Tuttle PE, DNV**	Leads this individual research project and manages the project team in accordance with PA and Energy Efficiency Resource Management Council Consultant-approved work plans and protocols. Coordinates with research area lead and QA lead. Drafts the work plan and final report.
Research Area Lead & Project Sponsor **Chad Telarico, DNV**	Research Area Lead: Engages in all projects within identified research area. Coordinates and shares information across all projects within research area. Identifies issues that need attention. May also be assigned to manage projects.

Title	Roles and responsibilities
	Project Sponsor: Holds overall project accountability for DNV and ensures that project objectives are met and have the resources required to meet those objectives. Project sponsor approval is required for all project-wide deliverables, either directly or by an expert authorized by the sponsor.
Quality Assurance (QA) Lead **Sue Haselhorst, DNV**	Reviews all major project deliverables to ensure compliance with the requirements for the deliverable and the existence of clear and consistent communication throughout the document. The QA Lead will also provide independent comment on the planned and utilized methodologies to determine ISPs for the major end-uses of the cultivation process in the Rhode Island market.
Senior Engineers **Individuals at DNV**	These team members are responsible for the oversight and sign-off of each site M&V activity to be completed. They ensure the appropriate planning, data collection, and analysis of each measure based on the technology and available data.
Junior Engineers **Individuals at DNV**	These team members are responsible for the completion of all site M&V activities. These team members are supported on each site by an assigned Senior Engineer.
Study Manager **Erin Crafts, RI Energy**	Primary PA point of contact for the Project Manager for project status updates, concerns, and potential changes. The Study Manager is responsible for providing PA approval of project-wide deliverables.

2.5 Organization of report

The rest of the report is organized as follows:

- Section 3: Study methods and approach
- Section 4: Data sources
- Section 5: Analysis and results
- Section 6: Conclusions and recommendations
- Appendices

3 METHODOLOGY AND APPROACH

This section presents a succinct summary of the study methodology and approach (additional details are provided in the appendices).

3.1 Sample design

The DNV team constructed a study population for service providers (primarily engineers and consultants) using various data sources to capture a full range of market actors. DNV conducted outreach to architects, engineers, contractors, and vendors who they have contact with, were referred to, or were part of the Massachusetts study and indicated they provided services in the broader market, to generate lists of firms serving the cannabis market nationally and specifically in RI. The team also leveraged the lists of survey respondents from the MA cannabis ISP study who mentioned they have also worked on facilities in RI. Once the list was compiled, DNV applied a random number generator to prioritize the population of service providers to achieve the target of five survey completions. No further weighting or segmentation of the population was performed; thus, each sample unit within a segment was selected randomly. Table 3-1 shows the sample group population.

Table 3-1. Sample design summary

Metric	Facility Designers, Engineers, and Contractors/Vendors
Source of population	Professional contacts, internet searches, and MA cannabis ISP survey respondents
Population size	Architects: 1 Consultants: 6 General contractor: 1 Engineer: 5
Target sample size	5
Final sample disposition	Architects: 0 Cannabis facility consultant: 1 General contractor: 1 Engineer: 3

3.2 Interview guides

The DNV team re-developed interview guides based on the documents created as part of the MA cannabis ISP study to cover each broad category of interest and to methodically review the design choices and motivations behind key decisions for all areas of interest. The interview guide sections were as follows:

- **Familiarity with Cannabis Technology** – This section allowed interviewers to use skip logic to avoid sections of the survey that interviewees were not proficient with.
- **Horticultural Lighting** – For each room type, interviewers asked about typical fixtures, wattages, and target PPFD, as well as controls equipment. Additionally, they asked questions probing for experience and feedback on LED lighting, changes in typical practice, and the rationale for design decisions.

- **Mechanical Systems and Dehumidification** – These questions covered typical air-side systems, cooling equipment, heating equipment, and dehumidification equipment. Additionally, interviewers asked questions probing for experience and feedback on advanced HVAC equipment configurations, and the rationale for design decisions.
- **HVAC Controls** – These questions covered typical control systems for HVAC as well as questions probing for experience and feedback on HVAC controls best practices, and the rationale for design decisions.
- **Program Influence** – These questions provided insight into how PA-sponsored incentive programs have impacted design, either through incentives or technical assistance.
- **General Questions** – The interviewers asked broader questions on the most important facets of facility design, barriers to greater energy efficiency, and the industry's biggest challenges.

The full interview guide is attached in APPENDIX A.

4 DATA SOURCES

Data sources on this project include expert interviews from cannabis professionals with experience working in Rhode Island facilities. For this study, the decision was made to focus efforts on the population of service providers as their insight would be on a broader market scale than that of cultivators. Service providers consist of all supporting vendor and consulting professionals that assist in the design and construction of a cannabis facility.

The team employed data screening during the execution of the service provider interviews. A service provider may have been selected based on their firm's involvement with designing facilities but have no first-hand experience with certain areas of the facility design. By allowing interviewers to focus on the parts of the interview guide that were most relevant, the interviews collected the best available insights while minimizing dead-end questions and weak responses. For example, one firm mainly provided consulting expertise for mechanical and dehumidification equipment and rarely worked on lighting. Interviewers would screen questions based on the interviewee's stated familiarity with the technology and focus on questions that would generate the most valuable information given the interviewee's particular experience and skill set. In this example, the interviewer would choose to ask about what types of systems they have observed in facilities and who made those design decisions, rather than the nature of how a lighting design was selected.

Some deviation from the interview guide was also permitted during interviews. Interviewers were given license to ask follow-up questions that were not included in the interview guide to probe prior responses for unanticipated findings. This also led to a more engaging and personal conversation for the interviewees, which in turn increased the quality of responses.

5 ANALYSIS AND RESULTS

5.1 Horticultural lighting

Horticultural lighting is the primary production process in indoor cultivation facilities and typically represents the majority of a facility's energy usage profile. Horticultural lighting technologies typically include high-pressure sodium, LED, and fluorescent fixture types. Fixture types and run hours vary by growth phase (seedling/clone, mother plants, flower/bloom, etc.) and by cultivator preference. The flower/bloom phase is by far the most energy-intensive phase of the growth cycle due to the high lighting levels, large sensible and latent loads on the HVAC systems associated with the lighting, and release of water vapor through plant transpiration. The service providers were asked what the standard lighting technology was for all cultivation phases. Table 5-1 summarizes the responses. All market actors interviewed that handle lighting in some way indicated LED as the typical option for each cultivation area. Some market actors indicated an alternative option to LED, where the ultimate decision on technology comes down to preference of the grower. Responses like this are indicated by half points and can be seen for areas such as vegetation, where one respondent mentioned LEDs or fluorescents as typical options. For the flower area, all respondents indicated LED or double-ended HPS as typical options. Percentages represent the primary responses from the completed surveys.

Table 5-1. Horticultural lighting survey responses for Rhode Island

Technology		Flower (N = 4)	Vegetation (N = 4)	Clone/seedling (N = 4)	Mother (N = 4)
LED		50% (n=2)	87.5% (n=3.5)	87.5% (n=3.5)	75% (n=3)
HID	Single-ended HPS	0%	0%	0%	0%
	Double-ended HPS	50% (n=2)	0%	0%	12.5% (n=0.5)
	Ceramic metal halide	0%	0%	0%	0%
	Metal halide	0%	0%	0%	0%
Fluorescent	T5	0%	12.5% (n=0.5)	12.5% (n=0.5)	12.5% (n=0.5)

The information presented differs from what was found for the MA cannabis ISP study in that LEDs are adopted much more frequently or are the preferred technology for most vendors in RI. This is likely due to the difference in timing between studies as research and benefits for LEDs such as access to a wider light spectrum have been explored and led to an increase in adoption rates. To show the comparison, the MA results are depicted below in Table 5-2.

Table 5-2. Horticultural lighting survey responses for Massachusetts

Technology		Flower	Vegetation	Clone/seedling	Mother
LED		0%	17% (n=1)	29% (n=2)	13% (n=1)
HID	Single-ended HPS	0%	0%	0%	0%
	Double-ended HPS	90% (n=9)	0%	0%	0%
	Ceramic Metal halide	10% (n=1)	0%	0%	0%
	Metal halide	0%	50% (n=3)	0%	63% (n=5)
Fluorescent	T5	0%	33% (n=2)	71% (n=5)	25% (n=7)

Market actors indicated that at the time RI approved adult medical use and began to build cultivation facilities, high intensity discharge (HID) technologies such as HPS and metal halide were more prevalent. If a facility is being built new or retrofitted today, then LEDs are typically the standard and the preferred option for vendors as they allow designers to install a higher quantity of fixtures to meet photosynthetic photon flux density (PPFD) targets for each of the cultivation areas.

5.1.1 PAR light equivalency and photosynthetic photon flux density

Translation to ISP requires consideration of one major factor, which is photosynthetically active radiation (PAR), the spectrum of light that drives photosynthesis in plants. Since PAR is a major factor in photosynthesis and plant growth, it is important to ensure that the comparison between lighting technologies produce equivalent PAR delivered to the canopy. PAR at the canopy is expressed as PPFD (µmol/m2/s) and is not only the appropriate metric for comparing lighting designs in terms of equivalent light intensity, but also the target metric set out by the owner that drives lighting designs. When comparing different horticultural lighting designs, it is important to ensure equal PPFD at the canopy, consideration of lighting technology and unique light distribution, fixture spacing, and mounting height when modeling designs.

5.1.2 Tiered cultivation

Tiered cultivation is a practice used by cultivators to take advantage of the vertical canopy space. Though most market actors indicated experience with tiered cultivation, all mentioned practices do not differ between regular canopy and tiered canopy in terms of lighting technology in RI. However, the main point of concern with vertical canopies are the emitted heat coming from the lights. LEDs are typically preferred to HID fixtures in this regard as HID lamps will output more heat and potentially burn the plant at higher wattages. Designers will need to account for this by ensuring there is enough vertical space between the ceiling and the height of the plant for the fixtures, or by installing smaller fixtures in terms of wattage. Given this information, the study recommends following the same ISP for tiered cultivation as non-tiered with the additional qualification that the height of the grow room must be able to accommodate the height of the racks, the grow media/container, the height of the mature plant, appropriate spacing between the mature canopy and the bottom of the fixture, and the technology and height of the fixture itself.

5.1.3 Horticultural lighting controls

Survey respondents were asked what the ISP is for horticultural lighting controls. Most respondents indicated that simple strategies deploying timers are typically used for the different cultivation areas, otherwise, sites perform manual switching.

Survey respondents were asked specifically about dimming control strategies. Though dimming is mostly associated with LED fixtures, it is rarely deployed consistently, as lighting designs are drafted around PPFD targets in RI and there is not typically enough capital left to install complex lighting strategies for the smaller facilities in the state. If dimming is installed, it

is primarily to reduce shock on plants when going between phases (e.g., cloning to flower). Market actors also indicated that rooms in facilities can have dual use (e.g., for flower or vegetative) where dimming strategies are used to reduce or increase lighting to meet PPFD targets at any given time when the use of the room changes to a different phase of growth.

As mentioned above, considering dimming as an efficiency measure presents the issue of light equivalency for PPFD targets. When dimming is deployed, less light is delivered to the plant over the same period as a non-dimming fixture. Considering light intensity is the primary factor in growth, it is not a direct comparison when analyzing dimming impacts when a facility has strict PPFD targets to adhere to.

With this information, the study concludes that dimming systems are not ISP. For projects that do propose dimming, it will be important to ensure PAR equivalency and PPFD targets at the plant, and savings calculations should make use of a site-specific PAR/PPFD target for the baseline.

One market actor referenced the installation of building management systems (BMS) to monitor all points of production including lighting levels, CO_2, etc. Though this is rare, as previously mentioned, the RI facilities are smaller and have less sophisticated controls. The study concludes that BMS systems are not ISP.

5.1.4 Lighting ISP

Based on the survey responses, ISP for each stage of growth is presented in Table 5-3, which also includes average PPFD targets and typical hours of operation. As mentioned in previous sections, custom incentive projects which compare different lighting designs for energy savings must consider equal PPFD at the canopy for a consistent comparison. PPFD is the target metric for growers to ensure to ensure lighting designs are optimal for plant growth. As such, typical target PPFDs per cultivation stage as well as operating hours (hours per day) are listed below and should be used as a reference for designs.

Table 5-3. ISP conclusions for horticultural lighting

Stage	ISP Technology	Target PPFD	ISP Photoperiod – Hours/day
Flower/bloom	1,000-watt double-ended HPS or 660-watt LED = 830-watt mixed LED and HPS technology	900	12
Vegetative	400-watt LED	450	18
Clone/seedling	200-watt LED	200	24
Mother	350-watt LED	600	18

5.2 HVAC systems

The responses to the questions on HVAC ISP were consistent and primarily revolved around packaged and split direct expansion (DX) systems. Responses also mentioned mini-splits and electric chillers, though those were fewer in comparison. Table 5-4 summarizes the survey responses. Percentages are based on the total number of times survey respondents indicated they had experience with a given technology. Similar to lighting responses, some market actors indicated multiple technologies, such as installing DX units or mini-splits, ultimately dependent on grower preference. Responses such as these were treated with half points.

Table 5-4. Environmental conditioning survey responses for Rhode Island

System Type		Percent of Responses (n=5)
Mini-splits		10% (n=0.5)
Chiller	Electric	30% (n=1.5)
	Gas fired	0%
DX units		60% (n=3)
Water source heat pumps		0%
VRF		0%

The above information indicated DX HVAC systems are the standard in RI. There is some familiarity with electric chillers, though these systems are typically much less common as RI cultivation facilities are smaller, less capital intensive which tend not to run complex chilled water systems. This information does not vary too much from what was found in the MA cannabis ISP study.

Table 5-5. Environmental conditioning survey responses for Massachusetts

System Type		Percent of Responses
Mini-splits		7% (n=1)
Chiller	Electric	33% (n=5)
	Gas fired	13% (n=2)
DX units		36% (n=5)
Water source heat pumps		7% (n=1)
VRF		7% (n=1)

The MA study concluded that there was a correlation between HVAC practices and size of facility, where Tier 1 (facilities up to 5,000 ft.2) and Tier 2 (5,001 to 10,000 ft.^{2}) facilities typically use DX units or chilled water systems, while Tier 3 and larger facilities nearly exclusively make use of chilled water systems. Since RI facilities are equivalent in size to Tier 1-2 facilities in MA, the use of DX units in RI is consistent with observations in MA.

5.2.1 Dehumidification

All survey participants agree that dehumidification is key for indoor cultivation facilities. The plants constantly release moisture through transpiration. Most of that moisture is released as water vapor throughout the lifecycle of the plant. Considering indoor warehouse style facilities (which is the standard in RI) attempt to introduce as little outdoor air as possible, all HVAC loads (sensible and latent) must be removed mechanically. Higher dehumidification loads experiences at some facilities exceed the capacity of commercial grade cooling equipment, resulting in many facilities installing supplemental dehumidification in additional to their primary HVAC systems.

The survey respondents were asked about primary dehumidification used in cultivation facilities. Responses are indicated below in Table 5-6 where percentages represent responses from market actors. Most market actors indicated that

supplemental portable dehumidifiers that typically hang from the ceiling (Quest or Arden brands for example) are often added. One market actor indicated they have only installed DX units that integrate additional dehumidification capacity on top of cooling and heating loads. They did not indicate supplemental portable units were typically installed for these facilities.

Table 5-6. Dehumidification survey responses for Rhode Island

System Type	Percent of Responses
DX units	20% (n=1)
Mini-split/heat pump	0%
Air handling unit	0%
Fan coil unit	0%
Portable unit	80% (n=3)

5.2.2 HVAC controls

The survey investigated ISP for HVAC control systems. Responses indicated the primary control devices are programmable thermostats and humidistats where manual thermostats are less common. Some respondents indicated experience with a centralized BMS, though as mentioned in other sections, this strategy is typically rarer as smaller RI facilities do not have the capital to install and maintain these sophisticated systems. However, if a facility does manage to install chilled water systems, then a BMS will typically be seen to provide the dynamic control strategies needed to achieve adequate control with chilled water systems.

One market actor referenced a strategy using aspirator sensor boxes located over the canopy to control temperature and humidity closer to the plant. This method was preferred with this vendor over programmable thermostats and humidistats, as “the plants don’t care what temperature is at the wall.” Using the aspirator sensor boxes allows the cultivators to remove microclimates and ensure set points at the plants are being optimized and maintained.

5.2.3 HVAC ISP summary

The findings on HVAC system type and controls indicate that ISP for HVAC systems can be defined as presented in Table 5-7. Note the identification of ISP does not promote one technology over the other. Potential custom applications should be treated as such with a focus for example to reduce kW/ton cooling or introduce controls strategies when appropriate to meet the needs of the grower.

Table 5-7. ISP conclusions for environmental conditioning

Facility size	Equipment ISP
All	Direct expansion (DX) type systems for typically smaller RI facilities
All	Programmable thermostats and humidistats. No hot gas re-heat for humidity control. Fixed speed supply fans.

Table 5-8 shows the relationships identified in the interviews between HVAC system type and HVAC control type. Note that this table largely reflects control equipment and not control strategies.

Table 5-8. ISP conclusions for HVAC systems and controls

Equipment Type	Equipment ISP
DX systems	Programmable thermostats and humidistats. No hot-gas reheat for humidity control. Fixed speed supply fans.
Chilled water system	Automated central system. Site-specific baseline for control strategies.

The responses for split and packaged DX systems indicate that ISP control for these unit types are programmable thermostats and humidistats responding to the dry-bulb temperature in the space. ISP for supplemental dehumidification should be based on static lights-on and lights-off relative humidity setpoints (different humidity setpoints during periods when lights are on or off), as detailed in the facility design.

While the responses for chilled water systems indicate that central automation is ISP for these system types, the study did not find an overall ISP as related to HVAC control strategies. A central automation system does not always indicate a sophisticated or optimized control strategy. Therefore, ISP for HVAC control strategies for chilled water systems should be based on a central automated system, but the specific baseline control strategy should be site-specific and based on a strategy that allows the baseline system to maintain the same environmental setpoints as the proposed higher-efficiency control system or strategy.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This section is organized by end use. While the study was able to identify ISP for some systems and end uses, there are many others where no ISP was identified, therefore, site-specific baselines for some energy efficiency projects at cannabis facilities are appropriate. The results of the interviews and experience of the DNV team in the cannabis sector illustrate the nature of this industry with unique facility needs and loads and a wide variety of solutions to meet those needs. As the industry grows and the state of RI matures (especially now that recreational adult use is legalized) the ISPs presented in this memo are likely to adapt. In the meantime, many potential energy efficiency projects for cannabis cultivation facilities will require site-specific baselines to ensure the best representation of a specific project's energy impact.

6.1.1 Horticultural lighting

Horticultural lighting is the primary driver when it comes to growth of the plant. Horticultural lighting technologies include high pressure sodium (HPS), metal halide (MH), fluorescent, and light-emitting diode (LED). Lighting designs in Rhode Island typically revolve around set PPFD targets by the owner. As mentioned in the report body, custom incentive projects which compare different lighting designs for energy savings must consider equal PPFD at the canopy for a consistent comparison. PPFD is the target metric for growers to ensure to ensure lighting designs are optimal for plant growth. As such, typical target PPFDs per cultivation stage as well as operating hours (hours per day) are listed below and should be used as a reference for designs. Table 6-1 summarizes the ISP technologies used for each stage of growth as well as typical PPFD targets and photoperiod hours.

Table 6-1. Horticultural lighting ISP summary

Stage	ISP Technology	Target PPFD	ISP Photoperiod - Hours
Flower/bloom	1,000-watt double-ended HPS or 660-watt LED = 830-watt mixed LED and HPS technology	900	12
Vegetative	400-watt LED	450	18
Clone/seedling	200-watt LED	200	24
Mother	350-watt LED	600	18

6.1.2 Environmental conditioning

There are both a substantial sensible load from the horticultural lights and large latent loads from the transpiration of plants. The moisture released through that transpiration must be removed from the space in order to maintain environmental targets. Managing these loads contributes to high cooling and dehumidification use. The sizing of HVAC systems should be based on the anticipated sensible and latent loads for the facility using site-specific load calculations. Table 6-2 summarizes the ISP findings for environmental conditioning.

Table 6-2. Space-cooling ISP

Facility size	Equipment ISP
All	Direct expansion (DX) type systems
All	Programmable thermostats and humidistats. No hot gas re-heat for humidity control. Fixed speed supply fans.

The team also found indication that supplemental dehumidification is needed for most facilities for all HVAC types except for chilled water systems. ISP for supplementary dehumidification is portable unit dehumidifiers.

Table 6-3 below shows the relationships identified in the interviews between HVAC system type and HVAC control type.

Table 6-3. HVAC systems and controls ISP

Equipment Type	Equipment ISP
DX systems	Programmable thermostats and humidistats. No hot-gas reheat for humidity control. Fixed speed supply fans.
Chilled water system	Automated central system. Site-specific baseline for control strategies.

6.2 Recommendations

Based on the findings and conclusions presented, the DNV team recommends the following:

6.2.1 Recommendation 1: Use identified ISP for baseline

The team recommends the use of the ISP practices identified in this study by implementors as the baselines for projects and by evaluators when evaluating those projects. For all systems and equipment where an ISP was not identified, a site-specific baseline should be used.

6.2.2 Recommendation 2: Future research

During the creation of this document, Rhode Island legislators legalized recreational cannabis for adult use. Most market actors who participated in the survey effort indicated that Rhode Island practices are typically not as sophisticated as other jurisdictions given the low capital investment for the smaller facilities. However, they expect that to change now that recreational use has been legalized. As capital investment increases for these facilities, owners may pursue more sophisticated options for systems and controls. The cannabis landscape in RI will likely evolve over the coming years. The PAs should consider revisiting this study later to research the adapting landscape and adjust ever-evolving ISP.

APPENDIX A. SERVICE PROVIDER INTERVIEW GUIDE

Memo to:
Rhode Island Program Administrators Research Team and Consultant Team

Prepared by: Ryan Brown, Cameron Tuttle, DNV

Copied to:
Srikar Kaligotla, Chad, Telarico, Wendy Todd, DNV

Date: October 26, 2021

RI Cannabis ISP Survey Design – Service Providers

Introduction

Intro1. Hello, my name is _____, and I am calling on behalf of National Grid. This is not a sales call. We are conducting research to determine if there are current design and installation practices for energy use equipment such as HVAC and lighting and to understand what they are for cannabis cultivation facilities in Rhode Island. Our research has identified you as a representative of [BUSINESS NAME] as someone who is familiar with the new construction and major renovation of cannabis cultivation facilities in Rhode Island. We are hoping you can share some general information that will assist with our effort to better understand the current design of these unique facilities and their installation practices including details on horticultural lighting, mechanical and dehumidification equipment, HVAC controls, etc. Are you someone who can speak to this information, or do you think there is someone who may be better suited to ask? [IF NECESSARY, YOU CAN VERIFY THE LEGITMACY OF THIS RESEARCH BY CALLING ERIN CRAFTS FROM NATIONAL GRID AT 781-907-1423]

01	Person answering phone is the appropriate contact	**Intro2**
02	Person answering phone is not key contact but provides name of key contact [RECORD FIRST AND LAST NAME OF CONTACT as well as PHONE NUMBER]	Intro1
03	Don't know	If respondent did not know phone # of maintenance officer, obtain phone # of building management/maintenance office. After calling this office repeat Intro1
04	Refused	Terminate

Intro2. Do you have availability now for a series of questions? We estimate this should take between 0.5-1 hours.

01	Yes	**Intro4**
02	No	Intro3
03	Don't know	
04	Refused	Terminate

Intro3. What date and time works best for you?

01	Record answer_____	Thank you for your time I will talk to you then!
02	Refused	Terminate

Intro4. The information you provide will help us understand current design and installation practices among cannabis facilities in Rhode Island and help us learn about energy related equipment being used today. The information provided will also be shared with National Grid, and the final report with aggregated results will be publicly available. I want to emphasize that no information will be attributed to any identifiable individual respondent. If at any point you do not feel comfortable answering a question, you can ask to pass. All of your response will be kept anonymous. I would also like to record this interview for my note-taking purposes to make sure I'm capturing everything in this survey. Do I have your permission?

01	Yes	Section 1
02	No	
03	Don't know	
04	Refused	

Section 1: Familiarity with Cannabis Cultivation Technologies

The following section will provide some general details on the facility's history and staffing.

F1. What is your background, and your company's background with cannabis cultivation facilities in Rhode Island?

a. Have you or anybody else in your firm designed/installed cannabis cultivation facilities or the systems serving these facilities in Rhode Island? [If no, thank them and end the survey]

F2. How long has you or your company been designing/installing cannabis cultivation facilities in Rhode Island?

F3. What is the typical size of the facilities you work on (sqft)?

F4. What is the typical size of canopy area in the facilities you work on (sqft)?

F5. Have you designed/installed the following systems in the last [*If F2<5, F2 otherwise 5*] years in Rhode Island in cannabis cultivation facilities?

Category	Response
Entire facilities – all systems	
Horticultural lighting	
HVAC systems (including dehumidification)	
HVAC controls	
Envelope systems (windows, walls, insulation)	
Other	

F6. For any technologies you or your firm has worked on, what building type(s) have you installed these system(s)? [indoor/warehouse, greenhouse, hybrid]

a. Does the design for these systems change as a function of building type?

i. [*If yes*] Why does it change?

ii. How does it change?

F7. How have you defined canopy space for cultivation projects? [space directly over growing area, sqft of the full room, square footage of tiered growing]

F8. Do you have any experience with facilities who utilize tiered growth?

F9. Have you designed/installed cannabis cultivation facilities in states other than Rhode Island?

a. Has/have the project(s) received incentives from utilities in states other than Rhode Island?

i. What did the project(s) receive incentives for?

[*Skip next respective sections if not outlined in F5*]

Section 2: Horticultural Lighting

Now I would like to ask you a series of questions about your experience designing/installing horticultural lighting in RI. These questions are used to gain a better understanding of how lighting is used rather than to learn about cultivation process. To gather that information, we will be going through the same series of questions for each of the different area types in a typical cannabis facility. [*If F2>5*] Please consider the projects you have worked on in the past 5 years.

Flower Rooms

HLF1. Starting with the flower rooms, what are the typical lighting fixtures you have installed/will install?

HLF2. What is the typical wattage of these fixtures?

HLF3. About how many fixtures do you typically install to the flower room?

HLF4. What is the typical square footage of the flowering room?

HLF5. What is the typical square footage of the canopy space?

HLF6. Can you estimate the typical target PPFD (Photosynthetic photon flux density μMol/s/m^2)?

HLF7. What are the general hours of operation for the lighting in the flower space?

Vegetative Rooms

HLV1. Now for the vegetative rooms, what are the typical lighting fixtures you have installed/will install?

HLV2. What is the typical wattage of these fixtures?

HLV3. About how many fixtures do you typically install to the vegetative room?

HLV4. What is the typical square footage of the vegetative area?

HLV5. What is the typical square footage of the canopy space?

HLV6. Can you estimate the typical target PPFD (Photosynthetic photon flux density μMol/s/m^2)?

HLV7. What are the general hours of operation for the lighting in the vegetative space?

Clone/Seeding/Propagation Rooms

HLC1. Now for the clone/seeding/propagation rooms, what are the typical lighting fixtures you have installed/will install here?

HLC2. What is the typical wattage of these fixtures?

HLC3. About how many fixtures do you typically install?

HLC4. What is the typical square footage of the clone/seeding area?

HLC5. What is the typical square footage of the canopy space?

HLC6. Can you estimate the typical target PPFD (Photosynthetic photon flux density μMol/s/m^2)?

HLC7. What are the general hours of operation for lighting in the clone/seeding space?

Mother Rooms

HLM1. Now for the mother rooms, what are the typical lighting fixtures you have installed/will install here?

HLM2. What is the typical wattage of these fixtures?

HLM3. About how many fixtures do you typically install?

HLM4. What is the typical square footage of the mother area?

HLM5. What is the typical square footage of the canopy space?

HLM6. Can you estimate the typical target PPFD (Photosynthetic photon flux density μMol/s/m^2)?

HLM7. What are the general hours of operation for the lighting in the mother space?

Non-Grow Spaces

HLN1. Lastly for the non-grow spaces that you typically see in cannabis cultivation facilities, what type of lighting fixtures do you typically installed/will install here?

HLN2. About how many fixtures do you typically install?

HLN3. What is the square footage of the non-grow spaces?

HLN4. What is the proportion of non-cultivation area to cultivation area in facilities you have worked on/will work on?

HLN5. What are the typical non-grow spaces you see in cannabis cultivation facilities? [storage, office space, lobbies, etc.)

Lighting Controls

HLC1. Do you typically install lighting controls in any of the cultivation areas?

[*If no skip to Experience with LEDs*]

a. Which area(s) do you/will you install lighting controls?

b. What are the typical lighting controls you install/will you install? [*ask about dimming*]

Experience with LEDs

L1. What has been your experience with LEDs in terms of performance? [*whether and how LEDs affect the yield and/or quality of the products produced*]

L2. Did you have to adjust cultivation techniques after installing LEDs?

L3. Are you aware of any potential interactions between LED fixtures and the operation or productivity of cannabis facilities?

L4. Would you recommend LEDs to cultivators based on your experience with quality and yield?

L5. Have your horticultural lighting installation and implementation practices changed [*over the last 5 years or F2*]?

a. [*If yes*] How does the design today compare to how these systems were designed [*5 years ago, or F2*]?

b. How has the knowledge of cultivators/cultivation facilities you've worked with changed over the last [*If F2<5, F2 otherwise 5*] years? *Probe: what specific areas are they more knowledgeable on, or focused on?*

General Questions

GL1. [*If F8 = yes*] Do facilities who utilize tiered growth methods differ from others?

a. [*If yes*] How do they differ? [*Probe: talk about technology, wattage, controls, etc*]

GL2. Do you consider energy savings when designing your lighting?

GL3. [*If F9=Yes*] Are lighting practices different in other states compared to RI?

a. [*If yes*] How do they change? [ask about controls]

Section 3: Mechanical HVAC and Dehumidification Systems

The next series of questions will be about your experience designing/installing mechanical (HVAC) and dehumidification systems in cannabis cultivation facilities in Rhode Island.

M1. In projects where you designed/installed HVAC systems over the last [*If F2<5, F2 otherwise 5*] years, what types of mechanical systems/equipment for cooling did you install/design? [*Record general response then check all that apply. Read if necessary*]. How many would you typically install? What size equipment would you typically install?

Category	Response	Quantity	Size [kBtuh, tons or specify]
Rooftop units			
Heat pumps/mini splits			
Air cooled chiller			
Water cooled chiller			
Gas-fired chiller			
Other			

M2. What proportion of your projects are [insert technology from below here]? [*Record general response then fill in the percentages; if unable to provide percentage, then ask them to rank the system types from least to most prevalent. Ensure responses add up to 100%*]

Category	Response
Rooftop units	
Heat pumps/mini splits	
Air cooled chillers	
Water cooled chillers	
Gas-fired chillers	
Other	

M3. What kind of air-side system(s) have you designed/specified/installed? [*Record general response then check all that apply. Read if necessary*]. How many would you typically install? What size equipment would you typically install?

Category	Response	Quantity	Size [kBtuh or specify]
Rooftop unit (constant volume)			
Rooftop unit (variable volume)			
Central air handling units			
Fan coil units			
Mini split			
Other			

M4. What kind of heating system(s) have you designed/specified/installed? [*Record general response then check all that apply. Read if necessary*]. How many would you typically install? What size equipment would you typically install?

Category	Response	Quantity	Size
Boiler (steam or hot water)			
Furnace			
Recovered heat			
Heat pump/Mini split			
Other			

M5. What is the primary source of heating in most cultivation facilities you have worked on? [*Record general response then check all that apply. Read if necessary*]

Category	Response
Natural gas	
Oil	
Propane	
Electricity	
Other	

M6. What is the primary dehumidification equipment for cultivation facilities you have worked on? [*Record general response then check all that apply. Read if necessary*]

Category	Response
Rooftop unit	
Mini split/heat pump	
Air handling unit	
Fan coil unit	
Portable dehumidifier	
Other	

M7. In projects where you designed/installed HVAC systems over the last [*If F2<5, F2 otherwise 5*] years, what percentage of the time have you installed the following advanced of efficiency systems/strategies? [*Record general response then check all that apply. Read if necessary*]

Category	Response
Dehumidification – desiccant wheel air handling unit	
Dehumidification – wrap around heat exchangers	
Dehumidification – variable discharge air temperature	
Direct or indirect air side economizer	
Evaporative condenser pre-coolers	
Horticulture specific HVAC products (e.g., GrowAire or Surna Systems)	
Water side economizing or dry coolers	
Other	

M8. Who (i.e., design team, owner) is typically driving the decision to consider energy efficient systems/strategies in cultivation facility equipment in Rhode Island?

M9. How do HVAC designs differ for different cultivation spaces? [*example flower versus vegetative spaces*]

M10. [*If F9=Yes*] Are HVAC practices different in other states compared to RI?

a. [*If yes*] How are they different?

M11. [*If F9=Yes*] Are dehumidification practices different in other states compared to RI?

a. [*If yes*] How are they different?

Section 4: HVAC Controls

The next section will ask details about HVAC controls that you may have designed/installed for cannabis cultivation facilities in RI.

HC1. Have you designed/installed controls to HVAC systems beyond manual thermostats?

[*If yes continue the section - if no skip to section 5*]

HC2. What type of controls have you installed on your HVAC systems? [*Record general response then check all that apply*]

Category	Response
Programmable thermostats	
Humidistats	
Central, automated control or EMS	
VFDs on fans or pumps	
Other	

HC3. What proportion of your project do you design/install the following equipment? [*Record general response and then fill in the percentages; if unable to provide a percentage, then ask them to rank the controls form least to most prevalent*]

Category	Response
Thermostats	
Humidistats	
Central, automated control	
VFDs on fans or pumps	
Other	

HC4. How do HVAC control design differ for different cultivation spaces? [*example flower versus vegetative*]

HC5. [*If F9=Yes*] Are HVAC controls practices different in other states compared to RI?

a. [*If yes*] How are they different?

Section 5: Program Influence

PI1. Considering all topics we have discussed (horticultural lighting, HVAC, HVAC controls, etc) how do your designs differ when energy savings are a factor?

PI2. What percentage of the projects you work on receive financial incentives from National Grid?

a. [*If >0*] Did these incentives impact your designs?

PI3. Is there any consistency in the designs you specify for projects that receive incentives/assistance?

a. [*If yes*] When utility incentives are available, do you generally propose different technologies or strategies? [*Example LED lighting over other types*]

PI4. Is there any consistency in the designs you specify for projects that do not receive incentives/assistance?

a. [*If yes*] Absent utility incentives, do you generally propose different technologies or strategies?

PI5. Have you received technical assistance from National Grid for any designs? [*a comprehensive engineering/energy consultant resource to identify energy saving opportunities to decrease energy costs*]

a. [*If yes*] Did the technical assistance you received impact your design?

Section 6: General Questions

G1. What are the top factors you typically focus on when designing cultivation facilities?

Category	Response
Maximizing crop yield	
Stage of growth (flower, veg, etc)	
Installation cost	
Speed of design/construction	
Ease of use	
Equipment reliability	
Energy efficiency options	
Operating cost	
Client interest in sustainable design	
How quickly/easily the equipment can be procured/installed	
How quickly equipment can be procured	
Availability of utility incentives	
Other	

G2. What are the biggest barriers to implementing energy efficiency measures at cultivation facilities?

Category	Response
New legislation	
Lack of background in cannabis equipment and available options	
Lack of background in facility management or design	
Cost	
Time [if so probe: longer to source, longer to install, hard to find contractor who can install, pressure to get from concept to production, etc]	
Priority is production (design is based on maximizing production)	
Efficient equipment not available	
Initial cost	
Other	

G3. In the next five years, where do you see the design/operation of grow facilities headed in regard to energy efficiency?

G4. What are the biggest challenges you expect to see?

About DNV

DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.