BUILDING EFFICIENCY CODES AS A VEHICLE FOR DEEP ENERGY AND CARBON REDUCTIONS IN THE INDUSTRIAL SECTOR: CALIFORNIA TITLE 24 CASE STUDY

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ABSTRACT

In California, the carbon emissions associated with operating buildings are dwarfed by the carbon emissions from transportation and industrial production. Industrial energy efficiency has frequently been held back by financial thresholds of 2-year or less simple payback. In contrast, economic thresholds for building efficiency standards have been based on life cycle costing with simple paybacks maximums that can exceed ten years. Building codes are widely enforced in factories for structural, electrical, and mechanical safety, but until recently state or local codes rarely addressed industrial energy use. Starting in 2006, the scope of California's Title 24, Part 6 building efficiency standards were expanded to cover certain industrial loads or process loads. Over time these industrial energy efficiency requirements have extended from manufacturing lighting to a broad range of process loads.

Similarly, national and state building energy efficiency codes, including ASHRAE 90.1, have increasingly covered "process loads," which were previously exempt. This paper summarizes the rationale behind the expansion of industrial energy efficiency proposed for the 2022 update to Title 24, Part 6 associated with: controlled environment horticulture, automated fault detection of steam traps, compressed air piping and monitoring, computer room power supplies and HVAC, process boiler O_2 trim control and transcritical CO_2 refrigeration. Finally, this paper estimates the statewide energy and carbon reductions resulting from enforcement of these new building code requirements.

Background

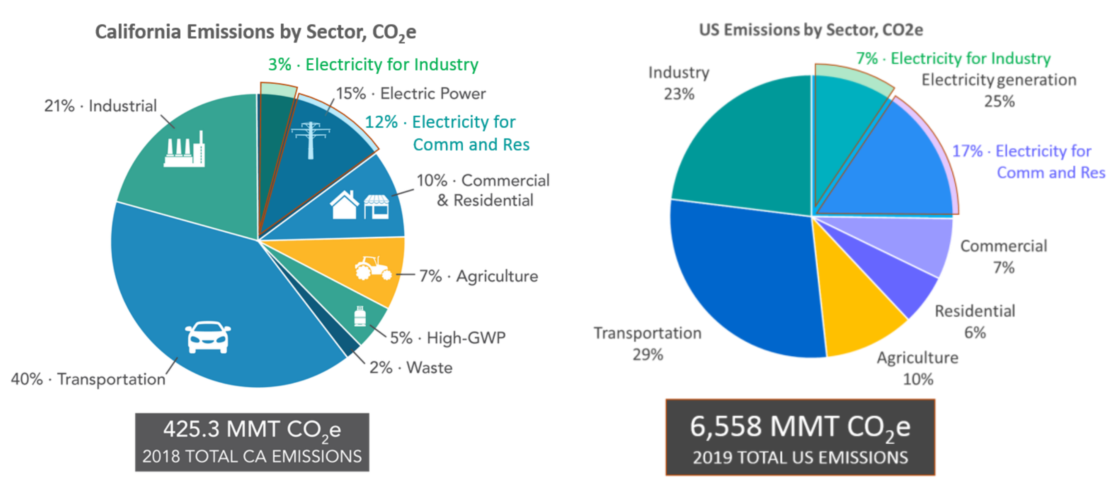

Figure 1: California and US GHG Emissions by Sector

As shown on the left side of Figure 1, the industrial sector is responsible for 24% (3% electricity and 21% other sources) of greenhouse gas emissions in California. (CARB 2020, EIA

2021) In California, the GHG emission fraction due to building operations (22%) is relatively low compared to other parts of the country because of California's electricity supply's relatively low GHG content and the long history of stringent building efficiency regulations. At 455 lbs CO_2e per MWh, the WECC California eGRID subregion emits approximately one-half the amount of greenhouse gas as the U.S. average. (USEPA 2021b)

For the United States as a whole, the industrial sector is responsible for 1,505 Million metric tons (MMT) CO_2e of direct emissions and 465 MMT CO_2e of indirect emissions associated with industrial electrical consumption or 30% (7% electricity and 23% other sources) of total U.S. greenhouse gas emissions. (USEPA 2021a) As shown on the right side of Figure 1, nationwide, the sources of GHGs are relatively evenly split between transportation, buildings, and industry. California's total industrial emissions are approximately 100 Million Metric Tons per year. The United States' industrial emissions are 20 times that. Thus, the statewide GHG savings from industrial energy efficiency measures that have been adopted in California's building codes, if adopted and enforced nationwide, would roughly have 20 times the greenhouse gas reduction impact.

The IPCC estimates that in 2012 the global industrial sector was responsible for 5,270 MMT CO2e of direct energy consumption emissions and 5,250 MMT CO2e of indirect emissions associated with industrial electrical consumption.[1] Thus global industrial energy consumption is responsible for over five times as much GHG's as U.S. industrial production and 100 times that of California. The research conducted and the lessons learned from bringing cost-effective industrial efficiency into the California building energy efficiency codes indicate a proportionately larger opportunity for the U.S. as a whole and even more so internationally.

The Warren-Alquist Act: Enabling the Building Energy Efficiency Standards

In 1974, the California legislature adopted the Warren-Alquist Act, which authorized the creation of the California Energy Commission (CEC) and its authority to regulate energy production and conserve energy. (CEC 2021) The Warren-Alquist Act directed the CEC to do the following in developing the building efficiency standards:

§25402. Reduction of wasteful, uneconomic, inefficient or unnecessary consumption of energy

The commission shall, after one or more public hearings, do all of the following in order to reduce the wasteful, uneconomic, inefficient, or unnecessary consumption of energy, including the energy associated with the use of water, and to manage energy loads to help maintain electrical grid reliability:

(a)(1) Prescribe, by regulation, lighting, insulation, climate control system, and other building design and construction standards that increase efficiency in the use of energy and water for new residential and new nonresidential buildings. The commission shall periodically update the standards and adopt any revision that, in its judgment, it deems necessary.

Additionally, this section of the Act recognizes that the local governments enforces the building efficiency standards through the building permit process.

Six months after the commission certifies an energy conservation manual pursuant to subdivision (c) of Section 25402.1, a city, county, city and county, or state agency shall not issue a permit for a building unless the building satisfies the standards prescribed by the commission

[1] Table 10.2 in Chapter 10 "Industry." (IPCC 2014)

pursuant to this subdivision or subdivision (b) that are in effect on the date an application for a building permit is filed.

Subdivision (b)(3) of this section also defines what was meant by uneconomic and unnecessary consumption. The energy code updates must be cost-effective, feasible, and retain amenity.

(3)The standards adopted or revised pursuant to subdivision (a) and this subdivision shall be cost-effective when taken in their entirety and when amortized over the economic life of the structure compared with historic practice. When determining cost-effectiveness, the commission shall consider the value of the water or energy saved, impact on product efficacy for the consumer, and the life-cycle cost of complying with the standard. The commission shall consider other relevant factors, as required by Sections 18930 and 18935 of the Health and Safety Code, including, but not limited to, the impact on housing costs, the total statewide costs and benefits of the standard over its lifetime, economic impact on California businesses, and alternative approaches and their associated costs.

Process Loads Originally Exempted

Process loads are defined in Title 24, Part 6 as, *"…an activity or treatment that is not related to the space conditioning, lighting, service water heating, or ventilating of a building as it relates to human occupancy."*[2]

Traditionally building energy efficiency codes covered only building energy consumption, while all other end-uses were not considered in the scope of the code. Energy consumption considered to be out of scope included outdoor lighting, lighting in unconditioned spaces, plug loads, refrigeration, and "process loads," including mechanical cooling that kept equipment cool, such as data center cooling. However, in California this was a tradition and not based on a determination of whether process energy was included in "*…other building design and construction standards that increase efficiency in the use of energy."*

Regulating Process Loads Pros and Cons

In response to the California power crisis of 2001, Senate Bill SB 5X (Sher, Chapter 7, 1st Extraordinary Session, Statutes of 2001) was passed, which gave the California Energy Commission the authority to adopt lighting for all outdoor lighting applications, including all non-conditioned areas. In response, the 2005 Title 24, Part 6 standards established outdoor lighting power allowances, signs and lighting power density requirements, and minimum skylight area requirements in unconditioned warehouses and in "industrial work buildings."

After regulating outdoor lighting and indoor lighting in conditioned spaces, and with a pressing need to do more to reduce the wasteful use of energy, the Commission evaluated whether process loads could be regulated through the building standards. As part of this evaluation, some concerns were raised about the feasibility of regulating industrial process.:

Concern: Factory process loads and equipment are out of the scope of the building codes

Response: Factory process equipment is regularly inspected by building departments as follows:

- Electrical connections inspected for compliance with Title 24, part 3 - California Electrical Code (State Amendments to the National Electrical Code)

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[2] Definition of "Process" from the 2019 Building Energy Efficiency Standards. https://ww2.energy.ca.gov/publications/displayOneReport_cms.php?pubNum=CEC-400-2018-020-CMF

- Ventilation (including laboratory ventilation), boilers and other pressure vessels, fuel gas piping, and process piping are inspected for compliance with Title 24, part 4 – The California Mechanical Code (State Amendments to Uniform Mechanical Code)
- Factories contain flammable and hazardous materials and thus are inspected for compliance with Title 24, part 9 The California Fire Code (State Amendments to the International Fire Code)

Concern: Industrial processes cannot be regulated by building energy efficiency codes because each process is so different, and regulating process equipment would negatively impact productivity

Response: Though the manufacturing process is very different for different products, there are many energy-consuming devices in factories that work the same way regardless of the production method; these common devices include:

- Compressed air systems
- Steam and hot water systems
- Refrigeration systems
- Space heating and cooling systems

Concern: Industrial processes are so complex that a local inspector would not know what to look for.

Response: For large facilities especially, this can be true not just for energy but also for safety. In many cases, inspections are conducted by a third-party inspector, often called the Inspector of Record, who has the requisite training. The Inspector of Record certifies to the authority having jurisdiction (local building department) that the factory complies with applicable health, safety, and energy codes.

Concern: Industrial processes are changing all the time in response to market demand and process improvements. Additionally, many facilities are operating 24/7, and equipment is being replaced all the time. If a permit had to be approved and work inspected for every major piece of installed equipment, this would pose an unacceptable cost and delay in keeping the factory fully utilized.

Response: This concern holds true not just for energy codes but also for the health and safety codes. For many plants the local jurisdiction has what is sometimes called the "annual permit" or something similar. This is an agreement with the local jurisdiction to have an inspector of record on-site to witness and confirm that all installations are up to code and to periodically submit updates detailing what changes have been made to the plant and documenting that these changes are to code.

After evaluating that there was no legal obstacle to regulating process loads and finding that there were no unsurmountable concerns with feasibility, "covered process loads" were introduced into the scope of the 2008 version of Title 24, part 6. Since that time, the inclusion of covered process loads into the energy code's scope has been increasing.

2008-2019 California Title 24, Part 6 Energy Code Process Requirements

As shown in Table 1, the number of process efficiency measures added has fluctuated widely depending upon the code cycle. In 2008, process efficiency measures were adopted for the first time with a comprehensive treatment of the design of refrigerated warehouses, including insulation R-values, variable speed condenser and evaporator fans, minimum condenser size, and requirements for minimum condensing temperature and compressor part-load performance.

After the conceptual barrier had been broken, the updates to 2013 Title 24 standards represented a significant ramping up of the scope of process measures. The reader is directed to McHugh (2013) for a description of each of the 2013 process measures.

It is worth noting that for the 2013 measures, we see a pattern of consolidation and expansion, which is repeated for process measures in future code cycles.[3] In terms of consolidation, additional requirements were developed for refrigerated warehouses built on the structure developed in 2008.

Table 1 California Building Efficiency Codes 2008-2019 Process and Industrial Measure Estimated Statewide Energy Savings for One Year's Construction Activity

Code Year	Description	Savings 1st Year Construction		
		GWh/yr	Million Therms/yr	Tons CO2e/yr
2008	Refrigerated warehouses: insulation, fan efficiency, condenser sizing, variable speed fans and compressors	0.7		172
2013	Process Boilers: parallel positioning controls and O_2 trim	0.6	0.91	5,109
2013	Compressed Air: trim compressor, staging control	8.7		2,101
2013	Laboratory Exhaust: Variable volume exhaust and make	39.3	2.43	22,733
2013	Commercial refrigeration: floating head and suction controls, condenser efficiency, lighting controls and heat recovery	12.3	1.29	9,961
2013	Refrigerated warehouse: floating head and suction controls, condenser efficiency	0.9		223
2013	Kitchen Ventilation: exhaust rates, make-up air and demand ventilation	20.5	0.68	8,657
2013	Parking Garages: VSD fans, CO DCV and monitoring	11.5		2,768
2013	Data Centers: Economizers, fan power, speed control, containment (isolate hot and cold aisles) prohibit simultaneous heating and cooling	22.8		5,486
2016	Elevators and Escalators: Lighting, HVAC and Shut-off controls	3.7		878
2019	Laboratory Fume Hoods: Automatic sash controls	14.9	0.92	8,582
2019	Laboratory Exhaust: variable flow control	7.9		1,904
2019	Loading dock infiltration: Dock Seals	0.1	0.02	104
2019	Refrigeration: Adiabatic Condensers	0.6		139
	2008-2019 Total Annual Savings Title 24, Part 6 Process Measures	**144.5**	**6.25**	**68,817**

During the 2013 updates to Title 24, similar refrigeration measures were also proposed for grocery stores. However, with Federal appliance efficiency standards coverage of walk-in refrigerators and freezers under the Energy Independence and Security Act of 2007 (EISA),

[3] As similar process also occurs for building measures as well, see McHugh (2008)

California was preempted from requiring additional efficiency measures for walk-ins which proved to be effective in refrigerated warehouses. Thus grocery refrigeration efficiency in building codes are limited to requirements for the rack system, but not the federally regulated refrigeration end-use devices such as unit coolers or dedicated condensing units for walk-in coolers and freezers.[4]

The 2016 Title 24 code cycle was primarily focused on getting within striking range of the Zero Net Energy goals for low-rise residences by 2020. (Cunningham 2018) Thus only elevator and escalator process measures were adopted during this code update. For elevators, maximum power limits were placed on the installed lighting power and installed ventilation fan power. Additionally controls were required that turned off the fan and lights when the elevator was stopped and unoccupied for longer than 15 minutes. For escalators and moving walkways, the energy code was updated to require automatic controls controls that reduce the operating speed to the minimum allowed by ASME Standard A17.1/CSAB44 when the escalator or walkway is not carrying passengers.

The 2019 code cycle included two measures for laboratory exhaust systems. First, for laboratories with a high density of fume hoods, vertical fume hoods were required to have an occupancy sensor control that would close the fume hood sash when there was no one in front of the hood. This reduces exhaust flow with thermal and fan energy savings. The other laboratory exhaust system measure required either a low installed Watt per cfm install fan power or an advanced control that would modulate the fan based on either wind speed or measured concentration of contaminants in the air around the exhaust stack.

Also, in 2019 dock seals were required around dock doors for warehouses. Standards were also set for adiabatic (hybrid) condensers, which operate in dry mode when it is cool outside and evaporatively cools the condenser when hot outside to maintain relatively high efficiency while reducing water consumption.

The California Statewide Codes and Standards program[5] has been providing technical support to the Title 24, Part 6 energy code development process since the 2005 code cycle. A key element of this technical support is the CASE (codes and standards enhancement) reports, which document the energy savings, feasibility, costs, and cost-effectiveness of various code change proposals. These reports are extensively reviewed by industry stakeholders and become a part of the public record in the code adoption proceedings along with comments form other stakeholders. All of the CASE reports from 2005 to the current code cycle are posted at https://title24stakeholders.com/, which is the public outreach and resources website for the California building energy code advocacy component of California Statewide Codes and Standards program.

The Statewide Codes and Standards program has delivered the benefits of energy efficiency to all utility ratepayers, as no program participation is needed to obtain the energy savings, environmental benefits, and bill reductions associated with more efficient appliances and buildings. As a method of low cost resource acquisition, codes and standards has been very

[4] Variable speed evaporator fans were one of the largest efficiency measures for refrigerated warehouses, they are not required in the federal standards for walk-in coolers or freezers of any size, even those connected to a multiplex rack system and are not part of the basis of the performance requirements for walk-ins. For a detailed discussion of how federal appliance efficiency preemption of state building codes limits cost-effective energy savings, see Chase (2012)

[5] Sponsored by the California Investor Owned Utilities (Pacific Gas & Electric, San Diego Gas and Electric, and Southern California Edison), Sacramento Municipal Utility District and Los Angeles Department of Water and Power

cost-effective; over the 2016 to 2020 time period, the codes and standards program has accounted for 64% of efficiency portfolio electricity savings, 58% of natural gas savings while expending only 4% of total efficiency program costs.[6] It is worth noting that 30% of electricity savings and 58% of natural gas savings attributed to the codes and standards program has been due to Title 24 building standards advocacy, the rest of the savings are attributed to advocacy for more efficient Federal and California appliance efficiency standards.

In a well-integrated energy efficiency portfolio, incentive programs and other industry transformation programs have an important role in filling the pipeline of efficiency measures for future codes. These programs help industry gain experience with efficient technologies and collect information on energy savings, costs, and feasibility instrumental to successfully advocate for more efficient codes. (Eilert et al. 2012)

2022 Title 24 – Consolidation and Expansion of Process Scope

Table 2 summarizes the energy savings, present-value energy cost savings, incremental cost, cost-effectiveness (benefit-cost ratio) and GHG reductions. This table also contains the simple payback of these proposals for comparison with the "two-year simple payback rule" often applied to evaluate the feasibility of industrial process efficiency improvements. The rows in the table have been sorted from shortest simple payback to longest.

Table 2: First Year's Construction 2022 Title 24, Part 6 Covered Process Measures

Covered Process	Electricity Savings (GWh/yr)	Natural Gas Savings (Million Therms/yr)	Incre-mental Cost ($ Millions)	GHG Savings (metric tons CO2e/yr)	PV Energy Cost Savings (PV$ Millions)	Benefit / Cost Ratio	Simple Payback (years)
Controlled Environment Horticulture	107.3	0.30	$49.7	27,434	$250.8	7.8	1.5
O_2 Trim for Process Boilers 5- 10 MMBtu/hr	0.0	0.62	$1.9	3,392	$13.3	7.2	1.7
Refrigeration System Opportunities	8.5	0.00	$2.7	539	$18.2	6.7	1.8
Compressed Air Piping & Monitoring	44.3	0.00	$25.1	10,632	$110.1	4.4	2.7
Steam Trap Monitoring	0.1[7]	3.37	$25.9	18,376	$69.2	2.7	4.5
Computer Room Efficiency	8.5	0.00	$7.7	2,040	$20.4	2.6	4.5
2022 Title 24, part 6 Process Measure Totals	**168.7**	**4.29**	**$113.1**	**62,413**	**$481.9**	**4.3**	**2.8**
Fraction with Simple Payback > 2 yr	31%	79%	52%	50%	41%		

These newly adopted code change measures are summarized as follows:

- **Controlled environment horticulture** in indoor spaces and mixed light greenhouses. Lighting has a minimum PPE (photosynthetic photon efficacy) and is controlled with a timeclock and dimming controls. Dehumidification makes

[6] California Energy Data and Reporting System (CEDARS)
[7] Electricity savings reflects the embedded electricity associated with water savings.

use of condenser heat recovery. Conditioned greenhouses are at least double-glazed.

- **O_2 trim for process boilers.** The threshold boiler size of 10 Million Btu/hr in 2013 Title 24 standards is dropped to 5 Million But/hr. The O_2 trim control measures stack gas concentrations and adjusts the air-fuel ratio for optimum performance.
- **Refrigeration System Opportunities** expands the efficiency requirements for refrigerated warehouses and supermarket refrigeration to transcritical CO2 systems, sets specific efficiency minimum requirements for evaporators and condensers, requires door closers, and introduces acceptance tests for commercial refrigeration.
- **Compressed air piping and monitoring**. Compressed air piping is sized for pressure drop and piping is leak tested similar to the requirements for natural gas piping in the International Mechanical Code. The monitoring system records system performance to track increasing loads (such as leaks) or performance anomalies.
- **Steam trap monitoring.** Steam trap automatic fault detection and diagnostic (FDD) equipment is required to be installed on new process plants or new process lines to alert operations personnel to failed steam traps and reduce the time between steam trap leakage and replacement. Also strainers are required to be installed upstream of steam traps to extend the period between steam trap failures.
- **Computer room efficiency.** This measure increased the ambient temperatures at which the computer room air-side or water-side economizer would be required to provide full economizing. This reflects the 2015 ASHRAE Thermal Guidelines for Data Processing that computers can operate reliably at temperatures higher than required for comfort cooling. The proposal included a reduction in the computer room size threshold for where air containment is required. Minimum computer room interruptible power supply (UPS) efficiency requirements were introduced which matched those in the ENERGY STAR program.

The 2022 code change proposals attempt to consolidate the savings from the last significant process code expansion in 2013. Over time, earlier process measures in the building standards lose their novelty and become common practice. Incremental costs often drop, and there is less concern about increasing the scope to a broader range of cost-effective applications. Thus after six years of requiring O_2 trim controls on process boilers, it was reasonable to lower the threshold size at which it applied. This same market experience was the basis of reducing the threshold size for computer room air containment (ducting the hot aisle up into the return plenum).

Two of the 2022 Title 24, Part 6 code change proposals were able to successfully make the case for monitoring as a method of saving energy. Automated steam trap fault detection sensors communicating to a central messaging console is an option offered by most of the steam trap manufactures and other control companies, was recognized as an important method for reducing steam system energy loss. Ideally, these would be installed on any steam trap replacement, but for this first introduction to the energy code, this was limited only to steam traps newly installed in new factories or new process lines. Though this would impact a relatively the relatively small percentage of steam traps in new factories or plant expansions

(1.8%/yr based on the growth of the industrial production index)[8], the natural gas savings are significant and thpaves the way for more broadly applying these systems to steam trap rreplacement in future codes.

A significant portion of the savings from the updates to the compressed air requirements was based on the compressor system monitoring. Much of the real-time data collection required for compressor system monitoring was already being measured as part of the optimal staging control requirements introduced in the 2013 building energy code. The 2022 proposal requires the storage and display of compressed air flow and compressor power consumption for at least the previous 24 months. By looking at trends in the data, the plan operator could determine whether compressed air leaks are growing over time and whether compressed air system efficiency in units of acfm/kWh are decreasing over time. A key question raised for both compressed air and steam trap monitoring was whether plant operators would act on monitored data. Typically, there has only been anecdotal data on the value of monitoring. CEC field study of a compressed air monitoring solution found clear, cost-effective benefit and customer satisfaction for a survey group of 102 industrial participants) who received a monitoring system that provided data, trending, and alerts. *"The main purpose of the EMS [energy management system] was to enable energy optimization by acquiring high resolution energy consumption data in real-time, identifying and generating insights from the data (i.e., identify and calculate leakage), and triggering alerts and actions for the facility's staff."* (Greenstone, et al. 2019) This points to the value of collecting data systematically across industrial efficiency projects so that statistically valid conclusions can be drawn and used to document the value of efficiency measures that are at least partially based on human factors (e.g., will the plant operator act on monitoring data).

The energy savings from the industrial process code change proposals for the 2022 code cycle are larger than prior code cycles. This is primarily due to the substantial energy savings opportunity associated with increasing the photosynthetic photon efficacy (PPE) of grow lights used indoors and in mixed light greenhouses. This expansion of scope to agricultural lighting is in response to the legalization of cannabis in California for recreational use starting in 2016 and a broad expansion of indoor and mixed-light cultivation. The other area of scope expansion was steam trap FDD which resulted in the most significant natural gas savings of all the 2022 updates to California's Title 24, Part 6 building efficiency standards. This points to the value of revisiting the scope of the energy code on a recurring basis.

Energy codes consider the life cycle savings over the life of the equipment or the life of the building. A 3% real (nominal minus inflation) discount rate is used for the California energy code. Thus for proposals with a 15-year period of analysis, even an 11-year simple payback can be considered cost-effective. As shown in Table 2, the measure with the longest simple payback was 4.5 years. However, if the Energy Commission considered only proposals with a 2-year simple payback or less, the greenhouse gas savings from process measures would have been reduced by 50%. Thus, energy codes should consider energy savings measures with longer than the 2-year simple payback often applied to industrial energy efficiency programs or the common rules of thumb concerning the feasibility of industrial energy efficiency measures.

[8] FRED (2020)

Additional Process Efficiency Opportunities through Codes

Table 3 lists potential industrial and process efficiency measures under consideration for inclusion in future building standards with rough estimates of energy savings and GHG reductions.

Table 3: Potential Future Process Code Measures, California Statewide Estimate of Energy Savings and GHG Emission Reductions

Code Measure Description	Savings 1st Year Construction		
	GWh/yr	Million Therms/yr	Tons CO2e/yr
Steam trap FDD on steam trap replacement	0.8	38.8	211,793
Horticultural lighting: Higher PPE	93.9		22,565
Laboratory exhaust: VAV turndown control	7.9		1,891
VSD's to trim or control process fans and pumps	16.6		3,980
Refrigerated warehouse refrigeration measures expanded to new and replacement process refrigeration	13.9		3,335
High frequency advanced battery chargers	1.3		309
Data centers: increased economizer design temperatures	0.8		192
Computer rooms: heat recovery		TBD	
Crankcase heater control on refrigeration equipment	TBD		
Process piping and tank insulation	TBD	TBD	
Totals	**133.0**	**38.8**	**243,563**

Some of these potential measures are building directly on prior measures already incorporated into the Title 24, Part 6 energy code.

- Steam trap FDD. The 10-fold increase in future savings result from **expanding the scope** from new construction to whenever a steam trap is replaced (approximately every 5 years).
- Horticultural lighting. Additional savings result from **increasing** the minimum photosynthetic photon efficacy **criteria** associated with efficient HID (high intensity discharge) sources to spectrally tuned LEDs for plant growth and flowering.
- Expand the refrigeration measures for refrigerated storage to process cooling. This estimate assumes 50% of systems are already doing many of these measures as the refrigerated warehouse measures which already apply to cold storage at factories.
- Datacenter economizing requirements were adjusted in the 2022 Title 24 standards. The analysis found it is feasible and cost-effective to have higher design temperatures.

Potentially newly introduced industrial efficiency measures to the California energy code include:

- Variable Speed Drives (VSD) to trim or control pumps and fans. Even for constant volume fans and pumps, they are typically oversized and either there is more flow than needed or balancing valves and dampers add an artificial pressure drop to control flow. According to the LBNL (2021) motor survey, only 25% of fans and blowers and 26% of pumps are controlled with VSD. This assumes this fraction could be doubled.

- High frequency advanced battery chargers more efficiently rectify electricity and have advanced controls to prevent overcharging that reduces battery life and wastes energy. These requirements are already contained in California's Title 20 appliance regulations. This estimate assumes that 25% more compliance could be achieved by referencing requirements in the building code for newly constructed warehouses.
- Controls to limit crankcase heater operation to times when the compressor is off and ambient temperatures are low. Crankcase heaters heat refrigerant entering the compressor so that incompressible liquid refrigerant does not enter the compressor and to keep liquid refrigerant diluting compressor oil. A significant fraction of crankcase heaters operate all the time, including times when not needed (e.g., when the compressor is running or when it is warm outside).

One measure that stands out is the huge amount of savings opportunity associated with legal cannabis cultivation indoors or in mixed light greenhouses. However, these savings are due to mitigating a fraction of massive growth in energy consumption in support of cannabis cultivation under electric lighting. We estimate there are 1.0 million square feet of new indoor cultivation spaces being added per year, 1.6 Million ft^2 each year of new mixed light greenhouses, and an additional 1.3 million ft^2 of greenhouses converted to mixed-light production. If the same amount of cannabis was grown outdoors, it is estimated that the embedded energy content per unit weight would drop approximately by 95% as compared to that grown indoors and would drop by 92% as compared to mixed-light greenhouses.[9]

If, in addition to regulating the efficacy of horticulture lighting, state policy was to remove the barriers to growing cannabis outdoors, substantially greater efficiency gains could be made. Growing cannabis outdoors requires more space for the same annual production. Current California policy of artificial scarcity limits the number of permits and levies fees per square foot of production rather than by value of product sold; and this encourages indoor and mixed-light greenhouse production. (Mills 2021)

National and International Opportunities

As described earlier, at the beginning of this paper, industrial carbon emissions are 20 times that of California, and global industrial carbon emissions are approximately five times greater or about 100 times that of California. Additionally, since industrial facilities are often designed by entities with a national or international scope, process energy codes are more readily implemented if the structure of these requirements is harmonized. This harmonization includes making use of similar: defined terms, test methods, and in some cases, the target efficiency levels.

ASHRAE 90.1-2019 is the United States model energy code for nonresidential buildings and high-rise residential buildings as recognized by the U.S. Congress. States are required to make a determination that their state energy code is at least as stringent as the latest version of ASHRAE 90.1. However, most states have designed their building energy codes around IECC (International Energy Conservation Code). A good deal of effort has been made to harmonize these two model energy codes. The IECC has adopted ASHRAE 90.1 by reference, which

[9] Embedded energy in cannabis: Indoor1.27 kWh/gram, Mixed Light 0.936 kWh/gram, Outdoor 0.0696 kWh/gram, from New Frontier Data. Cannabis Energy Report, 2018 as reported on www.edrosenthal.com

means one can show compliance with IECC by complying with the ASHRAE 90.1 code of the same vintage.

ASHRAE 90.1-2019 includes the following process efficiency measures:

- Computer room efficiency (for datacenters, users are referred to ASHRAE 90.4)
- Refrigeration systems. Besides repeating the federal walk-in cooler requirements, ASHRAE 90.1 includes requirements for suction pressure reset controls, liquid subcooling, and crankcase heaters being turned off during compressor operation.
- Kitchen exhaust system control, heat recovery, or make-up air requirements
- Laboratory exhaust fan power, heat recovery, or make-up air requirements

2021 IECC contains the following process efficiency measures:

- U-factor requirements for conditioned greenhouses
- Lighting for plant growth having a photosynthetic photon efficacy of at least 1.6 μmol/Joule.
- Monitoring process loads when these loads exceed 5% of building peak loads.
- Refrigeration systems. Besides repeating the federal walk-in cooler requirements, IECC includes requirements for suction pressure reset controls, liquid subcooling, and crankcase heaters being turned off during compressor operation.
- Datacenter requirements reference ASHRAE 90.4

Thus, California can use the analysis and work used to develop process requirements from ASHRAE 90.1 and the IECC. Similarly, both of these national model codes can use the research for Title 24 documented at https://Title24stakeholders.com/ and the California Energy Commission's Title 24 proceeding docket[10].

The U.S. industrial sector consumes 760,000 GWh/yr of electricity and 61,000 Million therms/yr of natural gas.[11] The California industrial sector uses 32,000 GWh/yr and 8,100 Million therms/yr,[12] so the U.S. industrial sector uses 23 times as much electricity and 7.6 times as much natural gas as California. Applying the U.S.-to-California ratio of industrial energy consumption, if the California requirements were enforced in building codes for the entire United States, the estimated energy savings would be around 6,400 GWh/yr of electricity and 340 Million therms/yr, for each year's new construction and alterations. Each year's construction adds further savings as compared to business as usual.

As a U.S. national energy policy issue, federal preemption of state appliance and building code requirements also restrict industrial efficiency opportunities in state building codes. For more details, see *Federal Appliance Standards Should be the Floor, Not the Ceiling: Strategies for Innovative State Codes & Standards*. (Chase 2012)

Conclusions

- Reliable and repeatable industrial energy efficiency measures can be enforced through building energy efficiency codes.

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[10] https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency

[11] EIA. 2018 Manufacturing Energy Consumption Survey (MECS). US Energy Information Agency

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- When industrial energy efficiency codes are evaluated using similar criteria as for building efficiency features, the 2-year simple payback barrier can be broken, enabling a broader range of efficiency measures than are typically contemplated for industrial incentive programs.
- Significant regional, national, and international energy and greenhouse gas reductions are possible by adopting a broader range of process efficiency measures into applicable building efficiency standards.
- Much of the supporting information for developing energy code update proposals for the California standards can be extracted from the detailed CASE Title 24 update proposals posted at Title24stakeholders.com.
- Bringing repeatable industrial efficiency measures into codes speeds up the process of diffusion and innovation. As a result, what used to be good practice becomes standard practice and raises the bar for industry leaders to innovate more quickly.

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