Designing for the future: Are today's building codes locking in the wrong strategies by using past climate data?

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ABSTRACT

California has set goals for zero net energy buildings and greenhouse gas emissions reductions that will be achieved in part through the state's building energy codes. Decisions about what measures to include in code are informed by building energy models that rely on historical climate data. However, even under moderate emissions scenarios, by 2050 mean temperatures in California are projected to increase by almost 4 degrees Fahrenheit compared to pre-1990 levels and there is evidence that current day temperatures are already shifted from the historical record.

Not only do these energy models underlie cost-effectiveness analyses which influence the prescriptive code, they inform building system selection and sizing, and they are the basis for program incentive awards. While the general trends are predictable – as temperatures increase, average cooling energy increases and heating decreases – the effects of future climate on the state's building policies have not been thoroughly analyzed. To what extent will lower winter heating loads increase the business case for buildings to electrify? Under future climate, are increased cooling efficiency measures cost-effective that aren't today? How will future climate affect the energy and emissions performance of California's buildings and what policies can be adopted today to future-proof them?

This paper starts to address these questions by examining the performance of prototype buildings within a subset of California's climate zones under past and future climate scenarios. It models energy efficiency measure variants to these prototypes and compares the energy, emission, cost, and thermal load outcomes under future climate scenarios compared to historical design weather and makes policy recommendations based on the results.

Introduction

Buildings today are typically designed based on temperature measurements from 12-40 years ago[1]. However, over the coming century global temperatures are predicted to likely exceed 1.1 to 4.8 degrees Celsius under all but the most stringent emissions mitigation scenarios, compared to 1986-2005 temperatures (IPCC). Given that building system useful life ranges from 25-75 years or more, the use of historic weather data has the potential to lock buildings into strategies that do not reflect the conditions they are likely to experience. This is particularly true for envelope, massing, and orientation measures which will often last for the building's lifespan, but is also true for equipment choices and sizing, since weather over the next 30 years is predicted to vary from pre-2005 data.

Current building codes do not consider the effects of future climatic changes. They rely on cost-effectiveness analyses of different efficiency measures to determine what measures

[1]Typical Meteorological Year 3 (TMY3) is developed from data from 1991-2005 or 1976-2005 depending on the data available for a given location. (Dickinson)

should be incorporated into code. These analyses typically take place over 15 and 30-year time frames using building energy models run on historical climate data. This is despite the fact that this data does not represent the conditions that the building will actually see. Would the results of these cost-effectiveness analyses be different using future climate data?

This paper seeks to answer the question: are today's building codes locking in the wrong strategies by relying on past climate data? It uses California as a case study, both due to California's fast approaching zero net energy goals and the availability of detailed Codes and Standards Enhancement (CASE) reports for various energy efficiency measures (EEMs) considered in California's code adoption process.

Specifically, the paper compares the energy use, thermal loads, costs, and emissions of a prototype home modified to meet the Title 24 2016 prescriptive building efficiency standards under past and future climate conditions. It also looks at this same prototype homes under two EEM scenarios that were considered during the Title 24 2019 development process: high performance attics and high performance windows. These measures were cost-effective and consequently proposed for adoption in some but not all climate zones. The paper analyses these prototypes under three California climate zones chosen to represent a range of California's climatic conditions: San Francisco (Climate Zone 3), Los Angeles (CZ 6), and Sacramento (CZ 12).

Methodology

This paper utilized the Pacific Northwest National Laboratory's (PNNL) residential single family EnergyPlus prototype model for the 2012 IECC in California as a starting point for the scenarios modeled (PNNL). EnergyPlus was chosen as the modeling software due to the ability to run scenarios under future weather conditions. While CBECC-RES is used for Title 24 CASE study development and compliance modeling, it utilizes specific weather files for each California climate zone and does not allow the user to input future (or alternative) weather data.

The PNNL 2012 IECC single family prototype model was modified as described below to be representative of the Title 24 2016 prescriptive path for each of the three climate zones considered. It was then further modified to incorporate the EEM scenarios.

Prototype Model Description

Title 24 2016 baseline model. The Title 24 2016 baseline model was built using the PNNL IECC 2012 EnergyPlus prototype model for Los Angeles as a starting point (PNNL). The prototype model used has a gas furnace with a slab-on-grade foundation and has 2400 square feet of conditioned floor area.[2] The prototype model was modified to meet the prescriptive Title 24 2016 requirements described in Table 1 for each climate zone considered.

Table 1. Title 24 2016 Prescriptive Requirements

	Climate Zone		
Measure	3	6	12
Wall U-Factor	0.051	0.065	0.051

[2] Comparatively, the Title 24 CASE analysis uses weighted average results from 2100 square foot and 2700 square foot prototype models.

Ceiling Insulation (R-Value)	30	30	38
HPA Option B - Batt Insulation R-Value below roof deck (with air space)	0	0	13
Radiant Barrier	Yes	Yes	No
Fenestration U-Factor	0.32	0.32	0.32
Fenestration SHGC	0.5	0.25	0.25
Max WWR	20%	20%	20%
West window area	5%	5%	5%
Duct Insulation (R-Value)	6	6	8
Furnace AFUE	80	80	80
AC - SEER	14	14	14
AC - EER	11.7	11.7	11.7

Specific changes to the PNNL prototype model made to represent Title 24 2016 included:

- Modifications to the fenestration U-Factor and SHGC values for each climate zone as described in Table 1.
- Recreating the HVAC system as an airflow network model with ducts located in the attic space. This change was made in order to capture the benefits of the high performance attic measures in Title 24 that reduce temperature of attic space and consequent duct losses.
- Changing the conductivity of interior wall and ceiling insulation material, so that the exterior wall U-factor matched the Title 24 prescriptive value for each climate zone while maintaining existing insulation thickness.
- Adding a new insulation material into the exterior roof construction with a material conductivity and thickness so that the below roof deck insulation met the Title 24 Option B below roof insulation requirement. Insulation thickness was fixed at 4 inches.
- The addition of a reflective radiant barrier in the San Francisco and Los Angeles prototype models.
- Modifications to window dimensions to meet the maximum window area on the west façade and total window-to-wall (WWR) ratio limits in the Title 24 2016 prescriptive requirements.
- Modifications to the heating and cooling system efficiencies to match the Title 24 2016 minimum requirements.

High performance attic scenario. The high performance attic measure was first adopted during the Title 24 2016 development process for climate zones 4 and 8 through 16, but was not found to be cost-effective in other climate zones. This measure allows a builder three options under the prescriptive path which are all intended to reduce cooling duct losses: A) above deck roof insulation; B) below deck roof insulation; and C) ducts in conditioned space. The Title 24 2019 development process analyzed increasing the high performance attic requirements and specifically analyzed increasing the below deck roof insulation required under option B to R-19.

To analyze the sensitivity of this measure under future climate conditions, the baseline prototype described above was modified to include R-19 below deck roof insulation. This was proposed for adoption in climate zone 12 in the 2019 standards but was not found to be cost-effective in climate zones 3 and 6 (Hoeschele). Table 2 summarizes these variations to the baseline model.

Table 2. High Performance Attic Energy Efficiency Measure Scenarios

		Climate Zone		
Scenario Description	**Measure**	3	6	12
2019 HPA	Option B - Batt Insulation R-Value below roof deck (with air space)	19	19	19

High performance windows scenario. The Title 24 2016 prescriptive path currently requires windows in all climate zones to meet a U-factor of 0.32. The SHGC requirements vary by climate zone, with a SHGC of 0.25 required in cooling-dominated climate zones (2, 4, and 6-16) and no SHGC requirement in heating dominated climate zones (1, 3, and 5) (CEC). The no requirement SHGC is modeled as an SHGC of 0.5 in the baseline model.

The Title 24 2019 development process considered an update of the U-factor requirement to 0.30 in all climate zones and an update to the SHGC requirements in cooling-dominated climate zones to 0.23 (Nittler). The high performance windows scenario modeled here modified the baseline prototype model for each climate zone as proposed for the Title 24 2019 Standards. It also considered an alternative higher SHGC scenario for San Francisco with an SHGC of 0.23. Table 3 summarizes these variations to the baseline model.

Table 3. High Performance Windows Energy Efficiency Measure Scenarios

		Climate Zone		
	Measure	3	6	12
2019 Fenestration	Fenestration U-Factor	0.3	0.3	0.3
	Fenestration SHGC	0.5	0.23	0.23
Alternate Fenestration	Fenestration U-Factor	0.3	N/A	N/A
	Fenestration SHGC	0.23	N/A	N/A

Weather Data

Each of the prototype model variants described above was run in EnergyPlus using historic and future climate data. For historic climate data, the typical meteorological year 3 (TMY3)[3] files for

[3] TMY3 relies on historical data collected from 1991-2005.

the Sacramento, San Francisco, and Los Angeles airports were used for each respective climate zone.

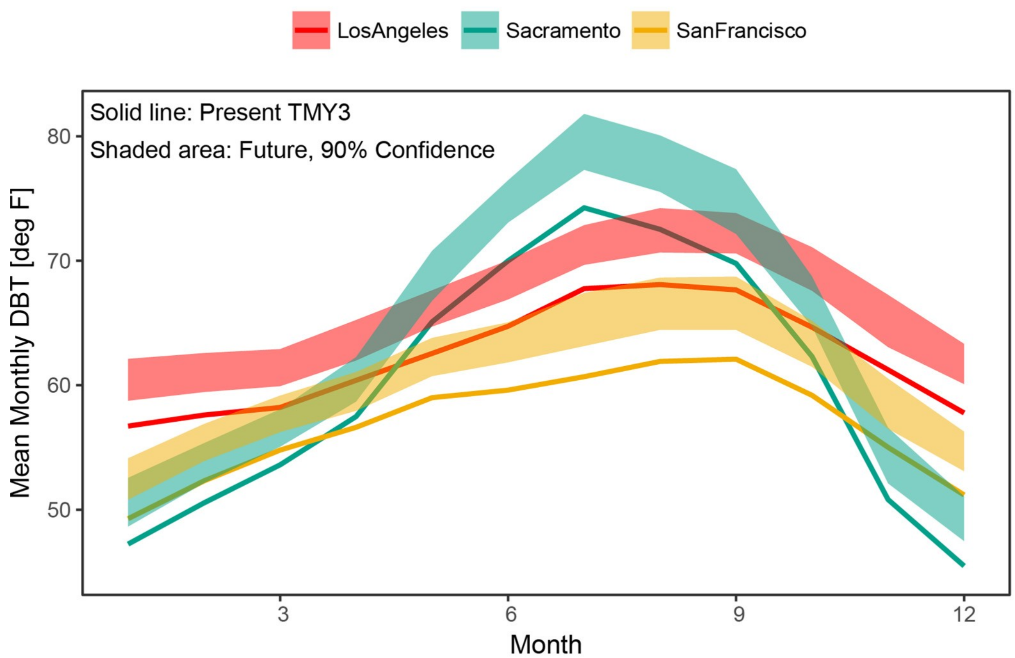

Figure 1: TMY3 and fTMY mean monthly dry bulb temperature in Los Angeles, San Francisco, and Sacramento.

Future TMY files from Weathershift™ were used for the future climate scenarios. Weathershift is a platform developed by Arup and Argos Analytics to develop future weather files. The Weathershift methodology relies on "morphing" historic TMY data files to generate future TMY (fTMY) files under given emissions scenarios in an energy plus weather file format (.epw) (Belcher). Offset climate values are developed from the difference between simulated historical climate and projected future climate from an ensemble of global circulation climate models, for a variety of weather variables including mean daily temperature, relative humidity, and wind speed. These offsets are then applied to TMY data, creating new typical files representative of the changed climate and the statistical uncertainty in projecting future climate. Since the morphing process uses historic climate files, the underlying climate signature is consistent between present and future (as compared to a stochastically generated future weather data), therefore removing randomized variability in the file and allowing for comparative energy analysis between energy model results (Dickinson).[4] The specific Weathershift files used in this analysis were for the time period 2040-2060 under the Representative Concentration Pathway (RCP) 8.5 emissions scenario, which represents continued anthropogenic emissions through the

[4] For a detailed description of the morphing process, see "Generating Future Weather Files for Resilience" (Dickinson).

21st century (IPCC). This time period reasonably represents the conditions that a building built today would be likely to experience over its useful life.

Within any given RCP, the actual future climate outcome is not a single known outcome, but a range of possible outcomes. This adds a new framework to the way buildings are typically analyzed – whereas typically energy use is analyzed under a single weather file, when analyzing with future climate data there are a range of possible outcomes. The 5, 25, 50, 75, and 95th percentile warming scenarios under the RCP 8.5 pathway were analyzed and consequently future climate results are reported as a range of outcomes.

Figure 1 summarizes the mean monthly dry bulb temperatures for each of the climate zones analyzed from the TMY3 data set and the fTMY 90 percent confidence values.

Emissions

The 2016 eGrid factor for the WECC California subregion total output emissions rate of 0.24 kg CO_2e/kWh was multiplied by annual electricity use of each model run to obtain the annual emissions from electricity use (EPA).[5] Emissions from direct use of natural gas were calculated by multiplying annual natural gas use for each model run by 5.31 kg CO_2/therm.

Cost

Costs were calculated in two ways: as 30-year TDV energy costs and as annual consumer costs. TDV energy costs were determined by multiplying the hourly TDV gas and electricity values for 2019 by the 8760 hourly energy use outputs for each model run (CEC 2017). Consumer costs were estimated using the 2017 average residential retail electricity rate for California of $0.164/kWh and the average residential price of gas for California of $12.51/thousand cubic feet (EIA).

Results

Today's Code: Historic and Future Climate

The first set of results look at the performance of the baseline Title 2016 prototype model under past and future climate scenarios. The annual electricity, gas, cost, emissions, cooling load, and heating load and 30-year TDV costs for each climate zone are shown in Figures 2 through 4. The dark red bars represent the 50th percentile warming scenario, with the light red bars representing the other warming scenarios. It is noteworthy that the minimum y-axis values on these figures are not zero and that the scales match across climate zones, both so that the difference between past and future results is easier to compare across the scenarios.

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[5] This emissions factor likely over predicts the emissions from electricity, as the emissions rate per kWh is projected to fall over the next thirty years due to the increased RPS.

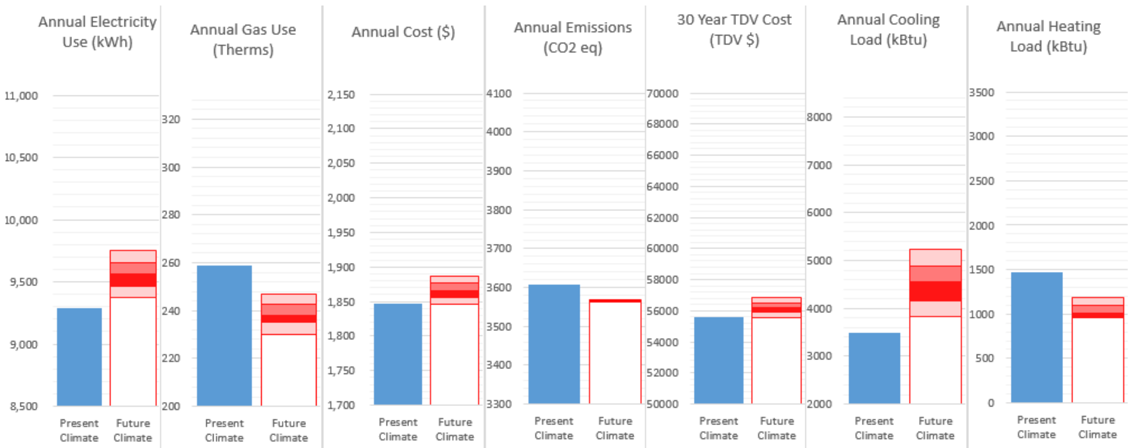

Figure 2: San Francisco Title 24 2016 prototype model run under TMY3 and RC8.5 2040-2060 climate scenarios

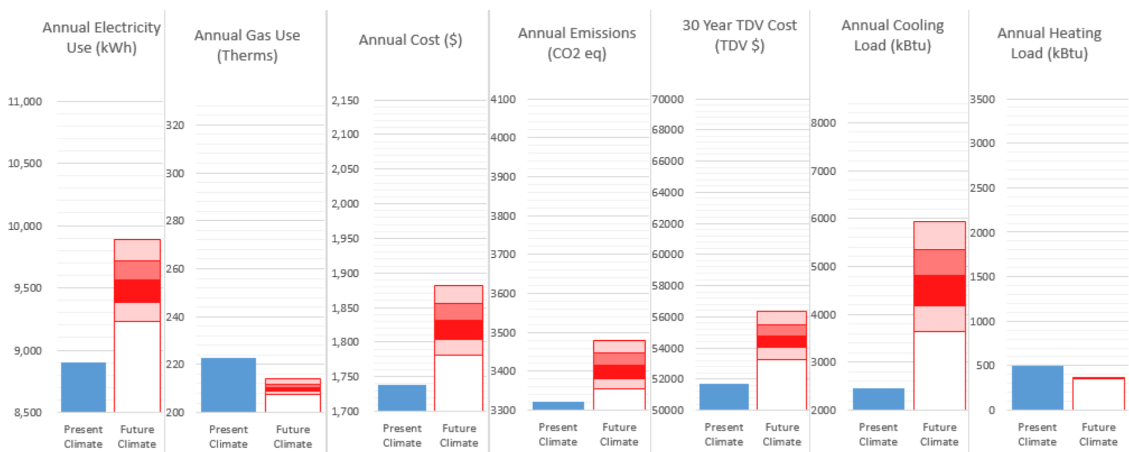

Figure 3: Los Angeles Title 24 2016 prototype model run under TMY3 and RC8.5 2040-2060 climate scenarios

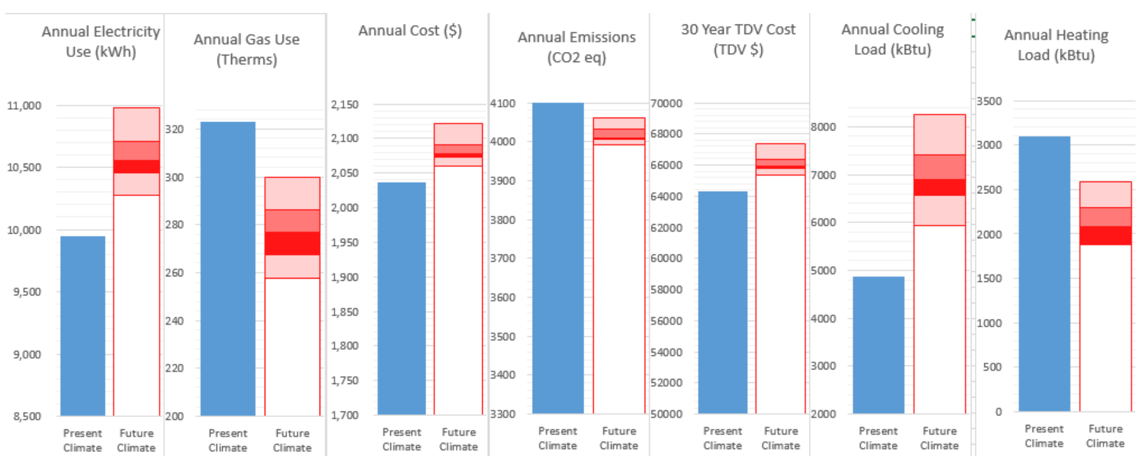

Figure 4: Sacramento Title 24 2016 prototype model run under TMY3 and RC8.5 2040-2060 climate scenarios

For all three climate zones, electricity use increased under the future climate scenarios, while natural gas use decreased, albeit more moderately. The biggest change under the future climate scenarios was the cooling loadsunder the median warming scenario, annual cooling load increased by 95 percent in Los Angeles, 40 percent in Sacramento, and30 percent in San Francisco, compared to present day loads. The absolute increase in cooling load was similar in Los Angeles and Sacramento. Heating loads generally decreased, although more moderately (30 percent in SF, 30 percent in LA, and 35 percent in Sacramento under the median warming scenario). It is noteworthy that a different prototype model was run in each climate zone (since code requirements vary) and so these changes in loads should be considered as relative to what a code-built home today would see, but are not directly comparable across climate zones.

Energy Efficiency Measure Scenarios

As described above, two EEM scenarios were analyzed for each climate zone: high performance attics and high performance windows. The results are shown in Figures 5 through 11. These figures show the savings for each variable of prototype building with the EEM compared to the Title 24 2016 baseline prototype run on the same weather file (e.g. under the 5th percentile warming scenario, both the baseline Title 24 model and the energy efficient variant model were run using the 5th percentile warming weather data file, and the reported results are the difference between these two runs). Because the weather varies in both the baseline and the EEM scenario runs, the 50th percentile future warming scenario does not necessarily produce a result that falls in the middle of the other warming scenarios. The results are therefore reported as a bar chart with the present day savings on left and each warming percentile shown as an individual bar to the right. Negative values mean an increase from the baseline.

High performance attic scenario. As described above, the high performance attic scenario was the addition of R-19 insulation under the roof deck. The intent of this measure is to reduce attic temperature during the cooling season, lowering cooling duct losses. It was proposed for adoption in 2019 for climate zone 12, but was not found to be cost-effective in other climate zones.

Overall, the savings from this measure using the modified PNNL EnergyPlus prototype model were much lower than those found in the 2019 CASE analysis. This is likely due to differences in the way that attic temperature and duct losses are modeled in EnergyPlus compared to CBECC-Res and other differences in the underlying CBECC-Res and EnergyPlus prototype models that were not captured in the prescriptive changes to the 2012 IECC prototype model described above.[6] Examining the variation in performance under the future weather runs leads to interesting results. Specifically, the high performance attic measure achieved greater electricity, cost, and emissions savings under most future climate scenarios in San Francisco and Los Angeles compared to the TMY3 weather analysis. TDV savings under the median future climate scenario increased by 41% in Los Angeles, a climate zone where this measure was not found to be cost-effective in the 2019 CASE report. Conversely, in Sacramento where the

[6] Due to the difference in savings projected under the EnergyPlus simulations compared to those projected in the CASE report, the absolute magnitude of the results are not directly comparable to the costs and savings identified in the CASE report.

measure was found to be cost-effective, savings did not vary significantly from the present day analysis under the future climate runs.

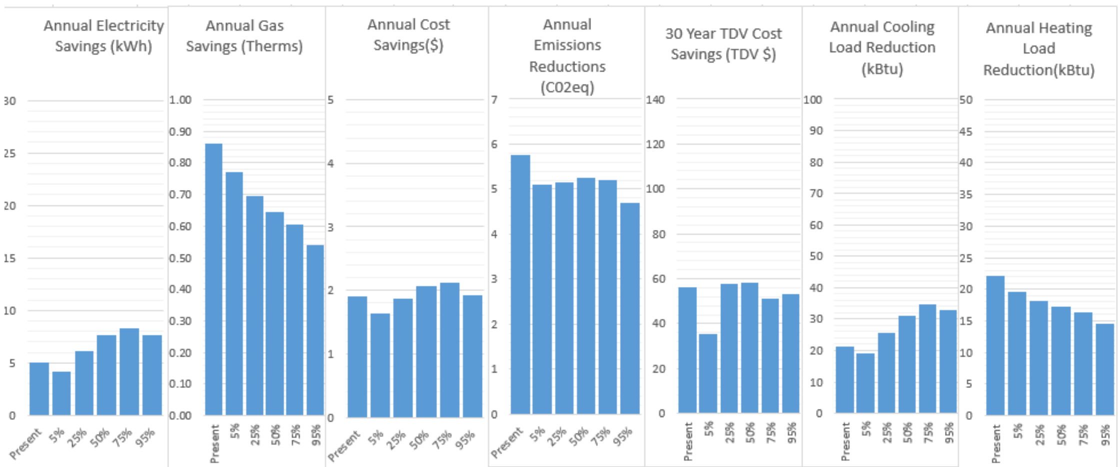

Figure 5. High Performance Attic Measure Scenario in San Francisco under past and future climate**.**

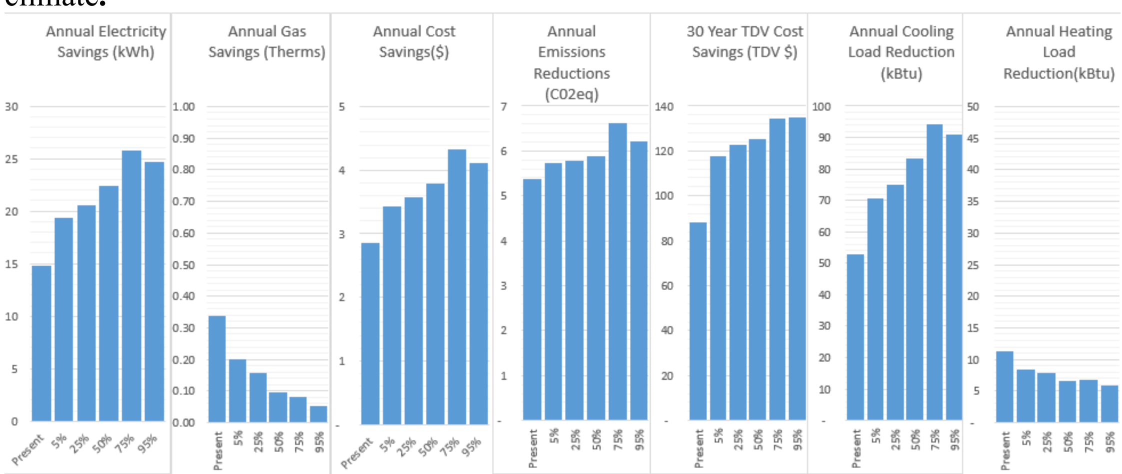

Figure 6: High performance attic measure in Los Angeles under past and future climate

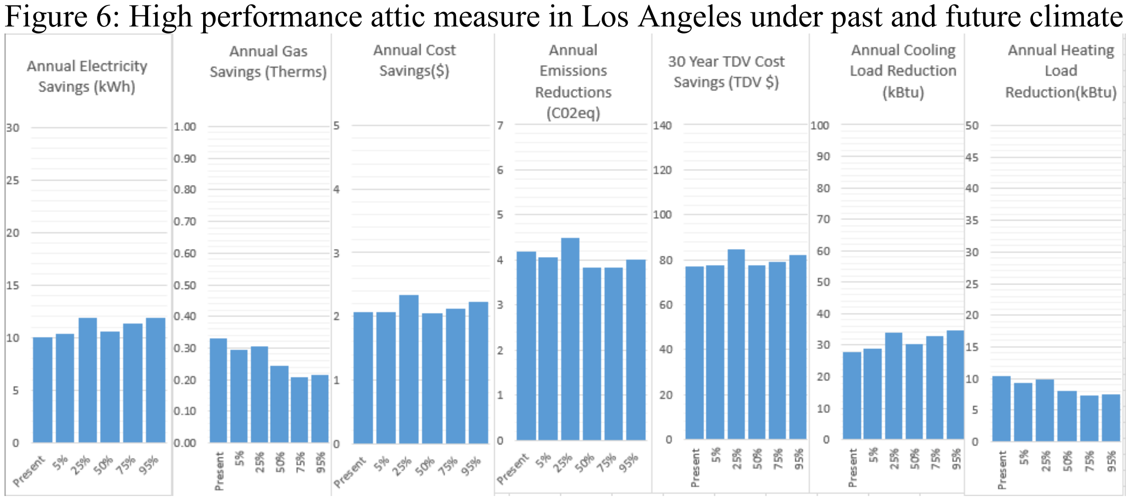

Figure 7: High Performance Attic Measure Scenario in Sacramento under past and future climate.

High performance windows scenario. As described above, the high performance window EEM scenario modified the baseline model with the U-factors and SHGCs proposed by climate zone in the Title 24 2019 development process. It also considered an alternate low-SHGC value for San Francisco, using the 0.23 SHGC value proposed for the cooling climate zones.

Similar to the high performance attic measure, the present day savings found using the EnergyPlus prototype did not align with the savings projected in the 2019 CASE analysis. Using the EnergyPlus model, higher energy savings were found in both climate zones 6 and 12, while the proposed window measure for climate zone 3 was found to increase energy use. This increase in energy use is due to the fact that, contrary to the CASE analysis, the EnergyPlus model runs found that the high SHGC window drove high cooling loads and resultant electricity use in San Francisco when compared to the baseline Title 24 2016 model. This finding was exacerbated under future climate conditions. Conversely, the high SHGC window achieved significant electricity savings in San Francisco, both under present and future climate runs.

For Los Angeles and Sacramento, electricity, cost and emissions savings all increased under future climate runs, enhancing the case that these measures are cost-effective in these climate zones. Gas savings under the future climate scenario were lower in San Francisco, but by a smaller order of magnitude than the increase in electricity savings. Gas savings from high performance windows varied in Los Angeles under the future climate scenarios, depending on the warming percentile considered. However, the increase in electricity savings under future climate still led to overall greater TDV savings for the high performance window measure in Los Angeles.

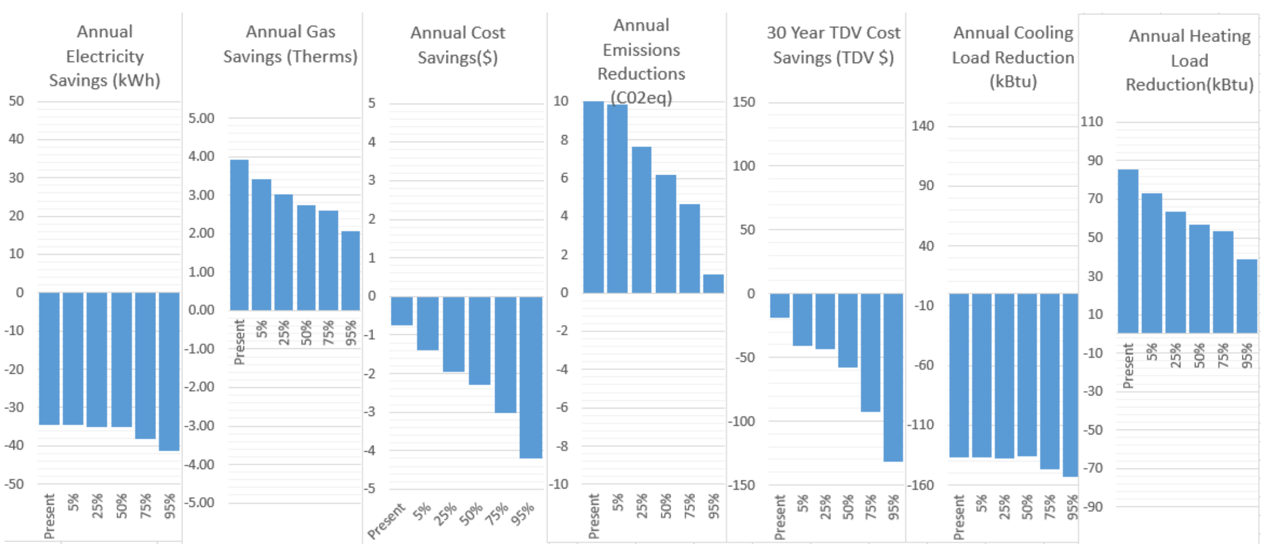

Figure 8: 2019 Proposed Window Measure (U=0.30, SHGC=0.5) in San Francisco under past and future climate.

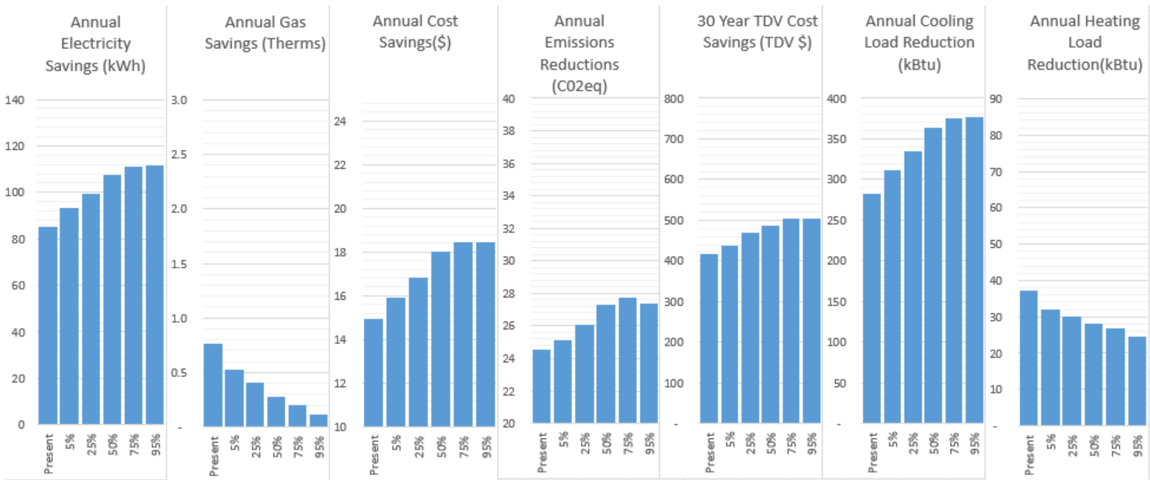

Figure 9: 2019 Proposed Window Measure (U=0.30, SHGC=0.23) in Los Angeles under past and future climate.

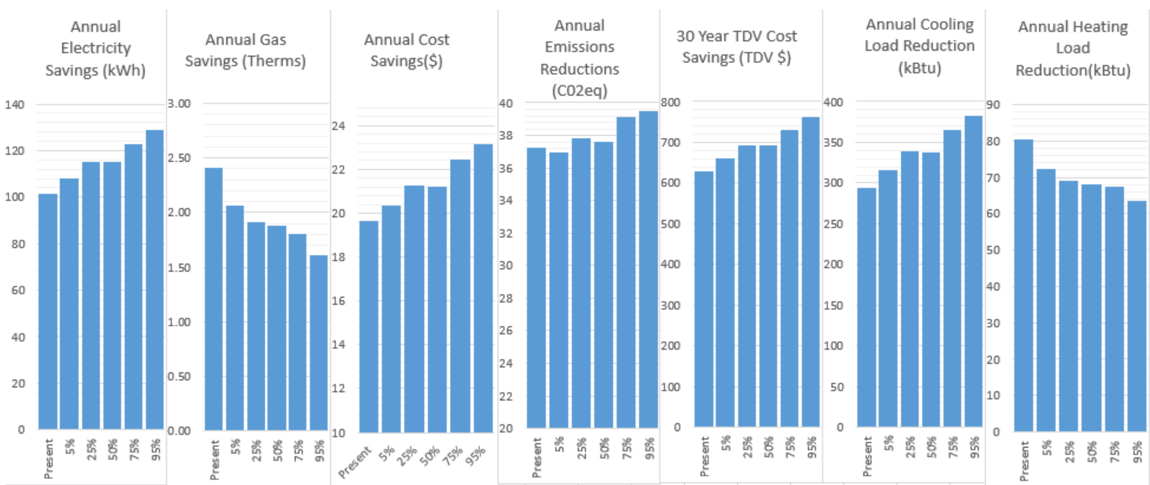

Figure 10: 2019 Proposed Window Measure (U=0.30, SHGC=0.23) in Sacramento under past and future climate.

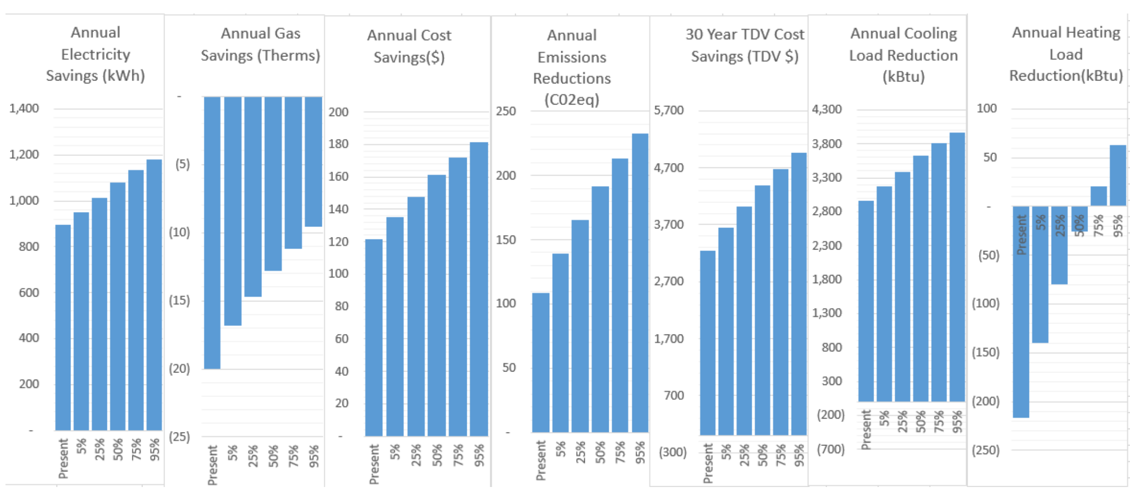

Figure 11: High performance window alternative low SHGC (U=0.30, SHGC=0.23) in San Francisco under past and future climate.

Conclusions

The results show that, for the climate zones studied, future climate conditions are likely to increase energy use and costs overall in California homes. Future climate conditions are likely to increase cooling loads in homes and consequently electricity use, while decreasing heating loads (more moderately). This decrease in heating loads may on the margin enhance the case for the use of electric heat pumps, in particular in climates where heating loads become more moderate and cooling loads increase compared to historical conditions (such as climate zone 3).

The results also show that future climate conditions are likely to affect the actual energy savings achieved by energy efficiency measures implemented under California's building energy standards. While the results using EnergyPlus are too different from those found in the Title 24 CASE analyses to conclusively determine whether there would have been different outcomes for the 2019 code if they been analyzed with future climate data, they indicate that future climate data has the potential to materially affect the impact of these analyses. This may be particularly true in more moderate climates, such as San Francisco and Los Angeles where future climate is likely to shift more significantly on a relative basis, as measures that are not cost-effective using historical weather data are likely to have increased relative savings under future climate scenarios.

This analysis was intended to be an initial study of how analyzing building codes using future climate data might shift code outcomes. It focused specifically on envelope measures and weather projections over the next 20 to 40 years. Future analyses should consider how future climate affects other efficiency measures, including on nearer-term time horizons. In doing this, the shift in emissions rates over time should also be carefully considered as this will affect these near-term tradeoffs.

Finally, the use of future weather data has the potential to shift how we analyze energy efficiency measures. The future is not a pre-determined outcome, but a range of outcomes with varying likelihoods. Shifting the way we think about designing and setting standards for buildings to reflect this may be a significant change, but may be needed to ensure that California achieves its zero net energy and emissions reductions goals within the spectrum of probable futures.

References

Belcher, SE. 2005. "Constructing Design Weather Data for Future Climates." *Building Serv. Eng. Res. Technol. 26,1 pp 49-61.* http://www.weather-shift.com/Constructing%20Design%20Weather.pdf

CEC (California Energy Commission). 2016. Building Energy Efficiency Standards for Residential and Nonresidential Buildings. http://energycodeace.com/site/custom/public/reference-ace-2016/

——. 2017 "2019 TDV Update." https://efiling.energy.ca.gov/getdocument.aspx?tn=215935

Dickinson, B. 2016. "Generating Future Weather Files for Resilience." *36th International Conference on Passive and Low Energy Architecture. http://www.weather-shift.com/Generating%20Future%20Weather%20Files.pdf*

EIA (US Energy Information Administration). 2017a. "Electricity Data Browser." https://www.eia.gov/electricity/data/browser/#/topic/7?agg=0,1&geo=000000000004&endsec=vg&freq=A&start=2001&end=2017&ctype=linechart&ltype=pin&rtype=s&maptype=0&rse=0&pin=

——. 2017b. "Natural Gas Prices." https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm

EPA (Environmental Protection Agency). 2016. "eGRID Summary Tables 2016." https://www.epa.gov/sites/production/files/2018-02/documents/egrid2016_summarytables.pdf

Hoeschele, M. 2017. "Codes and Standards Enhancement (CASE) Initiative): Residential High Performance Attics – Final Report." http://docketpublic.energy.ca.gov/PublicDocuments/17-BSTD-02/TN222203_20180118T145538_CASE_Report_High_Performance_Attics.pdf

IPCC (Intergovernmental Panel on Climate Change). 2009. *Fifth Assessment Report. Climate Change 2014 Synthesis Report, Summary for Policymakers.* https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Kneifel, J. 2012, *Prototype Residential Building Designs for Energy and Sustainability Assessment.* NIST Technical Note 1765. https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1765.pdf

Nittler, K. 2017. "Codes and Standards Enhancement (CASE) Initiative): Residential High Performance Windows and Doors – Final Report." http://docketpublic.energy.ca.gov/PublicDocuments/17-BSTD-02/TN222199_20180118T151312_CASE_Report_Residential_High_Performance_Windows_and_Doors.pdf

PNNL. 2012. Residential Prototype Building Models. https://www.energycodes.gov/development/residential/iecc_models