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DO OFFICE BUILDINGS 'SAVE' ENERGY IN THE UNITED STATES DUE TO DAYLIGHT SAVING TIME (DST)? A 50-STATE SIMULATION-BASED STUDY

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ABSTRACT

This paper investigates the "savings" in Daylight Saving Time (DST) through a comprehensive simulation-based study. A United States Department of Energy (US DOE) core and perimeter reference small office building was simulated with and without DST for each state across the seven US climate zones using benchmark inputs. The "lightswitch" model was used to represent probabilistically-valid user behavior for lighting energy, using DIVA for Grasshopper as the front-end for Radiance and Daysim, and resulting schedules were used as input for the EnergyPlus thermal zone models, using Archsim for Grasshopper. Results demonstrate a range up to 7% lighting energy savings when DST is not applied in 36 states. On average, the application of DST did not save energy in simulated small office spaces across the country, and caused an increase of 0.1% in total energy consumption. The paper concludes by discussing the validity of continuing to apply DST in the US.

INTRODUCTION

Daylight Saving Time (DST) is the practice of setting clocks an hour forward during summer and back during the winter, introduced in the United States during the first World War in order to save energy by reducing the amount of electric energy used for lighting in the evening (Gurevitz, 2007). DST in the United States is observed by moving the time forward one hour on the first Sunday in April and back one hour on the last Sunday in October (Yacker, 1998). 141 countries have applied DST at one point, however the number has decreased to just 76 countries around the world (Time and Date AS, 2016). While DST might have saved energy when it was first introduced, with the inclusion of heating and cooling costs, the benefits of DST has become less pronounced, and the US has been debating the benefits of its continued application (Gurevitz, 2007).

Previous research that has been conducted in order to investigate the savings DST provides has not been conclusive. Results supported both an increase and a decrease in energy savings. Within the US, investigations that utilized existing electrical consumption data showed that Indiana demonstrated a 1-4% increase in electrical energy consumption (Kotchen and Grant, 2011). California demonstrated a 3.4% decrease in winter (Kandel and Metz, 2001) whilst a similar experiment conducted a few years later showed no significant change in energy consumption (Kandel and Sheridan, 2007). A study that drew from electrical consumption data across the United States, however, found a 0.5% decrease in electrical consumption (Belzer, Hadley and Chin, 2008).

Outside of the United States, experiments in Victoria, Australia showed that extending DST would reduce electricity consumption in the evening, but these savings would be negated by increased demand in the morning (Kellogg & Wolff, 2008). Studies in Ontario, Canada show a 1.5% decrease in energy consumption (Rivers, 2016) and experiments in the United Kingdom showed a 0.3% decrease (Hill, Desobry, Garnsey, & Chong, 2010). Due to the specific nature of existing research, the results vary across the globe due to economical, geographical and climatological factors. Evidence of success is therefore limited, even contradictory, and there is no definitive proof of the benefits or disadvantages of DST (Aries & Newsham, 2008).

The application of DST, however, resulted in various negative effects on human health and well-being. Previous work has shown that transitions into and out of DST caused minor jet lag symptoms such as sleep disruption, fragmentation of the circadian rhythm, and fatigue (Lahti, Leppämäki, Lönnqvist, & Partonen, 2008). As a result, investigations conducted in the United States showed that there has been a significant increase in accidents in the week following the time change into and out of DST (Varughese & Allen, 2001). The use of DST has also been linked to an increase in suicide rates

(Berk, et al., 2008) and an increase in cardiac complications (Jiddou, Pica, Boura, Qu, & Franklin, 2013). Research relating energy savings to application of DST was inconclusive, but its possible hazard on issues of human health was not. It is therefore critical to understand the magnitude of expected energy savings, in order to qualify DST's further implementation. The problem lends itself to the use of computer simulation, in order to compare energy use with and without the implementation of DST in various climate zones. Simulation has been used before as a tool to investigate this issue for Osaka City, Japan. It was found that the energy reduction of lighting was 0.02% of the total annual primary energy consumption in the residential sector for the seasonal total. The energy use for cooling, however, increased by 0.15% of the total energy use and therefore, the primary energy use is increased by 0.13% of the total primary energy consumption residential sector due to DST.

This paper investigates the savings in DST through a comprehensive simulation-based study. A US DOE core and perimeter reference small office building was seleced to represent the office building type simulated for each state across the seven US climate zones, using benchmark inputs, to answer the research question: does the application of DST actually "save" energy use in office buildings?

METHODOLOGY

The research method was developed through a 4-step workflow (Figure 1) that is applied once without DST and once with DST. The first step is identifying representative cities for each of the 50 states, followed by setting up a daylighting simulation model in DIVA for Grasshopper that produces five lighting schedules for standard core and shell zones. The schedules are used as inputs for a five thermal zones model in Archsim for Grasshopper. Finally, fuel breakdown for heating, cooling, lighting and equipment outputs are produced and tabulated for analysis.

Location and Reference Model Setup

The 50 US states were demonstrated by modeling a reference building in a representative city from each state. Each city is classified into one of the 7 US climate zones (Baechler, Williamson and Gilbride, 2010). Not every state falls completely in a single climate zone, so cities were selected to ensure an even spread across all climates. While the distribution is still skewed, with only 2 states in Zone 1 and 7, as the majority of the US falls between Zone 4 and 5, this uneven distribution was unavoidable.

A standardized small office model was built in Rhino3D CAD software based off the benchmark reference buildings developed by the US DOE (U.S. Department of Energy, 2014). The small office model (Figure 2) has a floor area of 5500 ft^2 and consists of a rectangular room with windows on all four sides. The 10 windows are 6 ft wide and 5 ft high. For the purposes of our simulations, the office is located on the ground floor, with no surrounding obstructions that may cast shadows on the building.

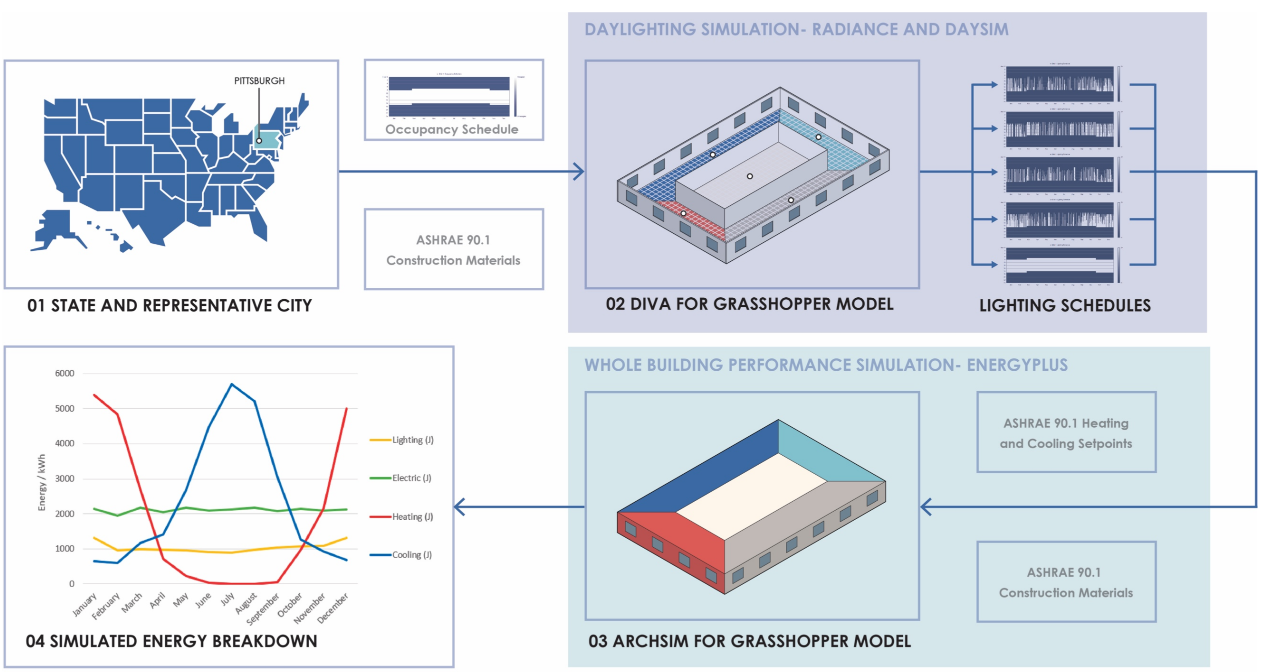

Figure 1 Simulation-based 4 step research method developed to run once without DST and another with DST

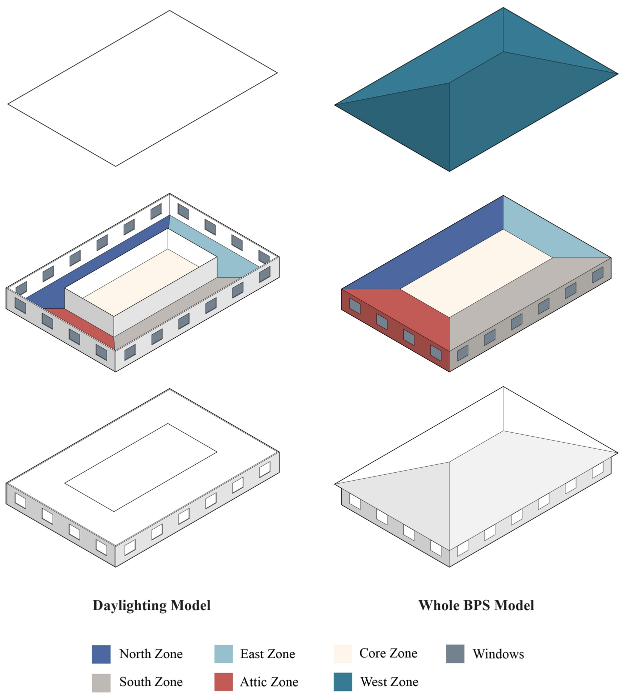

Figure 2 Daylighting and energy CAD model illustrations, with 4 perimeter zones and 1 core zone.

Daylighting Simulation

Daylighting performance was simulated using DIVA for Grasshopper as the front-end for the backwards raytracer Radiance (validated by Reinhart and Walkenhorst, 2001) and Daysim simulation engines. The model inputs include geometric definitions of space, finishing materials and occupancy schedules.

Office schedules were created according to the ASHRAE 90.1 standards for occupancy as well as equipment usage. The occupant is assumed to arrive at the office at 8 AM and leaves at 6 PM on both weekdays and weekends, although there is considerable lower occupancy during the weekends. Equipment schedules perform similarly, but equipment is kept running through the night. The occupant is assumed to take a lunch break at 1 PM, corresponding to a dip in occupancy at that time (Figure 3). The DST shift for the experiment starts on March 11th and ends on November 1st, and follows the same schedules but shifted forward an hour.

The "lightswitch" model (Reinhart, 2004) was used to represent probabilistically-valid user behavior for lighting energy. The model more accurately simulates lighting usage by taking into account the probability of an occupant to interact with lighting equipment according to daylighting performance. It demonstrates situations such as a user forgetting to switch off the lights even if daylighting performance become better, or a user not switching on the lights even though the illuminance has fallen beneath the required lux threshold. Radiance/Daysim and the lightswitch model simulate annual hourly illuminance values at the working plane, and uses the output to generate an hourly lighting schedule according to probabilistic occupant interaction. The simulation ran at a target illuminance of 500 lux for a control node in the middle of each of the 4 perimeter zones, and lighting was always on in the core zone. The resultant 5 lighting schedules were used as inputs in the whole building performance simulation model.

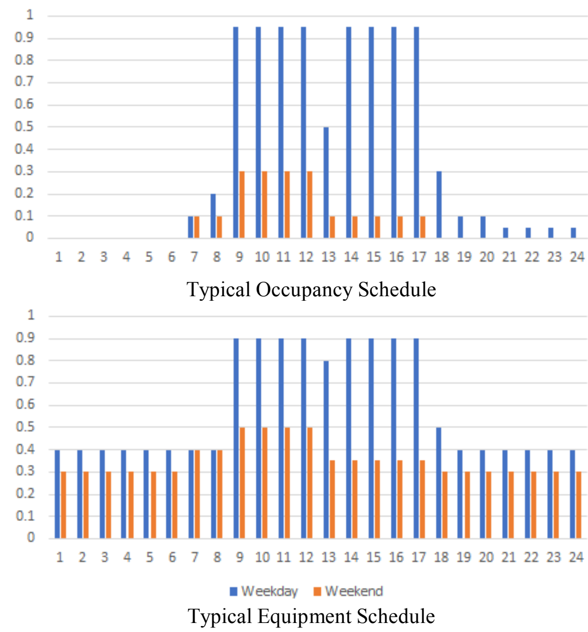

Figure 3 Occupancy and equipment schedules

Whole Building Performance Simulation (BPS)

Energy modeling was performed using Archsim for Grasshopper, which uses the US DOE EnergyPlus as the whole BPS engine. Inputs exceed the daylighting model requirements, by providing construction details beyond finish material reflectance. The model uses thermal zones to calculate heat transfer using inputs of weather data, geometry and zone definition details including construction features, schedules and equipment. Consequently, the simulation engine simulates multiple outputs, including loads for heating, cooling, lighting and equipment. Table 1 demonstrates primary inputs for the model. It is important to note that these inputs vary according to the climate zone based on the ASHRAE 90.1 standard. The model employs a thermostat that has a heating setpoint of 20°C and cooling setpoint of 25°C.

Table 1 Primary inputs for Archsim / Energyplus

CONSTRUCTION R-VALUE	Wall	1.76 m^2K/W
	Roof	3.32 m^2K/W
	Floor	0.54 m^2K/W
GLAZING	U-Value	3.35 W/m^2K
	Transmittance	70 %
WINDOW TO WALL RATIO (WWR)	North	24.4%
	East	19.8%
	West	19.8%
	South	24.4%
LIGHTING POWER DENSITY (LPD)		11.8 W/m^2
EQUIPMENT LOADS		10.76 W/m^2

Simulated Energy Analysis

For each city (representing a state) the reference office model ran with and without DST first for daylighting simulation to produce lighting schedules, then for energy simulations to produce energy fuel breakdown. The results were tabulated to compare the effect DST has on energy consumption, while disregarding equipment loads since they were constant. The differences were then mapped for each state.

RESULTS

Figure 4 demonstrates the outcomes of all simulations as the difference between applying and not applying DST. For the purposes of our analysis, we chose to consider each difference in the +/- 0.1% range negligible due to insignificance, and that the application of DST had no effect. We examined each type of energy system affected by the application of DST separately, then in total.

Lighting

Energy used in electric lighting was the most effected negatively by the application of DST. 36 states were effected, with Alaska's worst increase in energy use by 7.6% (2.7 kWh increase added to 35.46 kWh). 11 states were better with DST, with Arizona's best decrease in energy use by 2.9% (0.6 kWh decrease removed from 22.67 kWh). 3 states were not affected (Connecticut, for example), and the average energy use increase for all 50 states was 1.7%.

Heating

Conversely, heating energy was the most effected positively with the application of DST. 42 states benefited from the application of DST, with California's 3%, representing the best savings (0.2 kWh decrease from 6.67 kWh, which is marginal comparatively). The most savings in terms of value was Alaska's 1.72 kWh decrease from 83.39 kWh annually, which is saving 2.1%. 4 states did not benefit from the application of DST, but it was all marginal in terms of value, with maximum loses of 0.5 kWh yearly. Overall, the states would benefit 0.9% in heating energy savings with the application of DST.

Cooling

Most states were either effected negatively or not effected by the application of DST, where 21 states had better cooling energy performance when DST was not applied, and 13 were not affected. North Carolina is a representative state of that change, with 0.8% improvement without DST (0.68 kWh decrease from 83.12 kWh). However, 16 states had worse cooling energy consumption when DST was not applied. Wyoming had a 1% increase (0.45 kWh increase from 42.66). Overall, the average change of energy performance with and without the application of DST was 0%.

Total Energy Use

When combining heating, cooling and lighting, the effect cooling energy experienced had the most influence on total energy use results. Following the same trends for cooling, 23 states had better overall energy performance without DST, 13 didn't have a significant difference and 14 were better with DST applied. Maximum energy differences with and without DST were in the 1% range difference. The most savings when DST was not applied was in the state of North Caroline (1.6 kWh decrease from 172.25 kWh total), and the most savings when DST was applied was in Louisiana (1.17 kWh decrease from 194.92 kWh). The average savings across the country was 0.1% (typically in the 1.5 kWh range) if DST was not applied.

DISCUSSION

We discuss the "savings" value in applying DST across the US through three topics: possible policy implications in the US, future design trajectory features, and limitations within the research framework.

Possible Policy Implications

Results demonstrate that ineffectiveness of applying DST in the context of office buildings' energy performance. The study reveals negative implications of continued DST application in states that are typically affected in terms of cooling and lighting energy savings. This is because the simulation model accurately represented a core and shell building setup that has bordering lighting energy losses when

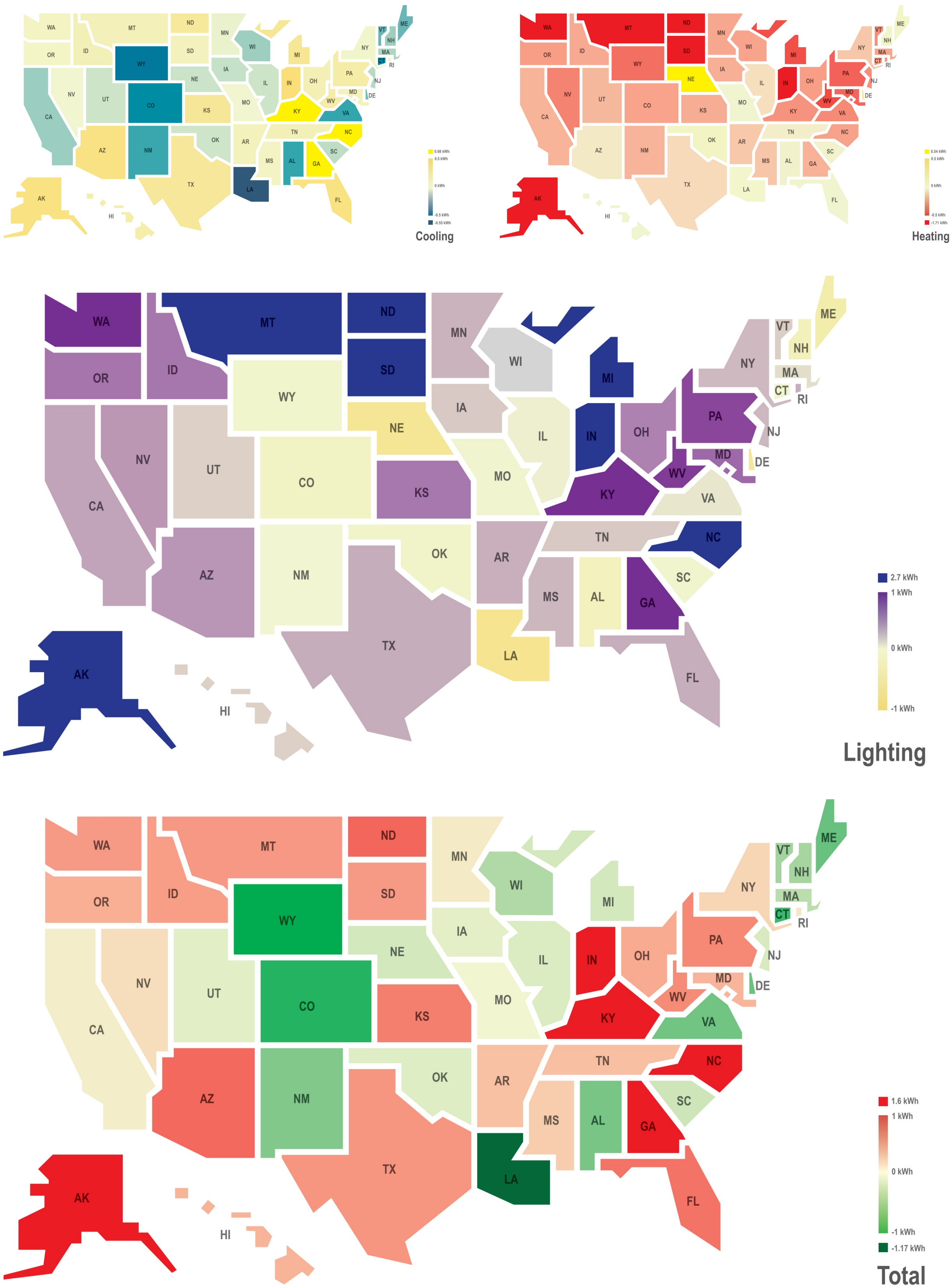

Figure 4 Heating, cooling, lighting and total energy consumption differences with and without the application of DST. Positive values denote energy saved when DST is not applied, and negative values signify energy saved when DST is applied.

compared to heating energy gains and mixed results with cooling energy. In cases where lighting energy is used continuously, and therefore there are also cooling implications, application of DST had a positive effect (e.g. WY and NM). However, when cooling energy is not saved when DST is not applied, but lighting energy savings are evident, there is no significant effect associated with applying DST (e.g. CA and UT). The cases that has the most critical effect on energy savings relevant to not applying DST are those who save both on cooling and lighting energy (e.g. KY and AK).

Considering the negative effects DST has on human health and well-being, as stated in the introduction, and with the findings that show the overall ineffectiveness of applying DST across the US, the authors question the validity of continuing to observe DST in the US. Possible positive social aspects of applying DST include boosting tourism because daylight in the evening hours would make people more likely to visit parks and other attractions, but such studies were anecdotal rathe than scientific. Therefore, if this practice continues, it is recommended that it remains only in Northeastern states ME, NH, VT, MA and CT, as well as Midwestern states WY and CO. Otherwise, other states that may benefit from the application of DST typically have negligible savings, or can be considered as an outlier case (e.g. Louisiana), as shown in table 2 in the appendix.

Future Design Trajectories

The goal behind applying DST is to save energy. The reference model that was simulated did not represent best practices that would be geared towards that particular goal. For example, the core area is relatively dominant, and construction materials, buildings systems and even WWRs were not designed to make use of environmental features relative to each climatic zone. Therefore, we speculate on a future that utilizes better design features by focusing on the southern oriented zone, and investigate the amount of energy that would be saved if DST was not applied to that zone only, which is less heating dominated and more lighting efficient.

The results of the south zone demonstrate that 35 states would benefit if DST was not applied, 2 states are not affected either way, and only 13 states would benefit from its application. On average, the states would save 0.5% of total energy if DST was not applied to southern oriented office zones. Most savings would happen in the state of Indiana, with 2.3%, and most losses would happen in the state of Alabama, with 1.5%.

It is important to note that speculation on better design can also make the application of DST promote certain features that might make its purpose useful. With the adoption of better lighting design practices, such as the use of LEDs, occupancy sensors, and overall reduction of lighting energy loads, savings in heating energy due to the application of DST could be justified. However, the expectation with designers, owners and building operators that promote such energy efficient practices is that all building systems will be energy efficient as well, and the savings effect will be observed across all end uses, rendering DST effects neutral once again.

Study Limitations

This simulation-based study has several limitations:

- The focus is on office buildings, with no built environment or any urban context.
- The building footprint is representing small offices, and medium to large office buildings should be studied as well.
- Although lighting schedules represent human behavior probabilistically, occupancy schedules don't, and should be researched stochastically as well.
- One building type is represented, and other building types should be investigated (e.g. residential, commercial, medical, etc.)
- The chosen error margin of +/- 0.1 should incorporate issues of uncertainty in BPS, and its effect on the variability in simulated parameters (Hopfe & Hansen, 2011).

It is therefore recommended that future studies address such limitations. Further building, neighborhood and city-scale investigations should be established through the continued development of Urban Building Energy Models (UBEMs) beyond single building investigations.

CONCLUSION

This paper investigated the "savings" in DST through a comprehensive simulation-based study. A US DOE core and perimeter reference small office building was simulated with and without DST for each state across the seven US climate zones using standard inputs. Results demonstrate that in most states lighting and cooling energy is saved or the effect is negligible when DST is not applied. Conversely, heating energy was mostly saved when DST was applied, but only marginally when compared to lighting and cooling. The paper discussed the validity of continuing to apply DST in the US, where on average total energy use in the simulated office building increased by 0.1% across the states. Furthermore, the paper speculates on future design trajectories in general and not specific to the study at hand, which demonstrated that as buildings are designed to be more energy efficient, the negative effects of DST are expected to be exacerbated. DST might have been linked to energy savings when it was first introduced. However, the benefits have become less evident. With human health and wellbeing in mind, this simulation-based building energy performance study concludes that in the case of DST in the US, the risks outweigh the benefits.

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Table 2 Appendix simulation outputs

ZONE	STATE	CITY	TOTAL ENERGY(KWH) WITH DST	TOTAL ENERGY(KWH) W/O DST	TOTAL ENERGY(KWH) % DIFF	SOUTH TOTAL ENERGY(KWH) WITH DST	SOUTH TOTAL ENERGY(KWH) W/O DST	SOUTH TOTAL ENERGY(KWH) % DIFF
1	Florida	Miami	221.18	220.41	-0.3	36.34	35.98	-1.0
1	Hawaii	Honolulu	214.96	214.55	-0.2	33.42	33.29	-0.4
2	Arizona	Phoenix	214.05	213.21	-0.4	35.18	34.66	-1.5
2	Louisiana	New Orleans	193.75	194.93	0.6	27.86	27.93	0.2
2	Texas	Houston	192.54	191.96	-0.3	27.15	27.01	-0.5
3	Alabama	Montgomery	180.47	180.98	0.3	23.48	23.83	1.5
3	Arkansas	Little Rock	187.28	186.95	-0.2	25.81	25.44	-1.4
3	California	San Francisco	125.47	125.40	-0.1	8.32	8.35	0.4
3	Georgia	Atlanta	174.70	173.30	-0.8	21.90	21.20	-3.3
3	Mississippi	Jackson	181.62	181.37	-0.1	23.98	23.80	-0.8
3	North Carolina	Charlotte	172.25	170.65	-0.9	20.97	20.80	-0.8
3	Oklahoma	Oklahoma City	179.75	179.83	0.0	23.28	23.16	-0.5
3	South Carolina	Charleston	182.16	182.31	0.1	24.39	24.28	-0.4
4	Delaware	Wilmington	172.91	173.45	0.3	21.67	21.60	-0.3
4	Kansas	Wichita	174.90	174.19	-0.4	21.96	21.77	-0.8
4	Kentucky	Louisville	179.76	178.55	-0.7	23.40	22.91	-2.2
4	Maryland	Baltimore	172.87	172.48	-0.2	21.35	21.09	-1.2
4	Missouri	Kansas City	182.18	182.18	0.0	24.16	23.87	-1.2
4	New Jersey	Trenton	174.59	174.70	0.1	22.36	22.28	-0.4
4	New Mexico	Albuquerque	163.98	164.46	0.3	18.35	18.30	-0.3
4	Oregon	Portland	148.26	147.82	-0.3	15.38	15.40	0.1
4	Tennessee	Nashville	179.93	179.59	1.0	23.46	23.40	-0.3
4	Virginia	Richmond	173.25	173.78	0.3	21.41	21.47	0.3
4	Washington	Seattle	143.51	142.95	-0.4	14.02	13.76	-1.9
4	West Virginia	Charleston	173.74	173.11	-0.4	21.88	21.72	-0.8
5	Colorado	Denver	166.50	167.27	0.5	19.52	19.73	1.1
5	Connecticut	Hartford	171.03	171.71	0.4	21.41	21.44	0.2
5	Iowa	Des Moines	189.60	189.66	0.0	26.66	26.53	-0.5
5	Idaho	Boise	167.28	166.75	-0.3	20.29	20.02	-1.4
5	Illinois	Chicago	181.23	181.32	0.0	24.40	24.45	0.2
5	Indiana	Indianapolis	184.83	183.59	-0.7	25.62	25.04	-2.3
5	Massachusetts	Boston	167.23	167.46	0.1	20.33	20.42	0.5
5	Michigan	Detroit	180.39	179.42	-0.5	24.54	24.39	-0.6
5	Nebraska	Omaha	188.19	188.32	0.1	26.77	26.58	-0.7
5	Nevada	Reno	164.90	164.75	-0.1	18.75	18.55	-1.0
5	New York	Syracuse	176.04	175.83	-0.1	23.32	23.26	-0.3
5	Ohio	Cleveland	178.61	178.15	-0.3	24.57	24.20	-1.5
5	Pennsylvania	Pittsburgh	171.36	170.71	-0.4	21.79	21.62	-0.8
5	Rhode Island	Providence	169.40	169.31	-0.1	20.89	20.87	-0.1
6	Utah	Salt Lake City	168.22	168.28	0.0	19.98	19.95	-0.2
6	Maine	Bangor	180.91	181.47	0.3	24.77	24.94	0.7
6	Minnesota	Minneapolis	192.64	192.55	0.0	27.65	27.51	-0.5
6	Montana	Helena	171.73	171.16	-0.3	21.29	20.98	-1.5
6	New Hampshire	Concord	178.94	179.26	0.2	23.59	23.70	0.4
6	South Dakota	Sioux Falls	191.43	190.87	-0.3	27.08	26.95	-0.5
6	Vermont	Burlington	180.13	180.47	0.2	24.60	24.91	1.3
6	Wisconsin	Milwaukee	180.93	181.21	0.2	24.67	24.77	0.4
6	Wyoming	Cheyenne	162.15	163.06	0.6	18.50	18.67	0.9
7	Alaska	Anchorage	195.15	193.76	-0.7	30.69	30.68	-0.1
7	North Dakota	Fargo	207.03	206.17	-0.4	32.06	31.98	-0.3