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ANALYSIS OF ENERGY PERFORMANCE OF UNIVERSITY CAMPUS BUILDINGS USING STATISTICAL AND ENERGY MODELING APPROACHES

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ABSTRACT

Buildings play a major role in total annual energy use worldwide. The purpose of this study is to evaluate the energy performance of University of Florida (UF) buildings and assess the effects of selected Energy Efficiency Measures (EEMs) on their energy performance. For this study, a set of buildings were identified based on a space functionality classification and two of them were chosen for simulation with energy modeling software. After calibrating the models to match actual energy use, we assessed their performance. The effect of EEMs on reducing the energy demands of buildings were analyzed. Analysis showed the potential energy saving for UF buildings. Modifying the EEMs, we could reduce the Energy Use Intensity values of the simulated buildings for 7-13%. Finally, using extrapolation and previous utility bills data, the campus-wide financial benefits of this saving were discussed.

1 INTRODUCTION

Except for a few, globally, several countries are facing energy crisis at all levels particularly affecting their infrastructure, industry, and economy. In the U.S., energy security and global warming are considered two of the greatest challenges the country is facing and energy conservation is the fundamental solution (Lstiburek 2008). Needless to say, buildings constitute major part of the total annual energy use. In developed countries, buildings use almost 40% of total energy usage and 30% of global annual green-house gas emissions (Ramesh, Prakash, and Shukla 2010; Goreham 2012).

Thus far, many green building rating systems have been developed with the purpose of assessing buildings to assure their energy efficiency and environmental sustainability. However, various studies show that, in some cases, they use more energy than similar non-certified ones (Diamond et al. 2006; Turner and Frankel 2008; Newsham et al. 2009; Scofield 2009). Furthermore, recent studies does not show that certified buildings use less energy as compared to non-certified buildings. One study conducted in the University of Florida (UF) campus showed that US Green Building Council's LEED certified buildings and non-certified buildings do not show significant differences (Agdas et al. 2015).

In order to provide energy efficient methods in building design, operation and maintenance, post-occupancy building energy modeling is a practical approach (Srinivasan, Lakshmanan, and Srivastav 2011). The purpose of this study is to provide a more reliable energy performance assessment of buildings in analyzing the potential to reduce their Energy Use Intensity (EUI), particularly for campus energy management and decision-making.

2 METHODOLOGY

The study uses four steps namely (1) grouping of buildings, which includes developing the building dataset with similar functionality characteristics; (2) selecting sample buildings for energy modeling; (3) estimating building energy use and calibration; and (4) identifying energy efficiency measures, regression analysis, and extending results to campus buildings to understand the energy savings and financial benefits.

2.1 Step 1 - Grouping of Buildings

Different operational and functional purposes lead to varied energy performance for buildings. Therefore, defining a suitable subset of buildings can help in achieving more consistent and reliable results. Accordingly, the first step is developing an appropriate group of buildings that have similar characteristics in terms of functionality. There are different types of buildings in UF campus such as schools, offices, residential complexes, sport complexes, stores, libraries, laboratories, and conference halls.

The energy usage and utility bill data of buildings used in this study were obtained from the UF Physical Plant Division (PPD). The data consisted of 45 buildings in UF campus containing 22 LEED and 23 non-certified buildings. Also, based on space classification data, the share percentages of different functional spaces were provided for each building used in this study. Offices, classrooms, teaching labs, research areas, auditoriums, gymnasiums, and residential areas are some of the critical functional spaces used for this classification. The space classification percentages are based on the area of the buildings.

Based on sorted space functionality percentages, a group of 12 buildings that have the same functionality and space percentages are chosen from the set of buildings. The selected 12 buildings are all schools with classrooms, offices, teaching labs, study rooms, and research labs and as a result have similar functionality and operation schedules. Besides, there is a wide range of area in this group. Furthermore, this set is comprised of 5 LEED and 7 non-LEED buildings that exhibit a variety of buildings with different ages and construction approaches

The electricity, chilled water, and steam data are derived from the 2011-2012 utility bills and are shown in kilo watt hours (kWh). The EUI values were calculated as the sum of electricity, chilled water, and steam use divided by the area of the buildings for one year; kWh/m² is the unit for this measure. Based on our data, the mean of building EUI values is calculated as 278 kWh/m². We sorted the buildings based on EUI values and introduced three subsets as “low”, “intermediate,” and “high” energy consumers.

2.2 Step 2 - Selecting Sample Buildings for Energy Modeling

Table 1 shows the energy use of the buildings set with low, intermediate and high energy consumers subsets. Regarding the three subsets, we chose Rinker Hall and Hough Hall from the high and intermediate energy consumer subsets respectively for energy estimating using modeling software. Both buildings have relatively the same area and both are LEED certified buildings. However, they have significantly different energy performance that can be assessed with comparing their energy performance models.

Rinker Hall is the school of construction management at UF. It is a three-storey building with almost 4,600 m² gross area that was completed in March 2003. It is completely oriented on a north-south axis and two major facades of the building are facing east and west directions. However, due to implementation of large glazing facades, most parts of the building are daylit throughout a year. Furthermore, recycled content, manufacturing proximity, low toxicity, low maintenance requirements and recyclability were considered in choosing the materials used for the building construction.

Hough Hall is the graduate school of business at UF. It is a three-storey building as well with almost 6,300 m ² gross area. This facility was completed in July 2010. Unlike Rinker Hall, Hough Hall is oriented on an east-west axis with its major facades facing north and south directions and it has relatively lower window to wall ratio comparing to Rinker Hall. Similar to Rinker Hall, sustainable and energy efficient approaches were implemented for construction of the building.

Table 1: Low, intermediate and high energy consumers subsets.

Building	Gross area (m^2)	Electricity kWh	CH.W. kWh	Steam kWh	EUI kWh/m^2	
Florida Gymnasium	12,580	1,540,799	N/A	N/A	122	**Low**
Plant Science Facility	577	1,121,807	N/A	N/A	134	
Norman Hall	20,392	1,844,034	1,455,977	1,760	162	
105 Classroom Bldg.	2,829	478,100	N/A	N/A	169	
Keene-Flint Hall	4,578	377,630	710,404	227	238	**Intermediate**
Hough Hall	6,299	670,900	1,009,337	844	267	
Little Hall	8,339	742,307	1,730,291	1343	297	
Pugh Hall	4,245	495,300	893,280	819	327	
Rinker Hall	4,544	432,900	1,114,842	244	341	**High**
Levin Advocacy Center	1,901	111,710	569,730	181	359	
Holland Law Center	19,042	7,130,007	N/A	6,994	375	
Matherly Hall	4,903	487,310	2,162,509	898	541	

The reason that we chose model buildings, Rinker Hall and Hough Hall, from the set of buildings was the similarity of them as they are both colleges with relatively close gross area. Also, the HVAC systems for the two buildings are quite the same, including building automation systems, cooling equipment and towers, heat pumps and equipment, condensate recovery, steam traps, domestic hot water heaters, variable speed control of pumps, reheat and re-cool systems, air economizers, fans and ductwork, and demand control ventilation systems.. Furthermore, they are both gold level LEED-certified buildings with relatively close scores and construction approaches. However, the annual EUI values of the buildings are not comparable and Rinker Hall is consuming much more energy than Hough Hall. The only considerable difference between the two buildings is their orientation. In Hough Hall, major facades are completely facing north and south directions while they are facing east and west directions in Rinker Hall. Figures 1 and 2 show a perspective of the building models.

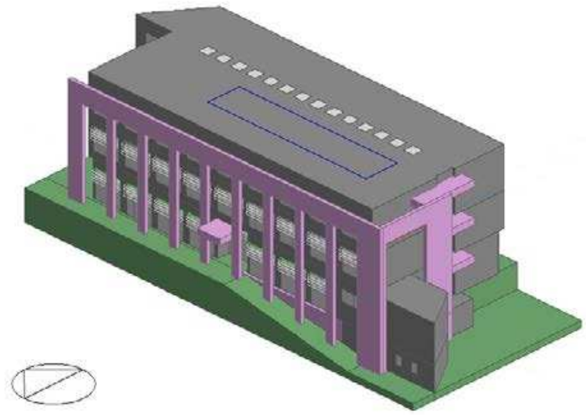

Figure 1: Rinker Hall DesignBuilder model.

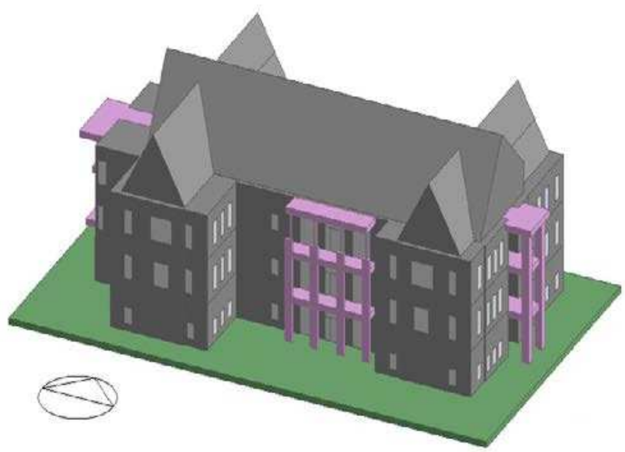

Figure 2: Hough Hall DesignBuilder model.

2.3 Step 3 - Estimating Building Energy Use and Calibration

For the purposes of this study, DesignBuilder v 3.2 was used to model Rinker Hall and Hough Hall. The result of the energy analysis included the annual and monthly energy consumption of the buildings in terms of room electricity, heating, cooling and lighting.

Based on the analysis, the simulated EUI values were calculated as 341 kWh/m² for Rinker Hall and 267 kWh/m² for Hough Hall. Furthermore, based on 3 years of utility bills data, the average actual EUI values were calculated as 355 kWh/m² and 260 kWh/m² for the two buildings, respectively. We can observe that the differences in actual versus simulated EUI values are 4.71% for Rinker Hall and 9.98% for Hough Hall.

Calibration is the process of assessing measurement tools and adjusting their precision based on measurement standards. In this step, the purpose is to calibrate the achieved energy performance models based on the actual energy consumption data that is taken from utility bills. In result, we can assess the reliability of our models so that we can use them as benchmarks for developing EEMs in order to discuss about potential ways for improved energy savings. Some of the calibration protocols include: (1) ASHRAE Guidelines 14-2002: Measure of energy and demand savings (ASHRAE Standards Committee 2002), (2) Measurement and verification (M&V) Guidelines for Federal Energy Projects, Federal Energy Management Program (FEMP 2008), and (3) International Performance Measurement and Verification Protocol (IPMVP 2002).

All of these standards use the Coefficient of Variation (CV) of the Root Mean Squared Error (RMSE) as the measure for calibration. The admissible ranges of tolerance for CV (RMSE) for monthly data calibration are ± 5%, ± 10% and ± 15% for IPMVP, FEMP and ASHRAE respectively (ASHRAE Standards Committee 2002; FEMP 2008; IPMVP 2002).

Based on these definitions, we calculated the CV (RMSE) values for monthly data calibration and checked them in comparison with the tolerance range accepted by the IPMVP, FEMP, and ASHRAE Standard. Figures 3 and 4 show the actual versus simulated monthly energy consumption for the two buildings. Furthermore, Table 2 shows the metered and simulated monthly energy consumption and the CV (RMSE) for the two buildings which both satisfy the tolerance range of the previously mentioned standards.

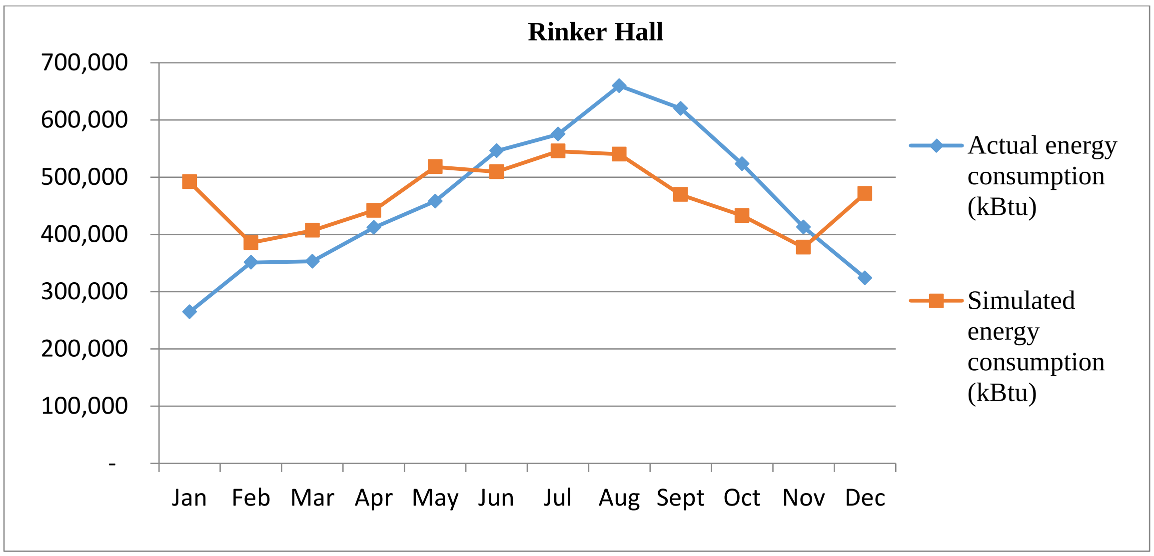

Figure 3: Actual versus simulated monthly energy consumption for Rinker Hall.

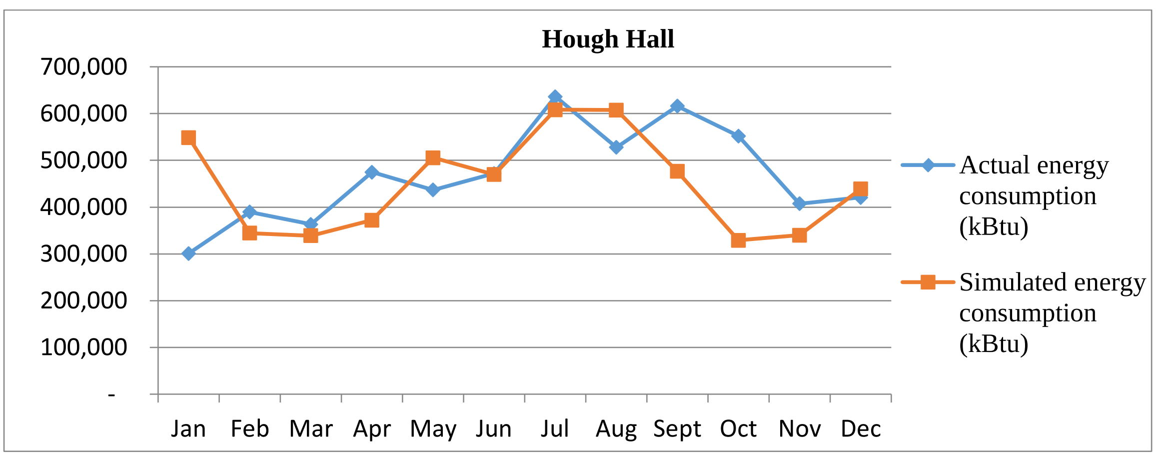

Figure 4: Actual versus simulated monthly energy consumption for Hough Hall.

Table 2: Metered and simulated monthly energy consumption and CV (RMSE) for Rinker Hall and Hough Hall.

	Rinker Hall			Hough Hall		
Month	Energy consumption (kWh) Metered (M)	Energy consumption (kWh) Simulated (S)	$(M - S)^2$	Energy consumption (kWh) Metered (M)	Energy consumption (kWh) Simulated (S)	$(M - S)^2$
Jan	77565.05	144171	4436352575	88173.05	160862	5283683452
Feb	102871.4	112982.4	102232321	114234.7	100965.3	176076976
Mar	103503.6	119281.9	248954751	106486.8	99302.71	51611149.1
Apr	120767.2	129540	76962019.8	139193.2	109064.6	907732538
May	134280.7	151843.9	308465994	127975.6	148229.7	410228567
Jun	160008	149308	114490000	138334.8	137689.2	416799.36
Jul	168559.5	159875.8	75406645.7	186476.1	178239.9	67834990.4
Aug	193320.5	158329	1224405072	154722.4	178074.6	545325245
Sept	181746.5	137578.1	1950847559	180563.4	139611.4	1677066304
Oct	153351.2	126919.7	698624192	161827.1	96444.98	4274821616
Nov	120953	110598.3	107219812	119398.3	99602.23	391884387
Dec	94941.82	138164.2	1868174133	123299.1	128636.5	28487838.8
Total	1611869	1638592	714118729	1640685	1576723	4091137444
RMSE (month)			30567.01	RMSE (month)		33930.3
CV (RMSE-month)			1.90%	**CV (RMSE-month)**		2.07%

It should be mentioned that the models were developed based on assumptions that could have minor differences with each or either of the two buildings' actual condition. Therefore, we observed differences between actual and simulated monthly energy consumption data for Rinker Hall. However, there was not such an issue for Hough Hall. The difference can be caused by the occupancy patterns that may be different from the occupancy schedules assumed for the buildings throughout the year. Also, it is caused by the different plug load patterns existent in the two buildings. On-site audits can show that there are much more computers and laboratory equipment existent in Rinker Hall that cause its actual plug load density to be considerably higher than what it is in Hough Hall. This difference was calibrated by adding 1.2 kWh/sf of plug load to the monthly simulated energy consumption data for Rinker Hall. This modification is based on measuring actual Rinker Hall plug load density by using implemented plug load sensors.

Regarding the annual energy consumption data for the two buildings, the consumption share percentages of each energy components are calculated. The results can be seen in Figures 5 and 6. Based on these results, it can be seen that almost 60% of the annual energy consumption for Rinker Hall pertains to cooling operations which is 20% more than Hough Hall. This can be interpreted as the result of orientation of the two buildings and relatively higher window-to-wall ratio (glazing percentage) in Rinker Hall. The simulated monthly energy use of both buildings reflects that the energy demand for cooling and heating are considerably higher during the three months of summer and three month of winter respectively.

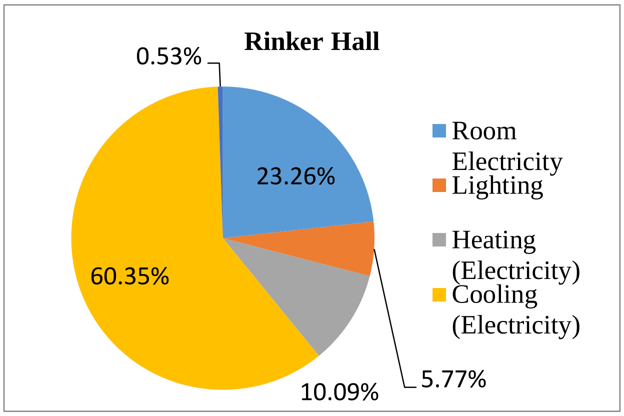

Figure 5: Rinker Hall annual energy consumption subdivisions.

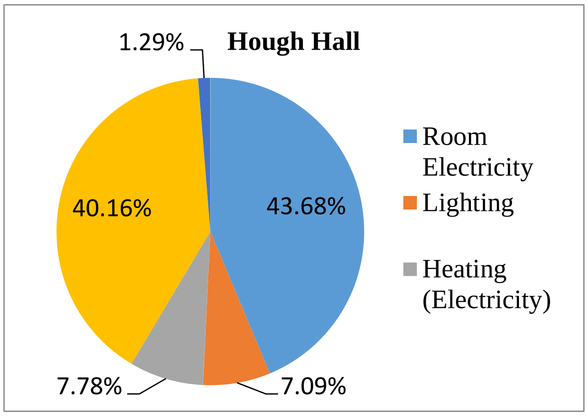

Figure 6: Hough Hall annual energy consumption subdivisions.

2.4 Step 4 - Energy Efficiency Measures, Regression Analysis, and Extending Results to Campus Buildings

After calibration of the energy models, different EEMs especially those related to air conditioning operations were chosen to assess the possible amount of savings in energy use and financial benefits. In order to conduct this analysis, four EEMs were used which are heating- and cooling- setpoint temperatures (˚F), minimum ventilation provided by the mechanical ventilation system for each person, sensible heat recovery system, and natural ventilation. Then, we changed each measure in the models and calculated the modified EUI values pertained to these changes. The set of EEMs selected are those that can be easily and effectively implemented in the buildings by UF PPD. Here are brief descriptions of the modifications conducted for each measure:

- Heating- and cooling- setpoint temperatures (˚F): The setpoint temperatures used for the initial models were 71.6°F (22°C) for heating and 75.2°F (24°C) for cooling operations. The modified values used for assessing the effects of these measures are 68˚F and 77˚F respectively.
- Minimum fresh air provided by ventilation system: The initial minimum ventilation was 21.2 cfm /person. We changed this value to 10 cfm/person based on Table 6-1, minimum ventilation rates in breathing zone, ASHRAE 62.1-2007 (ASHRAE, ANSI 2007).
- We defined a sensible heat recovery system with 70% effectiveness that was not initially implemented for mechanical ventilation.

- Although natural ventilation is allowed and all the windows are operable in both buildings, none of them are implementing natural ventilation. As another EEM, we included a natural ventilation system that operates with the same schedule as we assumed in our initial assumptions, which may at times not provide adequate thermal comfort, however, included for experimental purposes.

The new EUI values were calculated with modified EEMs and are shown in Table 3. Also, besides assessing EEM modifications separately, we developed a model including all modifications and calculated the new EUI for that. As it can be seen, all the EEM modifications decreased the EUI values except implementing natural ventilation for Hough Hall. Therefore, we did not consider natural ventilation for the Hough Hall model with all modifications. The reduced amounts of EUIs for all modification models were calculated lower but relatively close to the sum of decreased EUI values pertaining to the single modifications.

Here, we use regression analysis in order to find a relationship between the EEMs and the EUI values pertaining to each modification experiment. The purpose is to study the effects of EEMs in changing the EUI values and find a Confidence Interval (CI) for that. Regarding the shortage of data (experiments), we assume a linear behavior for this relationship and check the reliability of our assumption by assessing R^2 values of the regression model.

Table 3: New EUI values with EEMs.

Buildings	**Simulated EUI ($kWh/m^2/yr$)**	**Modified EUIs ($kWh/m^2/yr$)** Temperature setpoints	Minimum Ventilation setpoints	Heat recovery	Natural ventilation	All modifications	**Sum of all amounts reduced ($kWh/m^2/yr$)**
Rinker Hall	338.05	333.69	335.74	330.79	337.89	324.73	14.09
	Amount reduced	4.36	2.31	7.26	0.16	13.32	
Hough Hall	234.48	220.92	222.87	223.69	245.71	206.15	35.96
	Amount reduced	13.56	11.61	10.79	-11.23	28.33	

In this analysis, the Dependent Variables (DVs) are EUIs (Ys) and the Independent Variables (IVs) are EEMs (Xs). Here, we assume that IVs can only have 0 or 1 values that show the existence of each EEM modification in our experiments (X_1 to X_4). Also, in order to increase the degree of freedom for the model, we assume another IV (X_5) that shows the building that the experiment was conducted on (0 for Rinker Hall and 1 for Hough Hall). Tables 4a and 4b show the data that we used for regression analysis. The best possible regression was derived as (1).

Table 4a: Data used for EEM regression analysis.

	Experiment Number	1	2	3	4	5	6	7	8	9	10	11	12
IVs	X_1	0	1	0	0	0	1	0	1	0	0	0	1
	X_2	0	0	1	0	0	1	0	0	1	0	0	1
	X_3	0	0	0	1	0	1	0	0	0	1	0	1
	X_4	0	0	0	0	1	1	0	0	0	0	1	0
	X_5	0	0	0	0	0	0	1	1	1	1	1	1
DV	**Y**	338	334	336	331	338	325	234	221	223	224	246	206

Table 4b: Regression analysis coefficients, T values, and P values.

Predictor	Coefficient	SE Coefficient	T	P
Constant	340	0.58	185.78	0.000
X $_1$	-2.2674	0.7436	-3.05	0.023
X $_2$	-1.6324	0.7436	-2.20	0.071
X $_3$	-2.2874	0.7436	-3.08	0.022
X $_5$	-35.047	0.6934	-50.55	0.000

$$Y = 340 - 2.27\ X_1 - 1.63\ X_2 - 2.29\ X_3 - 35.0\ X_5 \tag{1}$$

$S = 1.13932$ $R^2 = 99.8\%$ R^2 (adjusted) = 99.6%

We can observe high R^2 and suitable P-values which express the reliability of the regression. In addition, it should be mentioned that X_4 (natural ventilation) was excluded from the data, due to having high P-value (experiments 5 and 11). As noted earlier, this means that natural ventilation does not have any positive effect on decreasing the amount of EUI values for the two buildings. Also, the highest reduction of EUIs is pertained to all modification experiments (6 and 12). Based on the regression model, we calculated 95% Confidence Intervals (CIs) for these two experiments as follows.

Experiment 6, all modifications for Rinker Hall:

95% CI = (314, 327)

Experiment 12, all modifications for Hough Hall:

95% CI = (204, 216)

This means, that if we modify the first three EEMs, with 95% probability, the EUI value of Rinker Hall will decrease for 11 to 24 kWh/m²/yr (3.3% to 7.2%) and the EUI value of Hough Hall will decrease for 18 to 31 kWh/m²/yr (7.8% to 13.2%).

With simple calculations of the average annual utility rates for the two buildings (based on 3 years of utility bill data), we can relate these amounts of energy savings to the annual savings in money. In other words, with 95% probability, by modifying the EEMs, we can save almost $15,700 to $33,800 for Rinker Hall and $7,400 to $12,400 for Hough Hall annually. Using extrapolation based on gross area, this annual saving will be between $133,000 and $272,000 for the two groups of intermediate and high energy consumer buildings assessed in this study. Also, this amount of saving can be increased by modifying more EEMs and optimizing modifications implemented for each of them. Obviously, this optimization takes plenty of time and effort for developing each model and conducting a lot of experiments in order to achieve more reliable data.

3 CONCLUSIONS

This study evaluated the energy performance of two buildings that represented a section of buildings located in UF campus. A set of EEMs were identified and implemented to these and their effects on their energy performance was assessed. Four different EEMs were used namely, heating and cooling setpoint temperatures, minimum fresh air provided by the mechanical ventilation system, sensible heat recovery system, and natural ventilation. Based on the EEM modification experiments, we assessed the feasible amount of energy savings for the two buildings and extended the results to UF campus buildings. An EUI reduction of 7-13%, i.e., energy cost savings between $133,000 and $272,000 is achievable with the EEMs. Using extrapolation and utility bills data, the campus-wide financial benefits owing to energy savings were identified as well. Our future study will include integration of optimization tool to gain improved energy savings. Besides, a larger set of buildings will be modeled in future such that potential EEMs can be evaluated from within a platform.

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