DREXEL UNIVERSITY
Department of Civil, Architectural and Environmental Engineering
AE 551: Building Energy Systems I
Term: Spring Quarter 2022





Project II

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June 6th, 2022

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REFERENCE BUILDING

This section shows details related to the reference building chosen and attributes related to the chosen location's climate.

Location: Albuquerque, NM USA

Weather file: Albuquerque NM USA TMY3 – 723650

Reference Building: Department of Energy (DOE) developed - Small Office – Used – After 1980

Tables 1 through 8 exhibit the properties of the reference building utilized in this study.

Table 1 Reference Building location and attributes

Latitude [deg]	35.05
Longitude [deg]	-106.6
Elevation [m]	1619.00
Time Zone	-7.0
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00

Table 2 Selected Thermal Zone

Thermal Zone	Thermal Climate Zone Name	Weather Location
4B	Mixed Dry	Albuquerque International Sunport, New Mexico

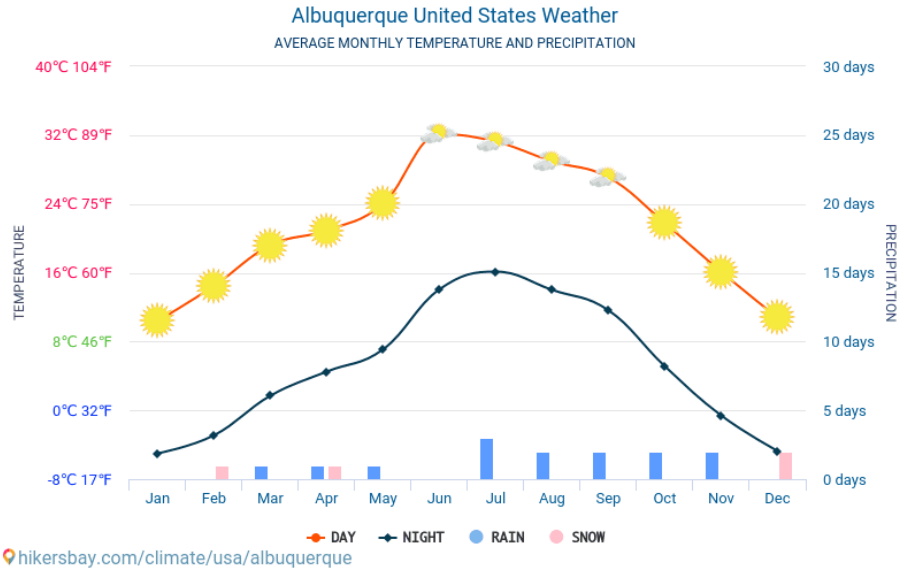


Figure 1 Albuquerque Weather by Month

Table 3 Building Attributes

NO. FLOORS	GROSS FLOOR AREA, FT2 (M2)	Roof type	Space type	Wall type	Window type
1	5,500 (511)	Attic roof	Non-residential	mass	fixed

Table 4 Window to Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area **[m2]**	281.51	84.45	56.30	84.45	56.30
Window Opening Area **[m2]**	59.68	16.73	11.16	20.64	11.16
Window-Wall Ratio **[%]**	21.20	19.81	19.81	24.44	19.81

Table 5 Skylight to Roof Ratio

	Total
Gross Roof Area [m2]	598.76
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

Table 6 Individual Zone's Attributes

Zone Name	Ceiling Height {m}	Volume {m3}	Floor Area {m2}	Exterior Gross Wall Area {m2}	Exterior Net Wall Area {m2}	Exterior Window Area {m2}	Number of Surfaces	Number of SubSurfaces	Number of Shading SubSurfaces	Part of Total Building Are
ATTIC	1.64	720.19	567.98	0	0	0	13	0	0	No
CORE_ZN	3.05	456.46	149.66	0	0	0	6	0	0	Yes
PERIMETER_ZN_1	3.05	346.02	113.45	84.45	63.82	20.64	6	7	0	Yes
PERIMETER_ZN_2	3.05	205.27	67.3	56.3	45.15	11.16	6	4	0	Yes
PERIMETER_ZN_3	3.05	346.02	113.45	84.45	67.72	16.73	6	6	0	Yes
PERIMETER_ZN_4	3.05	205.27	67.3	56.3	45.15	11.16	6	4	0	Yes

Table 7 Opaque Exterior Constructions

Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Azimuth [deg]
ATTIC NON-RES FLOOR	0.08	0.335	0.365	45.00
ATTIC NON-RES ROOF	0.30	4.035	16.833	90.00
EXT-SLAB	0.30	1.862	3.401	270.00
MASS NON-RES EXT WALL	0.08	1.079	1.287	180.00

Table 8 Fenestration

Construction	U-Factor [W/m2-K]	SHGC	Visible Transmittance	Shade Control	Azimuth [deg]
WINDOW FIXED	4.092	0.362	0.225	No	180.00

TOPIC I – SIMULATION PARAMETERS

In this topic, we see the impacts of various algorithms utilized in simulating heat transfer on the energy dissipated through envelope and zone exfiltration calculated using these algorithms.

EnergyPlus provides sets of simulation parameters for simulating heat transfer between zones' air, internal and external convective heat transfer through external opaque surfaces, and conductive heat transfer through external opaque surfaces.

Table 9 Surface Convective Algorithms

Inside wall	Outside wall
Simple	Simple combined
TARP	TARP
Ceiling Diffuser	MoWiTT
Adaptive Convection Algorithm	DOE-II

Inside wall:

Simple = constant value natural convection.

TARP = variable natural convection based on temperature difference.

Ceiling Diffuser = ACH-based forced and mixed convection correlations for ceiling diffuser configuration with simple natural convection limit.

Adaptive Convection Algorithm = dynamic selection of convection models based on conditions.

Outside wall:

Simple Combined = Combined radiation and convection coefficient using simple ASHRAE model.

TARP = correlation from models developed by ASHRAE, Walton, and Sparrow et. Al.

MoWiTT = correlation from measurements by Klems and Yazdanian for smooth surfaces.

DOE-2 = correlation from measurements by Klems and Yazdanian for rough surfaces.

Table 10 Convective Heat Balance Algorithms

Algorithms
CTF
EMPD
CondFD
CondFD Simplified
HAMT

CTF =Conduction Transfer Functions.

EMPD =Effective Moisture Penetration Depth with Conduction Transfer Functions.

CondFD =Conduction Finite-Difference.

Conduction Finite Difference Simplified.

HAMT =Combined Heat and Moisture Finite Element.

Table 11 Zone Heat Balance Algorithms

Algorithms
Analytical Method
Euler Method
Third Order Backward Difference

In the case of convective heat transfer, Simple and TARP for the interior and TARP and DOE-II for the exterior are the chosen methods for this study.

In the case of conductive heat transfer, CTF is the only applicable option. Methods including the Finite-Difference cannot be chosen because they have limitations regarding the thickness of the construction layers and their conductivity, making them unsuitable for realistic building simulations unless layers containing such properties can be exempted. The algorithms that consider moisture penetration cannot be chosen due to the lack of information on the moisture penetration properties of the selected building materials.

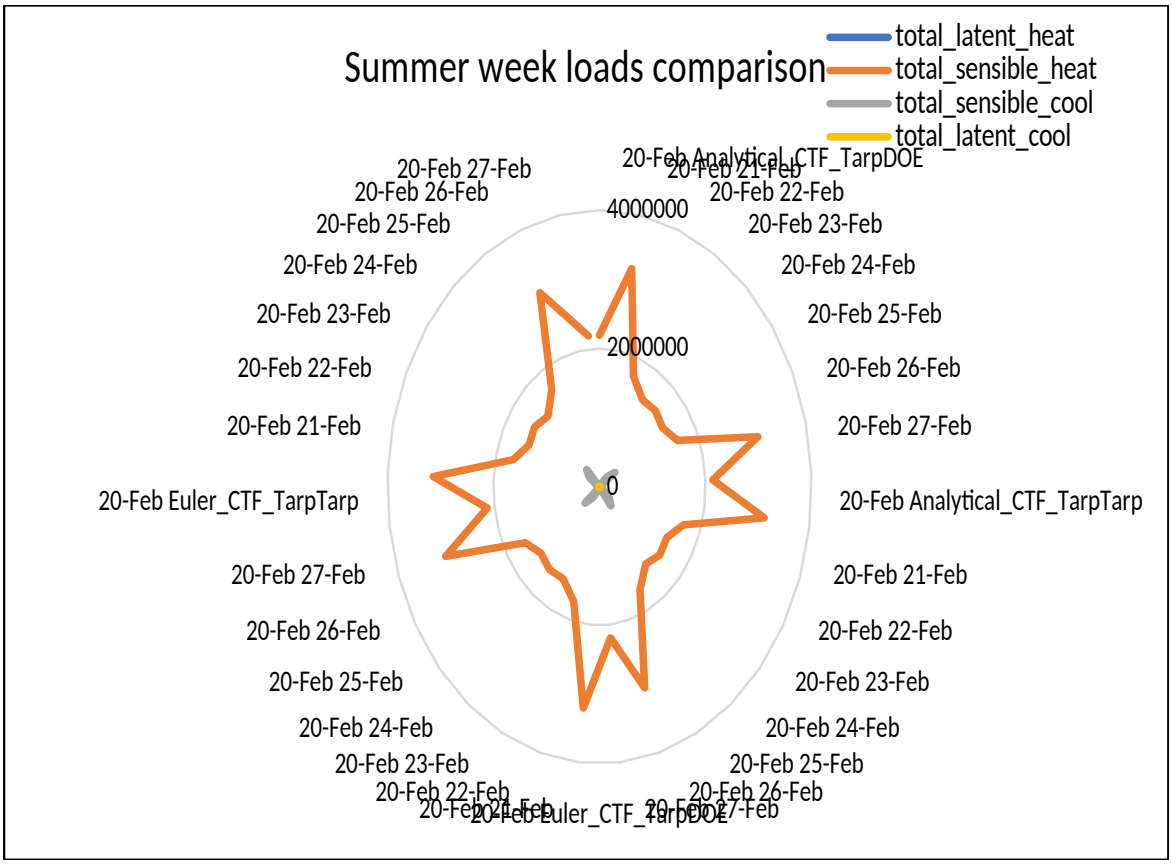
Finally, in the case of zone heat balance methods, the Analytical and Euler method are chosen to be studied.

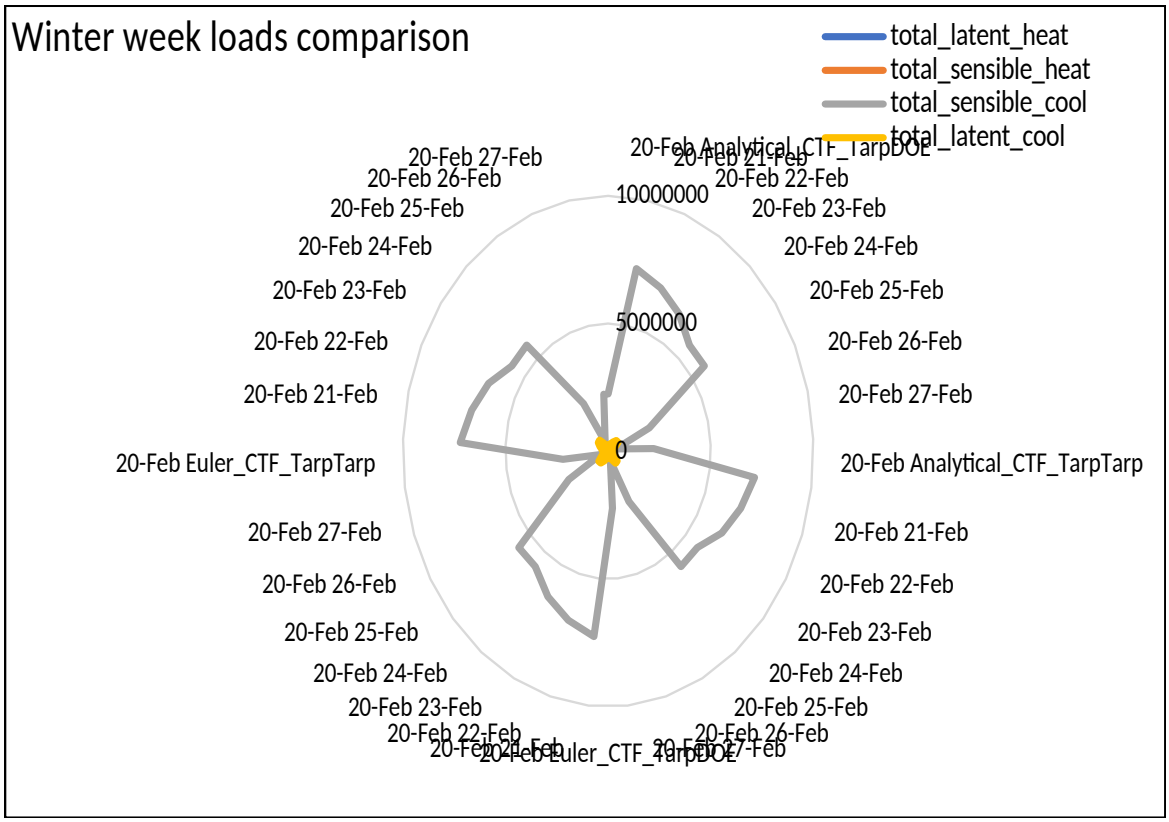
Results from the small reference building office (Table 12) indicate a minimal impact on energy dissipations, and the comparison also does not indicate a substantial difference in simulation runtimes.

Table 12 small office simulation parameters comparison

Strategy	**Envelope Convection [GJ]**	**Zone Exfiltration [GJ]**	**Total [GJ]**	**RUNTIME [sec]**
Analytical_CTF_TarpTarp	60.11	4.32	64.44	1.66sec
Analytical_CTF_TarpDOE2	61.62	4.27	65.90	1.58sec
Euler_CTF_TarpDOE	61.66	4.28	65.94	1.58sec
Euler_CTF_TarpTarp	60.14	4.33	64.47	1.50sec

We also look at two weeks in the year to see the effects of these parameters on the cooling and heating energies of the building. Comparing the parameters in this study, Slight changes in the outcomes occur when using different algorithms; however, these errors are small enough that they can be neglected.


Summer week loads comparison
total_latent_heat
total_sensible_heat
total_sensible_cool
total_latent_cool
20-Feb Analytical_CTF_TarpDOE
20-Feb 21-Feb
20-Feb 22-Feb
20-Feb 23-Feb
20-Feb 24-Feb
20-Feb 25-Feb
20-Feb 26-Feb
20-Feb 27-Feb
20-Feb Analytical_CTF_TarpTarp
20-Feb 21-Feb
20-Feb 22-Feb
20-Feb 23-Feb
20-Feb 24-Feb
20-Feb 25-Feb
20-Feb 26-Feb
20-Feb 27-Feb
20-Feb Euler_CTF_TarpDOE
20-Feb Euler_CTF_TarpTarp
20-Feb 27-Feb
20-Feb 26-Feb
20-Feb 25-Feb
20-Feb 24-Feb
20-Feb 23-Feb
20-Feb 22-Feb
20-Feb 21-Feb
4000000
2000000
0


Winter week loads comparison
total_latent_heat
total_sensible_heat
total_sensible_cool
total_latent_cool
20-Feb Analytical_CTF_TarpDOE
20-Feb 21-Feb
20-Feb 22-Feb
20-Feb 23-Feb
20-Feb 24-Feb
20-Feb 25-Feb
20-Feb 26-Feb
20-Feb 27-Feb
20-Feb Analytical_CTF_TarpTarp
20-Feb 21-Feb
20-Feb 22-Feb
20-Feb 23-Feb
20-Feb 24-Feb
20-Feb 25-Feb
20-Feb 26-Feb
20-Feb 27-Feb
20-Feb Euler_CTF_TarpDOE
20-Feb Euler_CTF_TarpTarp
20-Feb 27-Feb
20-Feb 26-Feb
20-Feb 25-Feb
20-Feb 24-Feb
20-Feb 23-Feb
20-Feb 22-Feb
20-Feb 21-Feb
10000000
5000000
0

To better study the effects of these simulation parameters, we repeated the study on the Large Office DOE reference building.

In this case, the zone heat balance algorithms influence the runtime of simulations. The error in the outputs with changing the zone heat balance algorithm is minimal; however, the runtime significantly decreases from the Euler method to Analytical and again from Analytical to the Third Order Backward Difference method.

Table 13 Large Office Zone Heat Transfer Balance Methods Comparison

Zone heat balance Algorithm	Envelope Convection [GJ]	Zone Exfiltration [GJ]	Total [GJ]	RUNTIME [sec]
Analytical	8831.72	141.64	54553.27	04min 26.68sec
Euler	8832.44	142.08	54706.29	04min 5.85sec
Third Order Backward	8832.36	141.36	54635.69	03min 55.14sec

Results tabulated in (Table 14) indicate the significant influence that external methods TARP and DOE-II have on Envelope Convection results, which is more than 10%. However, it is not simple to determine which one is closer to the actual condition.

Also, the influence of each combination of algorithms on runtime is indicated, showing SimpleTARP combination with the fastest runtime and TARPTARP with the slowest among these combinations.

Table 14 Large Office Convective heat transfer balance methods comparison

Convection Algorithm [Internal-External]	Envelope Convection [GJ]	Zone Exfiltration [GJ]	Total [GJ]	RUNTIME
TARPTARP	8831.72	141.64	54553.27	05min 22.33sec
TARPDOE2	10201.21	141.35	55655.19	04min 38.19sec
SimpleTARP	8823.08	141.07	56042.77	03min 50.83sec
SimpleDOE2	10191.80	140.68	57146.09	04min 4.39sec

Conclusion

From results reached in this topic, we can see that in smaller buildings, there is a relatively negligible difference between various algorithms of zone heat balance and convective heat transfer.

However, in the case of a larger building, some degree of discrepancy in the energy dissipated through envelope convection can be seen. Specifically, there is a difference larger than 10% between DOE-II and TARP algorithms utilized for the external surface convective heat transfer method.

Also, there are significant variations between the simulation runtimes in the case of larger buildings, which could be of potential importance in the case of more complex models with longer runtimes.

TOPIC II – OPTIMIZATION

In this topic:

- We see details of the step-by-step optimization process of the building:
  - First, we will see the effects of increasing the insulation level on opaque surfaces.
  - Next, we see the effects of different glazing configurations on building performance.
  - Next, we see the effects of improving the airtightness of the building and its lighting fixtures on overall energy consumption.
  - And finally, we see different shading schemes and their impact on building energy consumption.
- We see the effects of building orientation on its performance.
- And lastly, we see the overall improvement of the building performance after the optimization.

It is also worth mentioning that since we do not test or change any of the efficiencies related to the building's HVAC systems, in this comparison-based argument, "End-Use Energy" is considered as good as "End-Use Demand" as the basis of comparisons.

Step 1 – Opaque Insulation

In this step, since the existing insulation material conductivity is 0.049 W/m.K, considered an excellent insulating material, we test and see the effect of increasing its thickness on cooling, heating, fans, and overall end-use energies. In (Figure 2), increasing the thickness from 2cm up to 50cm results in a reduction of total end-use energy.

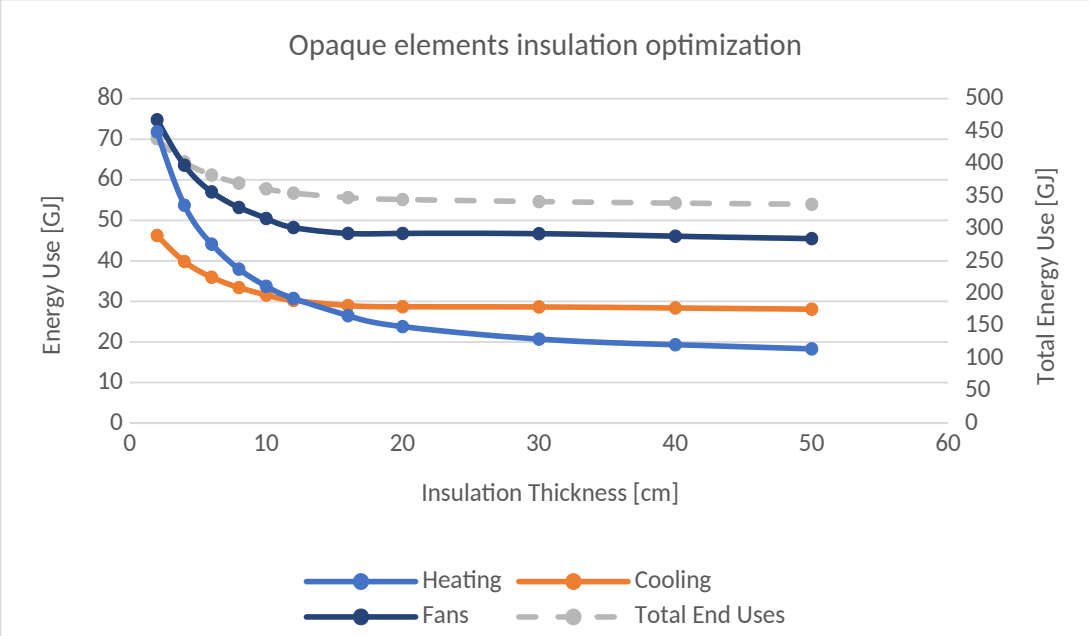


Figure 2 Effect of increasing the insulation thickness on Heating, Cooling, Fans, and total end-use energy.

However, this reduction slows down to nearly 0%, meaning the reduction curve becomes a flat horizontal line, somewhere between 12cm to 14cm. To continue this optimization process, we chose 12cm, considering the market prevalence and cost-effectiveness of 12cm insulation panels.

Step 2 – Glazing Optimization

In this step, we see the effect of different glazing configurations from single pane glazing to triple-pane glazing with different components of clear or low-E glass and air or Argon as the gas between the panes.

In (Figure 3), several variations of glazing configuration are sorted from the highest end-use energy to the lowest, and we can see their effect on cooling vs. heating end-use energy.

After the ninth case, the overall effect of configurations, meaning double-pane glazing with low-E, Argon, and low-E configuration, is less than 10GJ, which is less than a 3% improvement.

Considering the economic aspect of choosing between double glazing or triple glazing, the ninth case seems to be the better choice among these configurations.

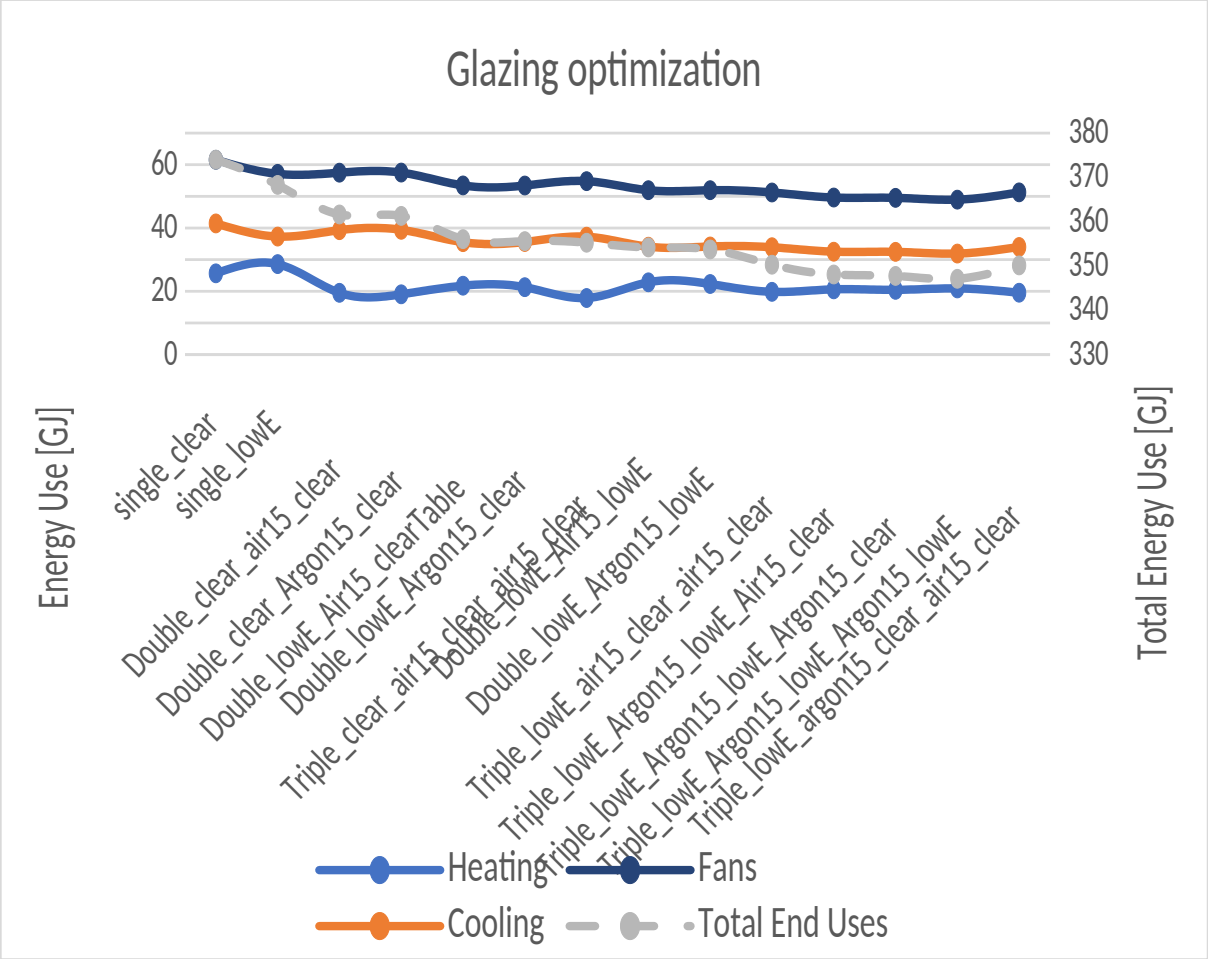


Figure 3 the effects of glazing configurations on heating, cooling, fans, and total end-use energy.

Step 3 – Airtightness

Although the building under study is practicing a typical value for infiltration, as an extra step, we added a super airtight standard infiltration value as suggested by ASHRAE fundamentals to examine its effects on this building.

Although this range value is recommended for residential buildings by ASHRAE, we deemed it fit to use in our building too due to the small footage of the office building, which is similar to a residential building.

Figure 1: Common Infiltration Assumptions

Source	Infiltration Value
Typically used value	0.35 ACH
eQUEST (DOE)	0.038 CFM/SF of envelope area, or 0.5 ACH
EnergyPlus	1.8 CFM/SF @ 75 Pa
ASHRAE – Fundamentals Chapter 16.15 and 16.29	0.1-2.0 ACH (Residential) 0.5-2.0 ACH (Commercial)
RS-29 (Seattle Energy Code)	Designed leakage of 0.4 CFM/SF at 75 Pa to be modeled at 0.045 CFM/SF

Figure 4 Speert, J., & Legge, C. (2012). Informed Mechanical Design Through Tested Air Leakage Rates. In Building Enclosure Science & Technology (BEST3) Conference (pp. 1-11).

It is visible in (Figure 5) that compared to the previous step of optimization, meaning the glazing optimization, we can see a 13.71 Giga J decrease in total end-use energy. This reduction mainly happens in fans, heating, and cooling end-use energy; however, heating end-use energy undergoes the highest reduction due to better airtightness.

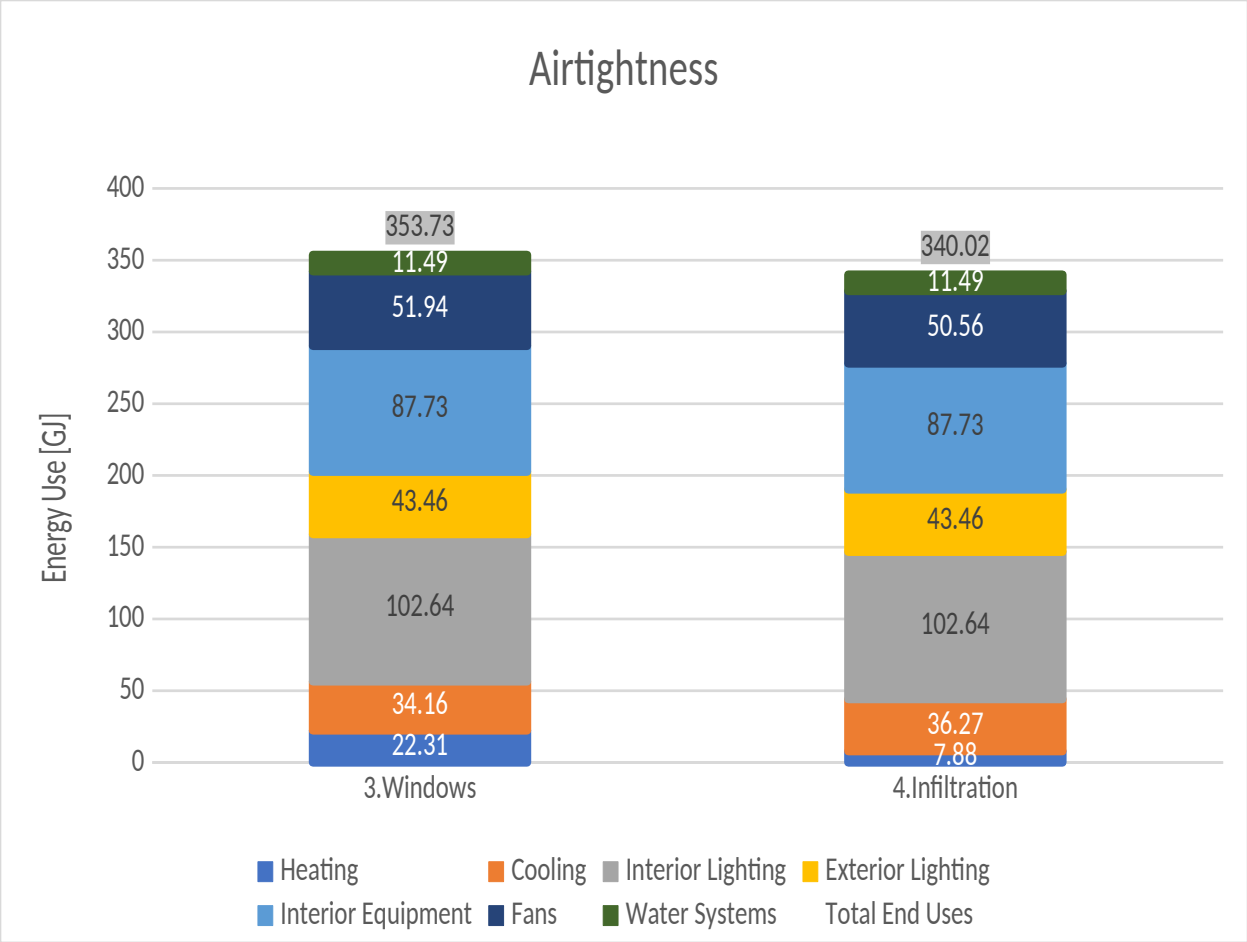


Figure 5 Effect of decreasing infiltration from 0.35 ACH to 0.1 ACH on end-use energy

Step 4 – Lighting Equipment Optimization

In this step, we introduced better quality lighting fixtures to the building, again as an extra step to examine its effect on the building.

The building uses 19.48W/m2 in lighting fixture load, which could mean any of the compact fluorescent, linear fluorescent, or poor-quality LED type of lighting fixtures.

We introduced high-quality LED fixtures with 12 W/m2 as the new and improved value in this matter. (LED Academy 2015). We see a considerable decrease in total end-use energy of almost 50 Giga J compared to the previous optimization step. This reduction is mainly caused by reductions in heating and interior lighting energy; however, it causes a 5 Giga J increase in cooling end-use energy.

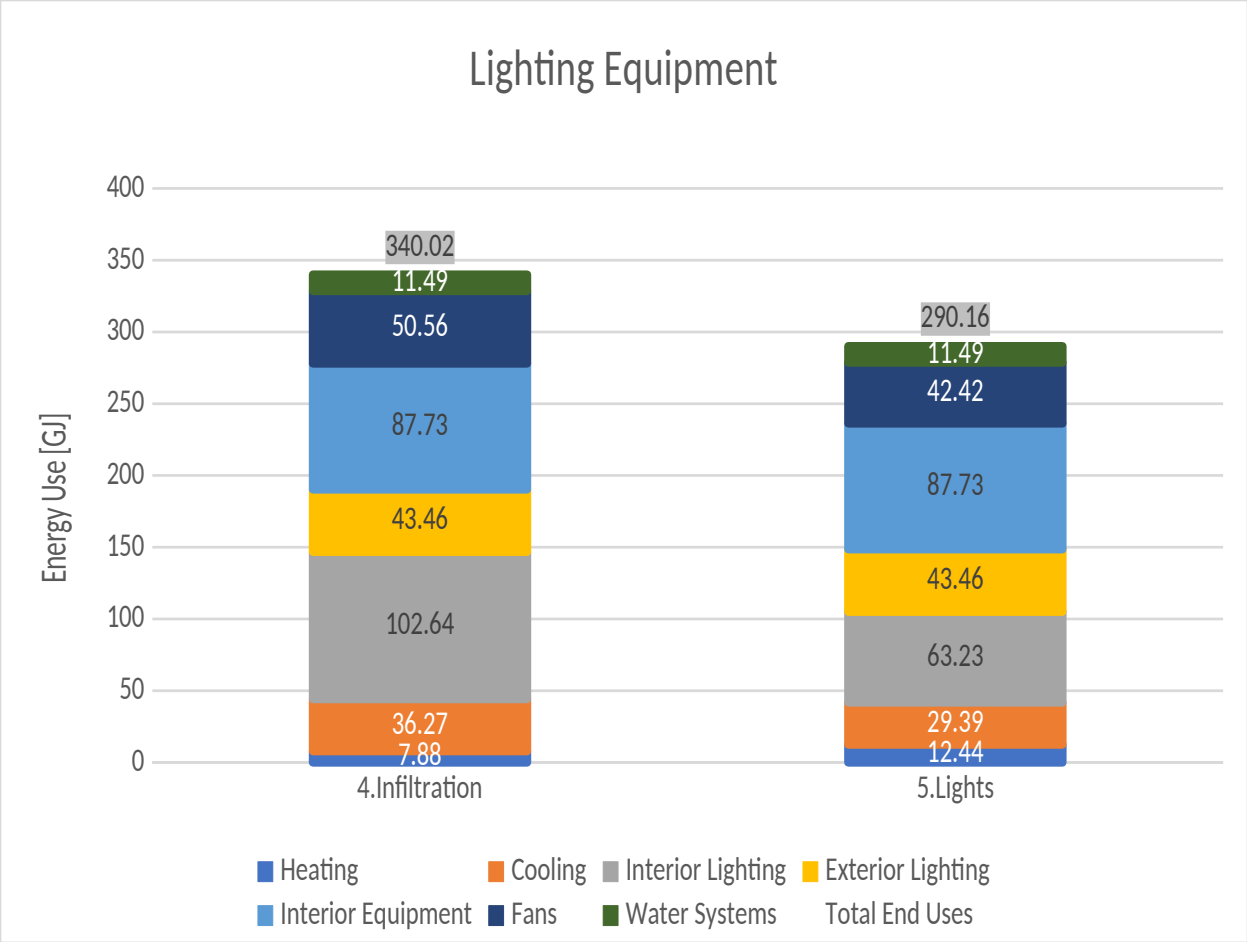


Figure 6 Effect of optimizing the lighting fixtures on end-use energy.

Step 5 – shading schemes

In this step, we see the effect of different shading schemes on the building's cooling, heating, and total end-use energy.

Schemes include interior Venetian blinds, interior fabric shading, exterior fins and overhangs in different sizes, and exterior overhang and interior Venetian blinds. As seen in the figure, we also tried to simulate the effects of shading by trees around the building.

As indicated in the graph, interior fabric shading, exterior overhang, and combination overhang and Venetian blinds are the best performing case, excluding the case of the trees.

We chose the case with the combination of overhang and Venetian because:

1. Overhang is better suited as permanent protection for Albuquerque, a sunny location.
2. Overhang's combination with Venetian allows the user to have some extent of control over the shading.

3. Fabric shading hinders the outside view factor, thus making it impossible to maintain a proper view factor and keep the solar gains out of the room simultaneously.
4. Solution with Trees is impractical since they require space, which might not be available in the urban fabric, and also, they are expensive, and they cause an increase in terms of heating, which means they are not the best permanent solution.

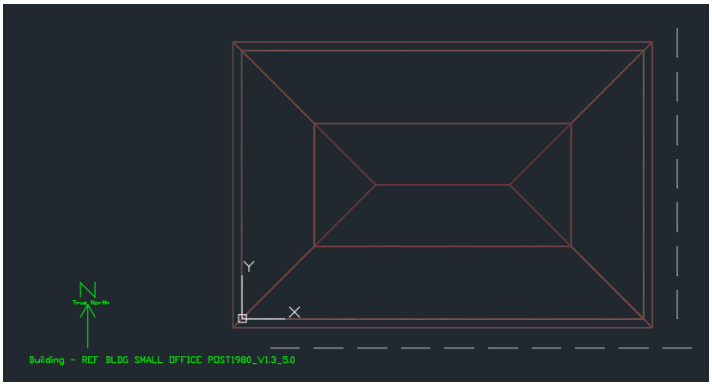


Figure 7 solution with the trees on the eastern and southern sides of the building.

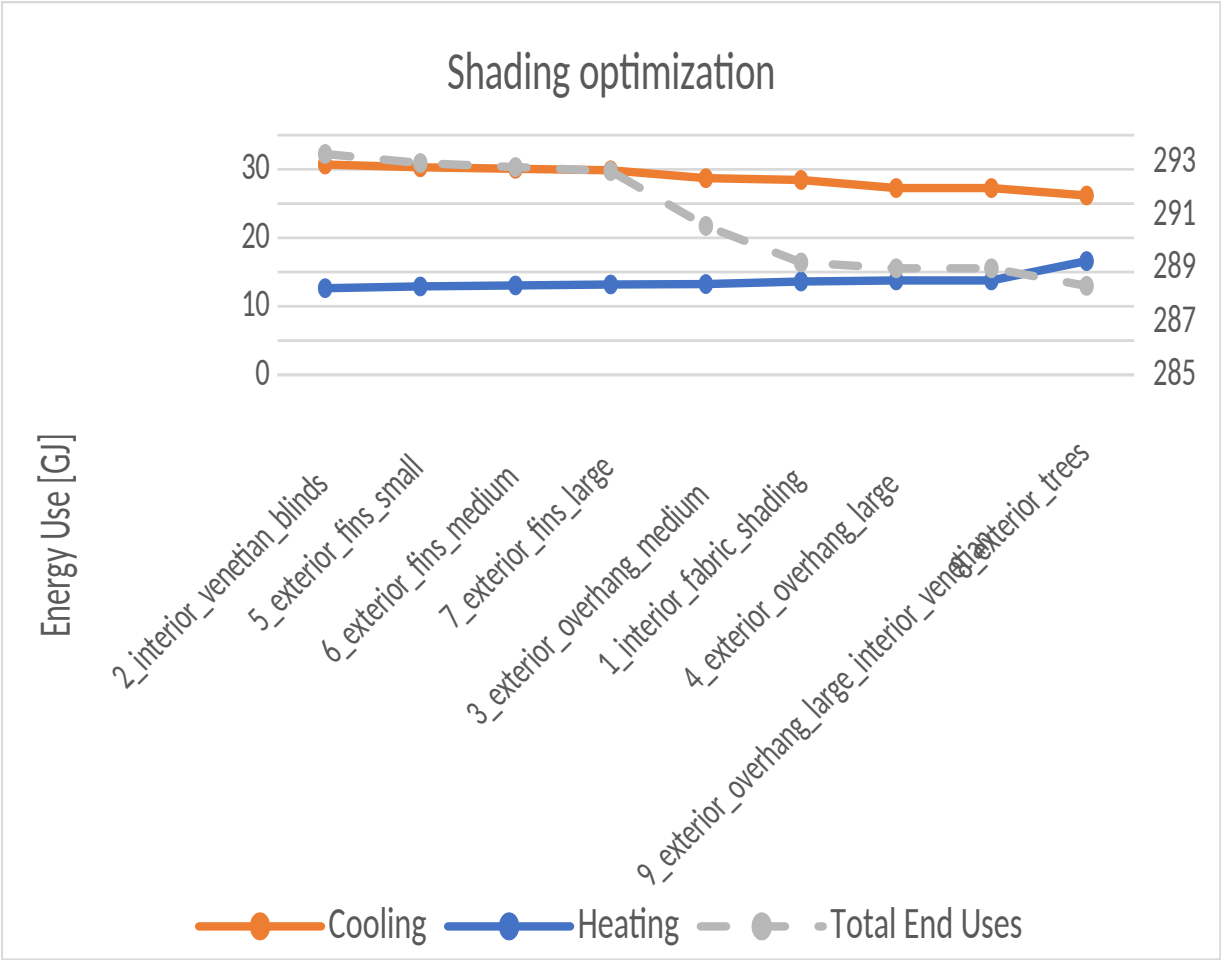


Figure 8 Comparison between effects of different shading schemes sorted from highest total end-use energy to the lowest.

Optimization Summary

Finally, we can see in (Figure 9) a summary of the overall step-by-step improvement of the building performance and the end-use energy at each step broken down into its components.

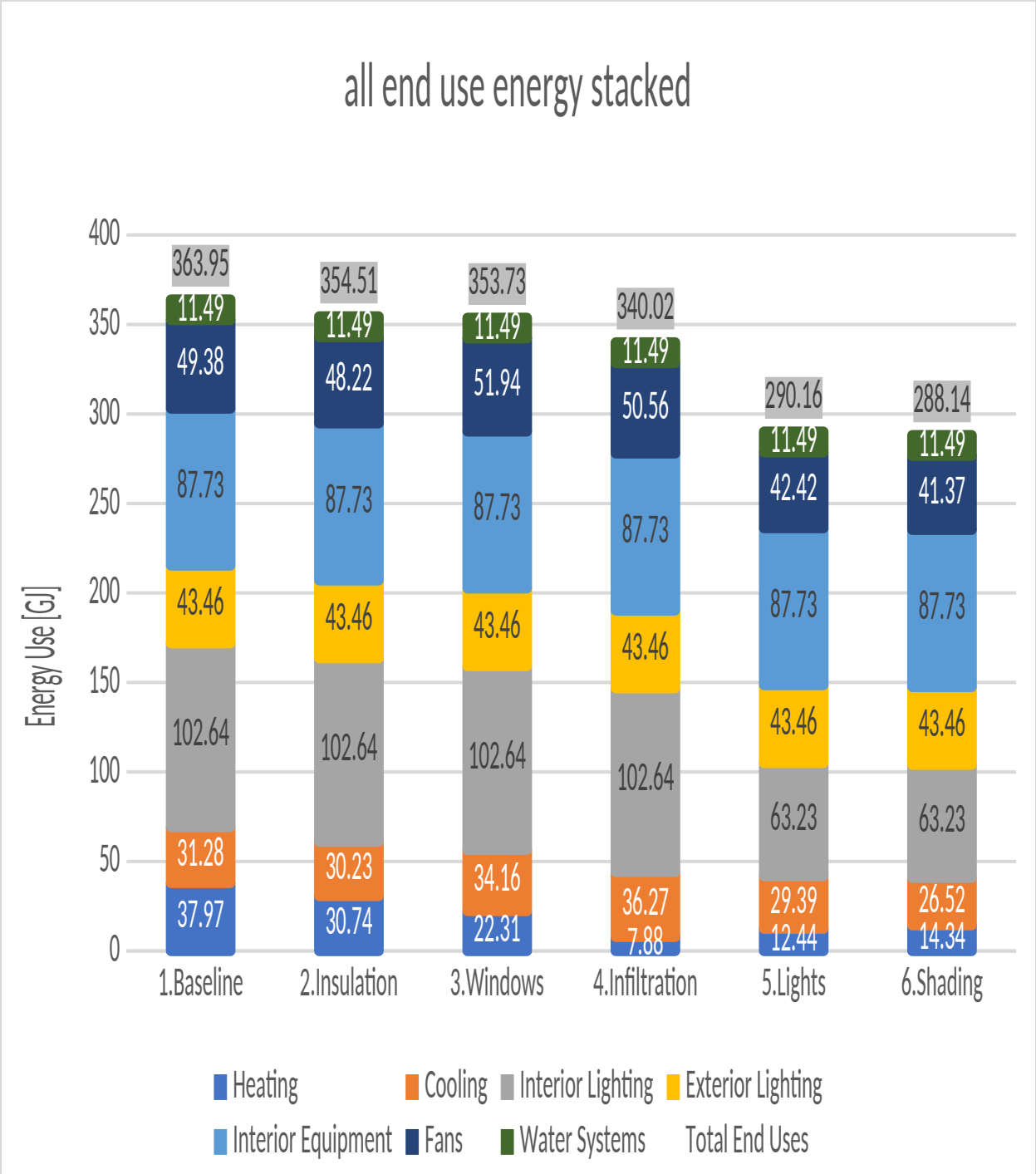


Figure 9 overall effects of optimization steps.

Effect of Orientation

Lastly, we studied four building orientations with 90-degree rotations to see what effects on the building performance might be seen.

Due to the somewhat symmetrical nature of our case study building, with elongation along the east-west axis, it was expected to see a very similar performance by the building, especially between south and north and west and east.

This fact is more reinforced when we consider that the shading schemes introduced in the last step are used in all transparent parts of the envelope all around.

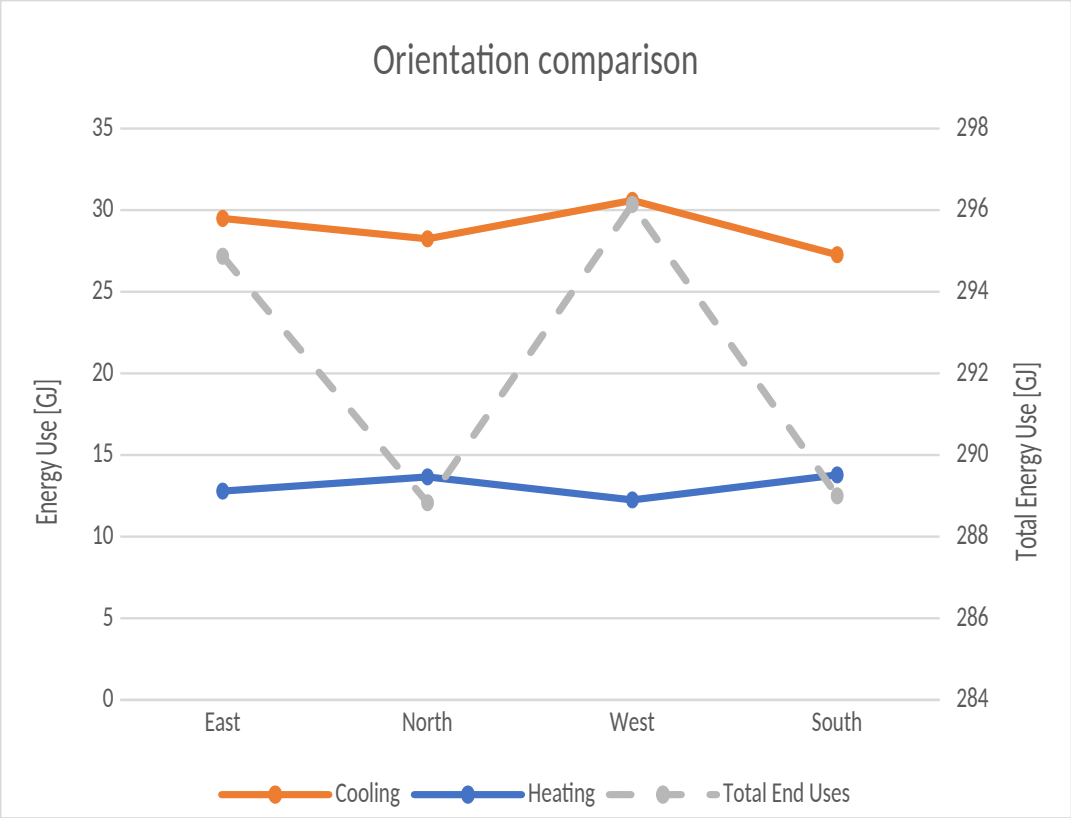


Figure 10 effect of rotating the building in 90-degree intervals on end-use energy consumption.

Conclusion

The reference building chosen has already been optimized to some extent. Thus further improvements studied here are minor and, in some cases, such as airtightness, not economical.

Envelope insulation, either opaque or transparent, has the most impact on heating energy consumption reduction.

A proper shading scheme can considerably reduce the solar gains and consequently reduce the cooling energy consumption; however, if chosen improperly, it can negatively impact heating energy consumption.

TOPIC III – HVAC SYSTEMS

In this topic:

- We will choose two HVAC systems.
- We will point out the key parameters of these HVAC systems through literature review and sensitivity analysis.
- We will use EnergyPlus to autosize these HVAC systems, considering each system's sizing factors.
- Finally, we will optimize these HVAC systems by improving the key parameters found earlier.

Two HVAC systems, namely PTAC and VAV, are chosen to be introduced into the same DOE building instead of its default HVAC system.

1. packaged terminal air conditioner (PTAC) with a DX cooling coil, a heating coil (electric, gas, or hot water), and an outdoor air mixer and hot water heating coil using a boiler fueled by Natural Gas.

2. variable air volume HVAC configuration with air-cooled chiller and hot water heating coil using a boiler fueled by Natural Gas.

We used EnergyPlus HVAC templates explained in the InputOutputReference book to set up these systems in the simulation model.

A flat setpoint of 18°C heating and 24°C cooling is implemented for sizing.

Sensitivity Analysis – Key Parameters

In the case of the PTAC system, after extracting seven critical parameters of the PTAC system from the literature, we performed a sensitivity analysis to see the impacts of each parameter.

Parameters 2, 5, 6, and 7 in the table show the most impact; however, it is worth mentioning that the parameters 6 and 7 impacts on cooling and heating would cancel each other in total utility use per conditioned area.

Table 15 PTAC sensitivity analysis

	Baseline	1.Supply_Fan_Total_Efficiency	2.Zone_Cooling_Coil_Gross_Rated_COP	3.Zone_Gas_Heating_Coil_Efficiency	4.Plant_Hot_Water_Design_Setpoint	5.Plant_Boiler_Efficiency	6.Zone_Cooling_Design_Supply_Air_Temperature	7.Zone_Heating_Design_Supply_Air_Temperature
Default Value	-	0.7	3	0.8	82	0.8	14	50
New Value	-	0.77	3.3	0.88	90.2	0.88	15.4	55
Electricity Per Conditioned Floor Area [MJ/m2]	59.01	58.81	54.33	59.01	59.01	59.01	60.26	59.77
Natural Gas Per Conditioned Floor Area [MJ/m2]	86.08	86.14	86.08	86.08	86.24	78.25	83.99	83.83
Total Utility Per Conditioned Floor Area [MJ/m2]	145.09	144.95	140.41	145.09	145.25	137.26	144.25	143.6
Impact on Electricity Use	-	0.34%	7.93%	0.00%	0.00%	0.00%	2.12%	1.29%
Impact on Natural Gas Use	-	0.07%	0.00%	0.00%	0.19%	9.10%	2.43%	2.61%
Impact on Total Utility Use	-	0.41%	7.93%	0.00%	0.19%	9.10%	4.55%	3.90%

Similarly for VAV system, after extracting nine critical parameters of the VAV system from the literature, we performed a sensitivity analysis to see the impacts of each parameter.

Parameters 1, 2, 4, and 5 in the table show the most impact; however, it is worth mentioning that the parameter two impacts on cooling and heating would cancel each other in total utility use per conditioned area.

Table 16 VAV sensitivity analysis

	Baseline	1.Supply_Fan_Total_Efficiency	2.System_Cooling_Coil_Design_Setpoint	3.System_Heating_Coil_Design_Setpoint	4.Main_Chiller_Nominal_COP	5.Main_Boiler_Efficiency	6.Zone_Cooling_Design_Supply_Air_Temperature	7.Zone_Heating_Design_Supply_Air_Temperature	8.Chilled_Water_Design_Setpoint	9.Hot_Water_Design_Setpoint
Default Value	-	0.7	12.8	10	4	0.8	12.8	50	7.22	82
New Value	-	0.77	14.08	11	4.4	0.88	14.08	55	7.942	90.2
Electricity Per Conditioned Floor Area [MJ/m2]	255.54	247.99	266.11	255.52	241.85	255.54	255.54	255.47	254.84	255.54
Natural Gas Per Conditioned Floor Area [MJ/m2]	112.55	112.54	107.2	112.58	112.55	102.32	112.55	112.55	112.55	112.5
Total Utility Per Conditioned Floor Area [MJ/m2]	368.09	360.53	373.31	368.1	354.4	357.86	368.09	368.02	367.39	368.04
Impact on Electricity Use		2.95%	4.14%	0.01%	5.36%	0.00%	0.00%	0.03%	0.27%	0.00%
Impact on Natural Gas Use		0.01%	4.75%	0.03%	0.00%	9.09%	0.00%	0.00%	0.00%	0.04%
Impact on Total Utility Use		2.96%	8.89%	0.03%	5.36%	9.09%	0.00%	0.03%	0.27%	0.04%

HVAC Sizing

In sizing the PTAC system, we considered 20% variation on the sizing factors, with a sizing factor equal to 1 as their default input.

The sizing factors are:

1. Zone cooling and heating
2. Plant Boiler

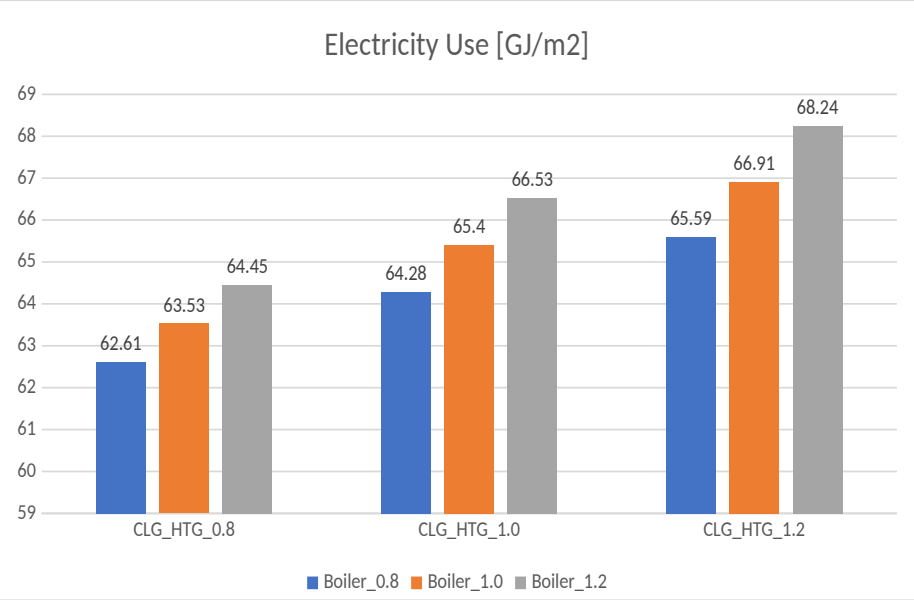


Figure 11 PTAC sizing by electricity use

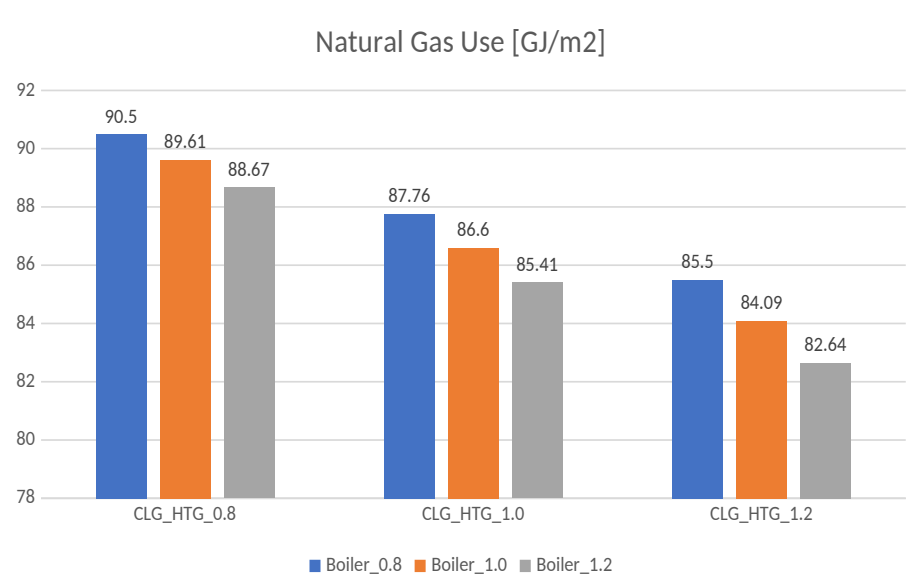


Figure 12 PTAC sizing by Natural Gas Use

Tables (17 and 18) indicate the calculated airflow considering the best-case scenario, meaning a sizing factor of 0.8 for both zone and plant.

Table 17 Best-case scenario HVAC sizing design values for sensible cooling

Zone Sensible Cooling	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]
CORE_ZN	4364.22	3491.38	23.33	0.432	0.346
PERIMETER_ZN_1	3679.69	2943.75	25.95	0.364	0.292
PERIMETER_ZN_2	3025.79	2420.63	35.97	0.3	0.24
PERIMETER_ZN_3	3804.26	3043.41	26.83	0.377	0.301
PERIMETER_ZN_4	3984.34	3187.47	47.36	0.395	0.316

Table 18 Best-case scenario HVAC sizing design values for sensible heating

Zone Sensible Heating	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]
CORE_ZN	2536.81	2029.45	13.56	0.078	0.076
PERIMETER_ZN_1	6181.56	4945.25	43.59	0.191	0.153
PERIMETER_ZN_2	3974.92	3179.94	47.25	0.123	0.098
PERIMETER_ZN_3	5979.38	4783.51	42.16	0.185	0.148
PERIMETER_ZN_4	3974.92	3179.94	47.25	0.123	0.098

Tables (19 and 20) indicate the calculated airflow considering the default case, meaning sizing factor 1.0 for both zone and plant.

Table 19 Default scenario HVAC sizing design values for sensible cooling

Zone Sensible Cooling	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]
CORE_ZN	4364.22	4364.22	29.16	0.432	0.432
PERIMETER_ZN_1	3679.69	3679.69	32.43	0.364	0.364
PERIMETER_ZN_2	3025.79	3025.79	44.96	0.3	0.3
PERIMETER_ZN_3	3804.26	3804.26	33.53	0.377	0.377
PERIMETER_ZN_4	3984.34	3984.34	59.2	0.395	0.395

Table 20 Default scenario HVAC sizing design values for sensible heating

Zone Sensible Heating	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]
CORE_ZN	2536.81	2536.81	16.95	0.078	0.078
PERIMETER_ZN_1	6181.56	6181.56	54.49	0.191	0.191
PERIMETER_ZN_2	3974.92	3974.92	59.06	0.123	0.123
PERIMETER_ZN_3	5979.38	5979.38	52.71	0.185	0.185
PERIMETER_ZN_4	3974.92	3974.92	59.06	0.123	0.123

Tables (21 and 22) indicate the calculated airflow considering the worst-case scenario, meaning sizing factor 1.2 for both zone and plant.

Table 21 worst-case scenario HVAC sizing design values for sensible cooling

Zone Sensible Cooling	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]
CORE_ZN	4364.22	5237.07	34.99	0.432	0.519
PERIMETER_ZN_1	3679.69	4415.63	38.92	0.364	0.437
PERIMETER_ZN_2	3025.79	3630.95	53.95	0.3	0.36
PERIMETER_ZN_3	3804.26	4565.11	40.24	0.377	0.452
PERIMETER_ZN_4	3984.34	4781.21	71.04	0.395	0.473

Table 22 worst-case scenario HVAC sizing design values for sensible heating

Zone Sensible Heating	Calculated Design Load [W]	User Design Load [W]	User Design Load per Area [W/m2]	Calculated Design Air Flow [m3/s]	User Design Air Flow [m3/s]
CORE_ZN	2536.81	3044.18	20.34	0.078	0.094
PERIMETER_ZN_1	6181.56	7417.87	65.38	0.191	0.229
PERIMETER_ZN_2	3974.92	4769.91	70.88	0.123	0.148
PERIMETER_ZN_3	5979.38	7175.26	63.25	0.185	0.222
PERIMETER_ZN_4	3974.92	4769.91	70.88	0.123	0.148

In sizing the VAV system, we considered 20% variation on the sizing factors, which had a sizing factor equal to 1 as their default input.

The sizing factors are:

1. Zone cooling and heating
2. Plant Boiler
3. Plant Chiller

(Figure 13) shows the impacts of each sizing factor on the Electrical and Natural Gas use. The chart shows that the zone sizing factor is the most impactful, then the chiller sizing factor, and finally, the Boiler sizing factor with a very slight impact.

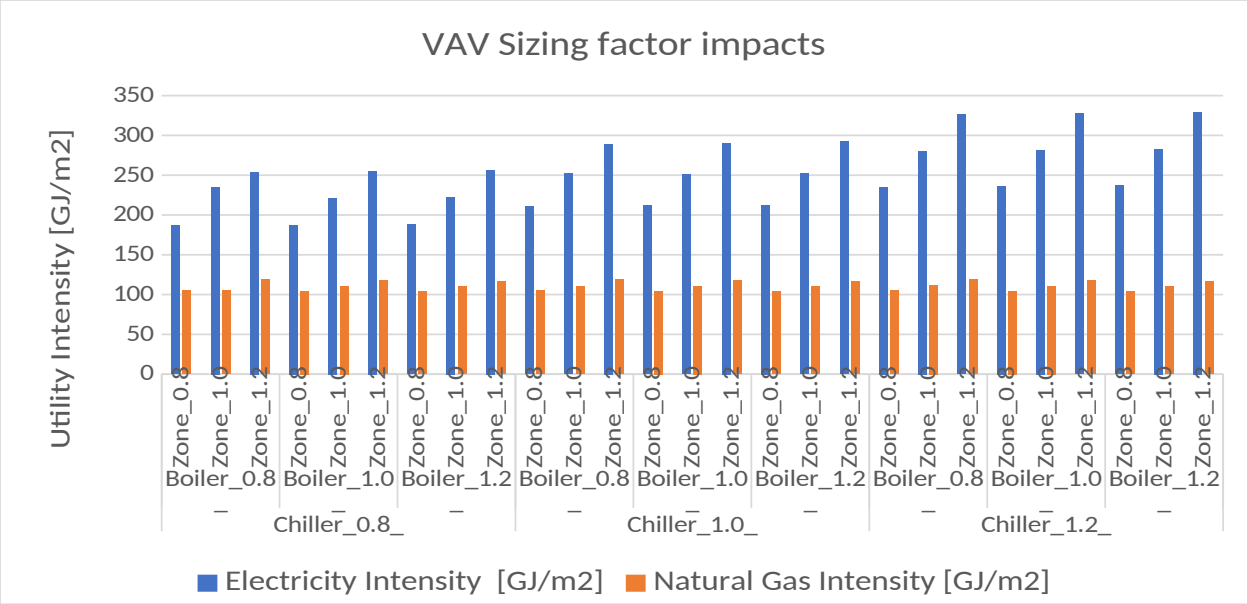


Figure 13 VAV sizing

Tables 23 to 25 show the calculated ventilation in m3/s for best, worst, and default cases.

Table 23 calculated airflow considering the best-case scenario, meaning sizing factor 0.8 for both zone and plant.

System Design Air Flow Rates	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]	Adjusted cooling [m3/s]	Adjusted heating [m3/s]	Adjusted main [m3/s]	Calculated Heating Air Flow Ratio []	User Heating Air Flow Ratio []
AHU1	1.33	1.33	0.57	0.57	1.3338	1.3338	1.3338	1	0.3

Table 24 calculated airflow considering the default case, meaning sizing factor 1.0 for both zone and plant.

System Design Air Flow Rates	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]	Adjusted cooling [m3/s]	Adjusted heating [m3/s]	Adjusted main [m3/s]	Calculated Heating Air Flow Ratio []	User Heating Air Flow Ratio []
AHU1	1.67	1.67	0.7	0.7	1.6673	1.6673	1.6673	1	0.3

Table 25 calculated airflow considering the worst-case scenario, meaning sizing factor 1.2 for both zone and plant.

System Design Air Flow Rates	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]	Adjusted cooling [m3/s]	Adjusted heating [m3/s]	Adjusted main [m3/s]	Calculated Heating Air Flow Ratio []	User Heating Air Flow Ratio []
AHU1	2	2	0.84	0.84	2.0007	2.0007	2.0007	1	0.3

PTAC Optimization

Optimization for the PTAC system is done over the four key parameters found in the previous section.

Parameter 1 – Zone cooling coil gross rated COP.

The default input is 3, and the literature says it can go up to 6.33, so we considered four steps to see the impact on total energy use. (Figure 14) shows that a COP equal to 6 is the best performing, so we chose this value from this step.

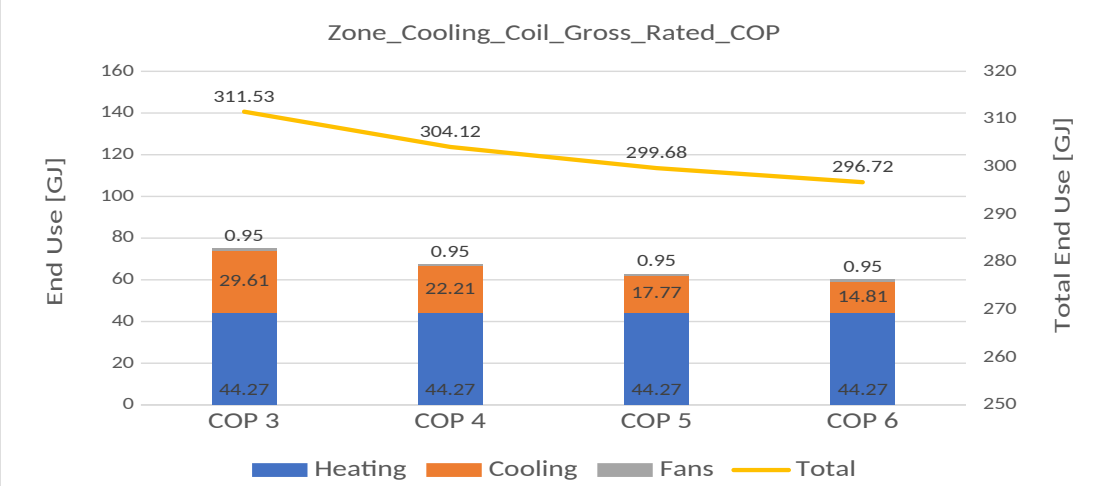


Figure 14 PTAC COP optimization

Parameter 2 – Cooling Supply Temperature Setpoint

The default input is 14°C, and literature says it can go down to 12°C (Figure 15). Although it slightly decreases the energy needed for cooling, it negatively impacts the energy required for heating. Thus, we keep the default value from this step.

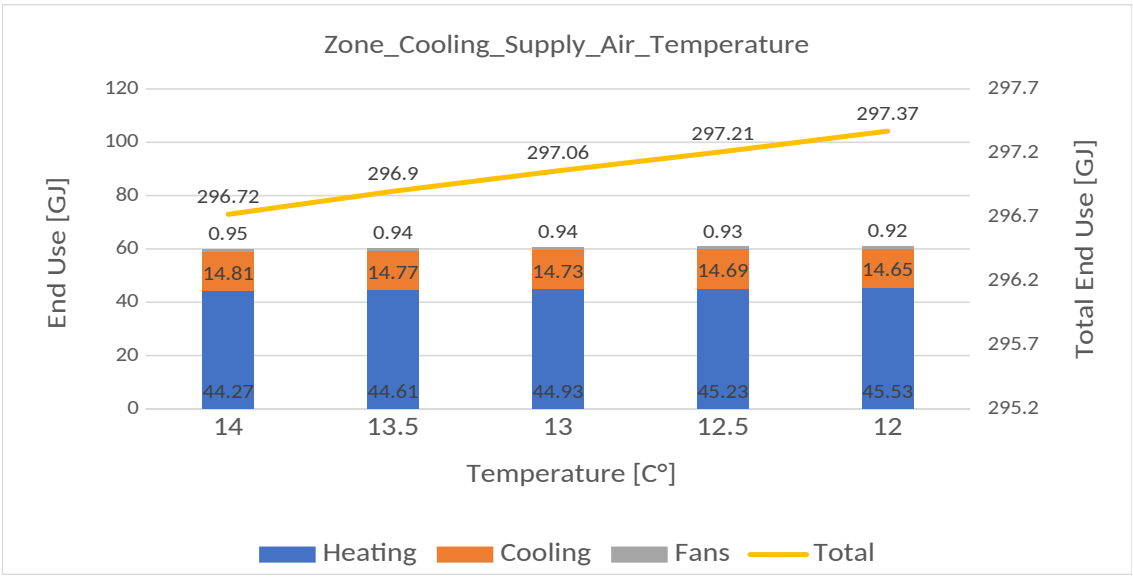


Figure 15 PTAC cooling supply temperature optimization

Parameter 3 – Heating Supply Temperature Setpoint

The default input is 50°C, and literature says it can go up to 80°C (Figure 16), showing that it slightly decreases the energy needed for heating and fans. Thus, although very slight impact, we choose 80°C for this step.

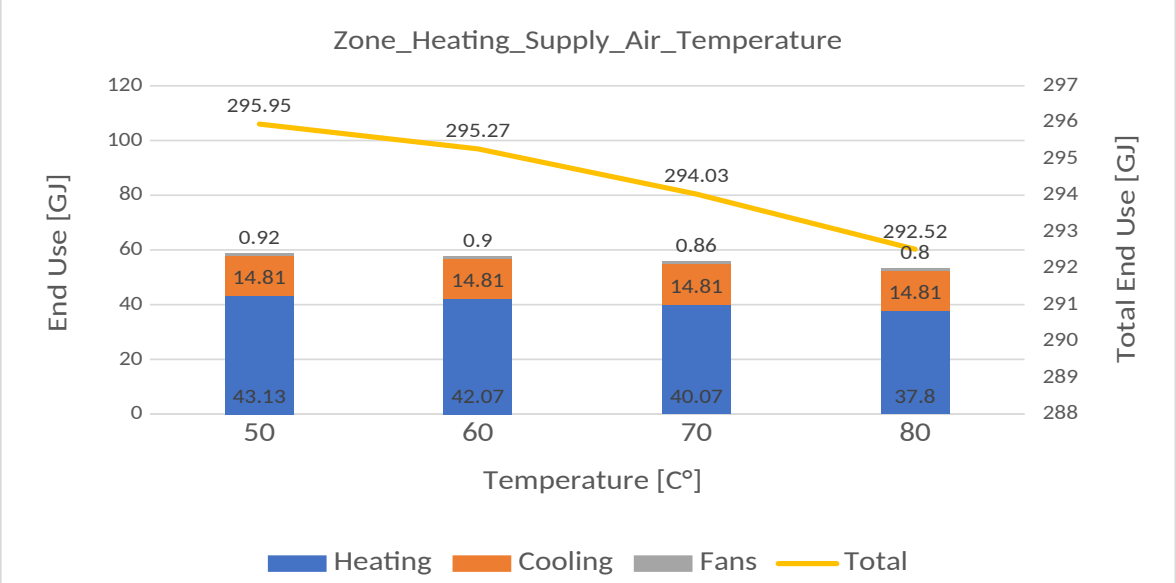


Figure 16 PTAC heating supply temperature optimization

Parameter 4 – Boiler efficiency

The default input is 80%, and literature says it can go up to 94% (Figure 17), which decreases the energy needed for heating. Thus, we choose 94% for this step.

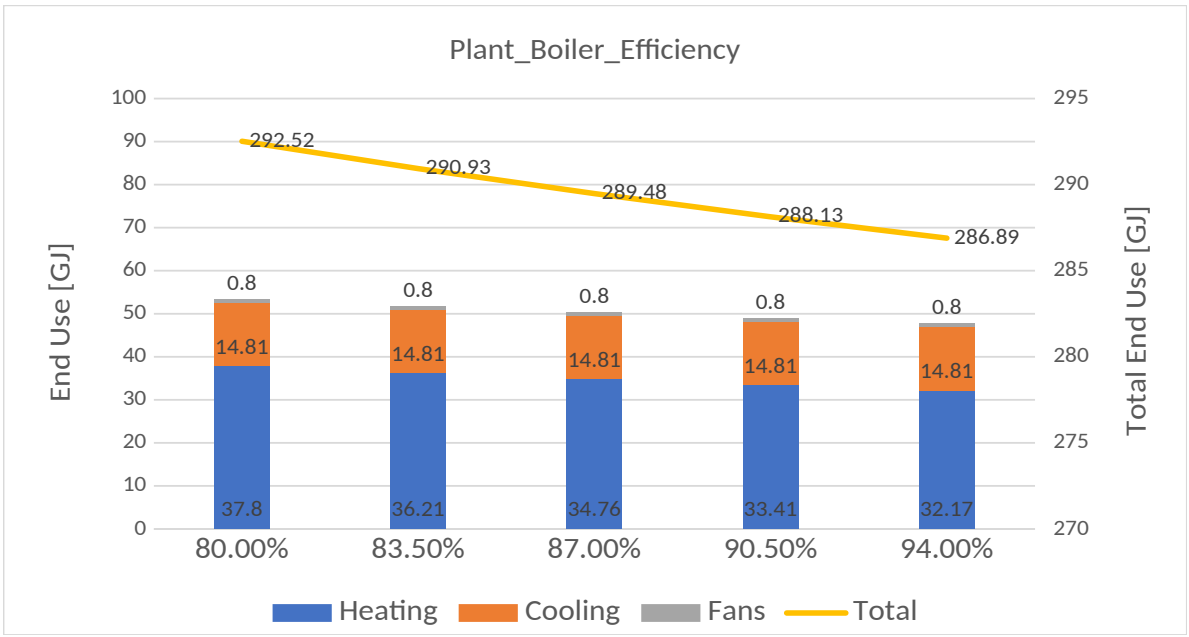
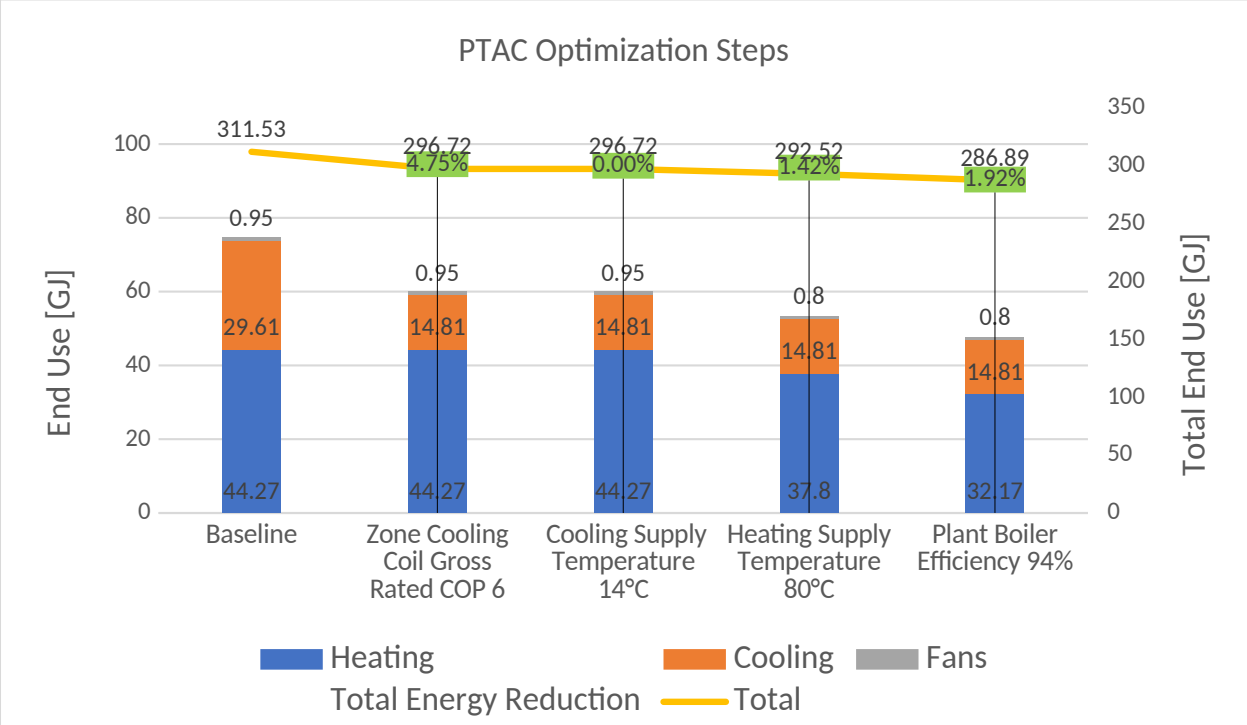


Figure 17 PTAC boiler efficiency optimization

PTAC Optimization Summary



VAV Optimization

Optimization for the VAV system is done over the four key parameters found in the previous section.

Parameter 1 – Chiller COP

The default input is 4, and the literature says it can go up to 6.33, so we considered four steps to see the impact on total energy use. (Figure 18) shows that a COP equal to 6 is the best performing, so we chose this value from this step.

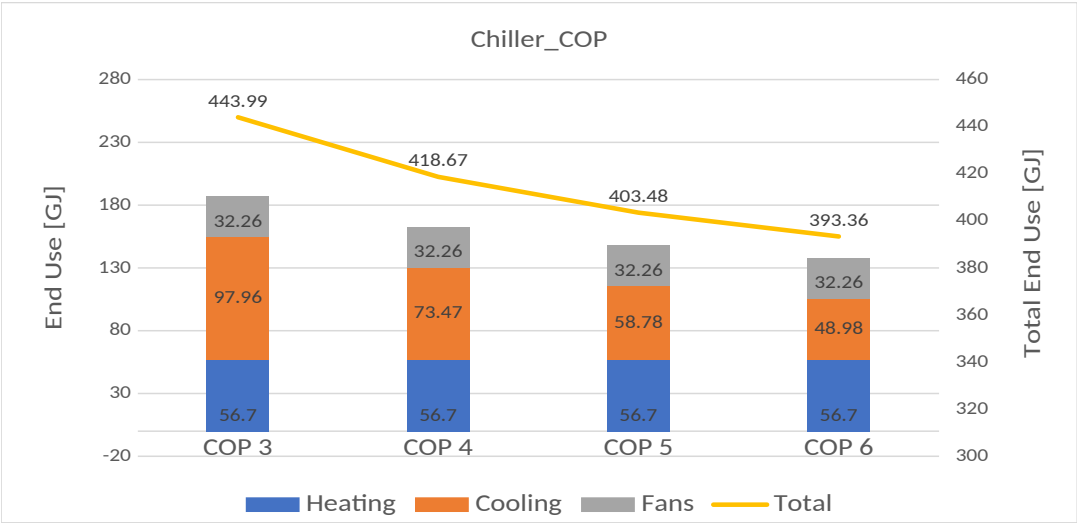


Figure 18 VAV Chiller COP Optimization

Parameter 2 – Supply Fan Efficiency

The default input is 70%, and literature says it can go up to 90% (Figure 19) shows that although it decreases the energy needed for fans, cooling, and even slightly heating. Thus, we choose 90% from this step.

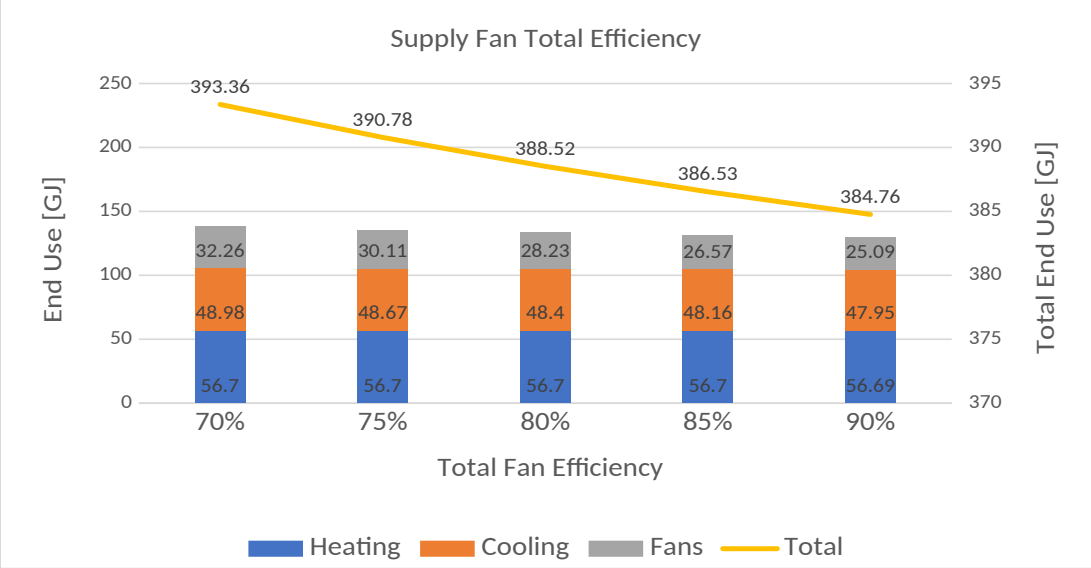


Figure 19 VAV Supply fan efficiency optimization

Parameter 3 – Cooling Design Setpoint

The default input is 12.8℃, and literature says it can go down to 11℃ (Figure 20), which shows that although it decreases the energy needed for cooling, it negatively impacts the heating. Thus, we stick to the default input from this step.

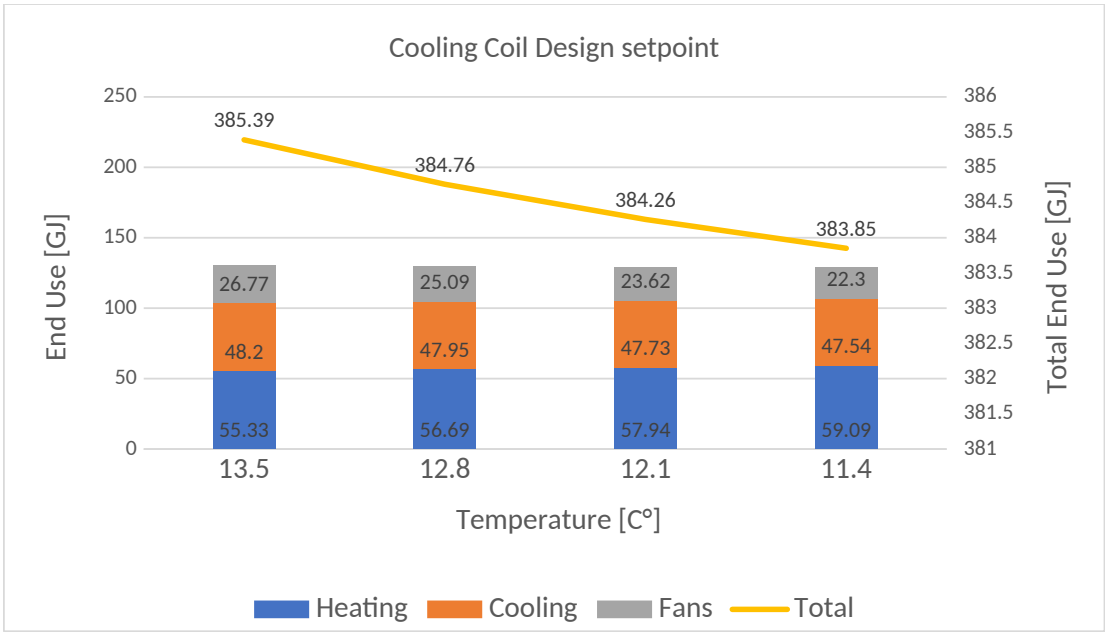


Figure 20 VAV Cooling design setpoint optimization

Parameter 4 – Boiler efficiency

The default input is 80%, and literature says it can go up to 94% (Figure 21), which decreases the energy needed for heating. Thus, we choose 94% from this step.

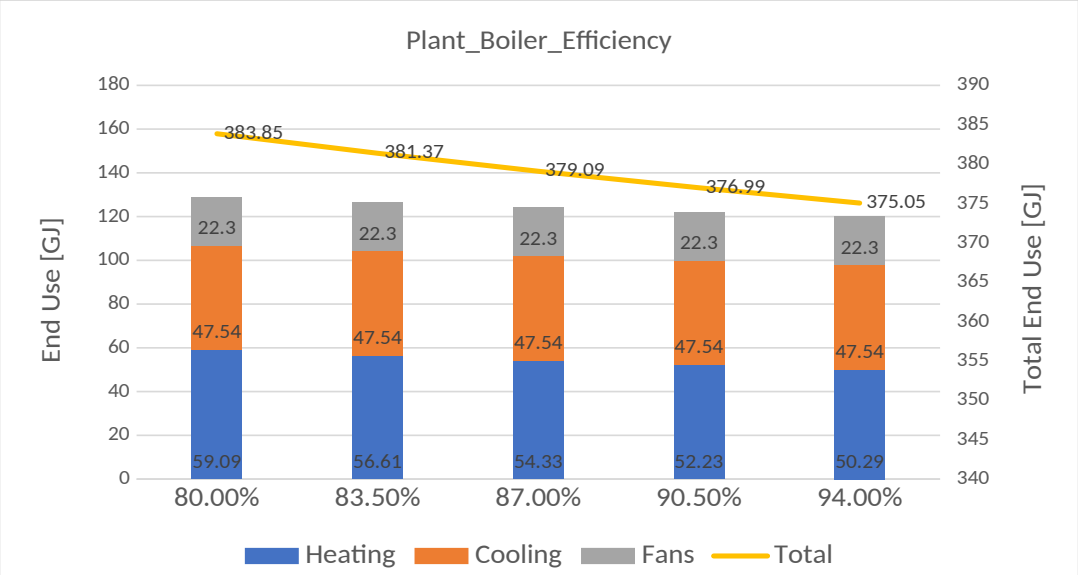


Figure 21 VAV boiler efficiency optimization

VAV Optimization Summary

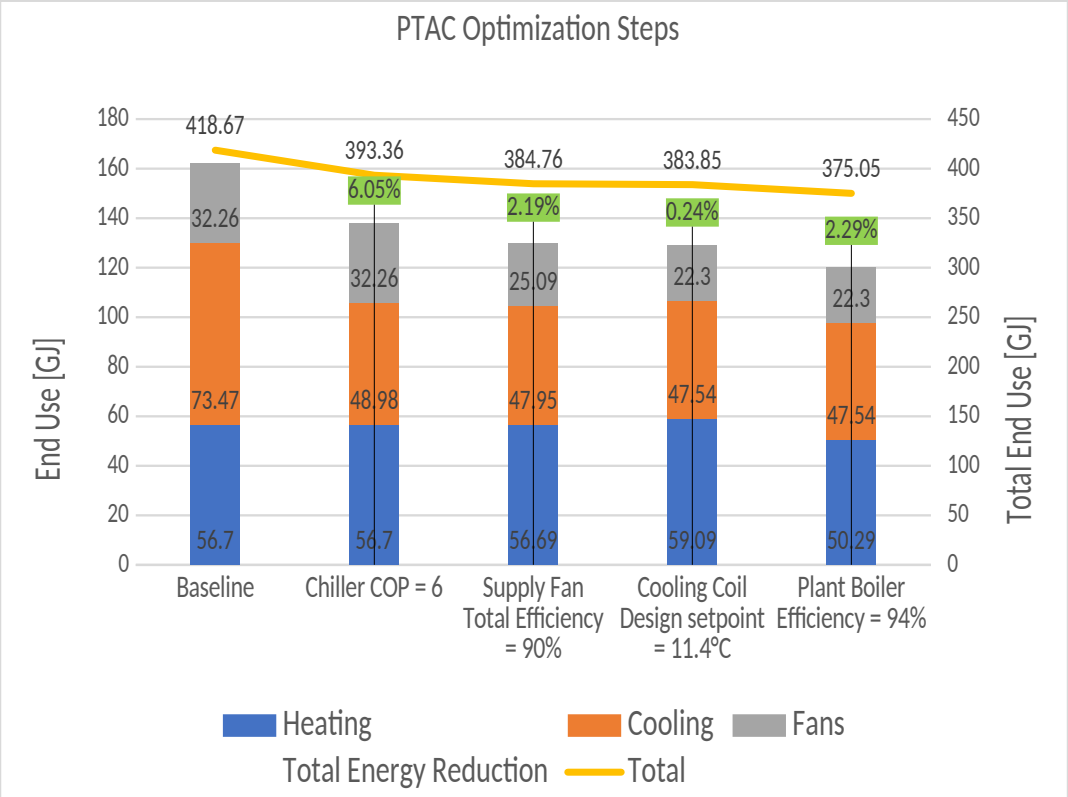


Figure 22 VAV optimization summary

Conclusion

In sensitivity analysis, although some parameters might have considerable individual impacts on cooling, heating, and fans' energy demand, it should be considered whether they cancel each other out when it comes to the total energy consumption. Optimization of those parameters is not necessary.

In the case of auto-sizing the HVAC system, it is evident that a lower sizing factor means a lower energy consumption. What is essential to make sure is the number of hours the system fails to provide comfortable conditions for users inside the building. Thus, the best possible solution is the lowest sizing factor with an adequate number of hours out of the comfort range.

In the case of HVAC optimization, the outcome of improving some parameters such as boiler efficiency and chiller COP have a linear relation. Thus an optimization process does not need several steps and only requires the optimal extent allowable.

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