Case – 9 Annual Power Consumption Analyze for Screw Refrigeration Systems

Case Background:

The refrigeration system requirement initiated by the preliminary study for a petrochemical plant is a simple compression screw refrigeration system even without economizing as the following:

Refrigeration capacity:	260 TR
Refrigerant:	R-717
Condensing Temperature:	102°F
Evaporative Temperature:	–40°F

One of the plant process engineers prepares four refrigeration system options to evaluate which of the options is the best for the project for the new plant. Each of the options is designed to have the refrigeration capacity 260 TR with R-717 refrigerant at the identical operating conditions of having condensing temperature of 102°F, evaporative temperature of –40°F. Intermediate temperature of 18.2°F is used for the evaluation for compound systems; same external pressure drops and same suction superheat are based for the evaluation.

The four system options were given to a refrigeration equipment manufacturer for quotes. The compressor selections, power consumption and the prices for each option are from the equipment manufacturer in accordance with the refrigeration system requirements and are outlined as the following:

Option-1　　This system is a single stage compression without economizing in accordance with the system shown in the preliminary study:

Compressor:	WB-II-856
Design point power:	884.1 KW
Initial investment:	US$268,565.00

Service and maintenance charge per year: US$5,370.00

Option-2:   This alternate is a single stage compression system, same as the Option-1 except only with liquid subcooling economizer is added:

Compressor: WB-II-676E
Design point power: 759.7 KW

Initial investment: US$248,013.00

Service and maintenance charge per year: US$4,960.00

Option-3:   This alternate is a 2-stage compound system, no economizer is used for both high stage and booster compressors:

Low Stage Compressor: WB-II-676B
Design point power: 260.5 KW

High Stage Compressor: WB-II-222
Design point power: 310.4 KW

Total design point power: 570.9 KW

Total initial investment: US$273,642.00

Service and maintenance charge per year: US$5,306.00

Option-4:   This alternate is also a 2-stage compound system with an economizer for the high stage:

Low Stage Compressor: WB-II-676B
Design point power: 260.5 KW

High Stage Compressor: WB-II-177E
Design point power: 281.9 KW

Total design point power: 542.4 KW

Total initial investment: US$291,062.00

Service and maintenance charge per year: US$5,400.00

The energy costs shown by the user are:

(a)   Fixed basic KW power supply charge is $8.30 per KW per month.

(b)   KWH usage charge is $0.08 per KWH.

The system is to be operated for 8,500 hrs per year in accordance with the user. The loading pattern for the refrigeration system is as the following.

100% load:	800 Hrs.
80% load:	2158 Hrs.
60% load:	2265 Hrs.
50% load:	2477 Hrs.
40% load:	800 Hrs.

Constant flow cooling water pump is used for the refrigeration system.

The Figure 9-1, Typical Part Load Power Input with Constant Condensing Temperature and Figure 9-2, Typical Part Load Power Input with Falling Condensing Temperature shown in the section of Related Technical Date and Engineering Information for the Case are the only information provided by the manufacturer.

Based on the information given by the user and the quotation given by the equipment manufacturer, the process engineer carried out an expanded feasibility study and overall evaluation using annual power consumption method for the four refrigeration systems, the results of the evaluation are shown in the section of Cogitation.

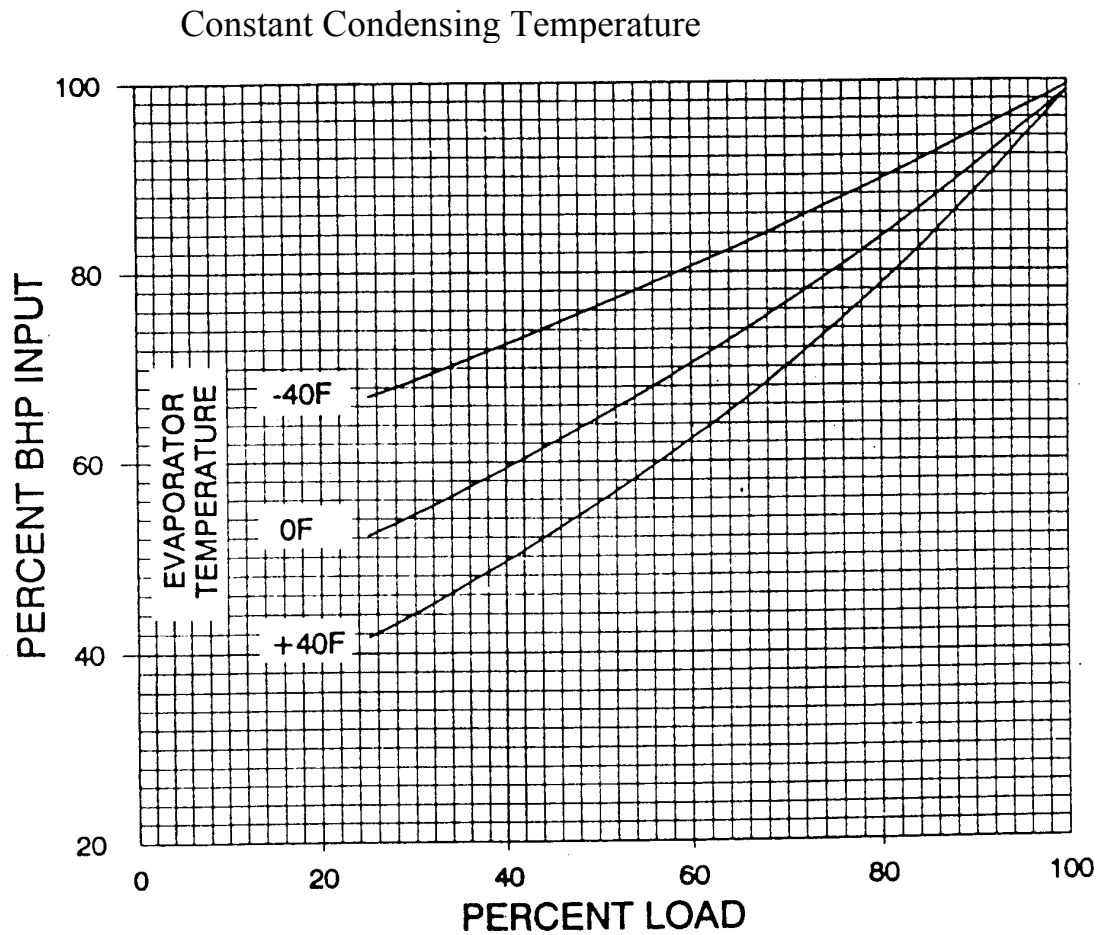Related Technical Data and Engineering Information:

Constant Condensing Temperature

Figure 9-1   Typical Part Load Power Input with Constant Condensing
temperature for High Stage Variable Vi Screw Compressor
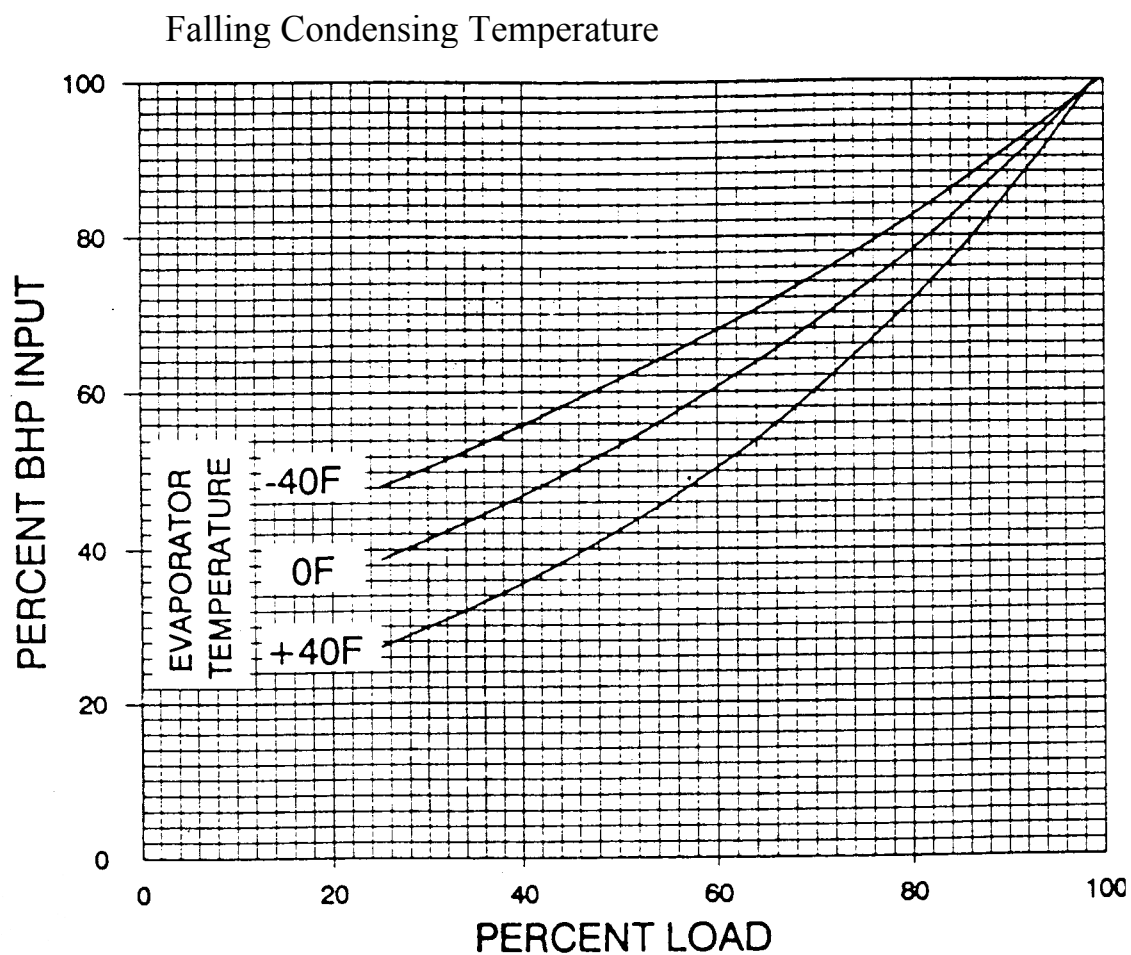
Falling Condensing Temperature

Figure 9-2   Typical Part Load Power Input with Falling Condensing
temperature for High Stage Variable Vi Screw Compressor

Cogitation

Based on the information given by the user and the quotation given by the equipment manufacturer, the overall evaluation using annual power consumption method for the four refrigeration systems are as the following:

Option	Option No. 1	Option No. 2	Option No. 3	Option No. 4
System	Single Stage without Economizer as preliminary study	Single Stage. Same as Option-1 except with Economizer	2-staage Compound System, no economizer	2-stage Compound System, with economizer for high stage

Compressor selected
   High Stage
   Low Stage
	WB-II-856	WB-II-676E	(H) WB-II-222
			(L) WB-II-676
				(H) WB-II-177E
				(L) WB-II-676

Initial Investment	$268,565	$248,013	$273,642	$291,062
Kw at design point: High Stage Low Stage	884.1 KW	759.7 KW	310.4 KW 260.5 KW	281.9 KW 260.5 KW
Total System power consumption at Design Kw	884.1 KW	759.7 KW	570.9 KW	542.4 KW
Service/Maintenance per year	$5,370	$4,960	$5,306	$5,400
KW Power Supply fixed charge per year	$88,056	$75,666	$49,581	$47,987

Notes:

[1] (H) – High Stage Compressor.
[2] (L)- Low Stage Compressor.
[3] "E" Annex designates the compressor is with economizer.
[4] The model number shows the relative size of the compressor.
[5] Fixed basic power supply charge is $8.30 per KW per month.

Use Partial Load Curve for Partial Load Power Consumption Estimation for the high stage compressor:

For partial load operation, the power consumption for the high stage is to use the partial load curve of falling condensing temperature as shown in Figure 9-2.

The intermediate temperature is 18.2°F; therefore, an 18.2°F evaporative temperature line is added for Figure 9-2 power consumption estimation as shown below:
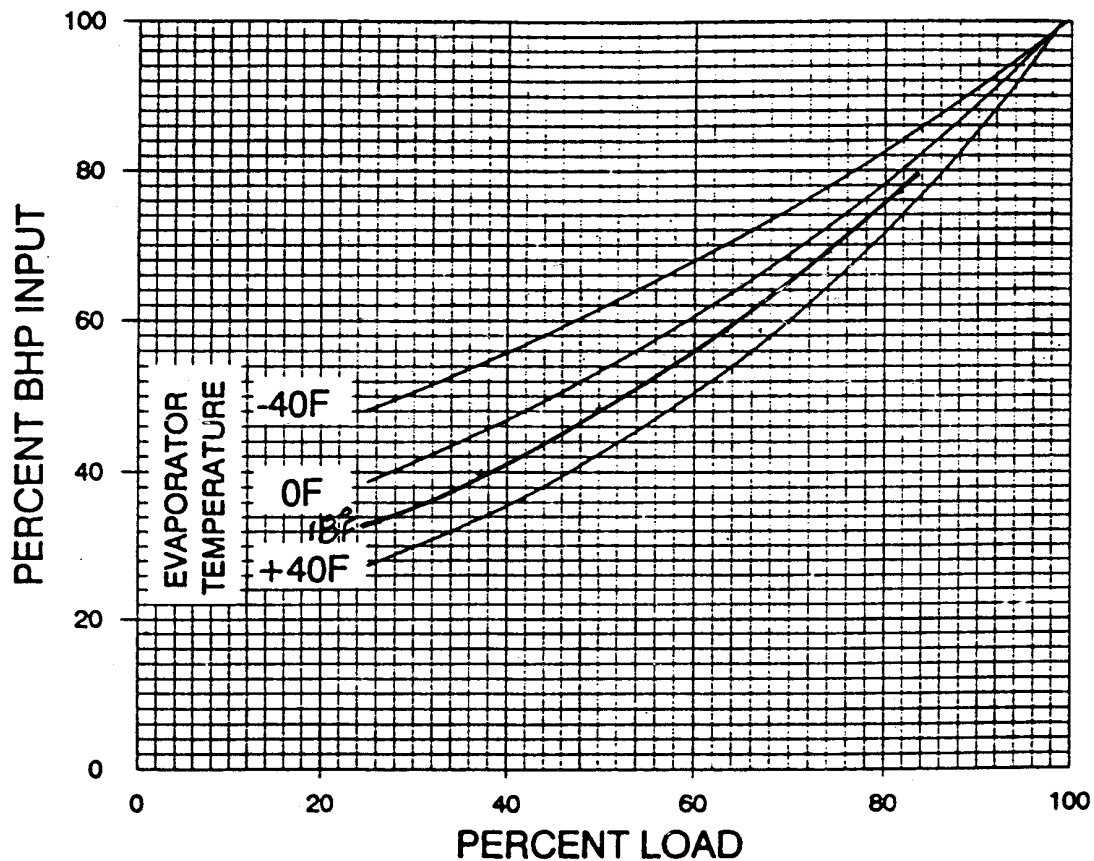

Figure 9-3 Part Load Power Input with Falling Condensing
Temperature for High Stage

Use Partial Load Curve for Partial Load Power Consumption Estimation for the low stage (booster) compressor:

The power consumption for the booster compressor is to follow the constant condensing temperature curve. Due to no partial curve available for the booster application, a line is to be established to represent the approximate equivalent line for the chart of high stage with constant condensing temperature Figure 9-1 for the evaluation for the booster compressor.

Compressor efficiency varies approximately in accordance with the compression ratio. The compression ratio for the booster compressor is:

$$\text{Booster compressor compression ratio} \cong \frac{46.3 \text{ Psia } (18.2°\text{F})}{10.40 \text{ Psia } (-40°\text{F})}$$

$$\cong \quad 4.45$$

The pressure equivalent to about the same CR (Compression Ratio) is:

$$= \frac{218.53 \text{ Psia (High Stage CT)}}{4.45 \text{ (CR of Booster Compressor)}}$$

$$= \quad 49.11 \text{ Psia}$$

The temperature is 21°F for 49.11 Psia; therefore, draw a 21°F line on Figure 9-1 as the equivalent shown below for the booster.
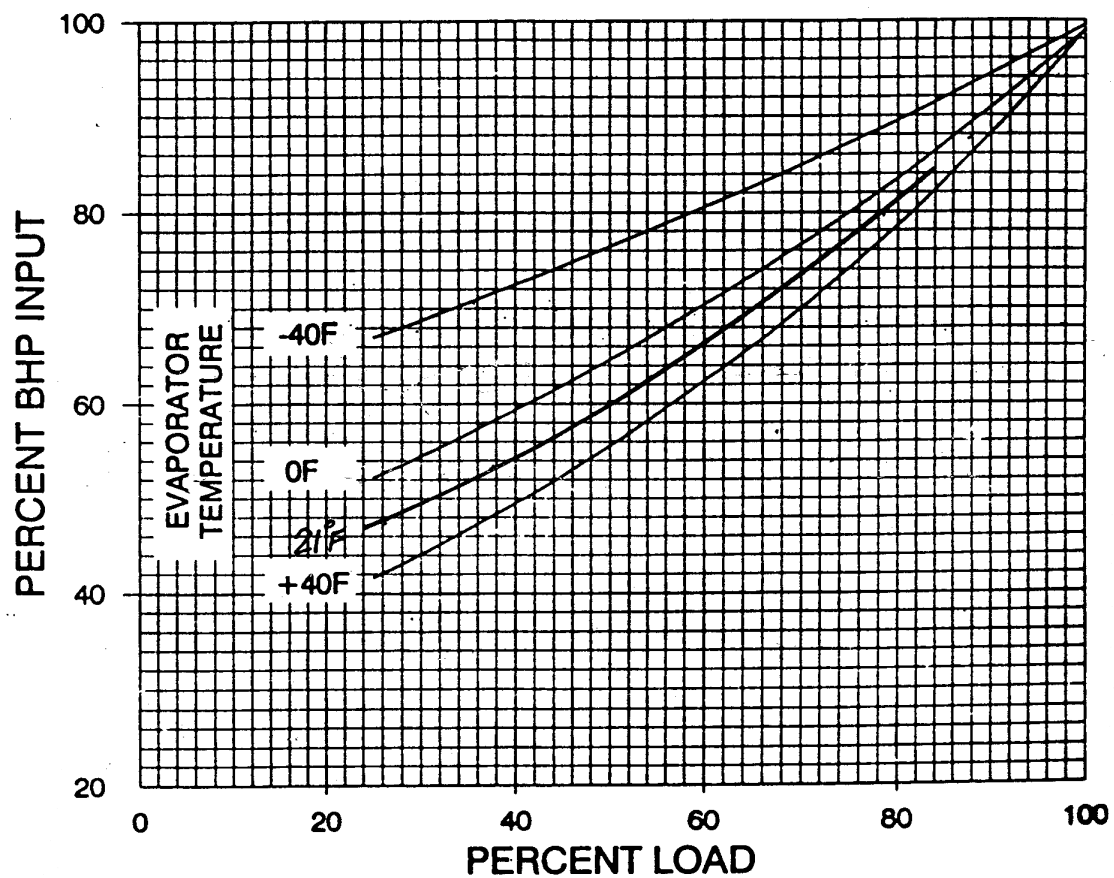

Figure 9-4 Part Load Power Input with Constant Condensing

Notes: [A] It would be more accurate if pressure drops are included when it is available. The temperature should be about 14°F instead of 21°F if pressure drops are included.

[B] The result of using this method for evaluation is good enough for comparison, because the base is the same for all the cases.

The percent of power consumption at the various percent partial load points using the partial load curves of Figure 9-3 and Figure 9-4 are tabulated as the following:

Percent of Power Consumption for the Compressor					
Percent Load	Hours Operation	System Option No. 1	System Option No. 2	System Option No. 3	System Option No. 4
100%	800 Hrs.	100%	100%	100%	100%
80%	2,158 Hrs	82.5%	82.5%	H 76% L 81.5%	H 76% L 81.5%
60%	2,265 Hrs	68.0%	68.0%	H 56% L 66.5%	H 56% L 66.5%
50%	2,477 Hrs	61.5%	61.5%	H 48% L 60%	H 48% L 60%
40%	800 Hrs	56.0%	56.0%	H 41% L 54%	H 41% L 54%

Note: For the Compound System of Option No. 3 and Option No.4:
H-high stage, L-booster

KWH Usage:

The KWH power usage for each compressor of various options is calculated as the following:

The KWH is calculated by:

> (Hours of Operation for the Percent of Load Allocated) x (Design KW at Design Point) x (Percent of Power Input Consumption)

Percent of Power Consumption					
Percent Load	Hours Operation	System Option No. 1	System Option No. 2	System Option No. 3	System Option No. 4
100%	800 Hrs.	100% 707,280	100% 607,760	100% 398,240	100% 385,440
80%	2,158 Hrs	82.5% 1,574,007	82.5% 1,352,532	H 76% 509,080 L 81.5% 458,160	H 76% 462,339 L 81.5% 458,160
60%	2,265 Hrs	68.0% 1,361,691	68.0% 1,170,090	H 56% 393,711 L 66.5% 392,372	H 56% 357,562 L 66.5% 392,372
50%	2,477 Hrs	61.5% 1,346,798	61.5% 1,157,293	H 48% 369,053 L 60% 387,155	H 48% 335,168 L 60% 387,155
40%	800 Hrs	56.0% 396,077	56.0% 340,346	H 41% 101,811 L 54% 112,536	H 41% 92,463 L 54% 112,536
Total KWH		5,385,853	4,628,021	3,122,118	2,983,195
Total running cost per year:		$430,868	$370,242	$249,769	$238,656

Total Operational Expense Per Year:

Summary of the operational expenses per year for each optional systems:

	System Option-1	System Option-2	System Option-3	System Option-4
Service/Maintenance Per year:	$5,370	$4,960	$5,306	$5,400
KW Power Supply Charge per year:	$88,056	$75,666	$56,862	$54,023
Running cost per year:	$430,868	$370,242	$249,769	$238,656
Total Operational Expense per Year	$524,294	$450,868	$311,937	$298,079

Accumulated Expenses:

If the analysis is based on 10 years operation period, the simple owning cost for the equipment is the initial investment for the equipment plus the 10 years operational expenses:

	System Option-1	System Option-2	System Option-3	System Option-4
Initial Investment:	$268,565	$248,013	$265,330	$278,865
Running Expense For 10 Years	$5,242,940	$4,508,680	$3,119,370	$3,980,790
10 Years Total Owning Cost:	$5,511,505	$4,756,693	$3,384,700	$3,259,655

Very obvious that the System Option-1 as specified in the specification is not the best choice, both the initial cost and the operation cost are the highest. Therefore, the Option-1 is not to be considered.

If we take the Option-2 as the base to evaluate the other three options:

	System Option-2	System Option-3	System Option-4
Cost difference:	Base	$17,317	$30,852
Operational Saving Per Year:	Base	$138,931	$152,789
Simple Payback:	Base	1.5 months	2.4 months

From the above analysis, it is very obviously, the System Option-4 is the best choice. Therefore, System Option-4 is recommended.

Summary of the overall evaluation for the screw compressor refrigeration systems:

	System Option-1 (Specified) Without Economizing	System Option-2 With Economizing	System Option-3 Compound No economizing	System Option-4 Compound W/economizer for high stage
Initial Investment	$268,565 (Even more expensive than option-2)	$248,013	$265,330	$278,865
Fixed KW Power Supply Charge/Year	$88,056	$75,666	$56,862	$54,023
Total KWH Usage of the System/Year	5,385,853	4,628,021	3,122,118	2,983,195
Total Operational Expenses Per Year	$524,294	$450,868	$311,937	$298,079
Total Simple Accumulated Owning Cost for 10 Years	$5,511,505	$4,756,693	$3,384,700	$3,259,655
Total Saving in 10 Years	System specified	$754,812	$2,126,825	$2,251,850
If compared to Option-2 instead of Option-1 (System specified by user)				
Initial cost difference		Base	$17,317	$30,852
Operational saving per year		Base	$138,931	$152,789
Simple Back		Base	1.5 months	2.4 months

System Option No. 4 is the best choice and should be recommended.

The reasons are outlined below:

1	The user indicates the energy costs and the fixed KW power supply charge for the refrigeration system. That implies the user is very much care about the system economic. Therefore, the systems are evaluated on the base of initial cost, operational expenses, owning cost and payback.
2	The initial cost of the System Option-1 (specified by the preliminary study) is even more expensive than System Option-2; The power consumption at the design point is higher than System Option-2. Therefore, the System Option-1 is not a good option.
3	The operational saving for Option-4 is $152,789 per year, resulting in saving of $13,858 more than the Option-3.
4	Also from the analysis of ten years total owning cost, the lowest owning cost is the Option-4.
5	The payback period for the Option-4 is only 0.2 years or 2.4 months as compared to the Option-2 and the payback time is only one month more than the Option-3.
	In view of the above, the Option-4 is to be recommended and is the best for the project.