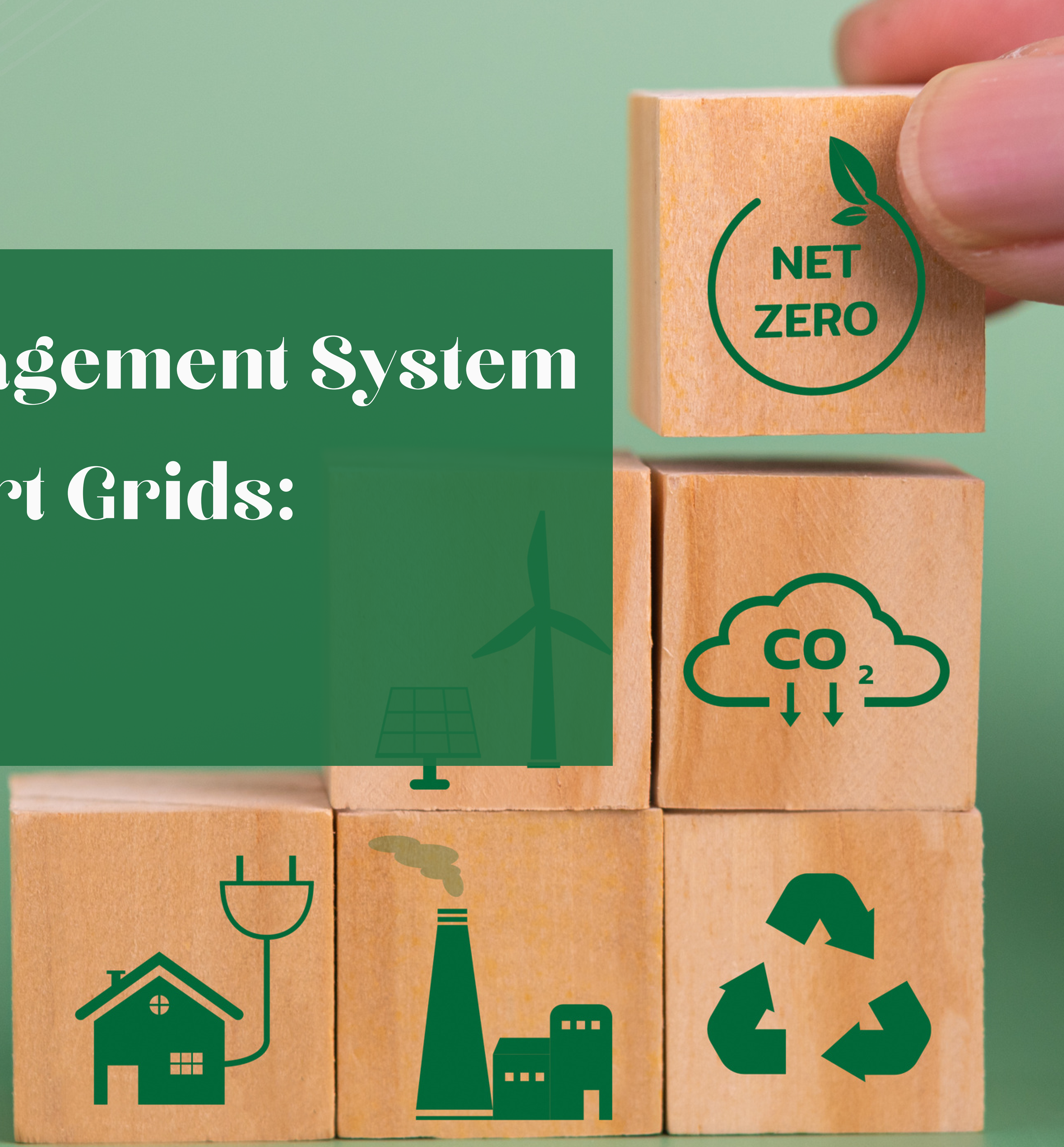
Design of Energy Management System (EMS) control for Smart Grids:

Case of NIDA Smart City



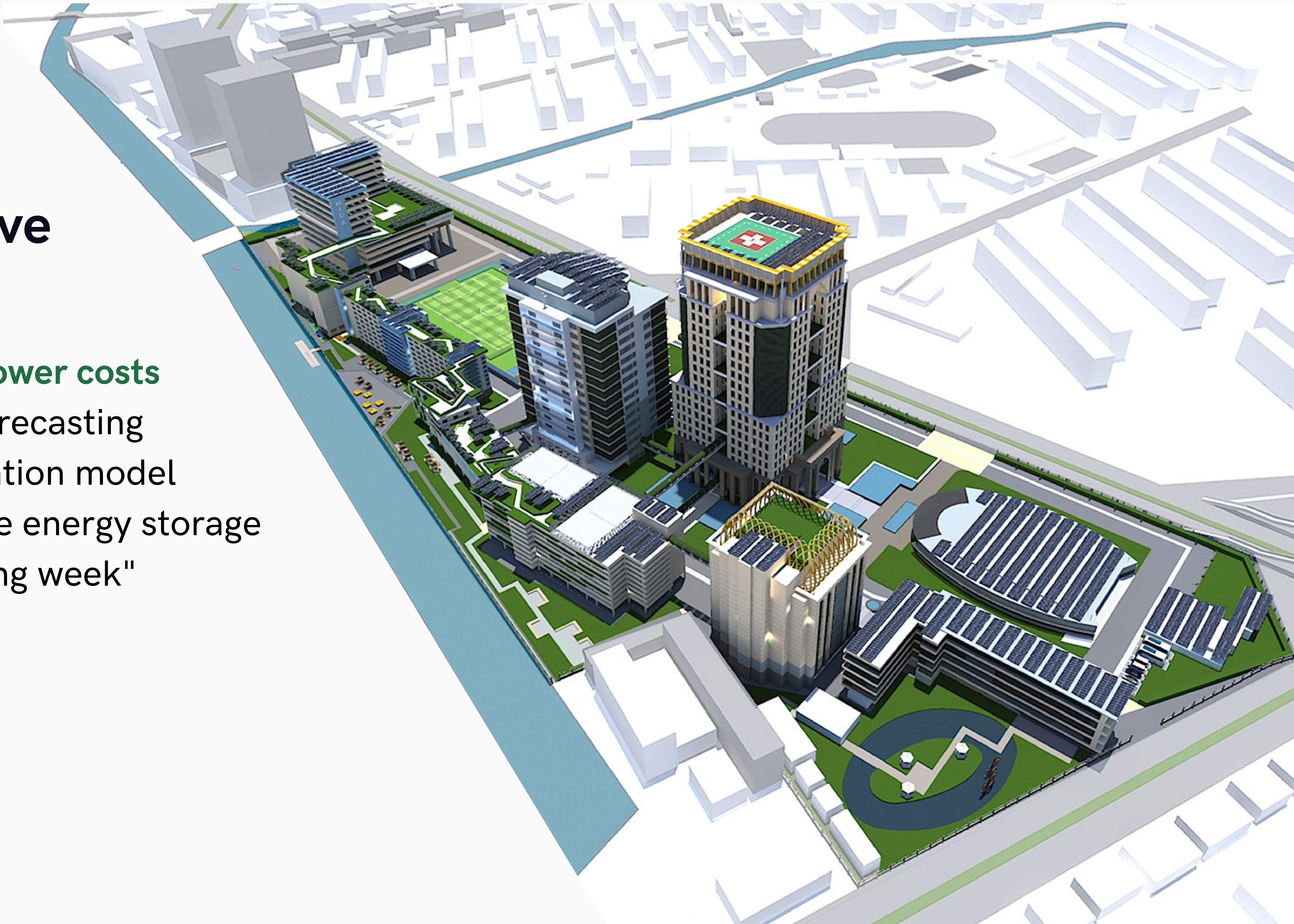
National Institute of Development Administration

Independent Study | 8th Jan 2023

Nattapong Thanngam

Objective

"**Minimize power costs**
by using a forecasting
and optimization model
to control the energy storage
for the coming week"



Conceptual

"3 cases comparison"

- No Solar cell installation (Present)
- Solar cell installation
- Solar cell installation with EMS

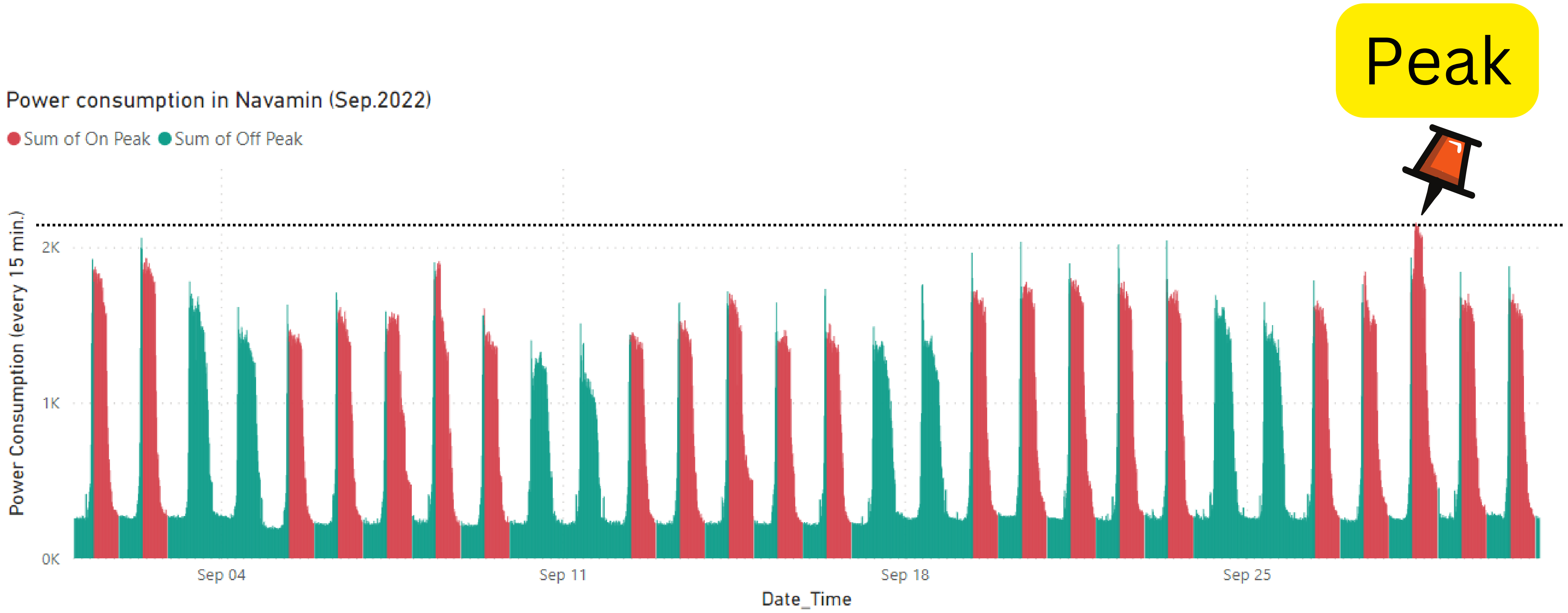
Data: Smart meter of NIDA Smart city

- Train Period: 1 - 30 Sep. 2022
- Calculated saving period: 1 - 7 Oct. 2022

POWER COST INTRODUCTION

On-Off Peak

- **On Peak** = Mon - Fri (9:00 - 22:00)
- **Off Peak** = Otherwise



Power Cost Calculation (TOU concept)

- Power Cost = Energy Charge + Demand Charge

	On Peak	**Off Peak**
• Energy Charge	210	0
• Demand Charge	4.3297	2.6369

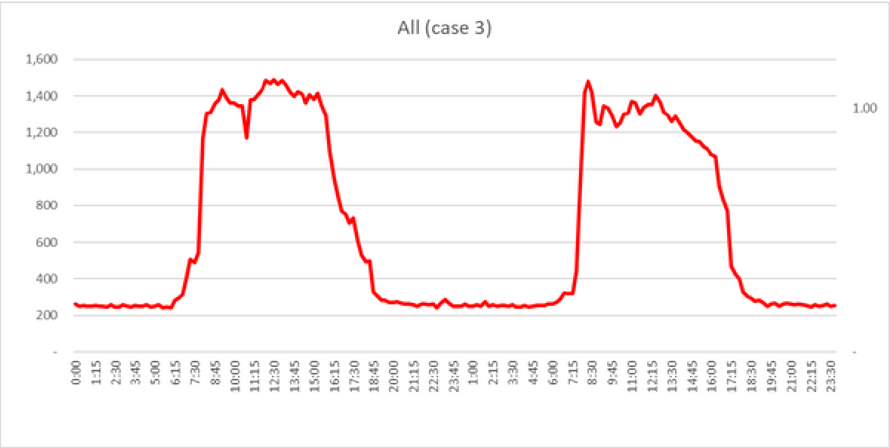
IDEA OF ENERY MANAGEMENT SYSTEM

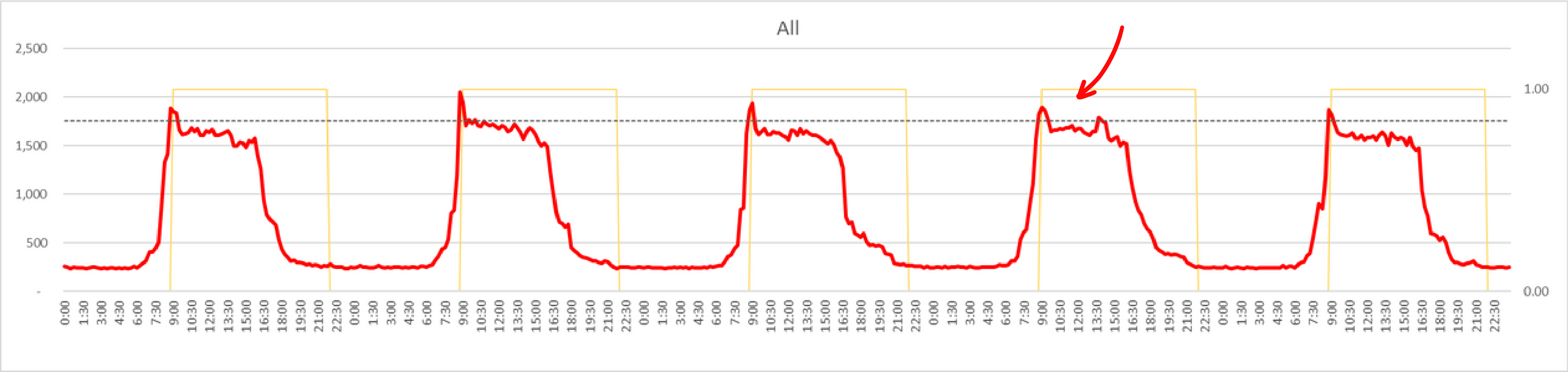
Weekend

Weekday

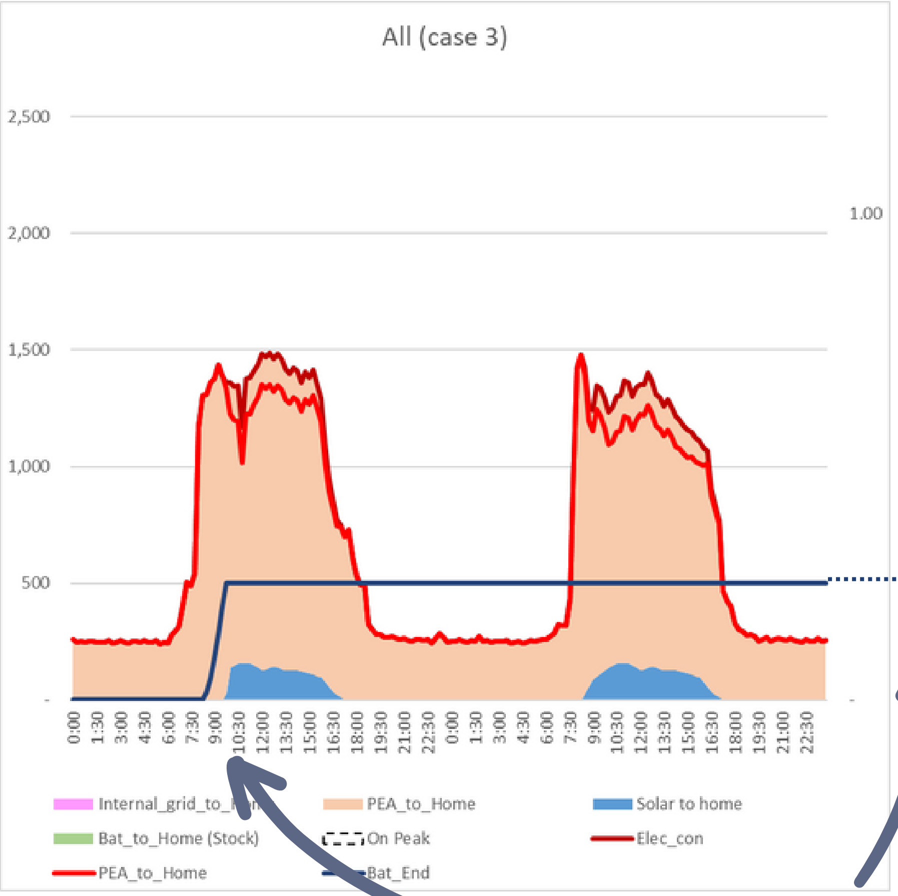
Demand = MEA Power

Current





Idea of new EMS

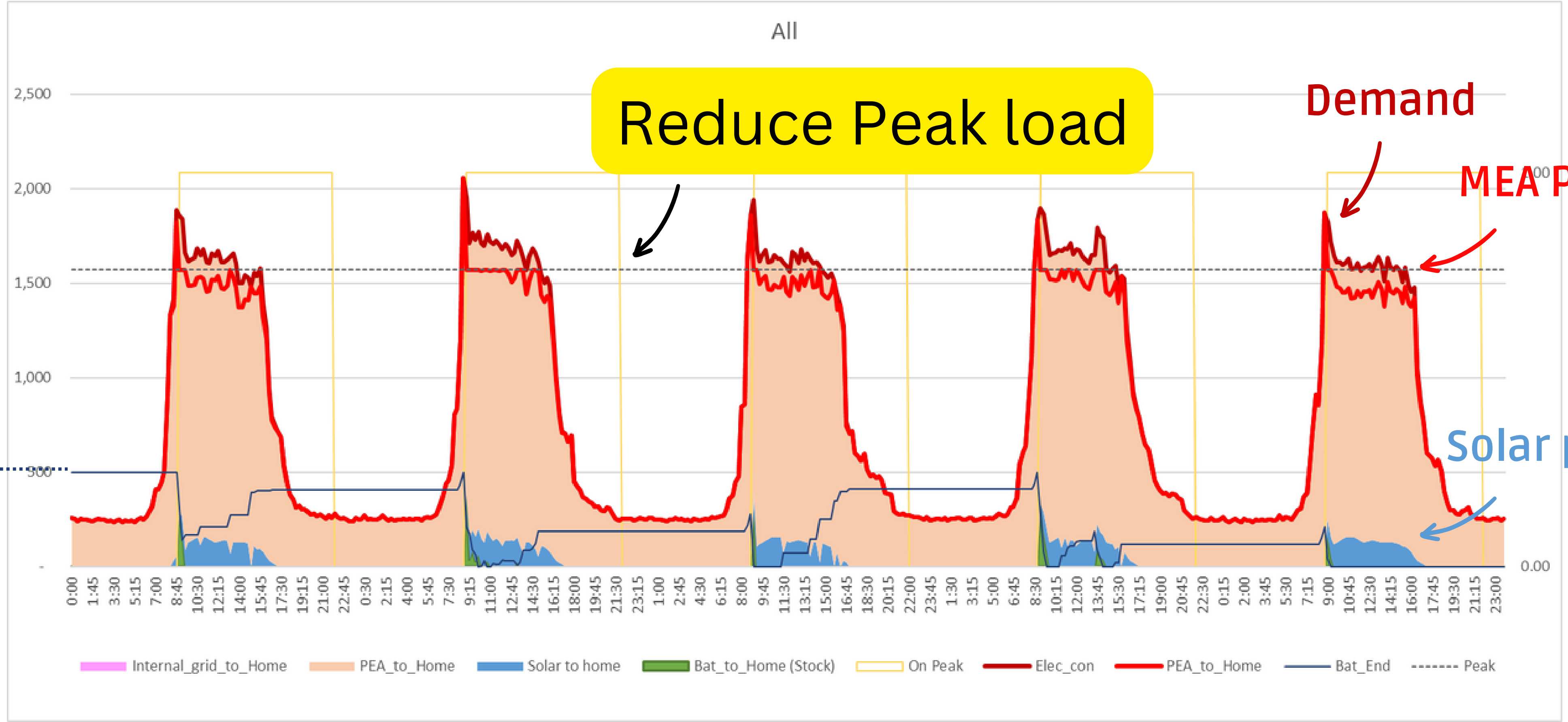


Reduce Peak load

Demand

MEA Power

Solar power



Charge power during off peak
discharge power during on peak

NIDA's Building

"11 Building"

- Auditorium
- Bunchana
- Chup
- Malai
- Narathip
- Navamin
- Nida House
- Nidasumpan
- Ratchaphruek
- Serithai
- Siam

SOLAR CELL INSTALLATION AREA

Image: solaredge.com

ESTIMATE POWER GENERATED FROM SOLAR CELL

Example input for Solar power generation

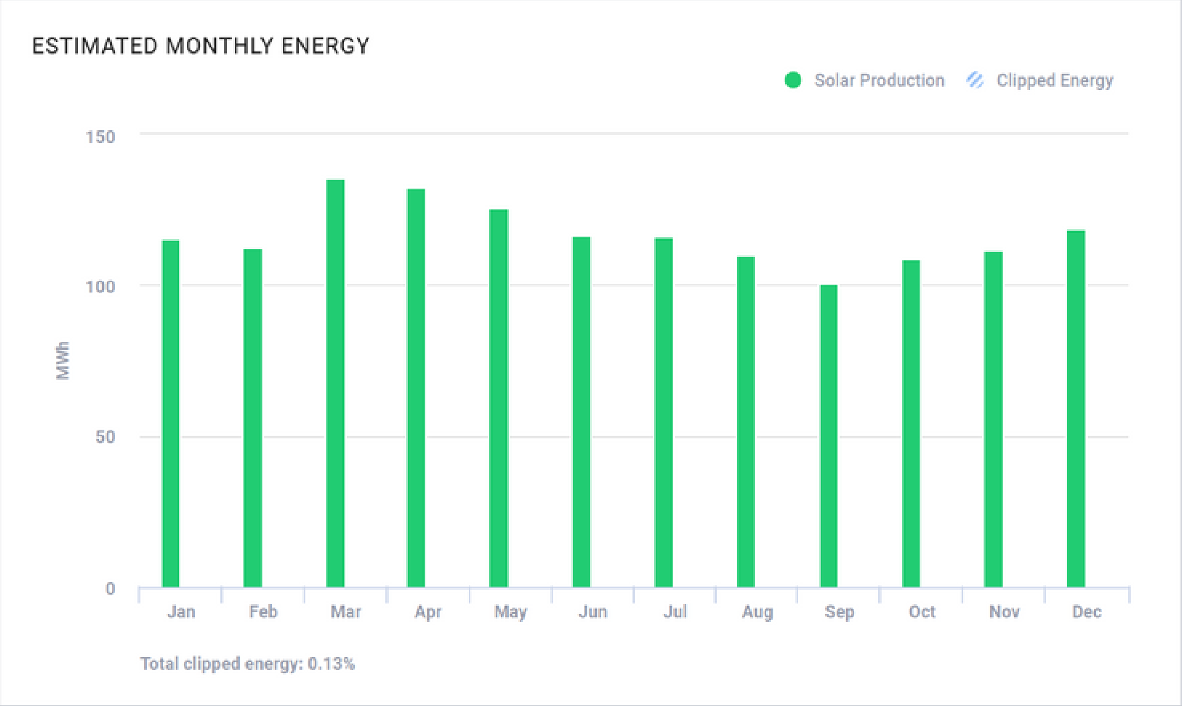
Source: solaredge.com

SYSTEM OVERVIEW | 2348 PV modules | 13 Inverters | 1174 Optimizers

SIMULATION RESULTS

Installed DC Power	Max Achieved AC Power	Annual Energy Production	CO2 Emission Saved	Equivalent Trees Planted
974.42 kWp	824.23 kW	1.41 GWh	551.25 t	25,319

- Full area at top of 11 NIDA's building
- Installed solar panel = 974.42 kWp
- Capacity (4 hr/day) = 3,898 kW

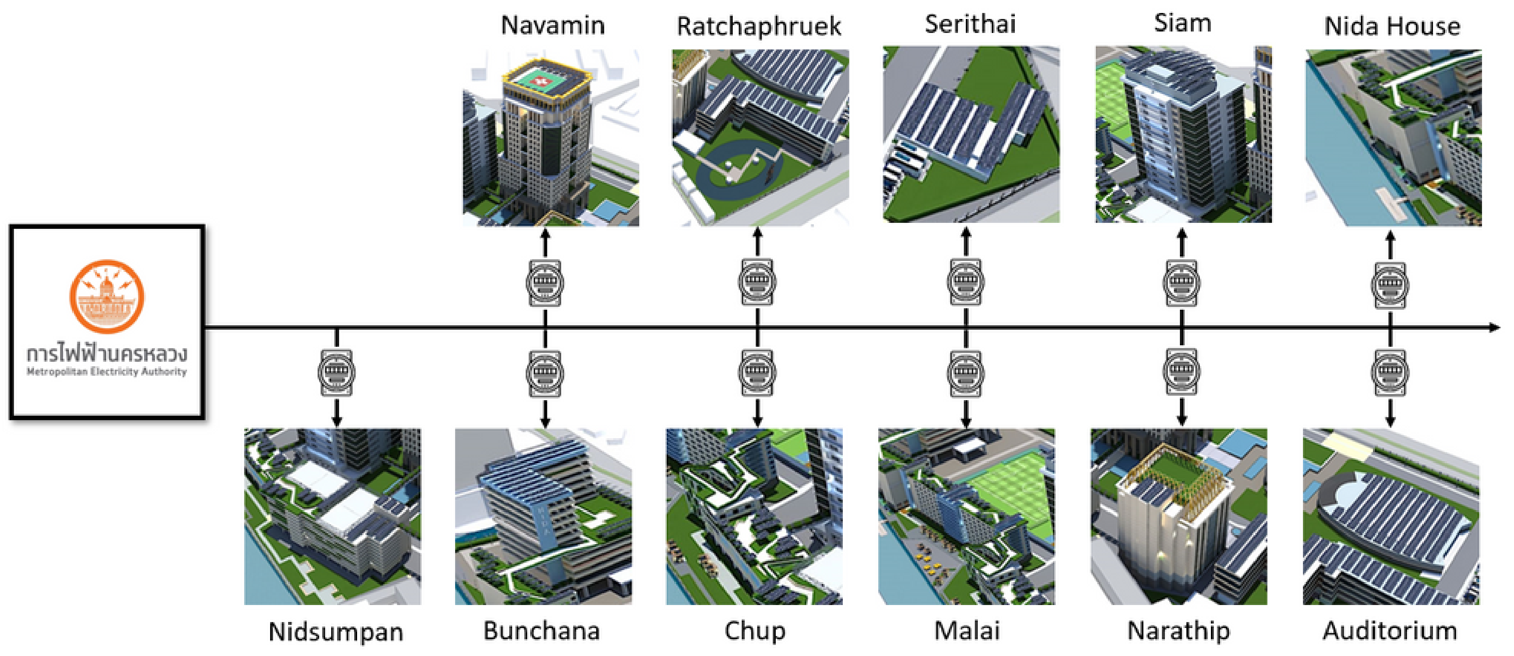


PV MODULES

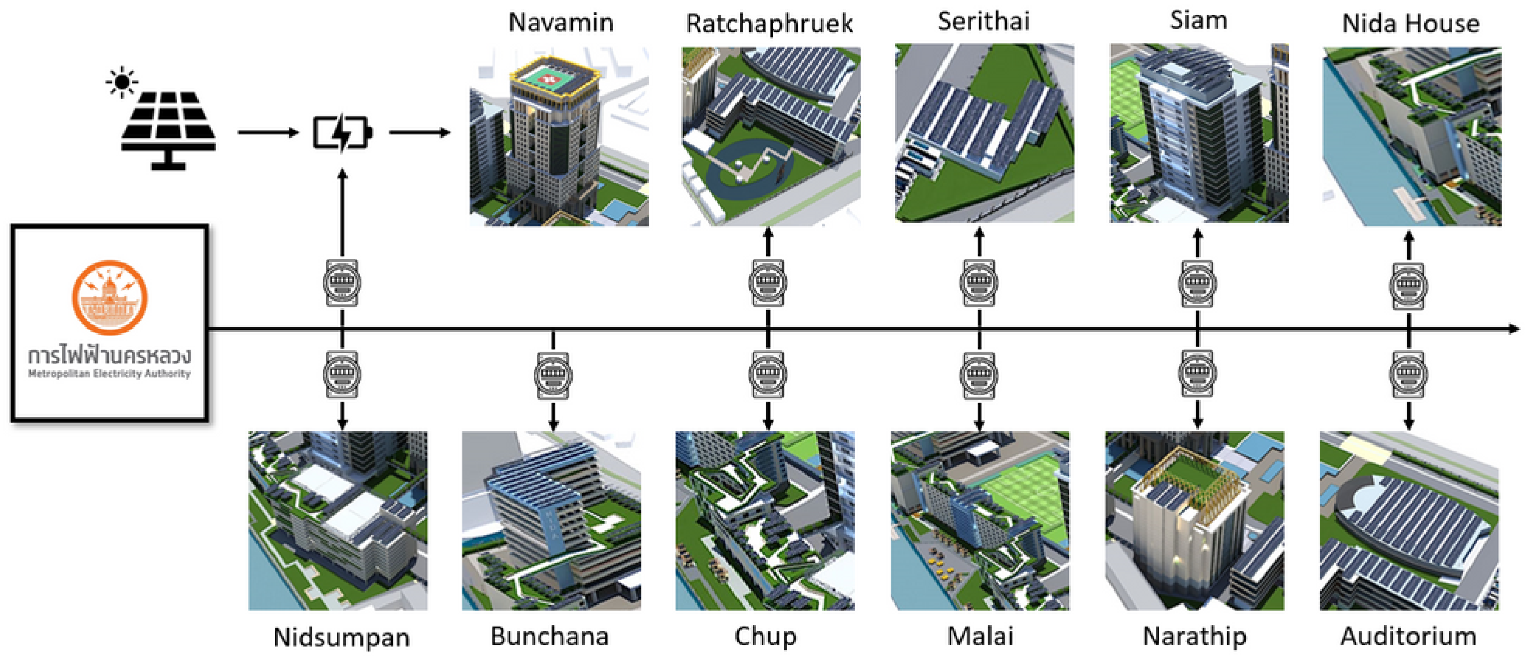
# Module	Model	Peak power	Racking type	Orientation	Azimuth	Tilt
360	SunPower, SPR-P3-415-COM	149.4 kWp			125°	8°
124	SunPower, SPR-P3-415-COM	51.5 kWp			323°	6°
64	SunPower, SPR-P3-415-COM	26.6 kWp			214°	15°
50	SunPower, SPR-P3-415-COM	20.8 kWp			304°	5°
64	SunPower, SPR-P3-415-COM	26.6 kWp			218°	15°
280	SunPower, SPR-P3-415-COM	116.2 kWp			214°	15°
96	SunPower, SPR-P3-415-COM	39.8 kWp			33°	5°

SIMPLE DIAGRAM WITH ASSUMPTION

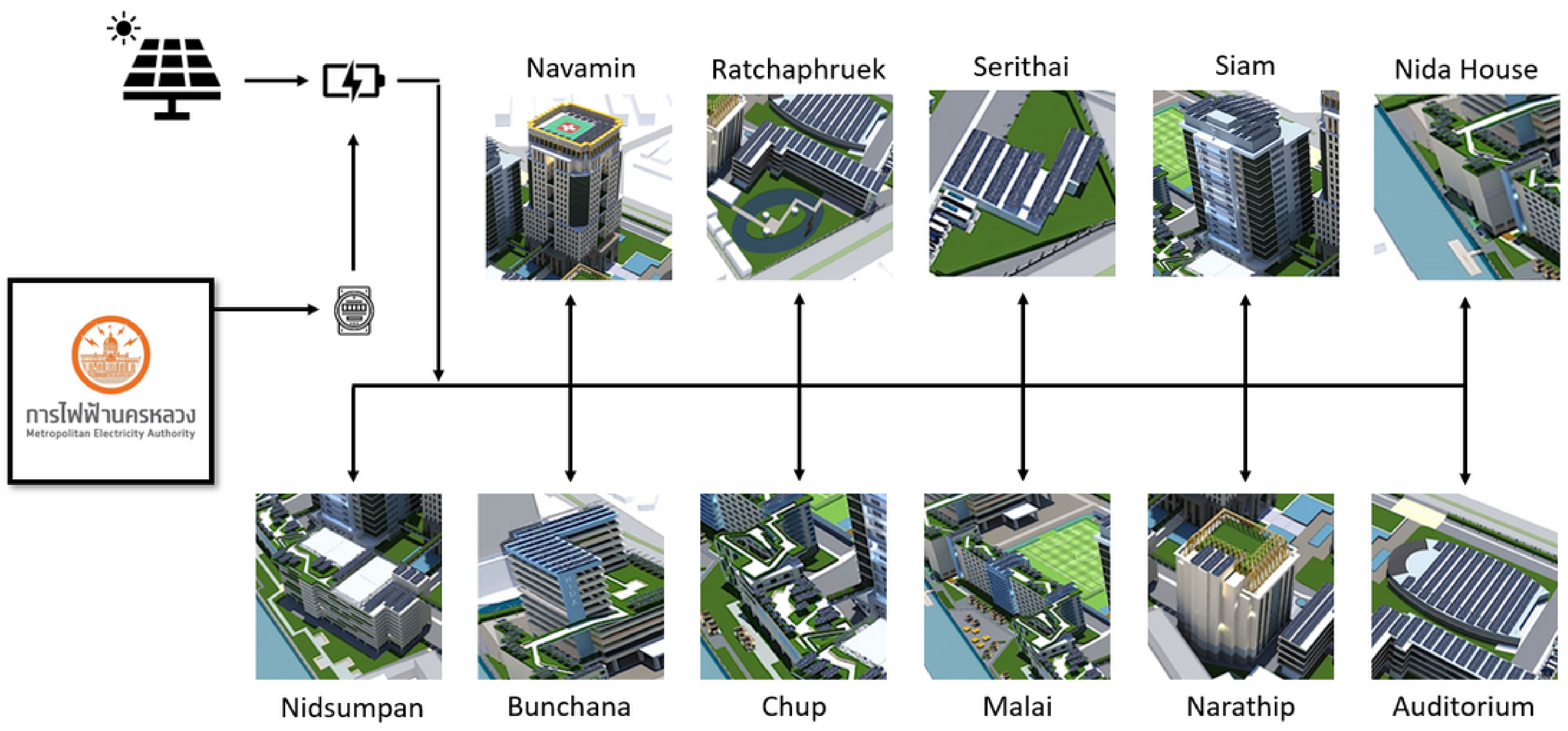
Case 1: Existing



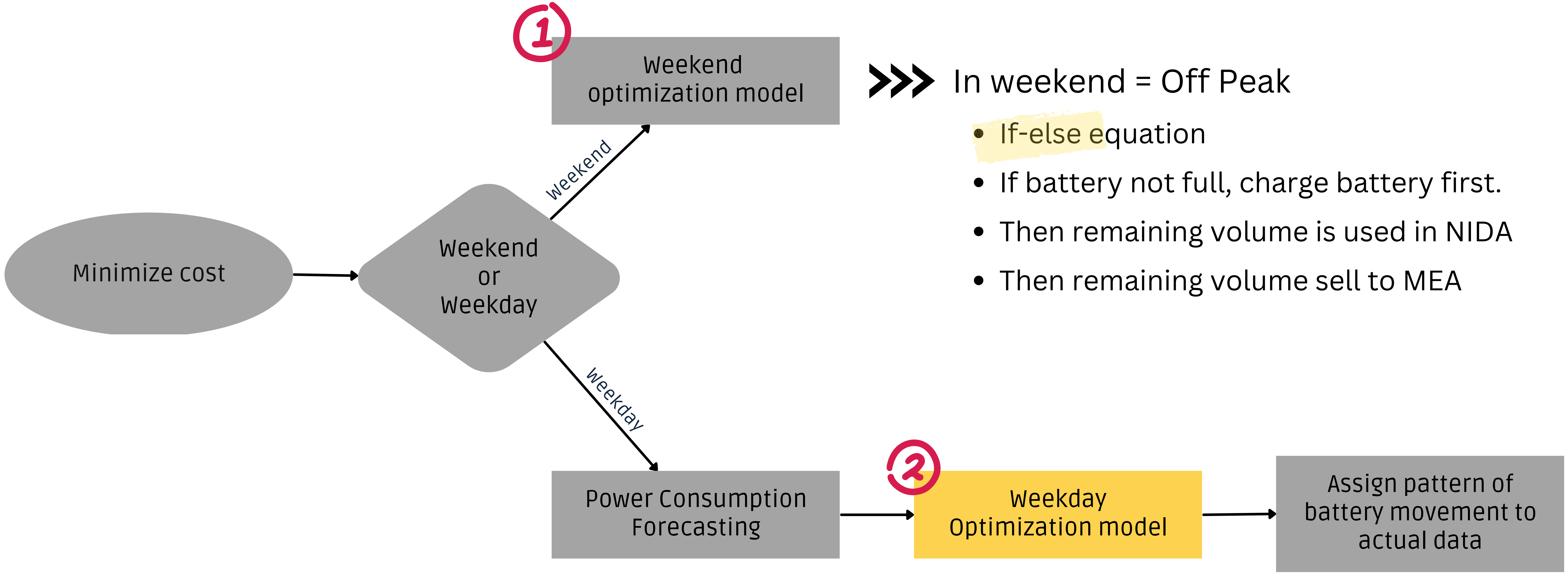
Case 2: Solar cell installation (No battery)



Case 3: Solar cell installation + EMS
(Battery = 100 kWh)



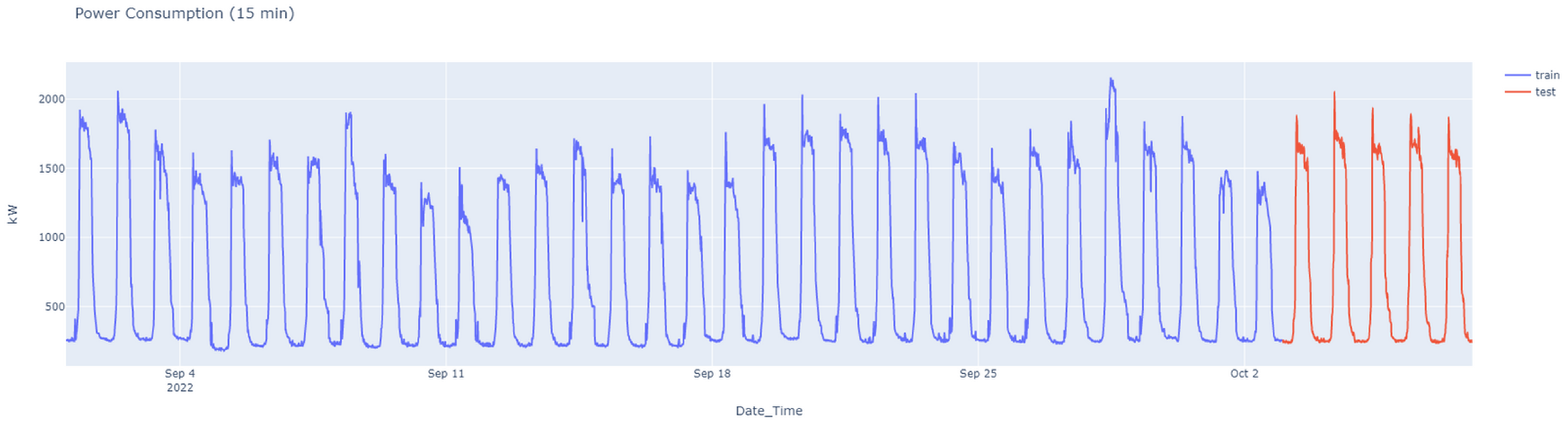
MODEL'S FLOWCHART - CASE 3



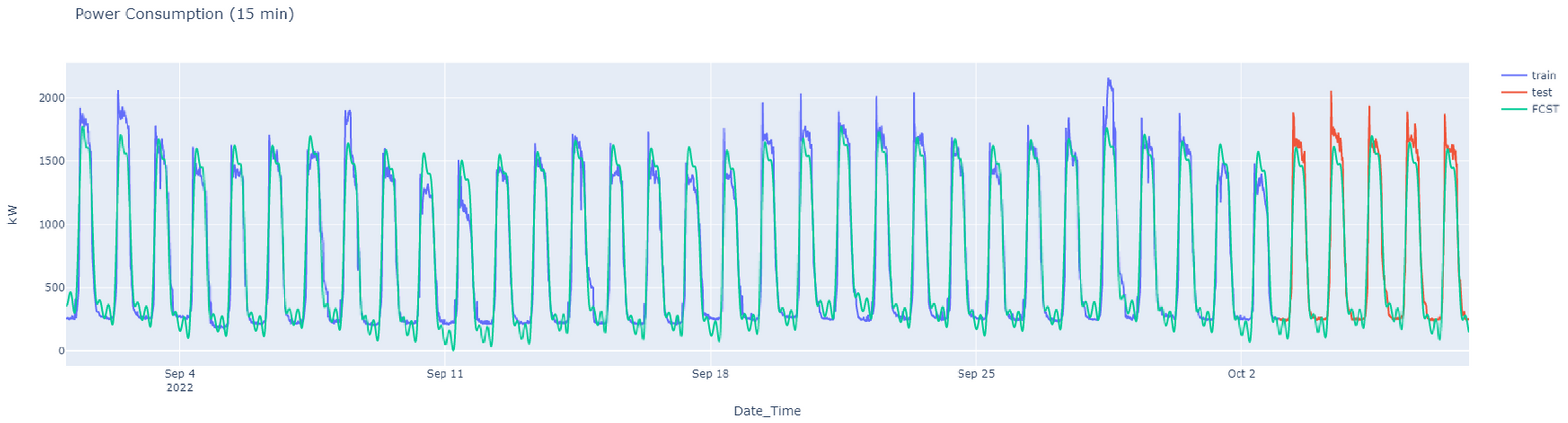
In weekend = Off Peak

- If-else equation
- If battery not full, charge battery first.
- Then remaining volume is used in NIDA
- Then remaining volume sell to MEA

MATHEMATICAL MODEL - CASE 3 (WEEKDAY)



- Building: All
- Train: 1 Sep - 2 Oct
- Test: 3 Oct - 7 Oct



- Prophet algorithm
- MAPE = 0.1685

MATHEMATICAL MODEL - WEEKEND (CASE 3)

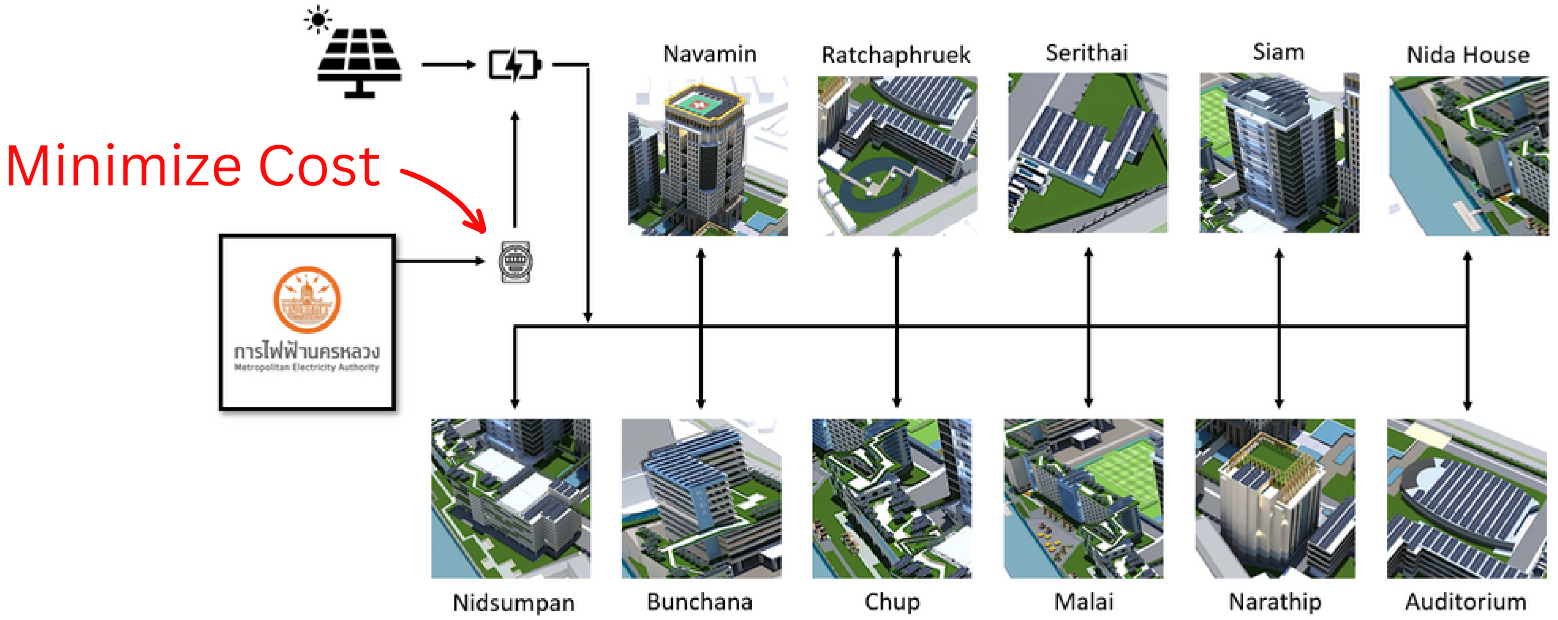
ฟังก์ชันวัตถุประสงค์ (Objective Function) :

- $Minimize\ C_{total}$
- $C_{total} = C_{demand\ charge\ j} + C_{energy\ charge\ j} - R_{Solar\ to\ MEA}$ <-- Total cost = Demand Charge cost + Energy charge cost - Revenue
- $C_{energy\ charge\ j} = \sum_d \sum_{t=1}^{96} [C_{t,i=MEA} * X^d_{t,i=MEA,j=l}]$ <-- Energy Charge cost = Power consumption * unit cost
- $C_{demand\ charge}$ <-- Demand Charge cost
- $R_{Solar\ to\ MEA} = \sum_d \sum_{t=1}^{96} [R_{sale} * X^d_{t,i=s,j=MEA}]$ <-- Revenue= Power to MEA * unit price

(0 = off peak, 1 = on peak)

ตัวแปรตัดสินใจ (Decision Variable) :

- $X^d_{t,i=s,j=b}$ <-- Solar power to Battery
- $X^d_{t,i=b,j=l}$ <-- Battery power to Load (NIDA)
- $X^d_{t,i=s,j=l}$ <-- Solar power to Load
- $C_{demand\ charge\ j}$ <-- Peak cost



MATHEMATICAL MODEL - WEEKEND (CASE 3)

>= 0 Decision variable

ข้อจำกัด (Constraints) :

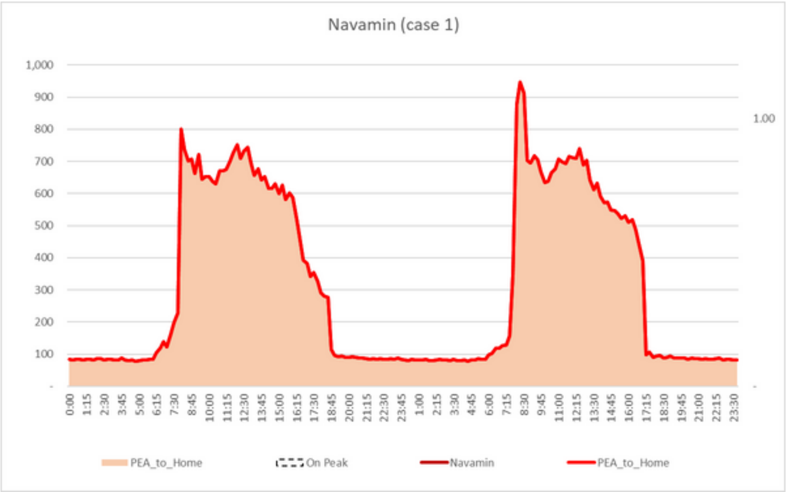
- $X^{d}_{t,i=s,j=MEA} = S^{d}_{t} - X^{d}_{t,i=s,j=l} - X^{d}_{t,i=s,j=b}\ ; \forall d, \forall t$ <-- Solar power to MEA = Solar generation - Solar power to load - Solar power to Battery
- $X'^{d}_{t,i=b,j=l} = X^{d}_{t,i=b,j=l} * P_t\ ; \forall d, \forall t$ <-- Actual Battery power to load = Battery power to Load * On/Off peak factor
- $B^{begin,d}_{t,i=b} = B^{end,d}_{t-1,i=b} + X^{d}_{t,i=s,j=b}\ ; \forall d, \forall t$ <-- Battery begin = Battery end (d-1) + Solar power to Battery
- $B^{end,d}_{t,i=b} = B^{begin,d}_{t,i=b} - X'^{d}_{t,i=b,j=l}\ ; \forall d, \forall t$ <-- Battery end = Battery begin - Actual Battery power to load
- $G^{d}_{t,i=b} = B_{capacity} - B^{end,d}_{t,i=b}\ ; \forall d, \forall t$ <-- Gap of charging = Battery capacity - Battery end
- $X^{d}_{t,i=MEA,j=l} = L^{d}_{t,l} - X'^{d}_{t,i=b,j=l} - X^{d}_{t,i=s,j=l}\ ; \forall d, \forall t$ <-- MEA power to load = Demand - Actual Battery power to load - Solar power to load
- $X^{d}_{t,i=s,j=l} \le S^{d}_{t}$ <-- Solar power to load <= Solar power generation
- $B^{end,d=1}_{t=0,i=b} = 0$ <-- Start level of battery at D-1 = 0
- $B^{end,d}_{t,i=b}, X^{d}_{t,i=s,j=b}, X'^{d}_{t,i=b,j=l}, L^{d}_{t,j}, G^{d}_{t,i=b}, X^{d}_{t,i=s,j=MEA}, X^{d}_{t,i=MEA,j=l} \ge 0\ ; \forall d, \forall t$

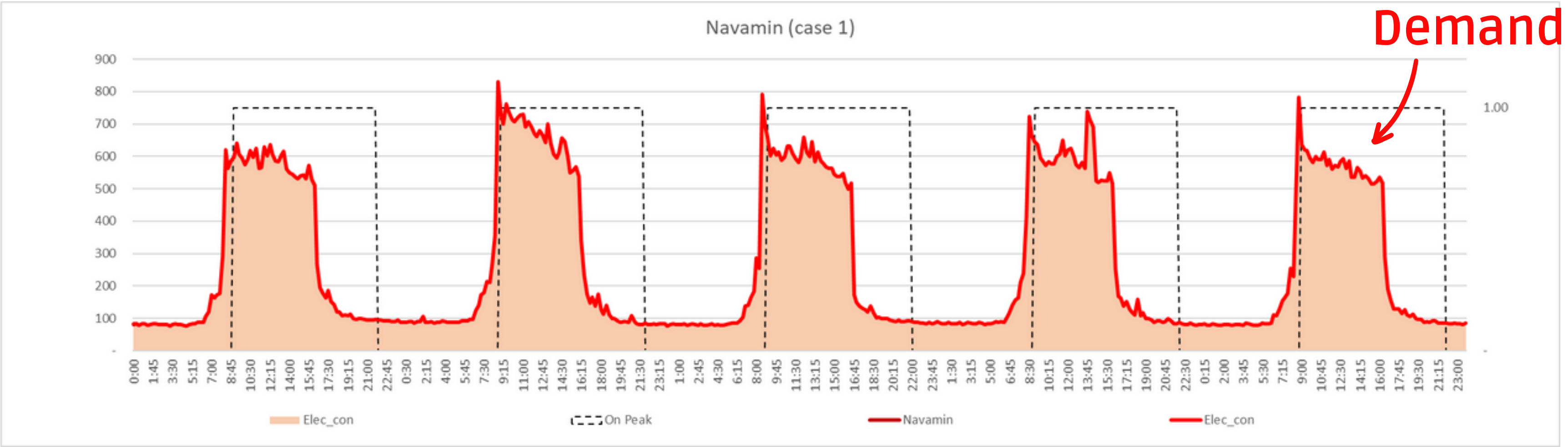
- $C_{demand\ charge\ j} \le X^{d}_{t,i=MEA,j=l} * C_{peak} * P_t\ ; \forall d, \forall t$ <-- Peak cost from Decision variable <= Actual Peak cost

A week comparison

Case 1: Existing

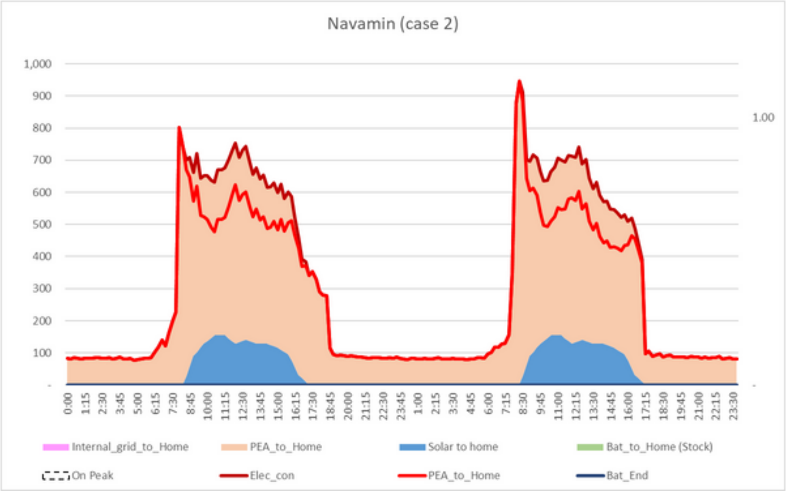
Note: Only Navamin building

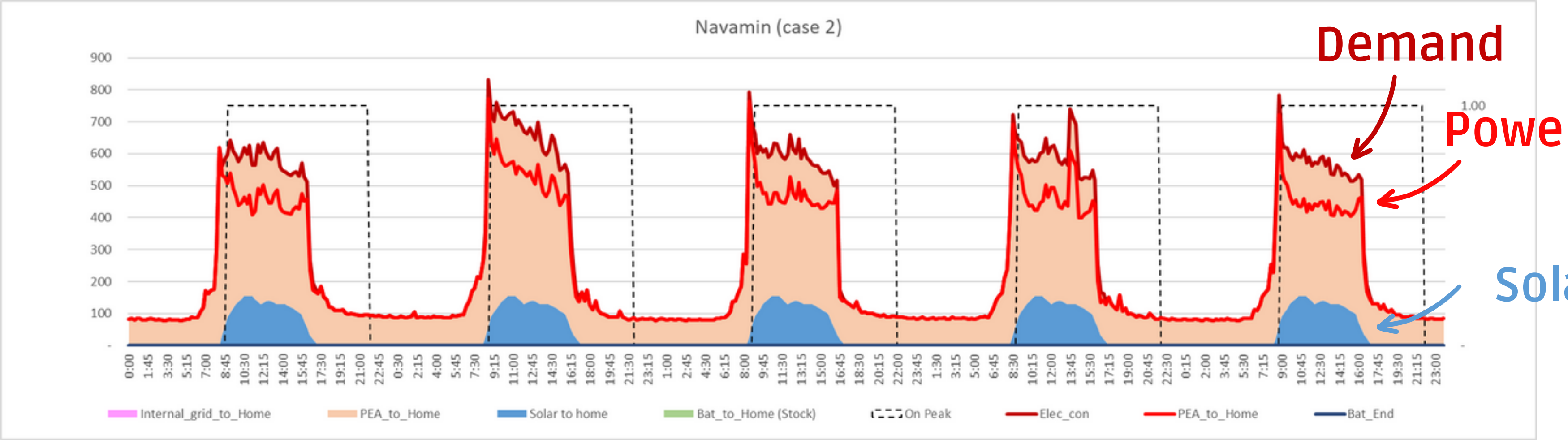




Case 2: Solar cell installation

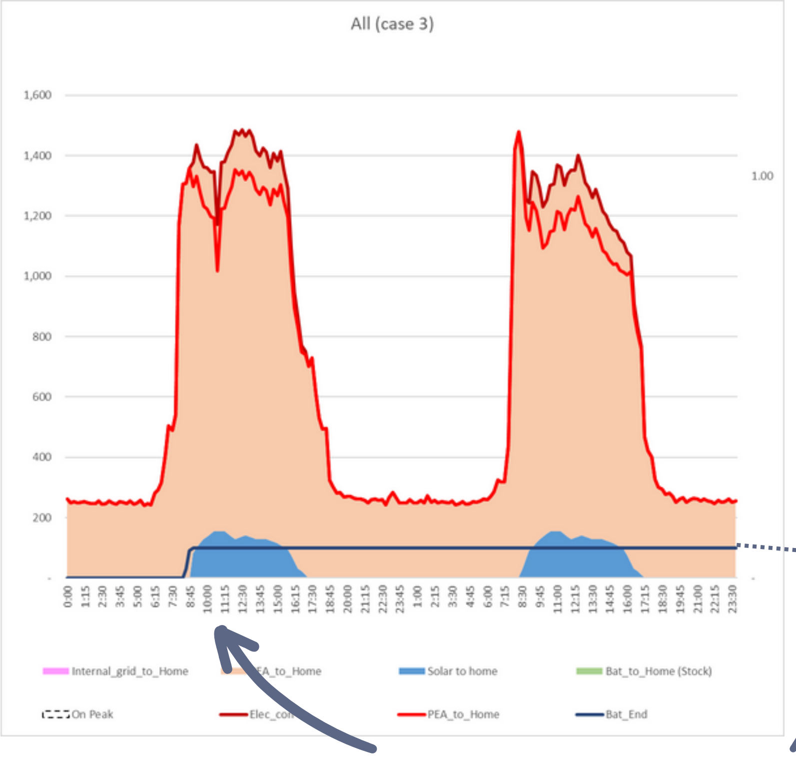
Note: Only Navamin building

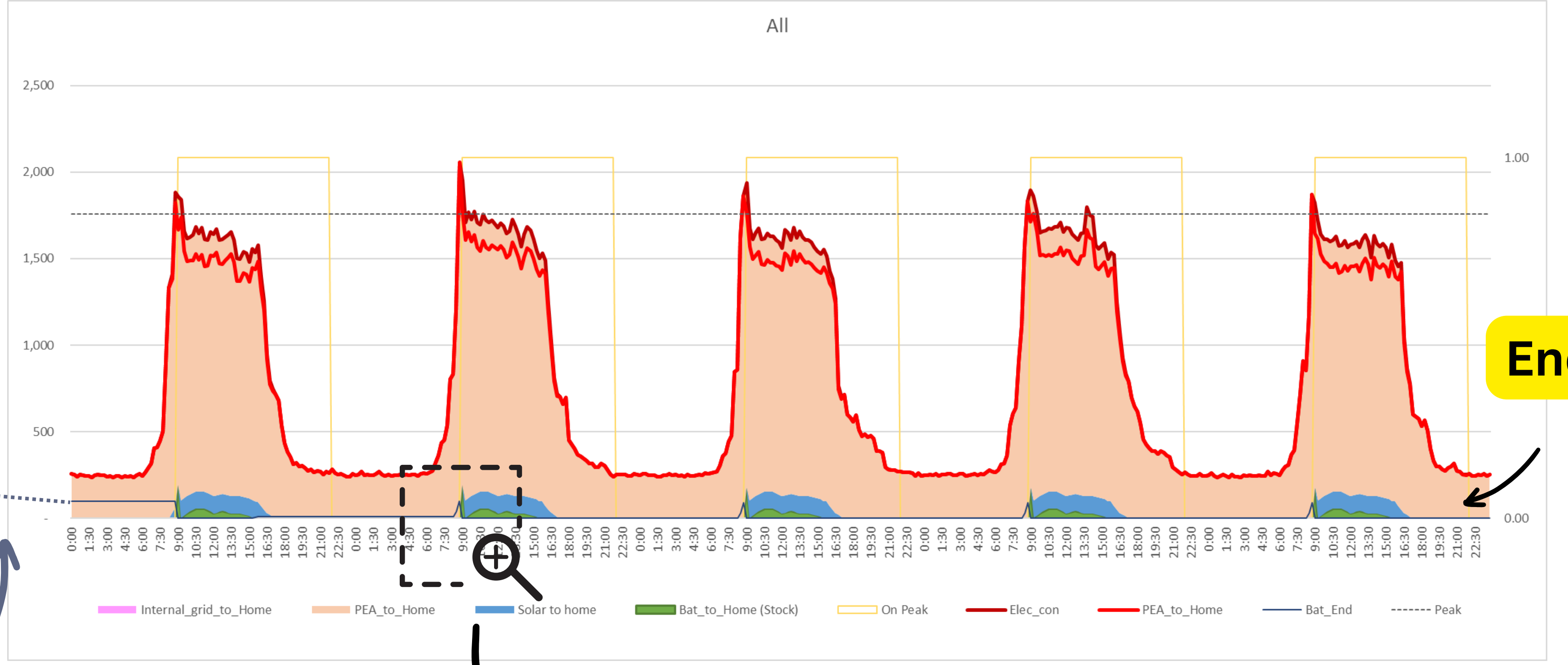




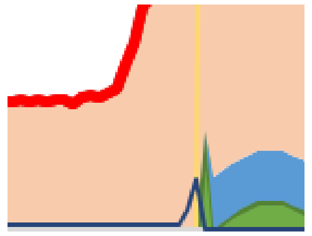
Case 3: Solar cell installation + optimization model

Note: All building





Charge power during off peak discharge power during on peak



Solar generation during off peak will charge to battery and discharge during on peak

DETAIL SUMMARY (7 DAYS) - IDEA CASE

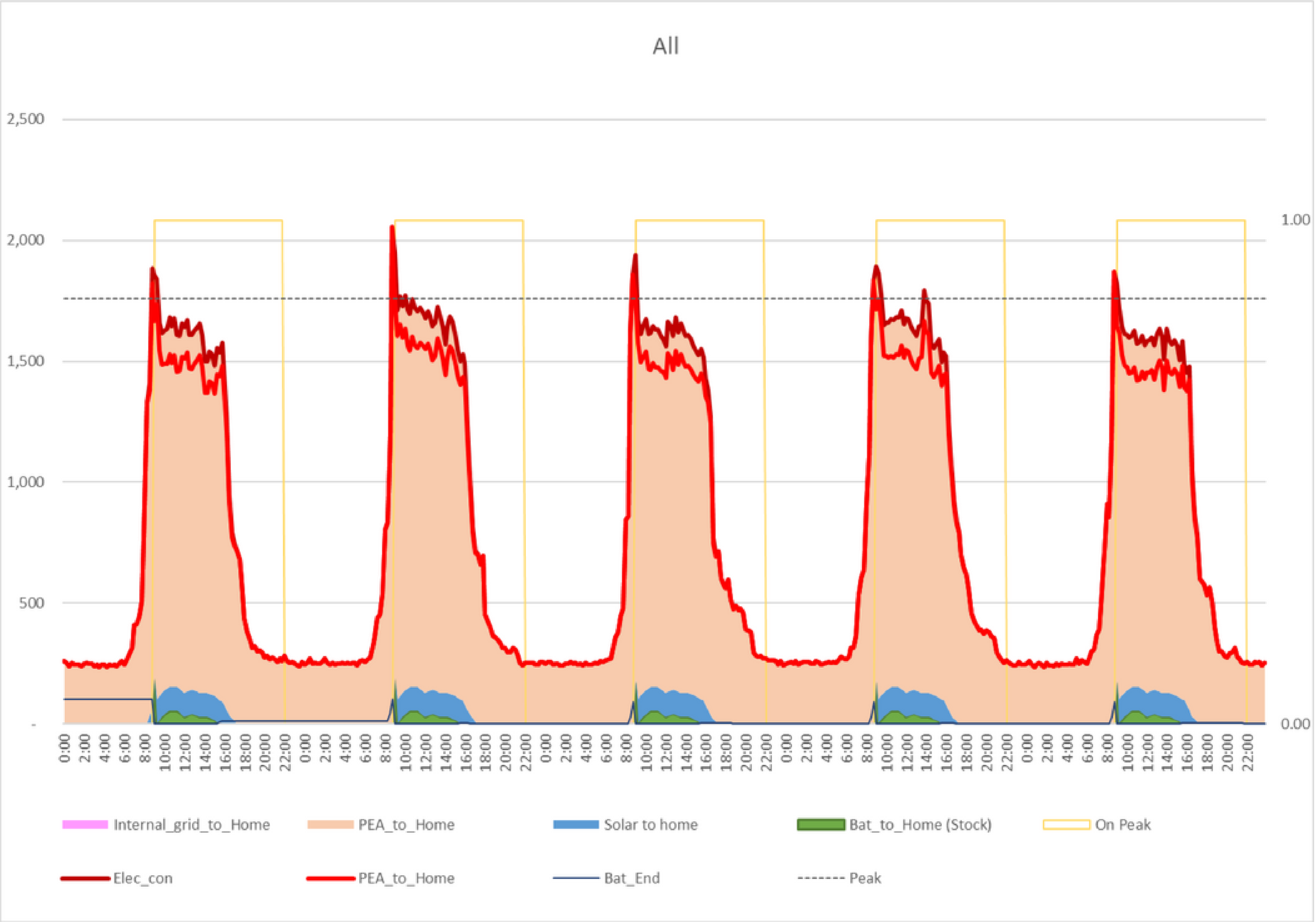
Case	Demand (kW)	Peak Demand (kW)	Energy charge (THB)	Demand charge (THB)	Total cost (THB)
1: No solar (Base line)	505,460.72	2,218.78	1,831,844.37	465,944.64	2,297,789.01
2: Solar	478,174.37	2,218.78	1,727,662.08	441,630.84	2,169,292.92
Improve from Case 1	5.40%	5.22%	5.69%	5.22%	5.59%
3: Solar cell + EMS	**478,174.37**	**1,758.35**	**1,726,883.05**	**369,254.13**	**2,096,137.18**
Improve from Case 1	5.40%	20.75%	5.73%	20.75%	8.78%

Note:

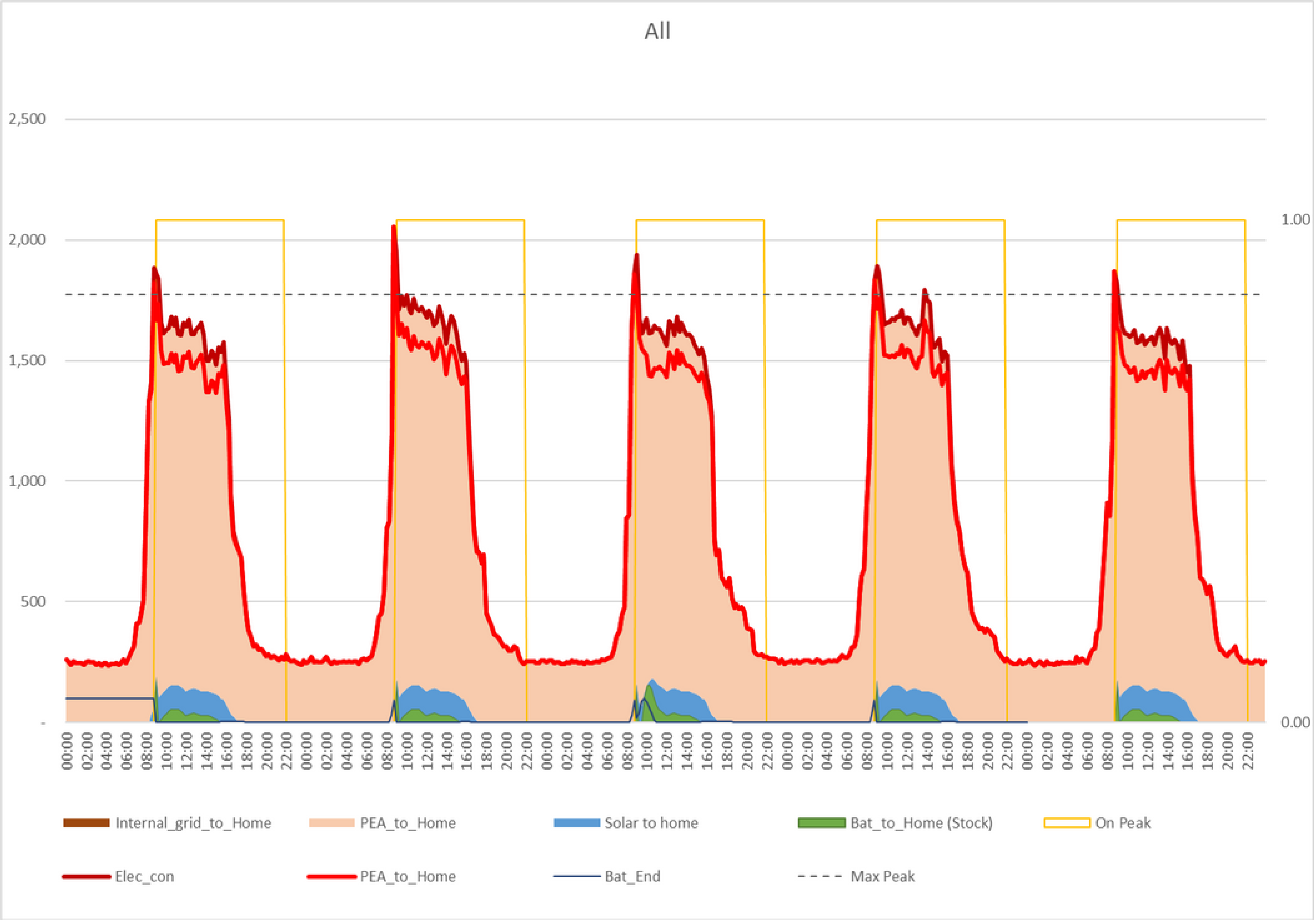
- Optimization model (case 3) can reduce peak load due to energy storage management.
- Energy charge of case 3 can lower than case 2 due to energy storage management.
- Case 2 saving = 128,496.09 THB/week base on case 1 and On top saving = 73,155.74 THB/week

Actual vs Forecast data

APPLIED MODEL COMPARISON (7 DAYS)



Actual data



Forecast data

DETAIL SUMMARY (7 DAYS)

Case	Demand (kW)	Peak Demand (kW)	Energy charge (THB)	Demand charge (THB)	Total cost (THB)
3.1 Actual data	478,174.37	1,758.35	1,726,883.05	369,254.13	2,096,137.18
3.2 Forecast data	**478,174.37**	**1,775.73**	**1,726,883.05**	**372,903.71**	**2,099,786.77**
Improve from case 3.1	0.00%	-0.99%	0.00%	-0.99%	-0.17%

Note:

- After simulate battery movement pattern and apply to actual data, the demand charge is increased 1%

A year comparison & feasibility study

4) SUMMARY ALL CASES (1Y BASIS)

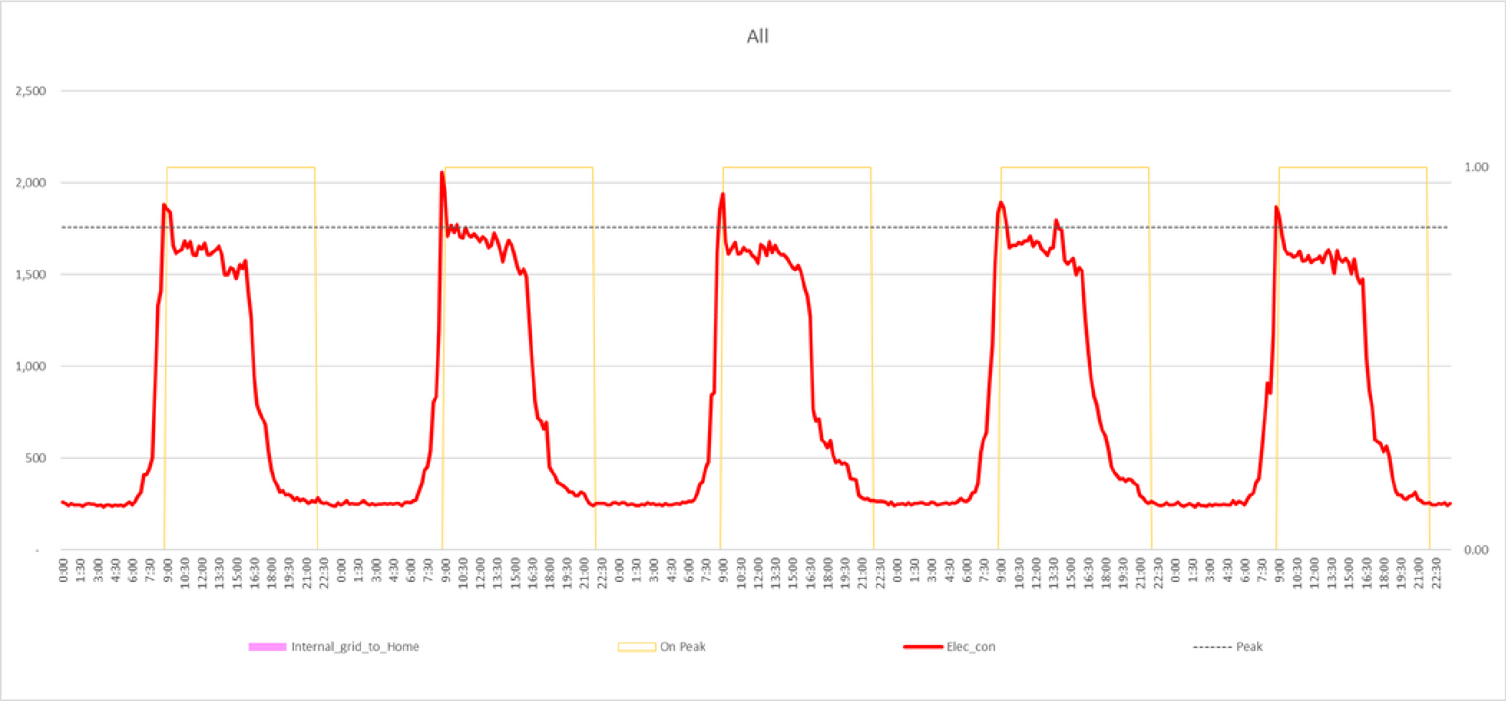
Basis: 974.42 kWp, Battery = 100 kWh

Case	Demand (kW)	Peak Demand (kW)	Energy charge (THB)	Demand charge (THB)	Total cost (THB)	Investment (THB)	Saving (THB/year)	Payback Period (year)
1: No solar (Base line)	26,283,957	2,219	95,255,907	5,591,336	100,847,243	-	-	-
2: Solar	24,865,067	2,103	89,838,428	5,299,570	95,137,998	34,104,700	5,709,245	5.97
Improve from Case 1	5.40%	5.22%	5.69%	5.22%	5.66%			
3.1: Solar + EMS (Actual)	24,865,067	1,758	89,797,919	4,431,050	94,228,968	36,904,700	6,618,274	5.58
Improve from Case 1	5.40%	20.75%	5.73%	20.75%	6.56%			
3.2: Solar + EMS (FCST)	24,865,067	1,776	89,797,919	4,474,845	94,272,763	36,904,700	6,574,479	5.61
Improve from Case 1	5.40%	19.97%	5.73%	19.97%	6.52%			

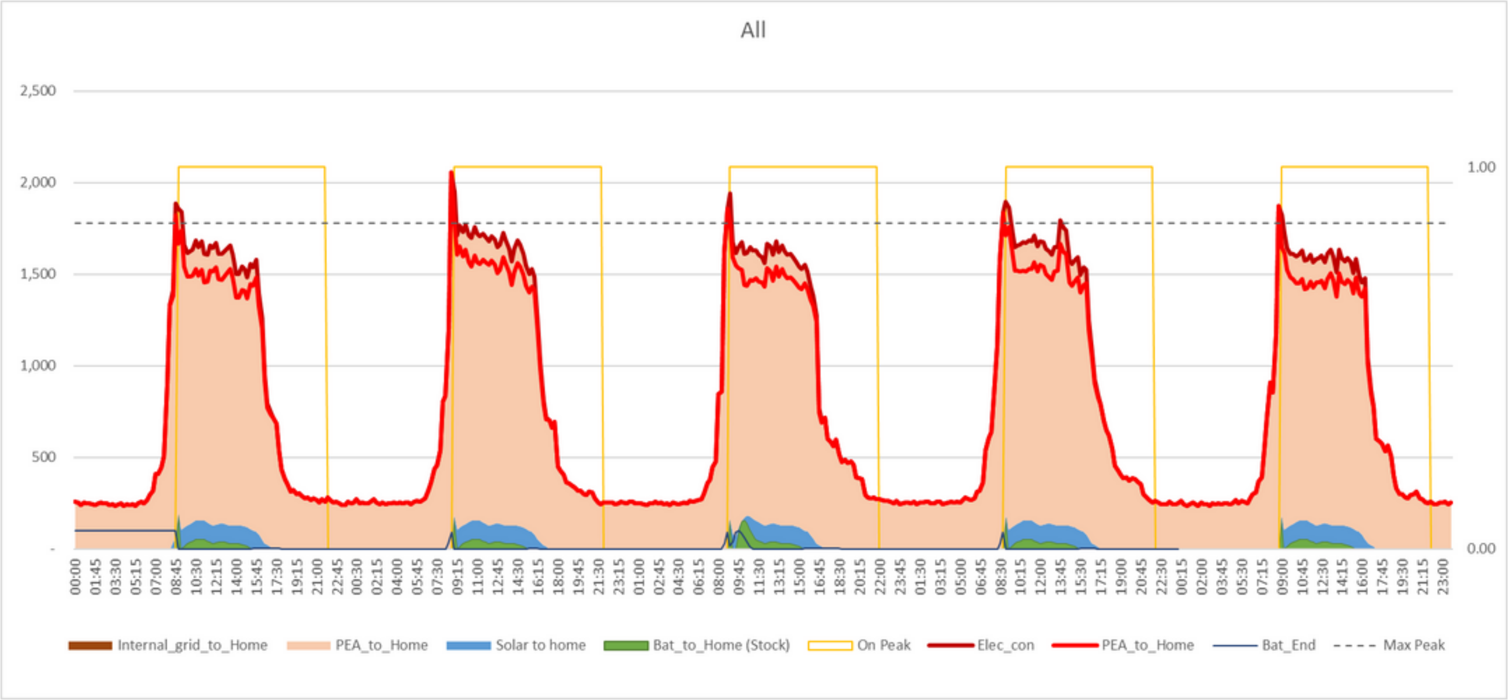
- Solar cell investment --> 1 kWp = 35,000 THB, Battery Storage --> 1 kWh = 15,750 THB
- Main saving = Solar cell installation (5.66%) or 5,709,245 THB/year
- Additional saving from Energy Management System (Case 4) = +0.86% (on-top solar cell) or 865,235 THB/year
- Feasibility Study: Case 4 (Battery + EMS system) has better Payback Period than Case 1 and Case 2

Battery size comparison

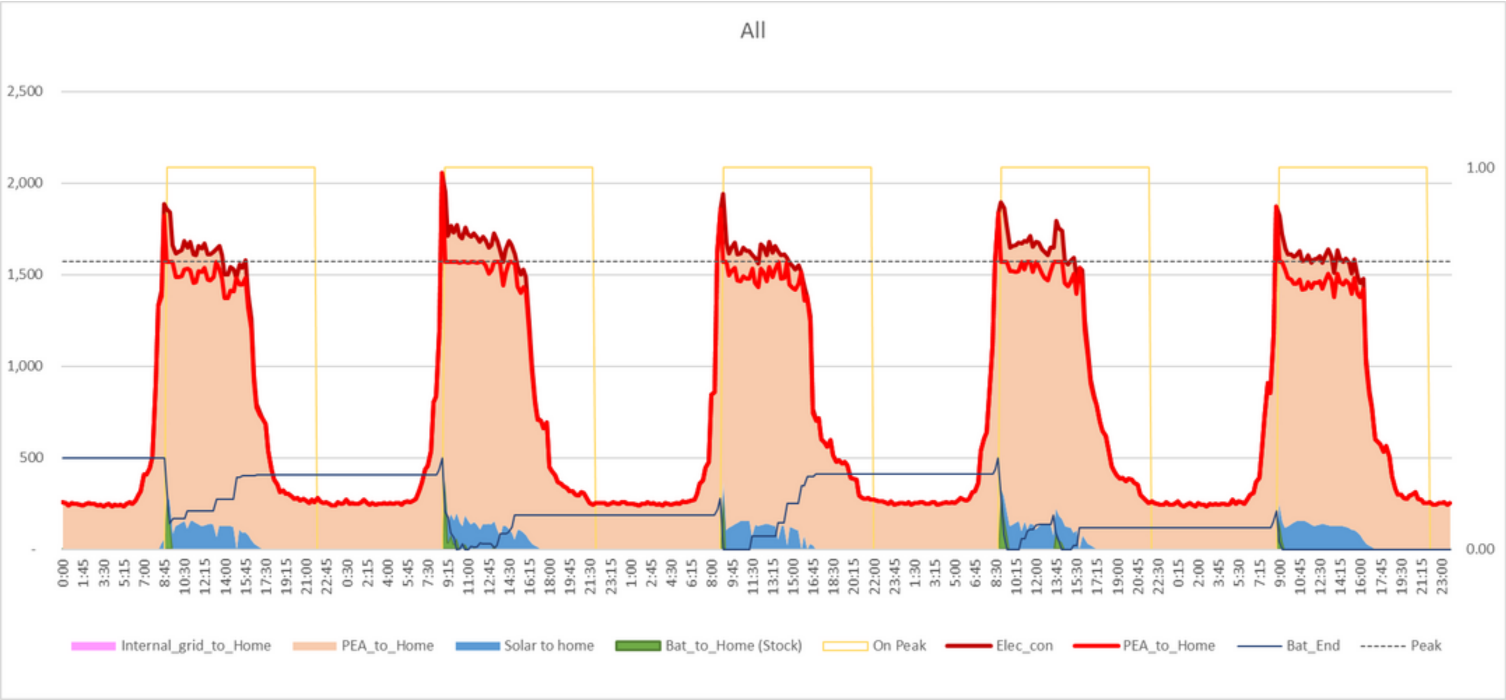
BATTERY SIZE COMPARISON



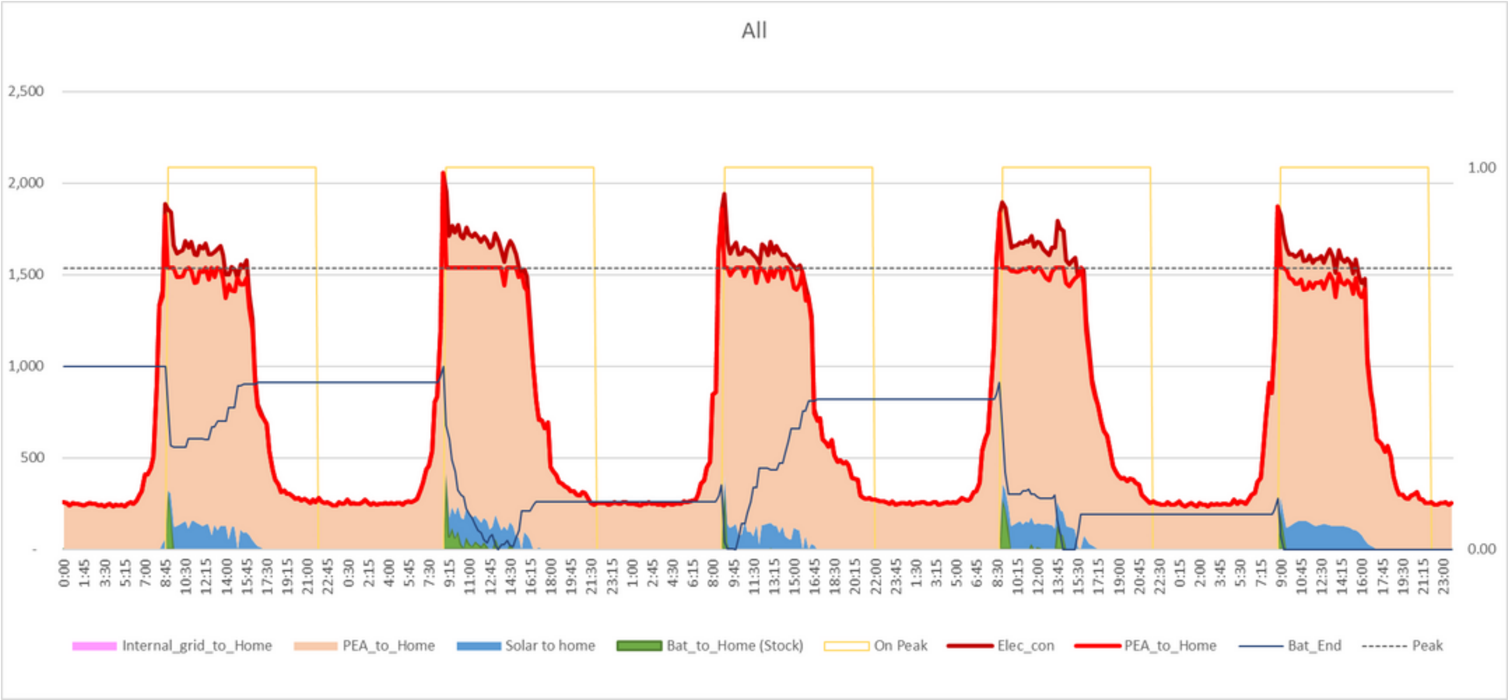
Solar + No Batter --> Peak load = 2,103



100 kWh --> Peak load = 1,758

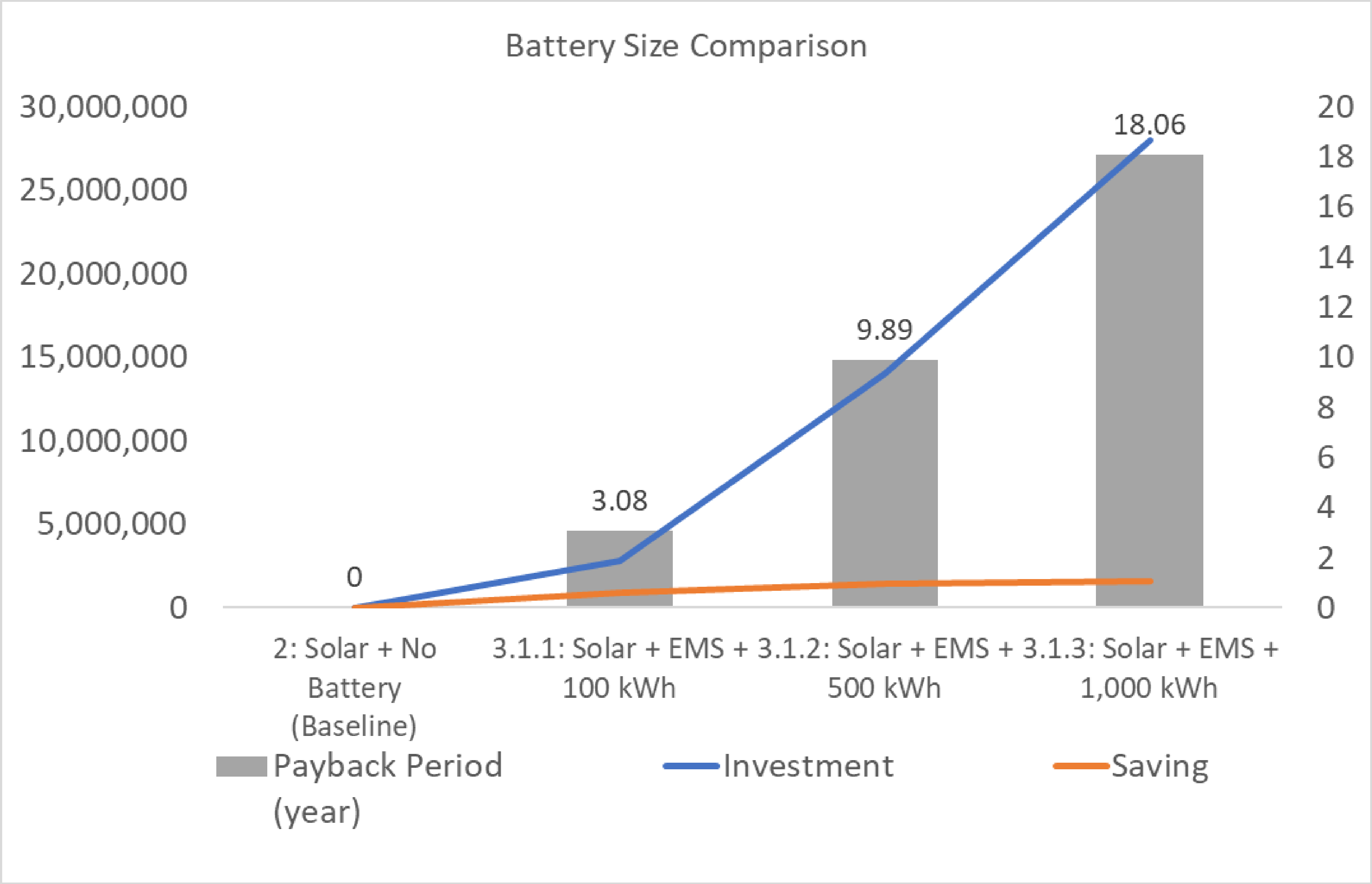


500 kWh --> 1,571 kW

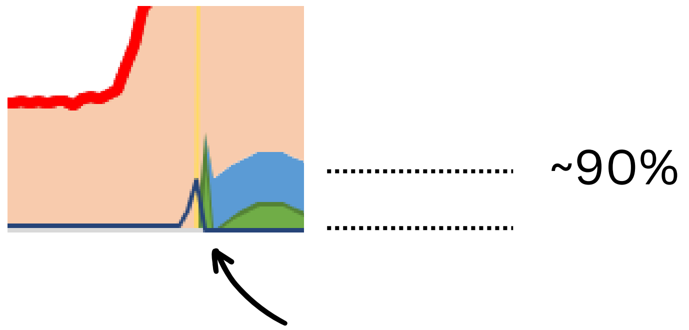


1,000 kWh --> Peak load = 1,535 kW

BATTERY SIZE COMPARISON



- Larger battery = Greater savings
- Bigger battery = extremely large investment
- 100 kWh is the best for NIDA



Battery Capacity ~ Solar cell generation during off peak period

Summary

SUMMARY

- Solar cell generation in NIDA area = 974.42 kWp
- The best case (base on Payback Period calculation) is

  "Solar cell + Battery 100 kWh + Energy Management System"
- Estimate investment cost = 36.90 MB
- Saving power cost = 6.57 MB/year
- Payback Period = 5.61 years
- Major saving = Solar cell installation
- Energy Management System can increase efficiency of solar cell system.

Observation/Suggestion

ENERGY MANAGEMENT SYSTEM (EMS)

- Integrating time series forecasting and optimization models into an Energy Management System (EMS) can optimize energy usage in solar cell systems by charging and discharging of power at the appropriate times.

- The feasibility study is preliminary and subject to change as it is based on assumptions regarding standard investment costs for solar cells and batteries, current electricity costs, and power consumption data for NIDA. Any changes in these parameters would affect the study's findings.

ENERGY MANAGEMENT SYSTEM (EMS)

- Currently, Energy Management System (EMS) technology does not feature Time Series Forecasting and Optimization capabilities.
- The implementation of this technique significantly reduced peak demand.
- This technique has broad applicability.
- In certain cases, it may be necessary to re-evaluate the battery size.
- In certain cases, it may be necessary to re-evaluate the forecasting model.

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WISDOM
for Sustainable Development

สร้างปัญญาเพื่อการพัฒนาที่ยั่งยืน

Thank You

Aj. Sarawut Jansuwan

Aj. Kannapha Amaruchkul