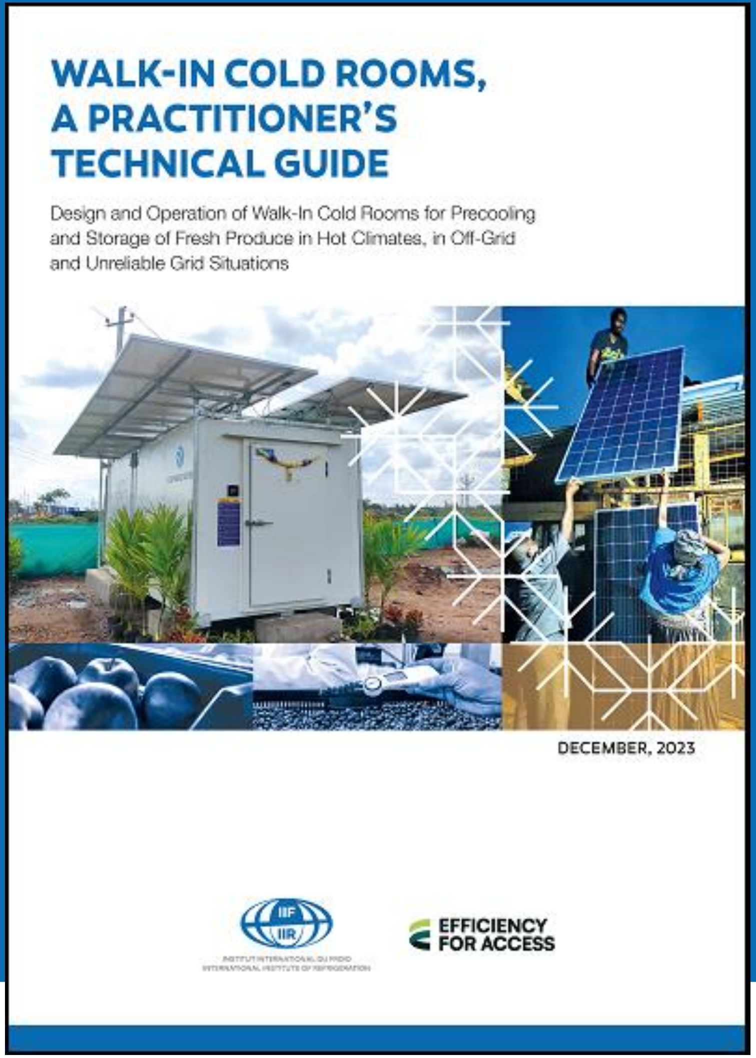

WALK-IN COLD ROOMS, A PRACTITIONER'S TECHNICAL GUIDE

Design and Operation of Walk-In Cold Rooms for Precooling and Storage of Fresh Produce in Hot Climates, in Off-Grid and Unreliable Grid Situations

DECEMBER, 2023

EFFICIENCY FOR ACCESS

Cool Insights:

How Much Cooling is Enough Cooling?

Estimating Cooling Demand and Electrical Power Demand

INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

EFFICIENCY FOR ACCESS

11 June 2024

Webinar programme

1) The Practitioner's Technical Guide to WICR
2) A roadmap to successful WICR projects
3) **Cold room plant and power sizing:**
    1) **Size and purpose of the cold room**
    2) **Quantifying cooling demand and plant sizing**
    3) **Types and sizing of the power supply**
4) Q&A on challenges faced by designers and buyers
5) Related initiatives and further resources

The Practitioner's Technical Guide to WICR

Souhir Hammami, IIR

Main Guide; plus Overview Guide in French and English

The Practitioner's Technical Guide is available free of charge here:
https://iifiir.org/en/fridoc (search for 'practitioner')

Scope of WICR types covered

Preassembled

Flat-packed kits, and customised

Reefers

Self-built

Size range 5 to 80m^3; chilled

Converted containers

Today's speakers

Bas Hetterscheid
Manager, Partnerships
Wageningen
University & Research

Giovanni Cortella
Professor,
Thermodynamics and
Refrigeration,
University of Udine

Jeremy Tait
Sustainable Products
Director,
Tait Consulting

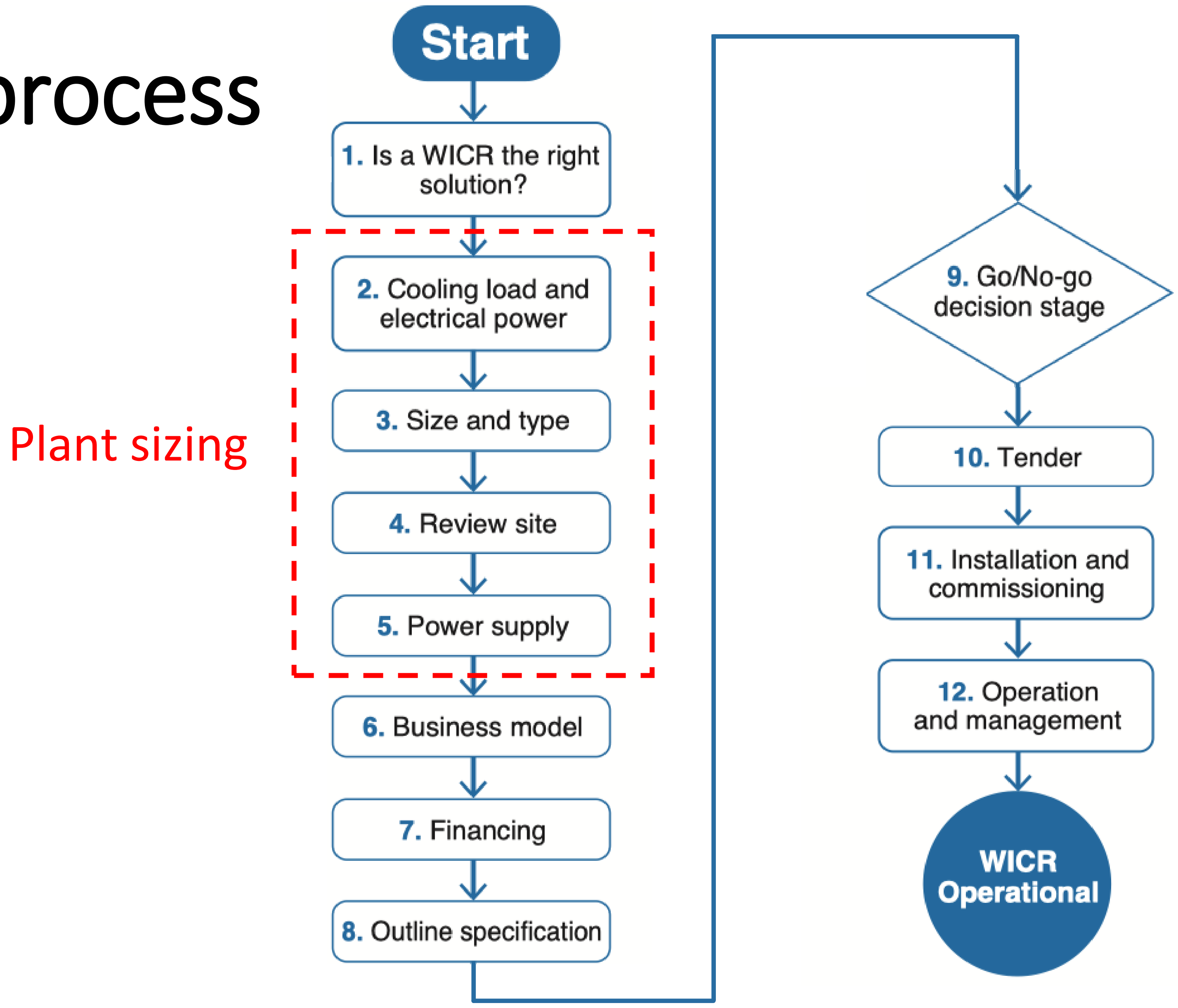
Victor Torres
Founder,
Solar Cooling
Engineering

A roadmap to successful WICR projects

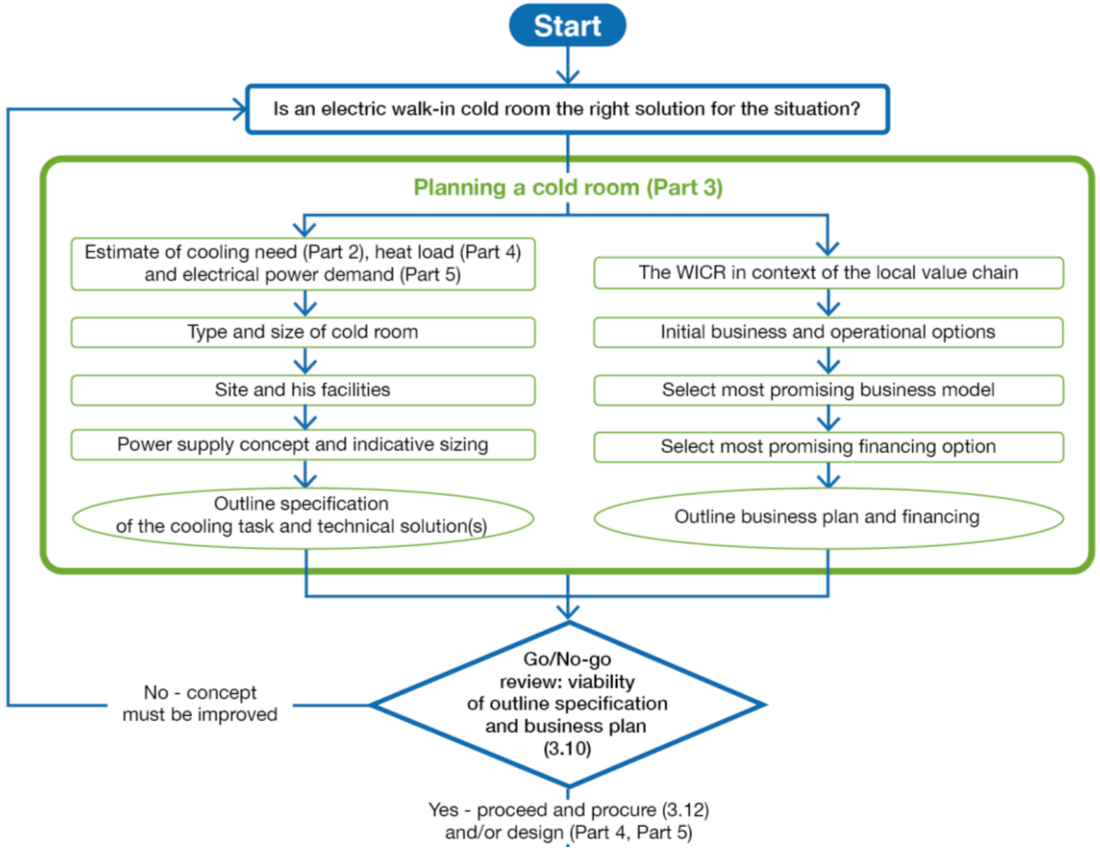
Giovanni Cortella, IIR

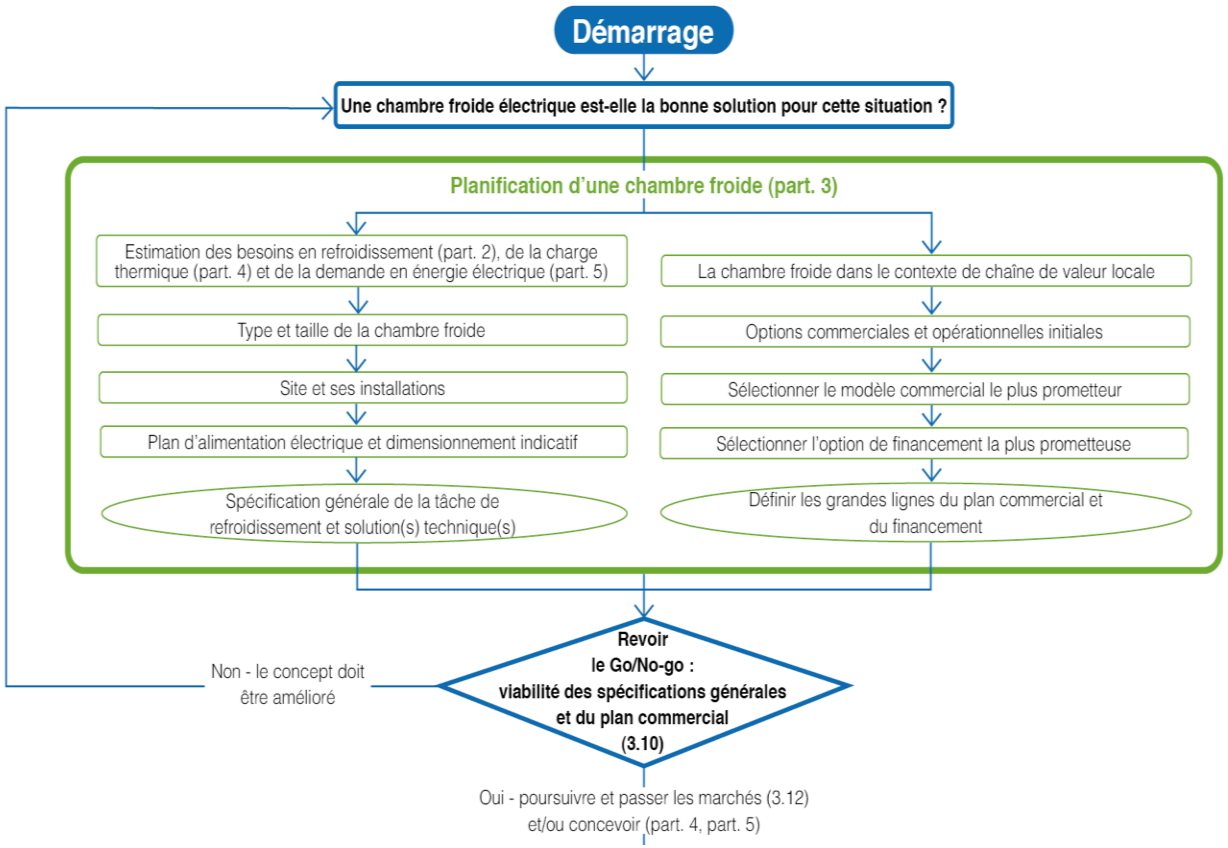
Holistic approach

The process

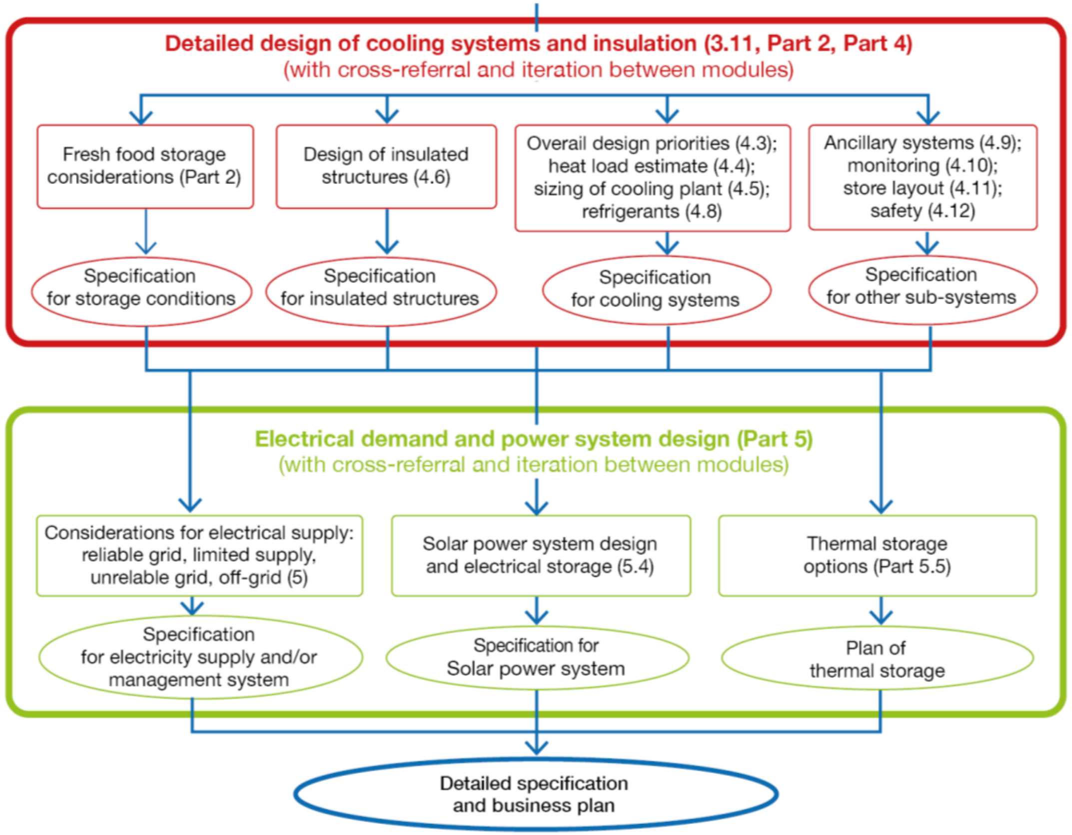

Start
1. Is a WICR the right solution?
Plant sizing
2. Cooling load and electrical power
3. Size and type
4. Review site
5. Power supply
6. Business model
7. Financing
8. Outline specification
9. Go/No-go decision stage
10. Tender
11. Installation and commissioning
12. Operation and management
WICR Operational

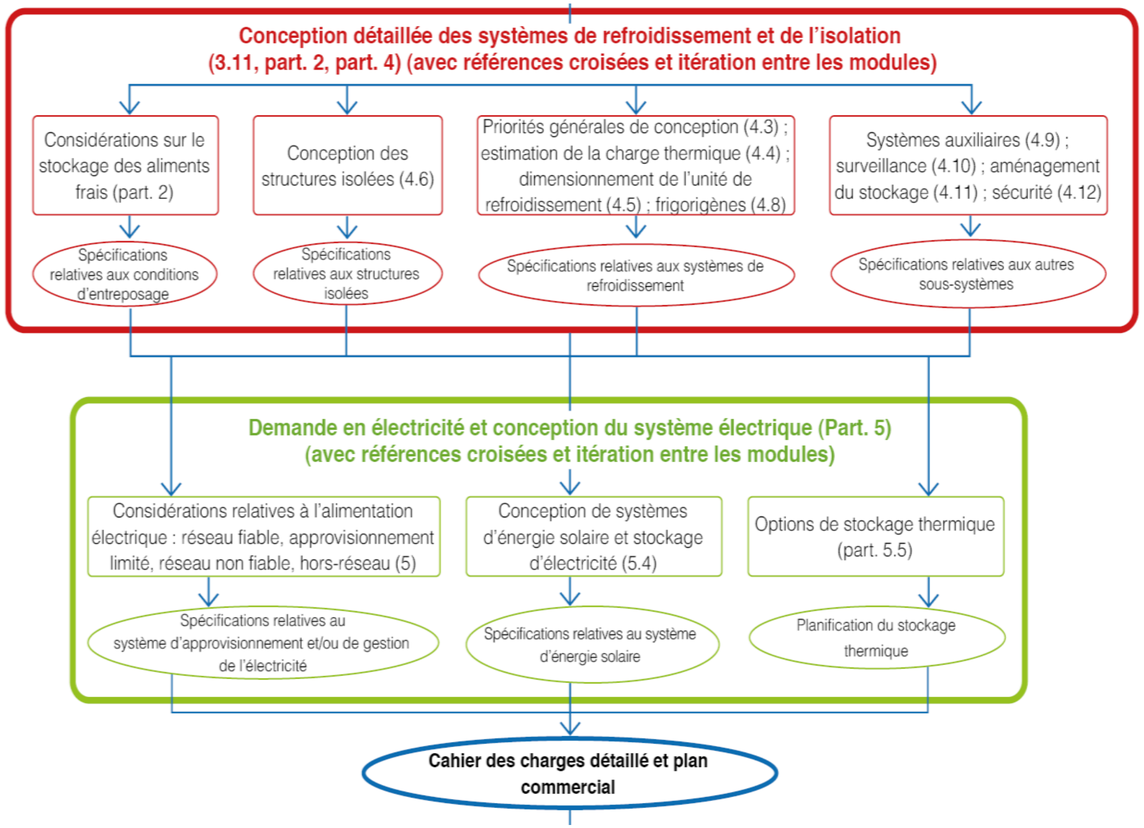
Plant sizing in the guide





Plant sizing in the guide



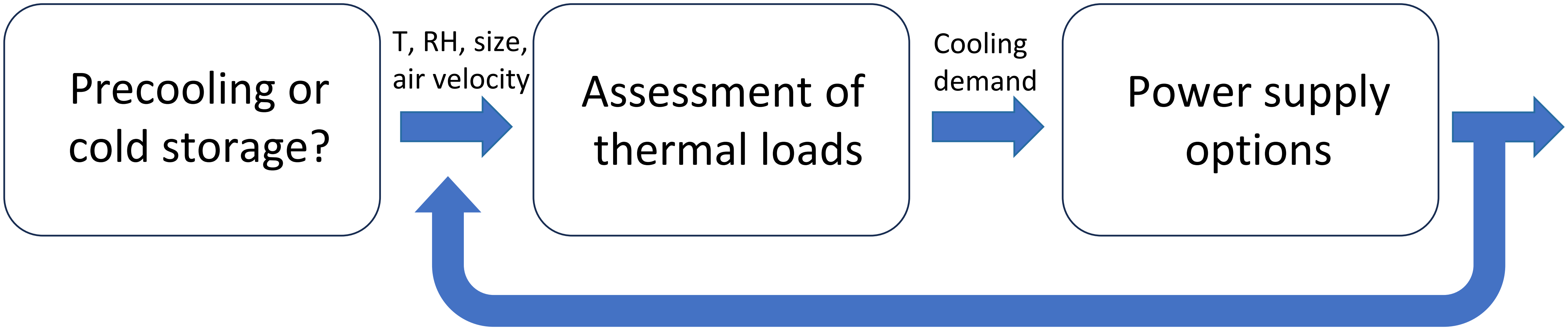


From cooling to power supply

- Effectiveness of precooling
- Timing from harvest to precooling
- Best practices

- External and internal heat loads
- Design day concept
- Technical options for precooling

- From cooling demand profile to electric power demand profile
- Power supply, energy storage



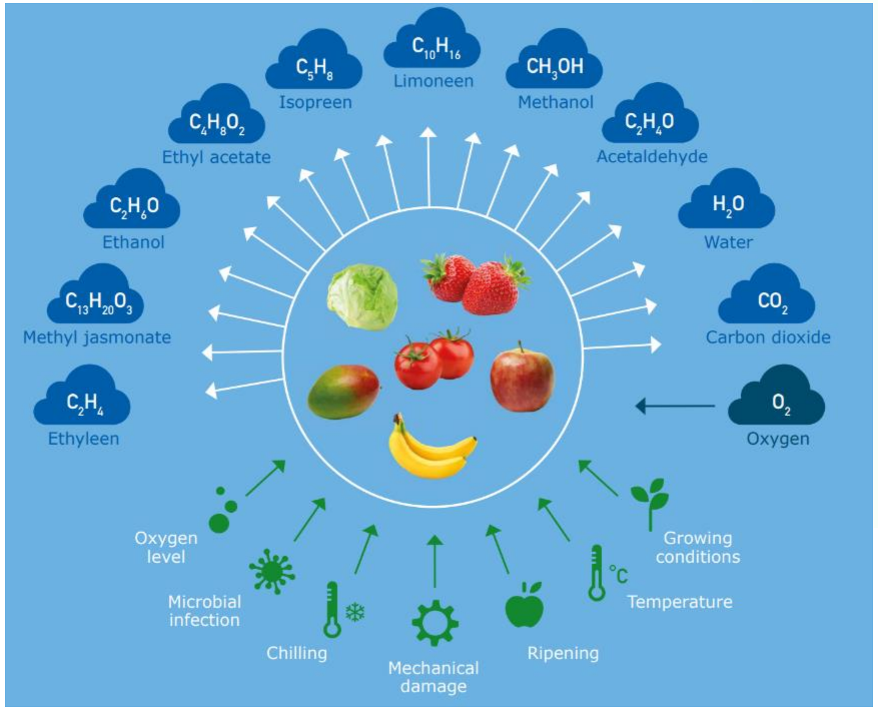
Cold room plant and power sizing:
1. Size and purpose of the cold room

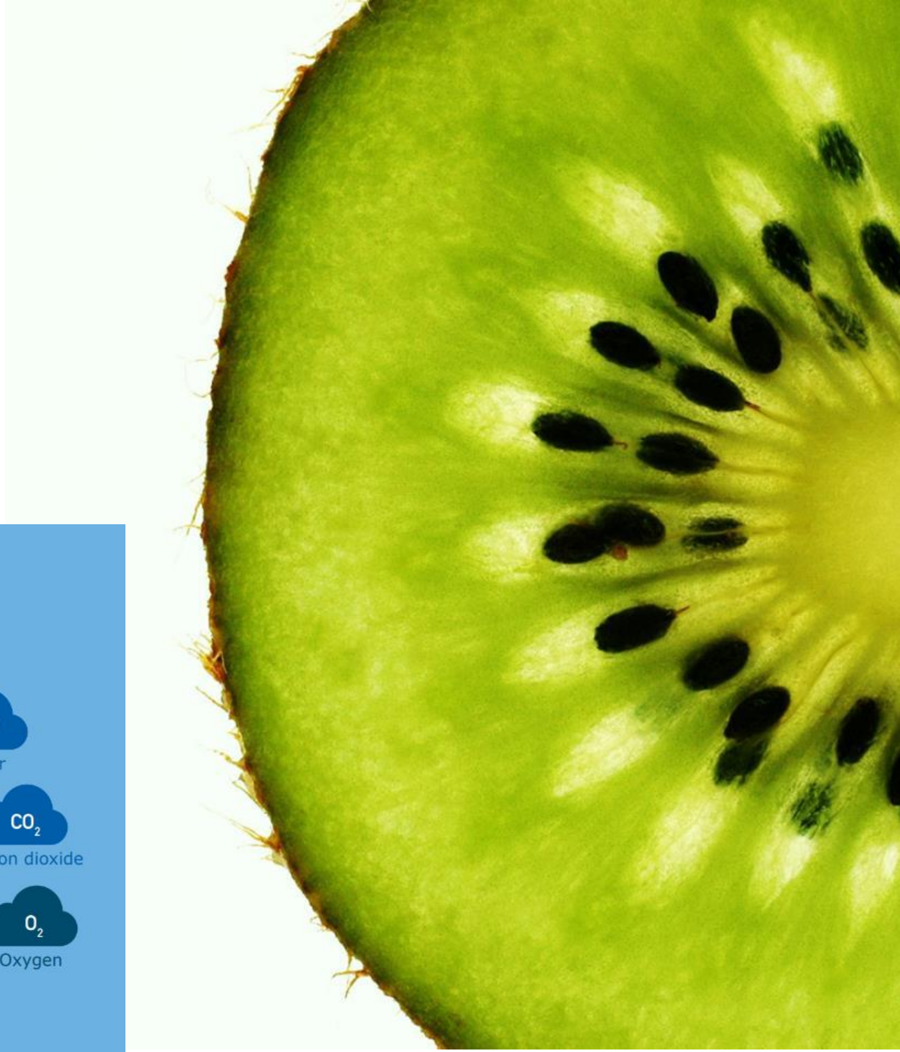
Bas Hetterscheid, Wageningen University and Research

Why is cooling so effective?

– Fresh fruits and vegetables are alive!
  - Breathing
  - Release heat
  - Dehydrates
  - Can be hurt
  - Get sick
  - Can die

Can be influenced with temperature, RH and airspeed





Impact of temperature, RH and airspeed

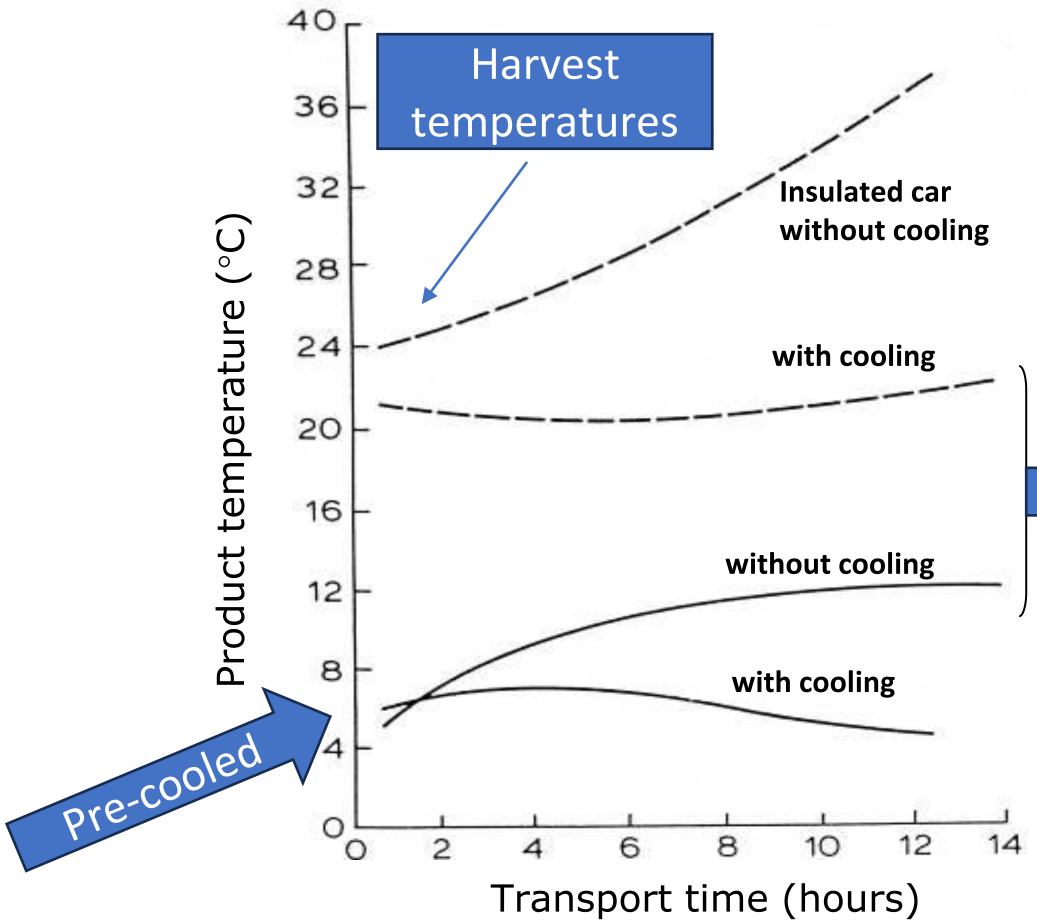
Factors ↘	If temperature is lower:	If temperature is higher:
Respiration	decreases	increases
RH (%)	increases	decreases
Water loss	decreases	increases
Microbial decay	decreases	increases
Ethylene production	decreases	increases
Ethylene sensitivity	decreases	increases
Chilling injury	risk increases	risk decreases

Factors ↘	If RH is lower:	If RH is higher:
Water loss	increases	decreases
Microbial decay	decreases	increases

Factors ↘	If airspeed is lower:	If airspeed is higher:
Rate of cooling	decreases	increases
Water loss	decreases	increases

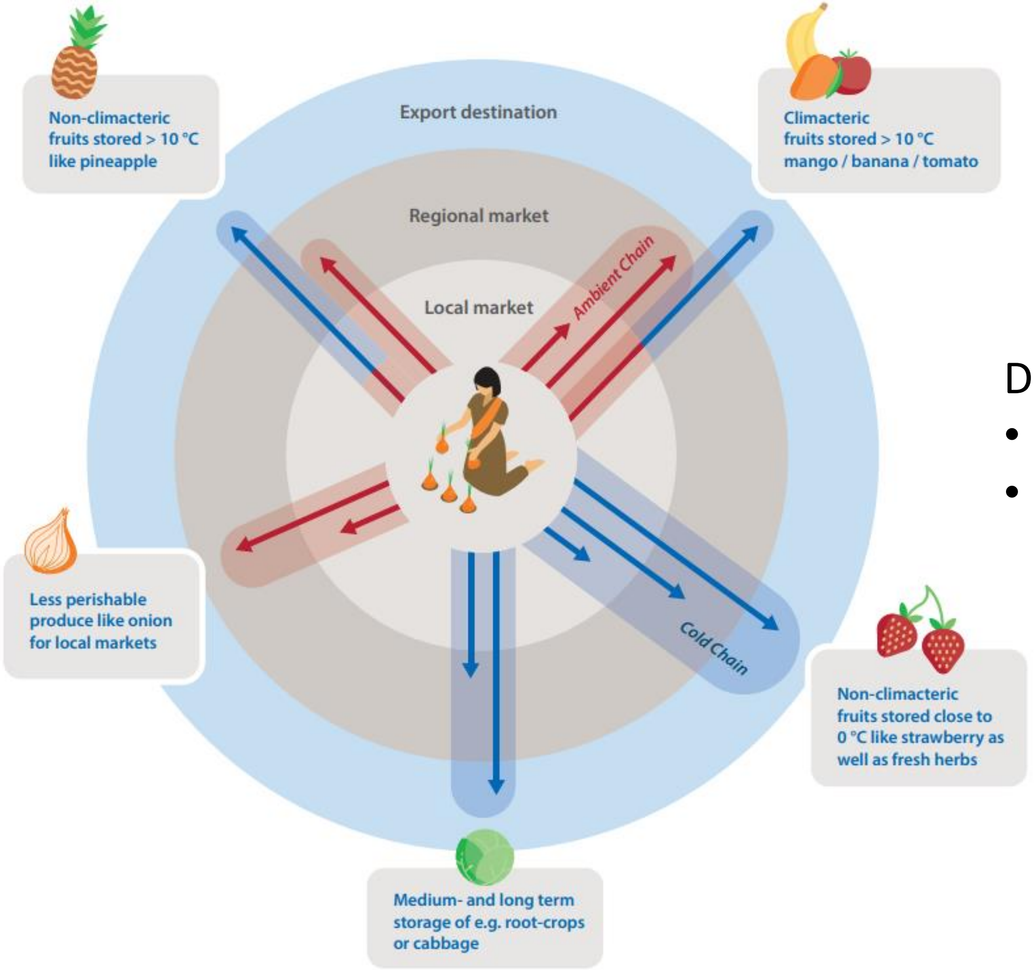
Source: Walk-In Cold Room, a Practitioner's Technical Guide (Section 2.3, page 26)

Pre-cooling – story of flowers



Conclusion:
Better to pre-cool and transport normally, than to only transport in refrigerated truck

When is (pre-)cooling needed?



Differentiate between need from:

- Postharvest perspective
- Economic perspective (limiting factor)

Source: Wageningen (2022): Postharvest assessment methodology - https://edepot.wur.nl/582556

Delay between harvest & start of cooling

Acceptable delay (hours)	Fresh produce	Consequence of extended delays between harvest and cooling
Vegetables		
4	broccoli	water and firmness loss, reduced shelf life
4	spinach	water loss
4	sweet corn	sugar loss
4-8	leafy greens	water and crispness loss
8	cauliflower	water loss
8	carrot	water and crispness loss
8	cucumber	water loss, yellowing
8	green beans	water and crispness loss
8	summer squash (soft skin)	water loss
16	tomato	increased decay and rapid ripening

Acceptable delay (hours)	Fresh produce	Consequence of extended delays between harvest and cooling
Fruit		
2	berries	water loss, decay, loss of visual quality
8	cantaloupe melon	water loss
8	mandarin	increased rind disorders, decay
8	watermelon	loss of sugar and texture if above 27°C
12	avocado	premature ripening with high fruit maturity
16	honeydew melon	loss of firmness, ripening
16	orange	increased rind disorders, decay
16	pomegranate	water loss
16	persimmon	water loss
24	grapefruit	water loss, increased rind disorders, decay

Source: Walk-In Cold Room, a Practitioner's Technical Guide (Section 2.3.1, page 28, table 2.3)

Storage life at optimal temperatures and RH

Crop	Storage temp (°C)	RH (%)	Ethylene production	Ethylene sensitivity	Approx. storage life (weeks)
Banana	13-15	85-95	M	H	1-4
Cabbage	0	95-100	VL	H	20-24
Carrot	0-1	95-100	VL	H	20-24
Cassava	0-5	85-95	VL	L	4-8
Cocoyam *(Xanthosoma)*	7-15	80-85	VL	L	12-20
Collards	0	95-100	VL	H	1-2
Courgette (zucchini), summer squash	5-10	90-95	L	M	1-2
Cucumber	10-13	85-90	L	H	1-2
Eggplant (aubergine)	10-12	90-95	L	M	1-2
Lettuce	0	95-100	VL	H	2-3
Loquat	0-5	90-95	-	-	3
Lychee (litchi)	1-5	90-95	M	M	3-5
Mandarin	5-10	90-95	VL	M	2-4
Mango	10-13	85-90	M	M	2-3
Okra	7-10	90-95	L	M	1-2
Onions (dry bulbs)	0	65-75	VL	L	4-32
Onions (green)	0	95-98	L	H	1-4

Source: Walk-In Cold Room, a Practitioner's Technical Guide (Section 2.3.1, page 29, table 2.4)

Pre-conditions & considerations

– Early morning harvest (lower temperature)

– Pre-cooling in separate room

– Ensure air can flow around product (prevent overfilling)

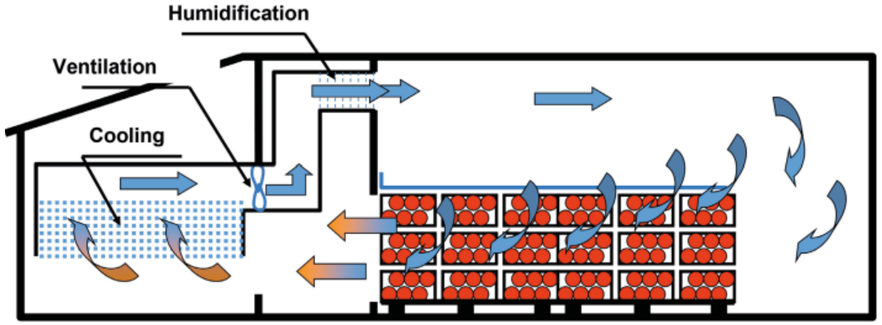
– After pre-cooling, move directly into cold room (preventing water loss due to rapid airflow)

Source: Walk-In Cold Room, a Practitioner's Technical Guide (Section 2.3.2, page 31)

Pre-conditions and best practices

Early morning harvest
(lower temperatures)

Pre-cooling in separate room
Keep cooled and to be cooled product apart

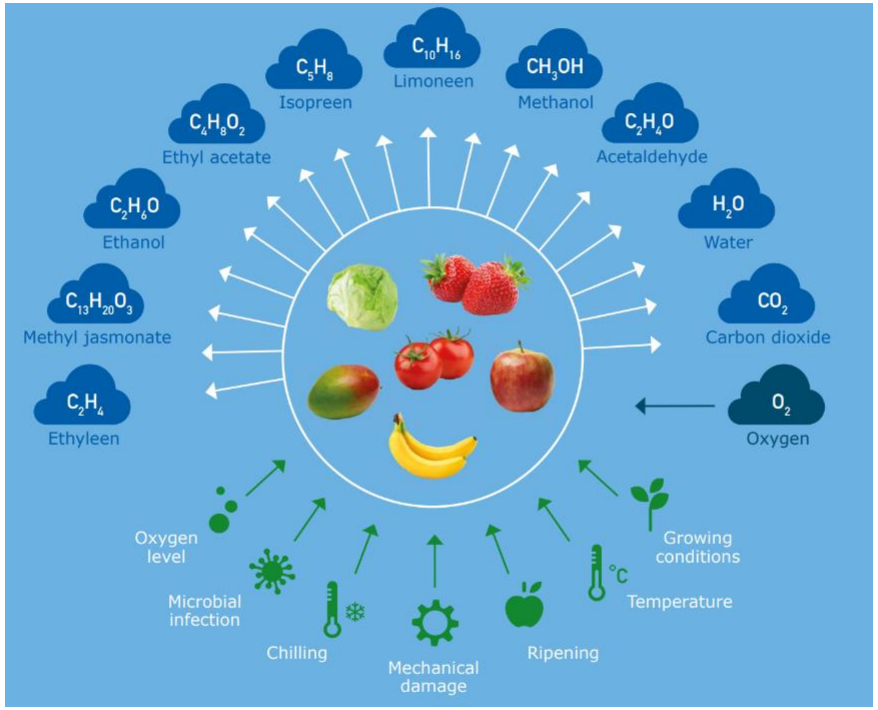


Ensure air can flow around product (prevent overfilling)

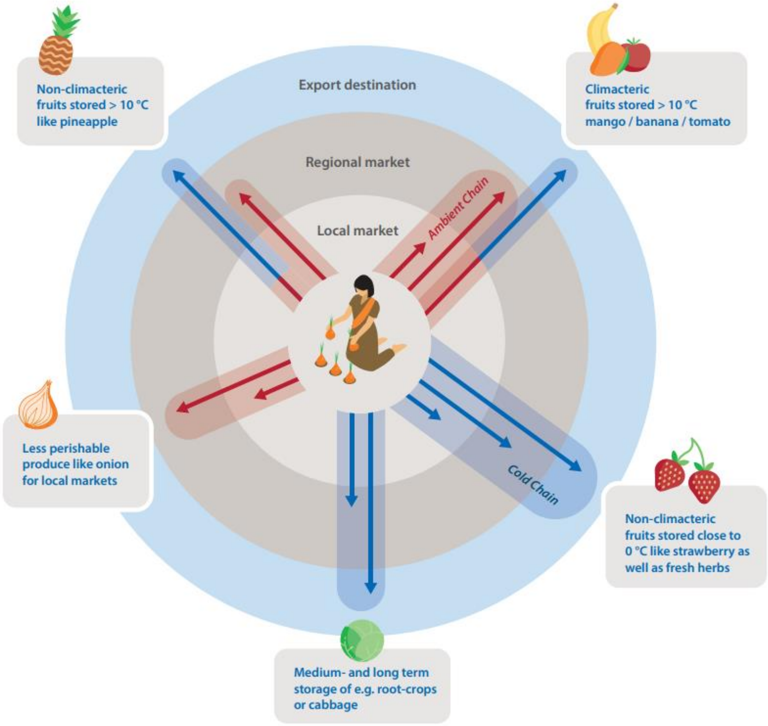
Source: Walk-In Cold Room, a Practitioner's Technical Guide (Section 2.3.2, page 31)

Recap

1: Product are alive; treat them as they like (Handling, temperature, RH)



2: Value of pre-cooling (Postharvest vs economical)



Cold room plant and power sizing: *2. Quantifying cooling demand and plant sizing*

Jeremy Tait, Tait Consulting GmbH, and IIR

The ‘Design Day’: a representative cooling demand level, chosen from the demand profile

Cooling demand varies with:

- Volume and temperature of produce loaded (including precooling?)
- Ambient temperature by day, week and time of year
- Thickness & type of insulation, other design features
- How well operation of store is managed
- Number of door openings
- Storage set point temperature
- Type of produce
- Future plans (expansion, higher utilisation)
- And more

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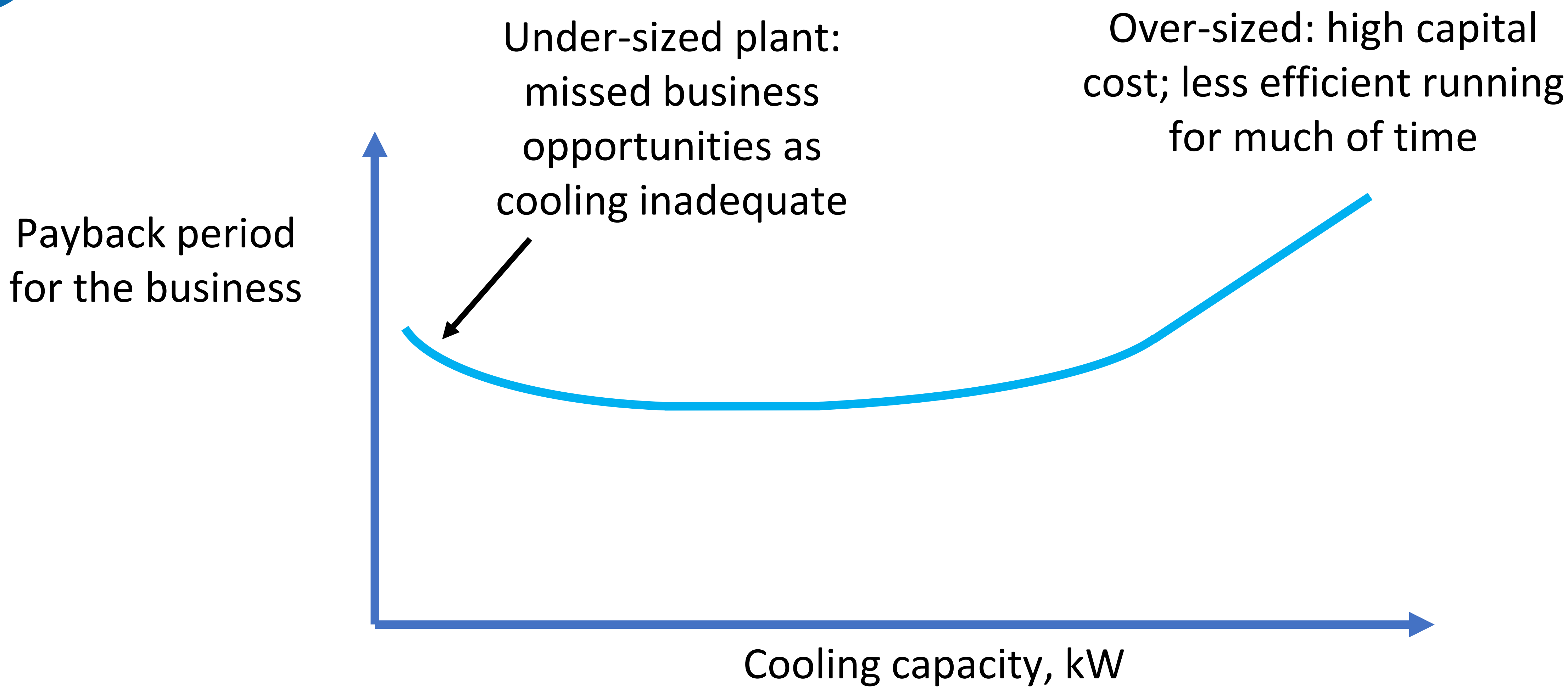
- How well operation of store is managed
- Number of door openings
- Storage set point temperature
- Type of produce
- Future plans (expansion, higher utilisation)
- And more

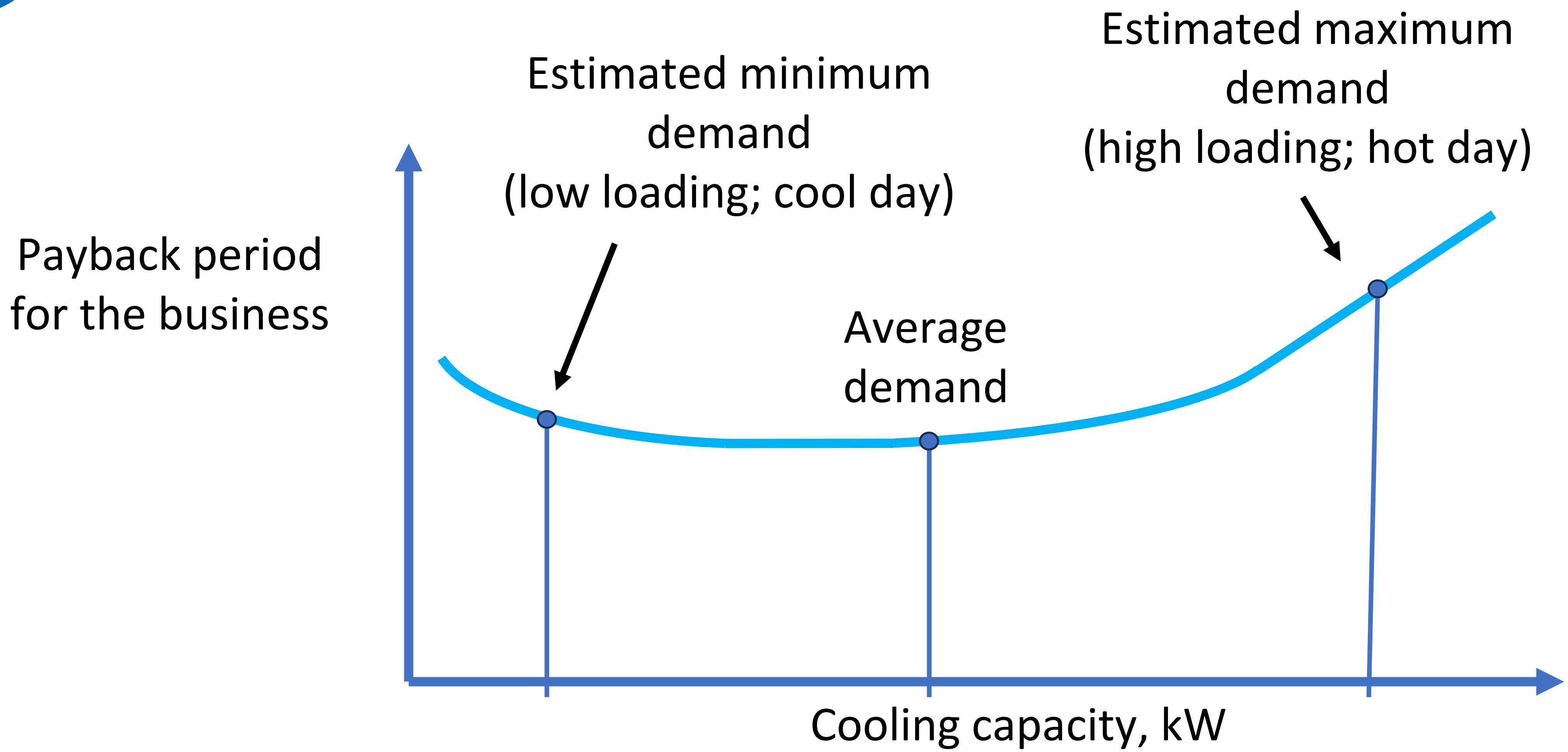
- The 'design day' demand is indicative for plant sizing
- A compromise between capacity and cost
- Somewhere between demand of a Typical Day and a Peak Day
- Should take advantage of thermal storage

Main Guide ➡️ *Sections 4.4, 4.3.5*

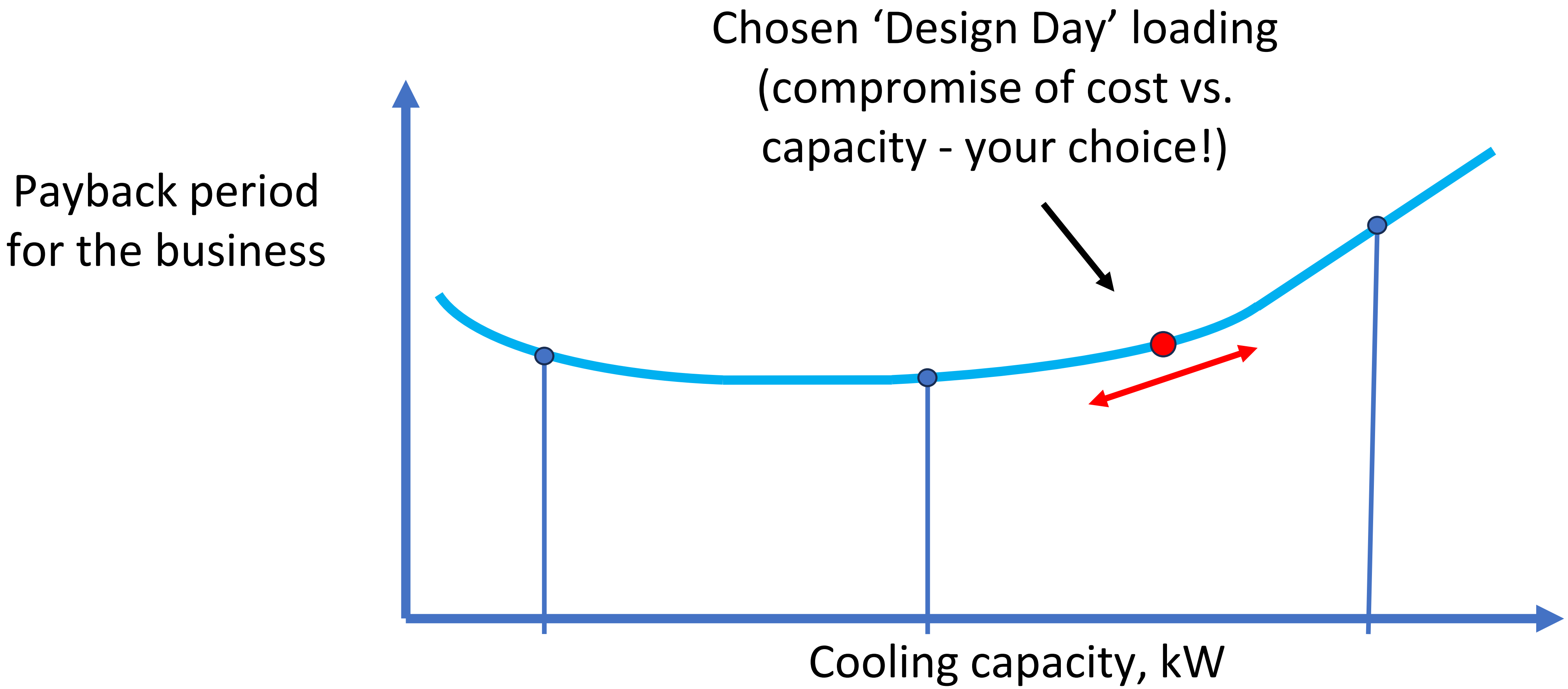
Sizing of plant – risk and cost



Sizing of plant – risk and cost

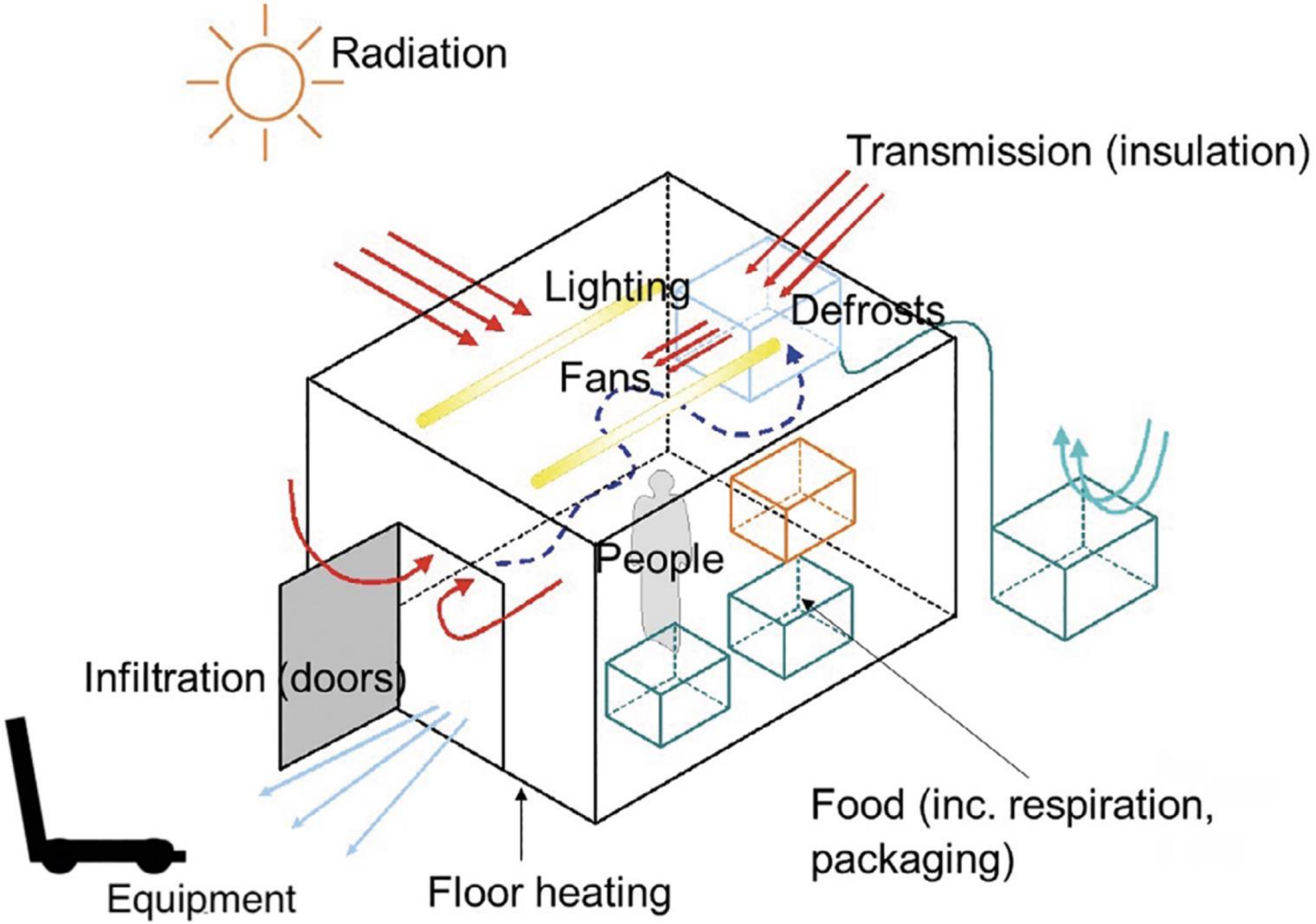


Sizing of plant – risk and cost



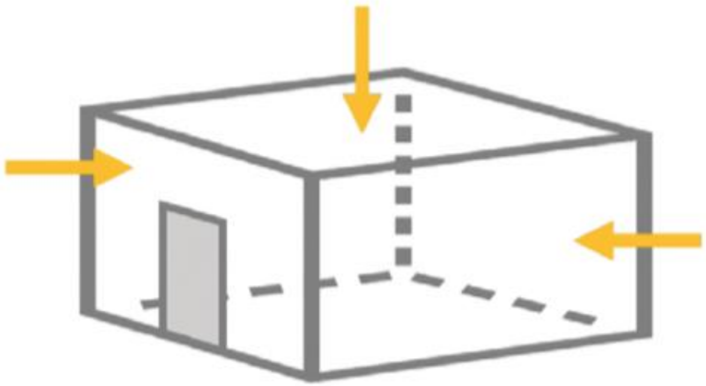
Each heat load can be estimated

- Estimating loads ➡️ *Section 4*
- Consider thermal storage to meet peak loads ➡️ *Section 5.5*
- Matching capacity with power availability ➡️ *Section 5.5.3*



Suggestion: start simple

- Calculate the heat through the insulation on a typical day. Compare it with the cooling capacity of the refrigeration plant.
- *What capacity is left for all other demands?*



Transmission

4.14.3 Heat through the insulation (transmission)

The shape of the cold room can generally be assumed to be a rectangular box. The heat load through the cold room walls is calculated using (2). Since this includes the solar gain temperature (T_s), this calculation must be made separately for any surfaces that are in direct sun (see Subsection 4.15.3 Solar gain):

$$Q_w = U \cdot A_w \cdot (T_0 - T_i + T_s) \qquad (2)$$

The overall heat transfer coefficient, U is calculated using (3).

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} + \frac{\Delta_w}{k_w} \qquad (3)$$

Most chilled cold rooms will have wall panels at least 100 mm thick. Some typical values for thermal conductivity are presented below. Calculation of transmission across cold room walls provides an

Main Guide ➡️ *Section 4.14.3*

Some benchmarks for cooling capacity

Table 4.1

Approximate refrigeration capacity for small scale cold rooms. *Source: Thompson J.F. and Spinoglio M., 1996.*

Size of cold room (m^2)	Storage capacity (MT)	Range of refrigeration capacity (kW)	
		Target = 1°C	Target = 13 °C
10	3	3.5	2.6
20	6	5.3-8.8	3.5-5.3
40	12	12.3-14.1	7.0-10.6
60	18	17.6-22.9	10.6-14.1
80	24	22.9-29.9	14.1-19.4
100	30	26.4-35.2	15.8-24.6

Main Guide ➡️ *Section 4.5*

Lower number is for moderate climates;
Higher number is for hot climates (lowland tropics, semi-arid regions).

Effective cooling needs cold *and* air flow

Air flow m³/hr

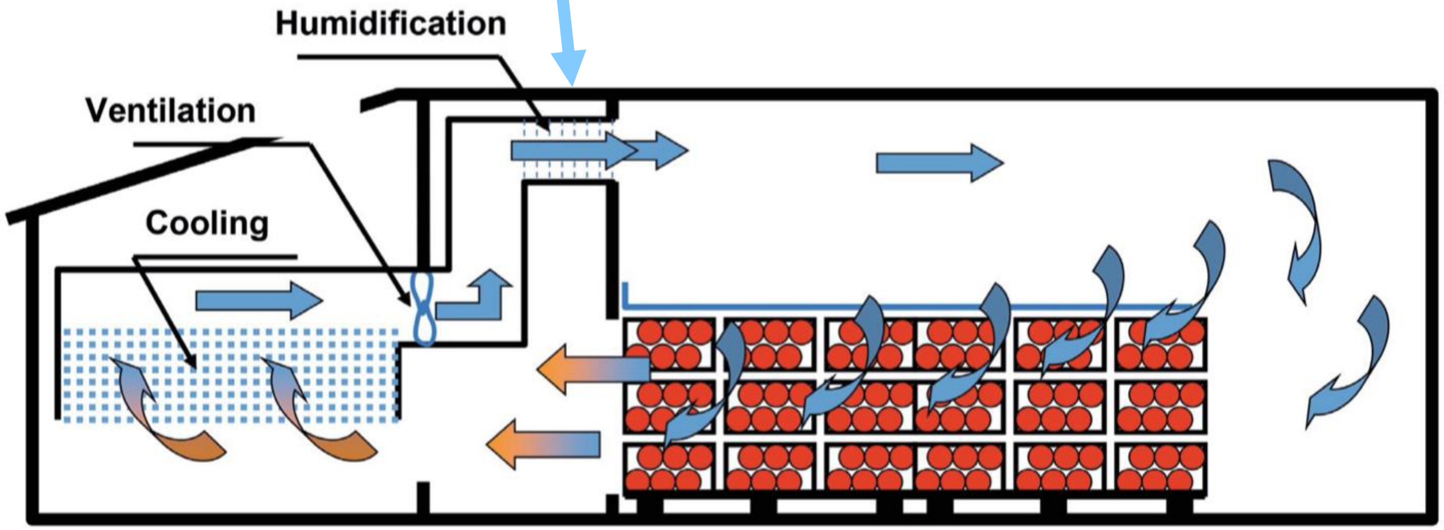


Figure 2.5

Example configuration for precooling of produce, with forced air circulation drawn through the racked produce and in which air is cooled using thermal storage (source: *Solar Cooling Engineering and Josef Streif*).

Effective cooling needs cold *and* air flow

$$\frac{\text{Air flow } m^3/hr}{\text{Total storage volume in } m^3} = \text{Air changes per hr}$$

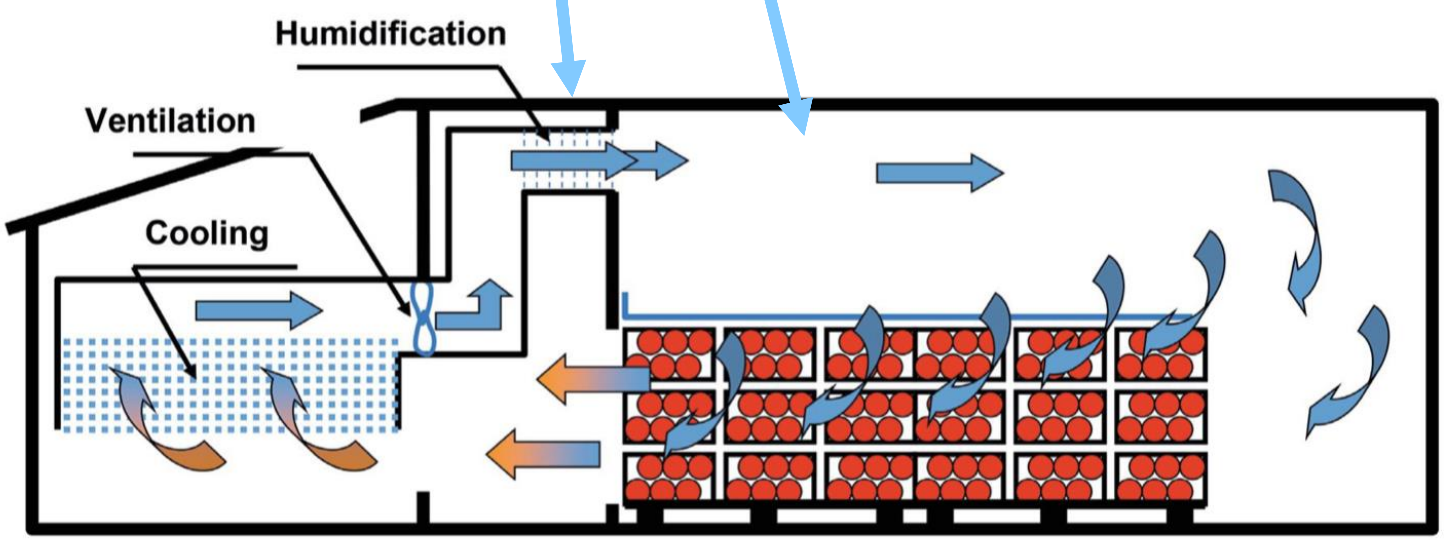


Figure 2.5

Example configuration for precooling of produce, with forced air circulation drawn through the racked produce and in which air is cooled using thermal storage (source: *Solar Cooling Engineering and Josef Streif*).

Benchmarks for air flow:

Number of times per hour the air in the chamber is drawn through the evaporator / thermal store by the fans

EU best practice suggests:

– For storage, 50 x per hour

– For pre-cooling: 120 x per hour

(Benchmarks are needed for Global South and off-grid systems! – Ongoing work)

Main Guide ➡️ *Sections 4.3.4, 4.11.2, 4.11.3, 7.7.5, 2.3.7*

Convert cooling demand to an electrical demand

- Electrical demand of monobloc cooling unit quoted in brochure
- Electrical demand of custom assembled systems can be added from components (compressor; condensing unit; evaporator fans; defrost; controllers etc)

Main Guide ➡️ *Section 4.14.3*

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- Electrical demand of monobloc cooling unit quoted in brochure
- Electrical demand of custom assembled systems can be added from components (compressor; condensing unit; evaporator fans; defrost; controllers etc)

Main Guide ➡️ *Section 4.14.3*

Add other loads:

- Heaters (door seal, other)
- Other controls and loggers
- Lights
- Battery charging
- Other demands for equipment and staff
- ***> Estimate the Design Day electrical demand profile for the electrical system sizing***

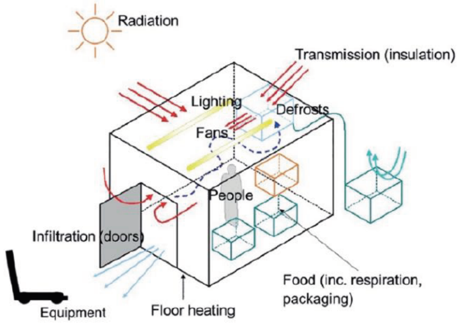
Cold room plant and power sizing: *3. Types and sizing of the power supply*

Victor Torres, Solar Cooling Engineering GmbH

Review of sizing process

Loads

1. Transmission through walls, ceiling and floor, solar gain
2. Air infiltration at door openings and fresh air exchange (for dispersing ethylene and CO_2)
3. Heat from fan, motors, and lights
4. Defrost
5. Heat from precooling produce (best practice: using a separate cooling plant)
6. Heat from any produce and packaging
7. Heat generated by respiration of produce
8. Heat from equipment and staff
9. Cooling of thermal storage



Convert heat load to an electrical demand

- List heat load elements
- Assess heat loads over days/seasons and consider use of thermal storage to estimate a 'Design day' heat load and profile
- If packaged refrigeration unit is used, look up its power demand;[1] or for bespoke cooling plant, estimate COP to calculate power[2]
- Add up all electrical loads to estimate power demand
- Specify power system to meet electrical demand
- Refine design, heat loads and cooling - iterate to balance cost and service

1 Use the rated electrical input power of the condensing unit at the envisaged temperature and duty

2 Estimate COP: using the cooling capacity and an assumed or calculated coefficient of performance (COP), knowing that COP = (delivered cooling capacity, kW) / (input power, kW)

Types of Power Supply

Reliable grid:

- electrical grid connection with sufficient quality of voltage and frequency and continuity of supply ≥22 hours power per day

Limited supply:

- electrical supply of reasonable or good quality but operating hours of <22 hours per day

Unreliable grid:

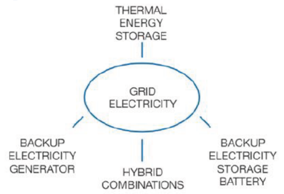
- electrical grid is available, but power is subject to highly variable quality and reliability often without prior notice of problems →some form of electrical or thermal storage is essential

Off-grid supply:

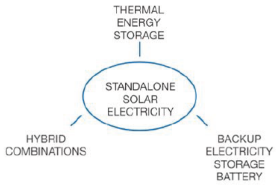
- no electricity grid connection is available at the site →standalone generation system is therefore required

Power Supply Strategies

Strategies for reliable and limited grids



Strategies for unreliable grid and off-grid



The back-up strategy must consider:

- For how long is an operation without power necessary
- Temperature sensitivity and economic value of the produce
- Costs of the backup including lifespan, maintenance and repair
- Environmental impacts
- Energy efficiency

Example design of a WICR

- 20 feet container size
- 100 mm PU insulation
- 2 °C WICR Temperature
- 35°C Ambient max.

Source: WeTu, Kenya

Table 5.6

Example of sizing of components for a 20 ft container cold room, off-grid with energy storage.

	Chilled storage	
Room temperature	2	°C
Outdoor temperature	35	°C
Refrigerating unit running time	24	h/day
Solar energy availability time (on PV time)	8	h/day
Autonomy (off-grid hours)	16	h
Length x Width x Height	2.30 x 6.00 x 2.30	m
Room walls surface area	51.98	m^2
Room floor surface area	13.8	m^2
Insulation material	Polyurethane	
Thickness	100	mm
Floor insulation	0	mm
U-value insulation panel	0.21	W/m^2K
Cooler fans	70 - 12	W - h/day
Illumination	25 - 3	W - h/day
Products	Vegetables	
Heat loads		
Transmission losses	581	W
Ventilation losses	464	W
Other heat sources	915	W
Respiration	24	W
Total Heat loads	1984	W

Heat load of pre-cooling (kg/day) needs to be added depending on the user-case!

Cooling System and Power Supply

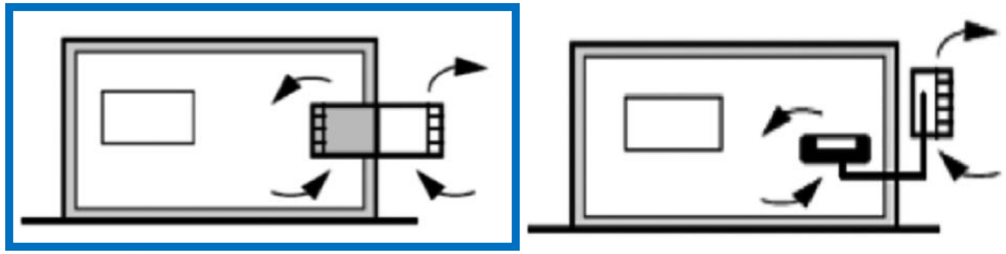


Figure 4.2
Through the wall packaged unit or monobloc (left) and split type unit (right).

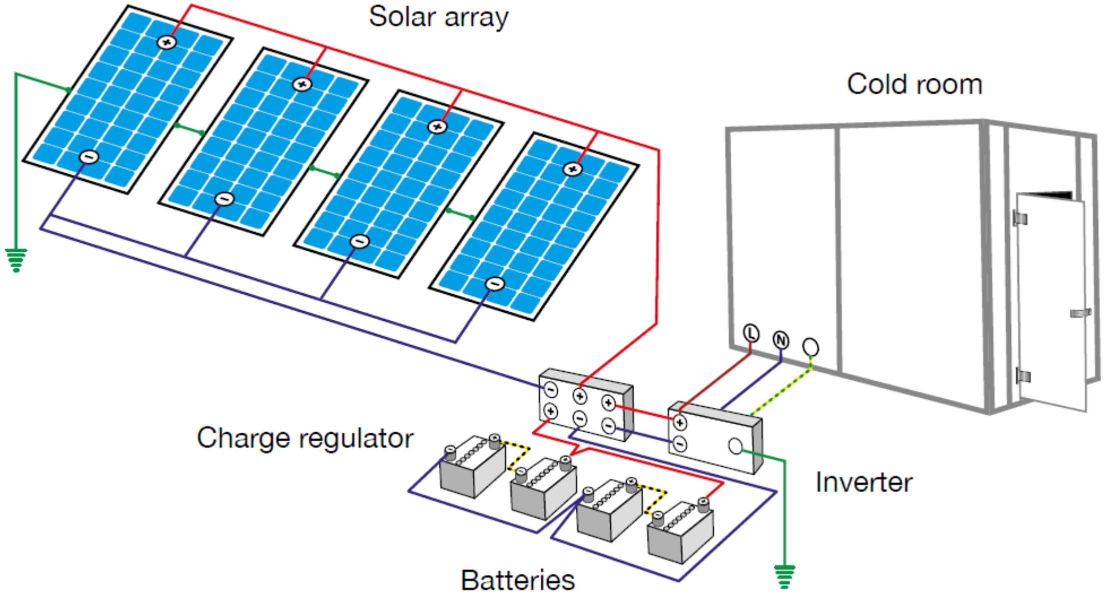
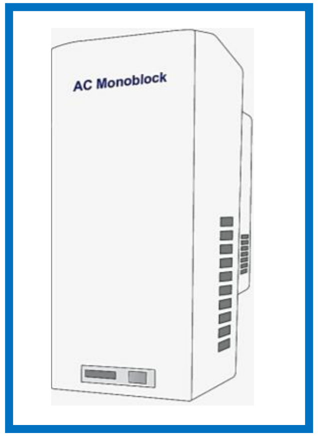


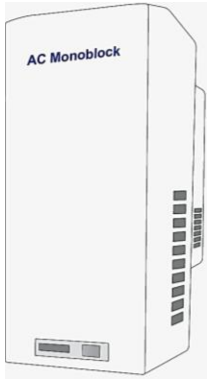
Figure 5.8
Key components of a battery-based PV system for AC loads.



- Which monobloc do we need?
- What size solar system is right for us?
- Is electrical or thermal storage cost efficient?

Cooling Demand and Energy Consumption

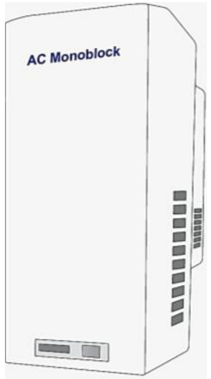
Total Heat loads	1984	W



Model	Compressor Input power	Cooling capacity * *Ambient Temperature 35 °C* according to cold room temperature		
		0 °C	5 °C	10 °C
	W	W	W	W
1	520	1 050	1 220	1 410
2	680	1 340	1 560	1 780
3	940	1 824	2 170	2 540

Cooling Demand and Energy Consumption

Total Heat loads	1984	W



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1	520	1 050		1 220	1 410
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3	940	1 824	1962	2 170	2 540

2°C

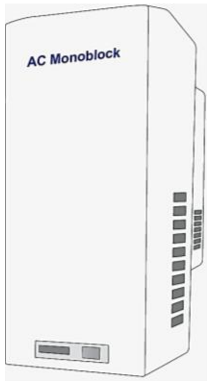
COP = 2.08

Coefficient of Performance

For 2°C and 35°C Ambient

Cooling Demand and Energy Consumption

Total Heat loads	1984	W



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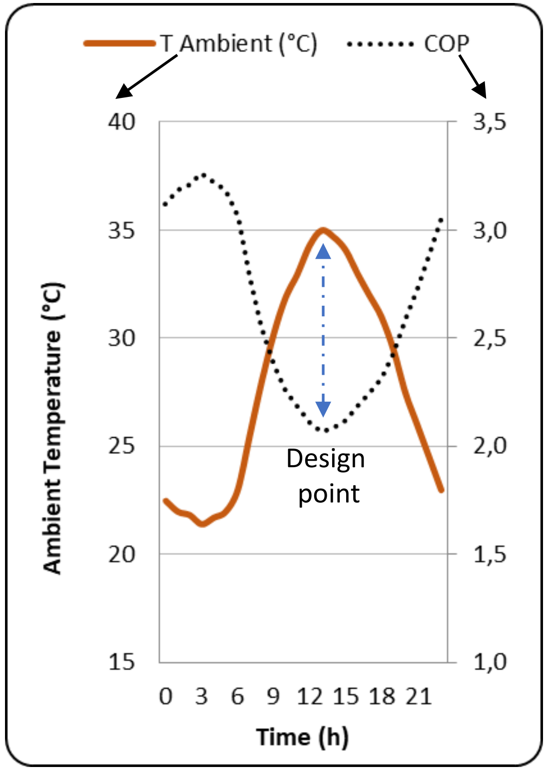
1962

2°C

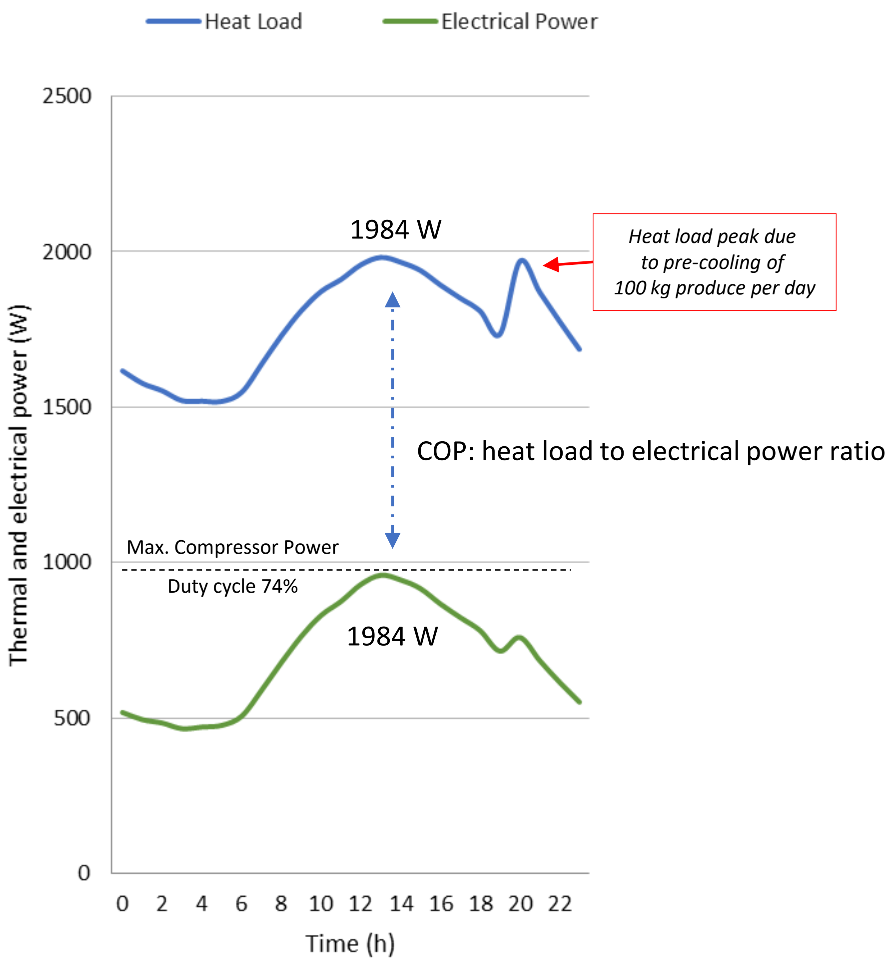
COP = 2.08

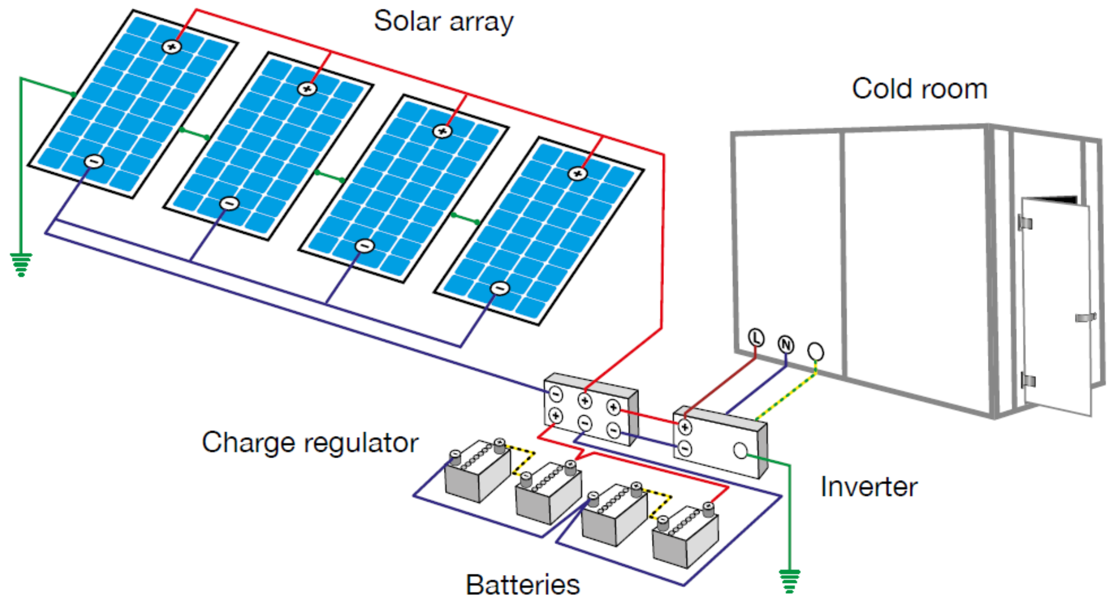
Coefficient of Performance

For 2°C and 35°C Ambient

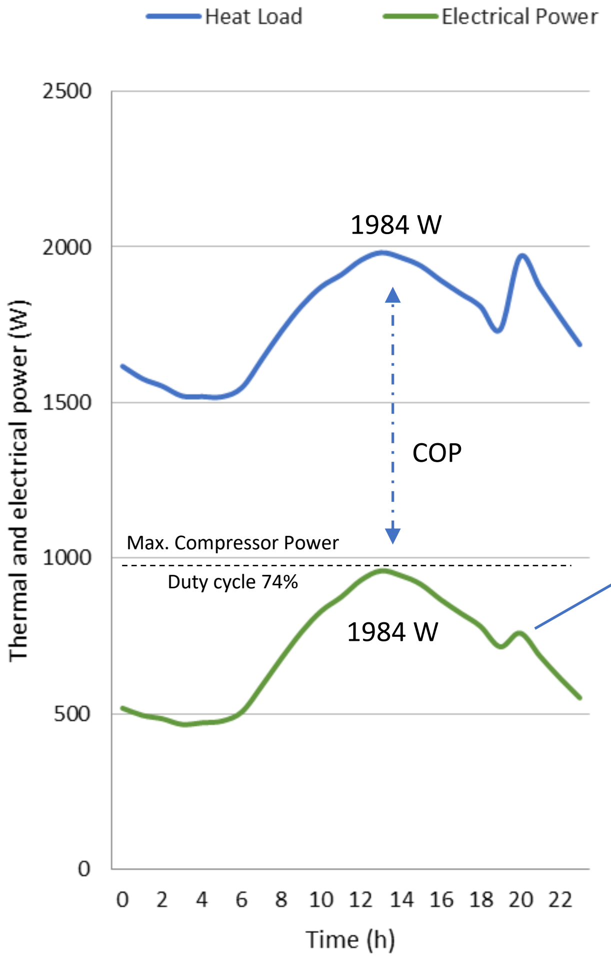


Daily energy consumption

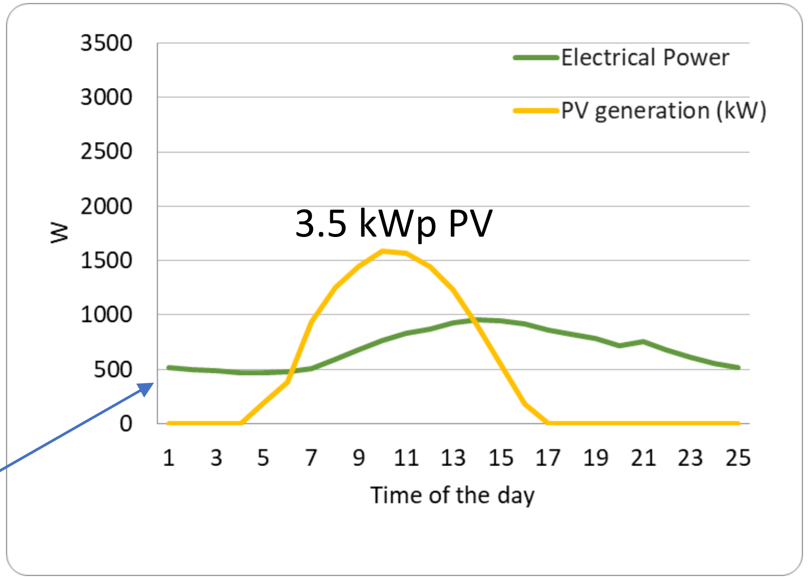




Daily energy consumption



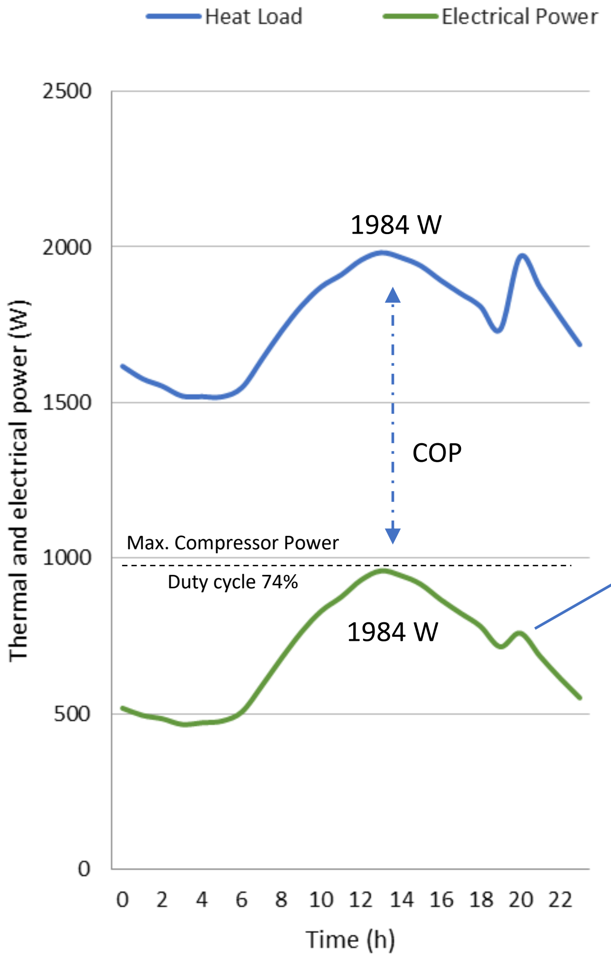
Scenario Solar + Grid



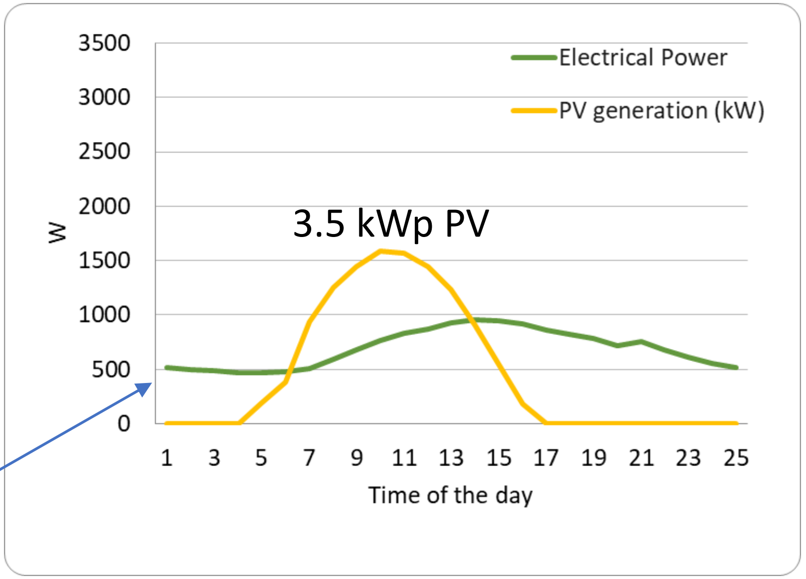
<u>For typical tropical weather conditions:</u>

- 45 % energy savings with only 3.5 kWp solar

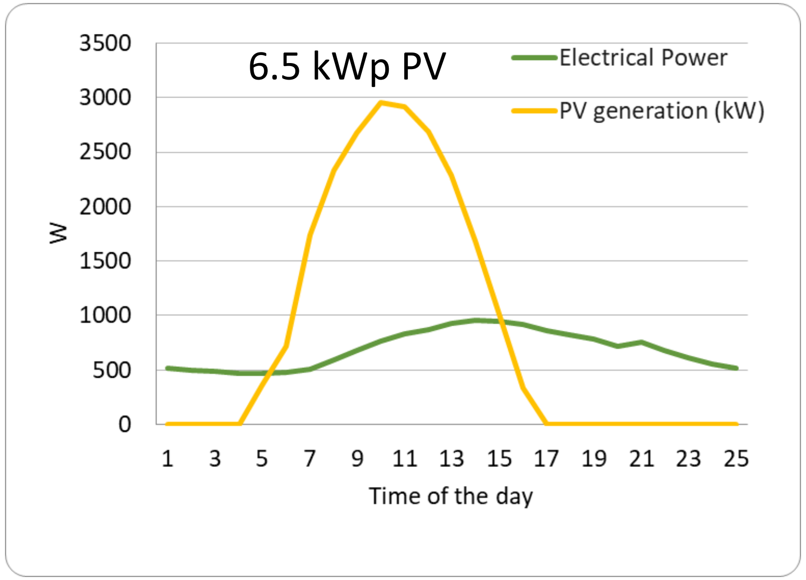
Daily energy consumption

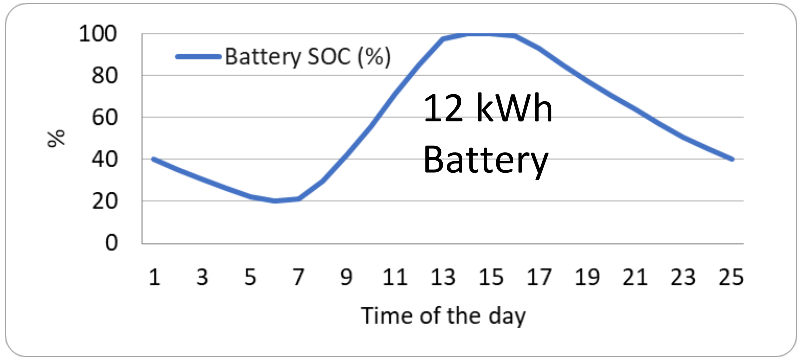


Scenario Solar + Grid



Scenario Solar Off-Grid





<u>For typical tropical weather conditions:</u>

- 45 % energy savings with only 3.5 kWp solar

- 100 % energy savings with 6.5 kWp solar and 12 kWh usefull battery capacity

Recap

- The Coefficient Of Performance (COP) gives us the relation between heat load and energy consumption. Valid for a given ambient and cold room temperature!
- Up to 50% of the energy consumption can be covered directly by solar without batteries (Ideal for reliable grids)
- Electrical batteries can be used for unreliable grids (more cost efficient than gensets)
- Thermal storage can not only substitute electrical batteries but serve as a buffer of thermal energy for high cooling power scenarios. The decision is taken with help of a cost–benefit analysis.

Main Guide ➡️ *Section 5*

Q&A on challenges faced by designers and buyers

Monique Baha, IIR

Related initiatives and further resources

Jeremy Tait, Tait Consulting GmbH, and IIR

A quality framework for WICR by VeraSol

Aims:

- To help programmes, buyers and suppliers to assess the suitability of walk in cold rooms for perishable food storage in the Global South, covering grid-connected, off-grid and hybrid power situations.
- To encourage the market to develop more suitable and affordable WICR.

https://verasol.org

VeraSol

A quality framework for WICR by VeraSol

Timeline and process

VeraSol

Sep 2023 | Jan 2024 | Apr 2024 | May 2024 | Oct 2024

VeraSol Programme

- 8 product groups covered so far

WICR Landscape report

- Research on WICR quality aspects
- What makes an effective WICR
- How performance is declared and tested
- Relevant test methods around the world

WICR test method expert group

- Tech experts on WICR and ATP testing
- Advising VeraSol on lab tests

WICR Interest group

- Promoting what we are doing
- Inviting feedback
- Open to all
- Meeting May, July, September 2024
- Ongoing as needed

First set of quality advice

GOGLA sales data – new market research on WICR from July 2024

- GOGLA aggregates and reports sales trends and impacts
- Data helps attract investment
- Aggregated data is published (company data remains confidential)
- GOGLA plans to cover WICR
- Online surveys start July 2024
- *Please consider submitting your sales data*

The Voice of the Off-Grid Solar Energy Industry

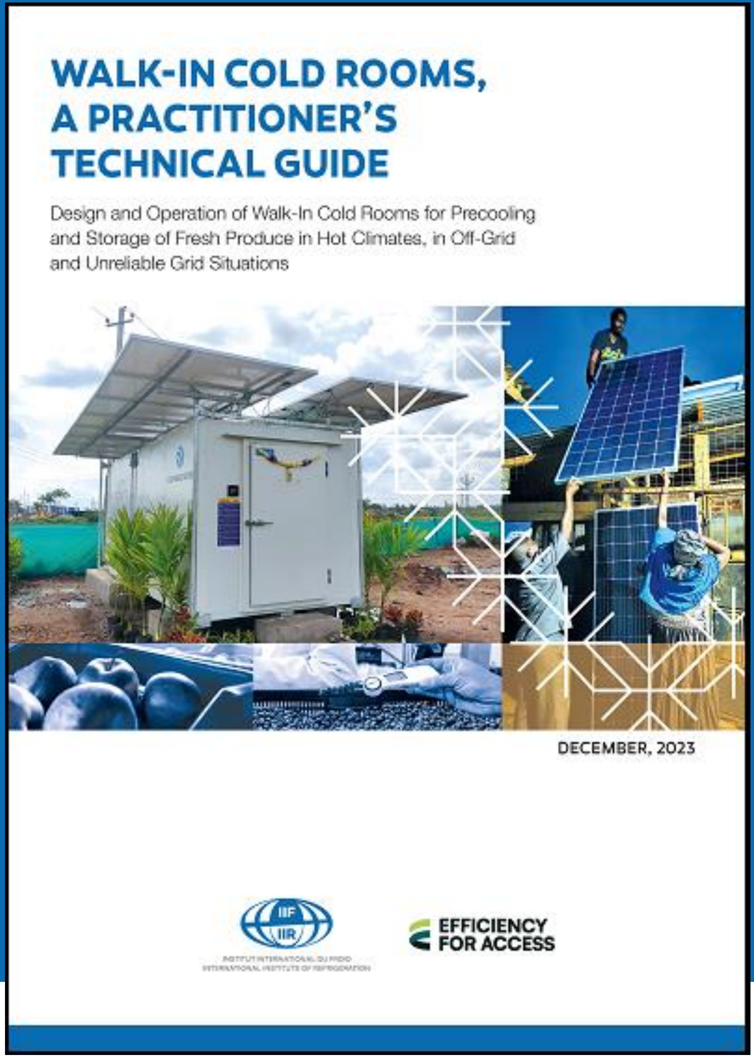
Details from:

- Serra Paixao s.paixao@gogla.org
- https://www.gogla.org/reports/global-off-grid-solar-market-report/

Some further resources

- Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops (5th Edition, 2015). University of California, Davis. Available from: https://postharvest.ucdavis.edu/publication/small-scale-postharvest-handling-practices-manual-horticultural-crops-5th-edition
- Manual for the preparation and sale of fruits and vegetables, from field to market, Food and Agriculture Organization of the United Nations, Rome, 2004. Accessible as an online book at https://www.fao.org/3/y4893e/y4893e00.htm#Contents
- Energy Efficiency in Cold Rooms, Design Application manual DA12, Australian Institute of Refrigeration, Air Conditioning and Heating, May 2020. Available from: https://airah.org.au/site/iCore/Store/StoreLayouts/Item_Detail.aspx?iProductCode=DA12 (fee applies)
- Precooling systems for small-scale producers, Lisa Kitinoja and James F Thompson, Stewart Postharvest Review v. 6, n. 2 (01 June 2010) : 1-14, ISSN_17459656. Accessed 16.8.2023 at https://access.portico.org/stable?au=phx64r6d413
- A Practical Guide to Solar Photovoltaic Systems for Technicians, Sizing, Installation and Maintenance, Jean-Paul Louineau, 2020. Available from: https://practicalactionpublishing.com/book/2482/a-practical-guide-to-solarphotovoltaic-systems-for-technicians
- Postharvest Assessment Methodology: conceptual framework for a methodology to assess food systems and value chains in the postharvest handling of perishables as a basis for effective interventions, 2022. Report 2359 / Wageningen Food & Biobased Research. Available from: https://doi.org/10.18174/582556

Main Guide ➡️ *Section 8*



Thank you!

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