Design of Solar Thermal Systems

A Process Integration Approach

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What is Process Integration?

Systematic and General Methods for Designing Integrated Production Systems, ranging from Individual Processes to Total Sites, with special emphasis on the Efficient Use of Energy and reducing Environmental Effects.

Objectives:

- ⇨Minimize *total cost* by identifying the optimal trade-off between operating cost (raw materials and energy) and investment cost (equipment).
- ⇨Increase *plant capacity* by plant debottlenecking.
- ⇨Increase plant *controllability and flexibility*
- ⇨Minimize undesirable plant *emissions*
- ⇨Aims for *sustainable* development

Applications of Process Integration-1

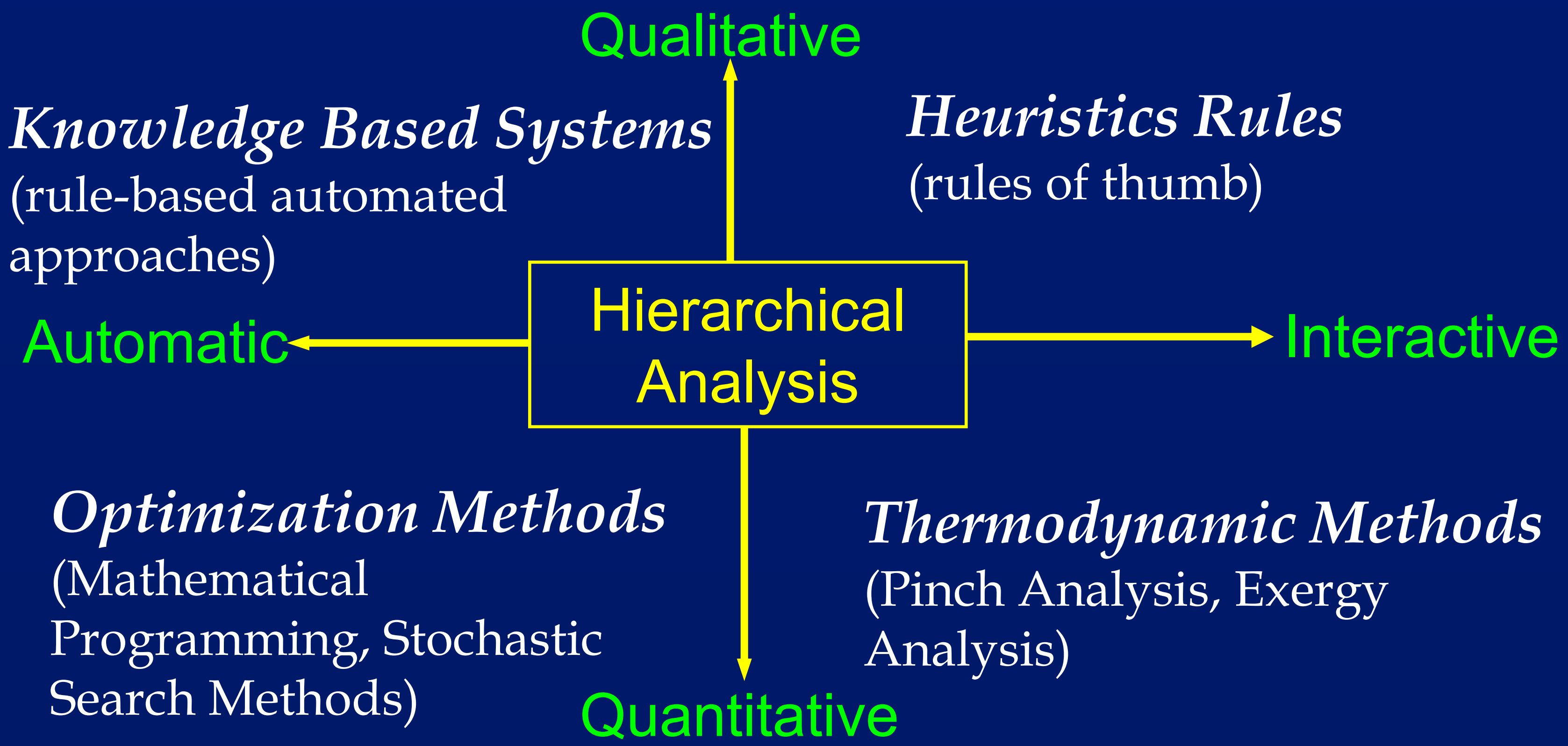
- Planning, Design and Operation of Processes and Utility Systems
- Short Term (Scheduling) and Long Term Planning (including Strategic Planning)
- Improving Efficiency (Energy and Raw Material) and Productivity (Debottlenecking)
- Continuous, Semi-Continuous and Batch Processes
- All aspects of Processes, such as Reactors, Separators and Heat Exchanger Networks
- Integration between Processes w.r.t. Material Streams and Energy Streams

Applications of Process Integration-2

- Integration between Industrial Sites
- Operability Issues (Flexibility, Controllability and Switchability)
- Waste and Wastewater Minimization
- Various aspects of Emissions Reduction
- Pollution prevention
- Hydrogen Management
- Aggregate Production Planning

- Sizing different renewable energy systems
  - Special emphasis on analyzing solar thermal systems

Classification of Design Approaches



Design of Solar Water Heating Systems

Qualitative

Evolutionary search algorithms (Panteliou and Dentsoras, 1996; Loomans and Visser 2002; Kalogirou, 2004)

Utilizability (Duffie and Beckman, 1991), F chart (Klein et al., 1976), $\bar{\phi}$-F chart (Klein and Beckman, 1979)

Automatic

Hierarchical Analysis

Interactive

TRNSYS (Klein et al. 1975), SOLCHIPS (Lund 1989; Lund and Peltola, 1992)

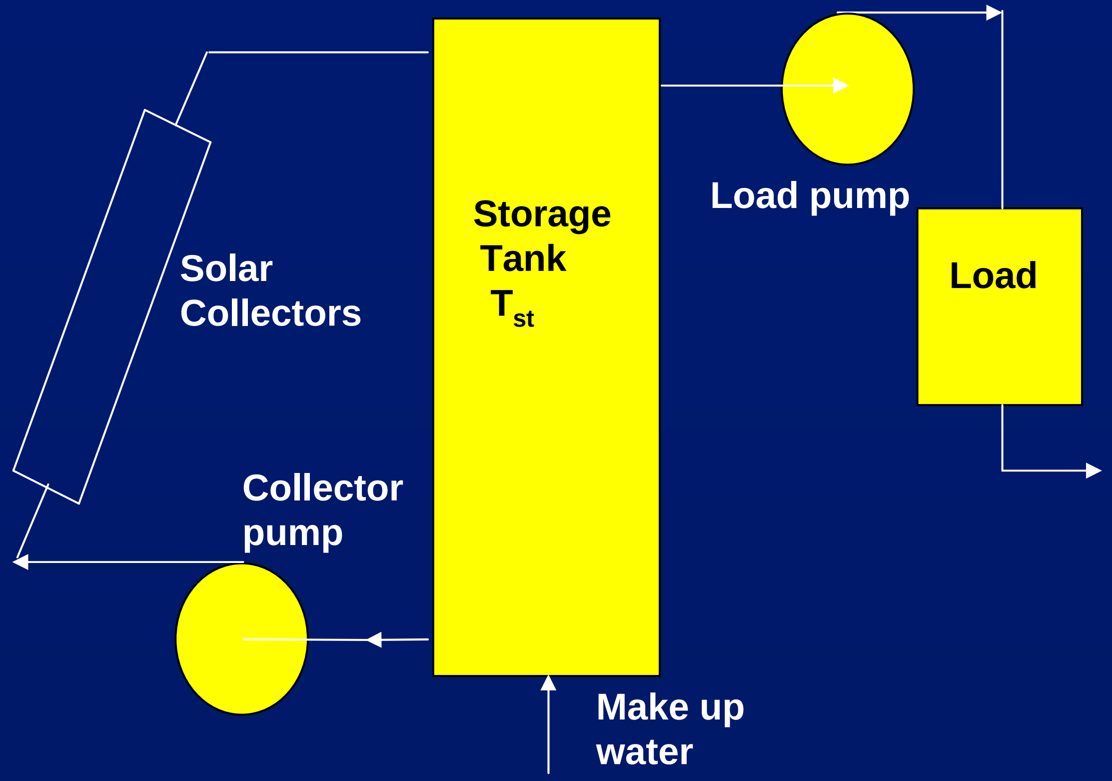
Design Space Approach

Quantitative

Solar System Design Issues

- System parameters
  - Collector area
  - Storage volume
  - Solar fraction
- Objective functions for optimization
  - Total annual cost, annualized life cycle cost (Hawlader et al., 1987), life cycle savings (Gordon and Rabl, 1982), pay back period (Michelson, 1982), internal rate of return (Gordon and Rabl, 1982) etc.
- Design of a practical solar hot water system is actually a multi-objective task.
- Determination of the entire range of feasible designs may be identified through *Design Space*.

Solar Hot Water System



⇨ **Design Space:**

- Design space is a region depicted on collector area vs. storage volume diagram that represents all possible system sizes, corresponding to a desired output

Mathematical Model

- Solar useful heat gain:

$$q_s = A_c\left[I_T F_R\left(\tau\alpha\right) - F_R U_L\left(T_{st} - T_a\right)\right]^+$$

- Energy Balance for the well mixed storage tank:

$$\left(\rho C_p V_{st}\right)\frac{dT_{st}}{dt} = A_c\left[I_T F_R\left(\tau\alpha\right) - F_R U_L\left(T_{st} - T_a\right)\right]^+ - q_{Ls} - U_{st} A_{st}\left(T_{st} - T_a\right)$$

- Solution of the above equation enables one to determine storage temperature profile with time

Example

Load: Domestic, 4500 LPD at 60°C

ISO 9459–3:1997 load profile

Location: Pune, India

Collectors: FPC, Single Cover,

$F_R (\tau\alpha) = 0.675$,

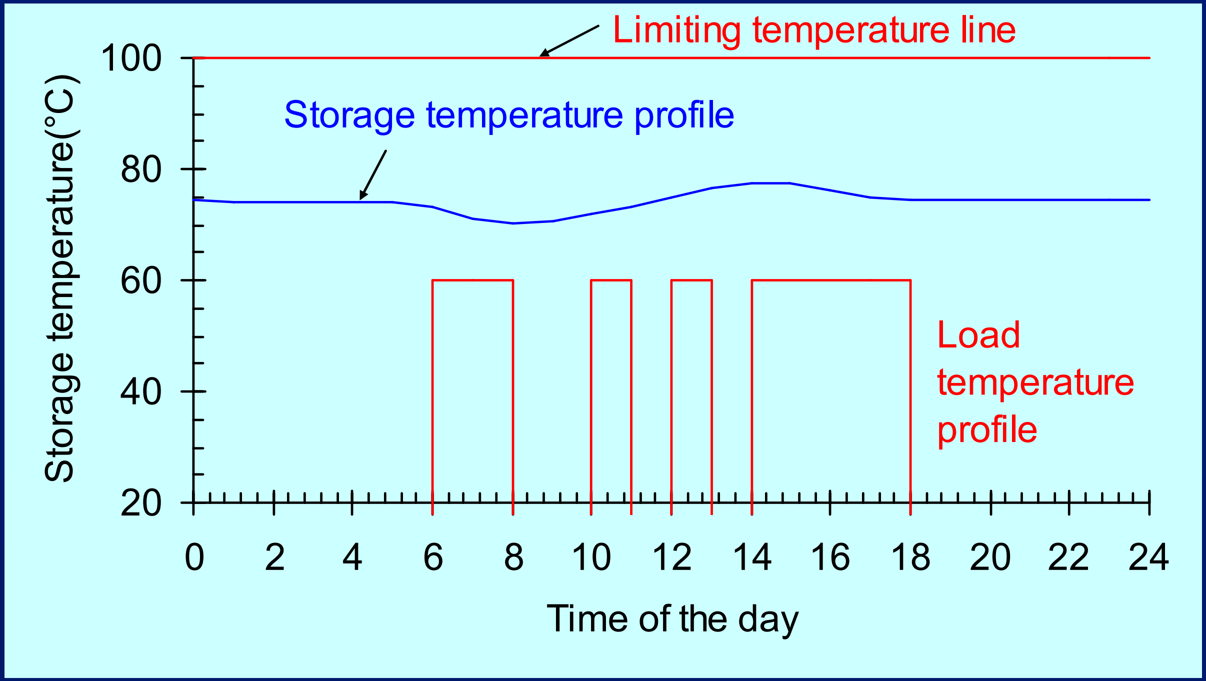
$F_R U_L = 5.656$ W/m2K.

Storage: M.S., h/d = 1

Insulation: 0.14 m, Glass wool

(k = 0.04 W/mK)

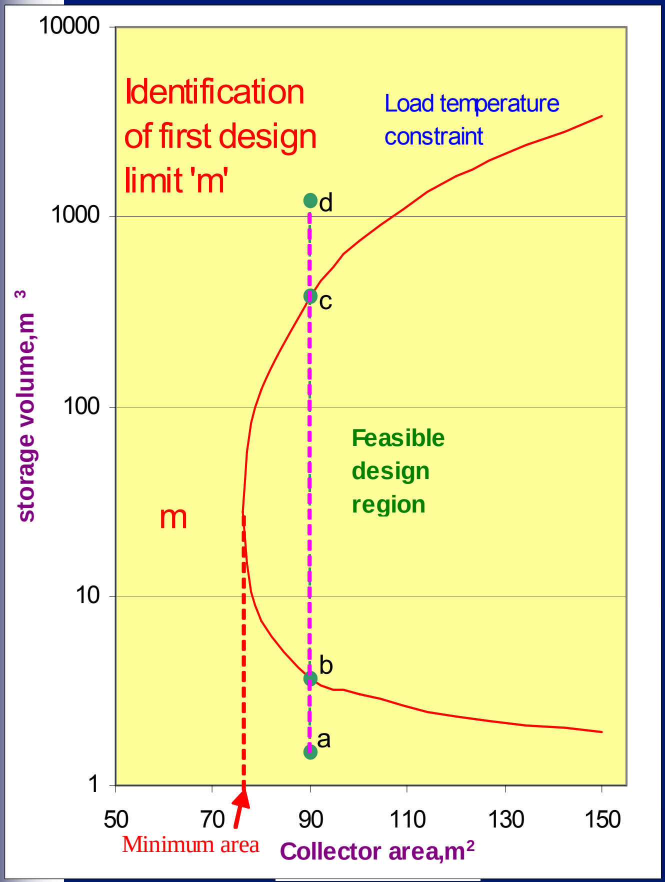
Storage Temperature Profile (F =1)

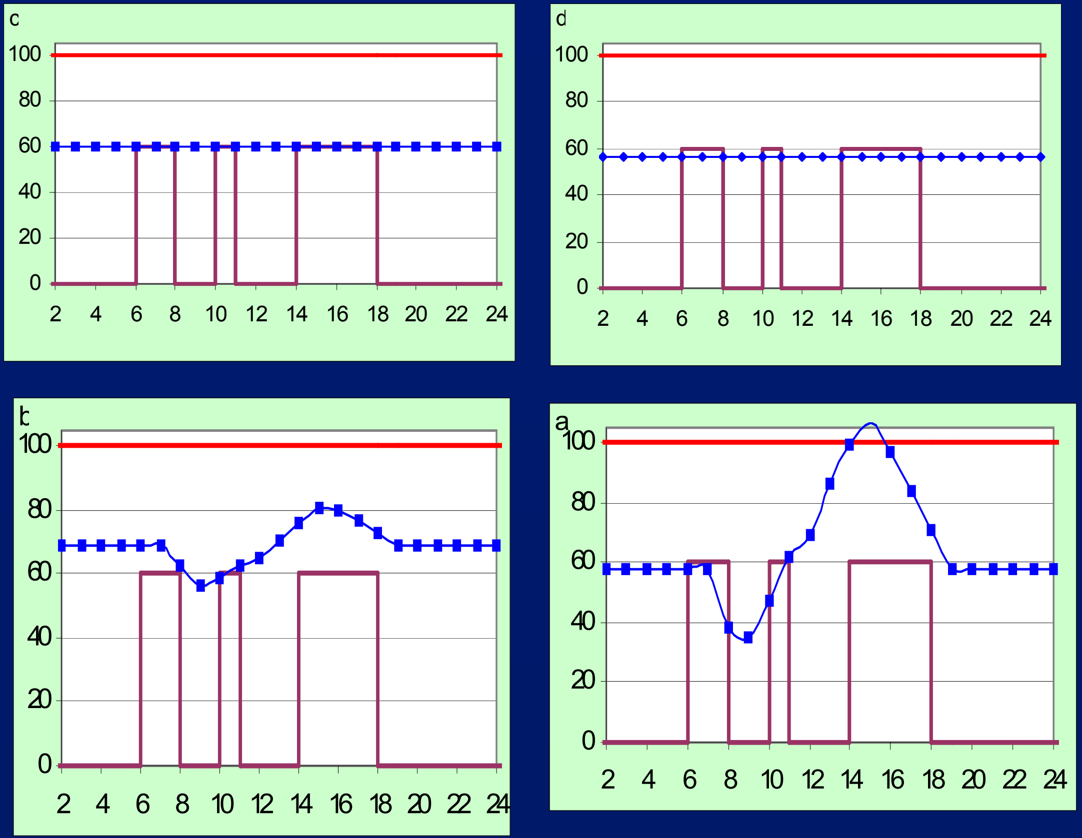


The design space is identified as possible values of collector area and storage volume such that the temperature profile of the storage tank lies within the limiting temperatures

Kulkarni et al., Proceedings of International Congress on Renewable Energy 2006, pp302-305.

Collector Area Vs. Storage Volume Diagram for F =1

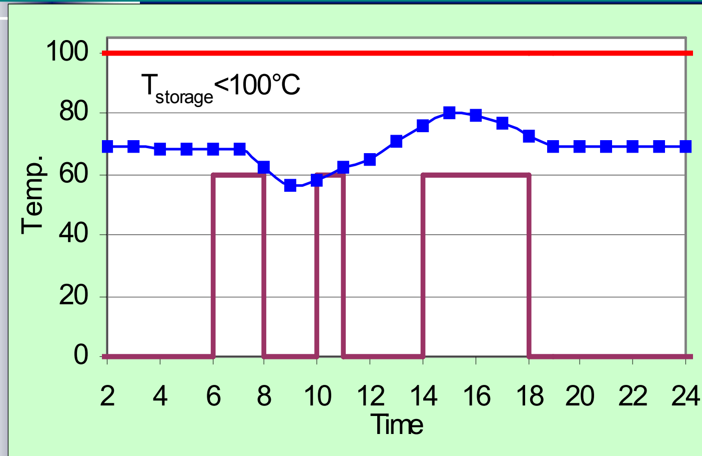


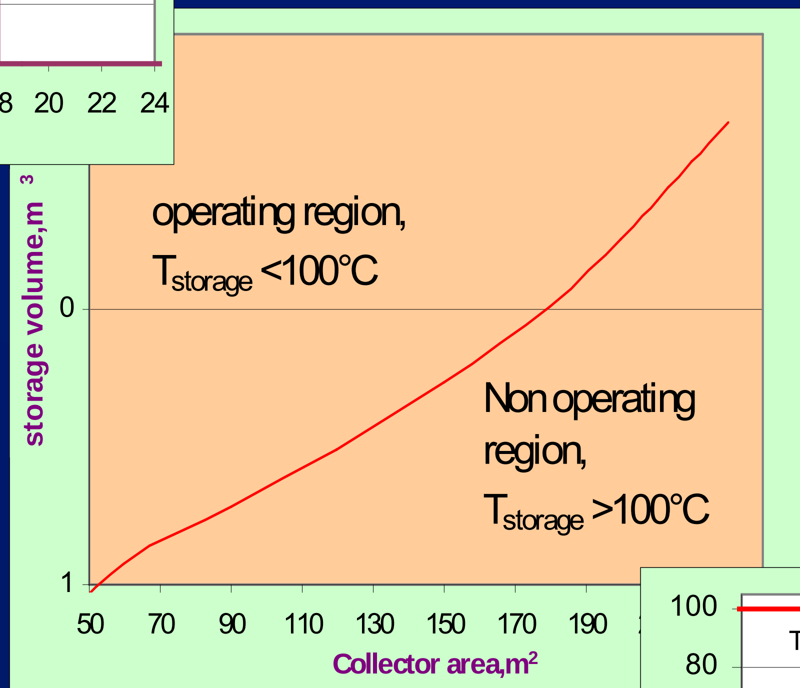


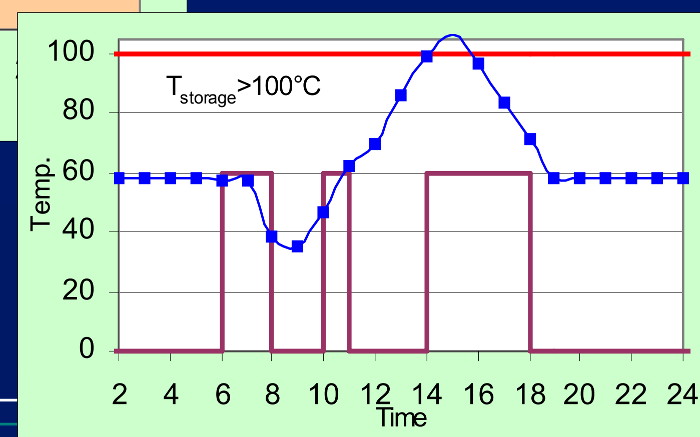
Storage Temp profiles

Kulkarni et al., Proceedings of International Congress on Renewable Energy 2006, pp302-305.

Limiting Storage Temperature







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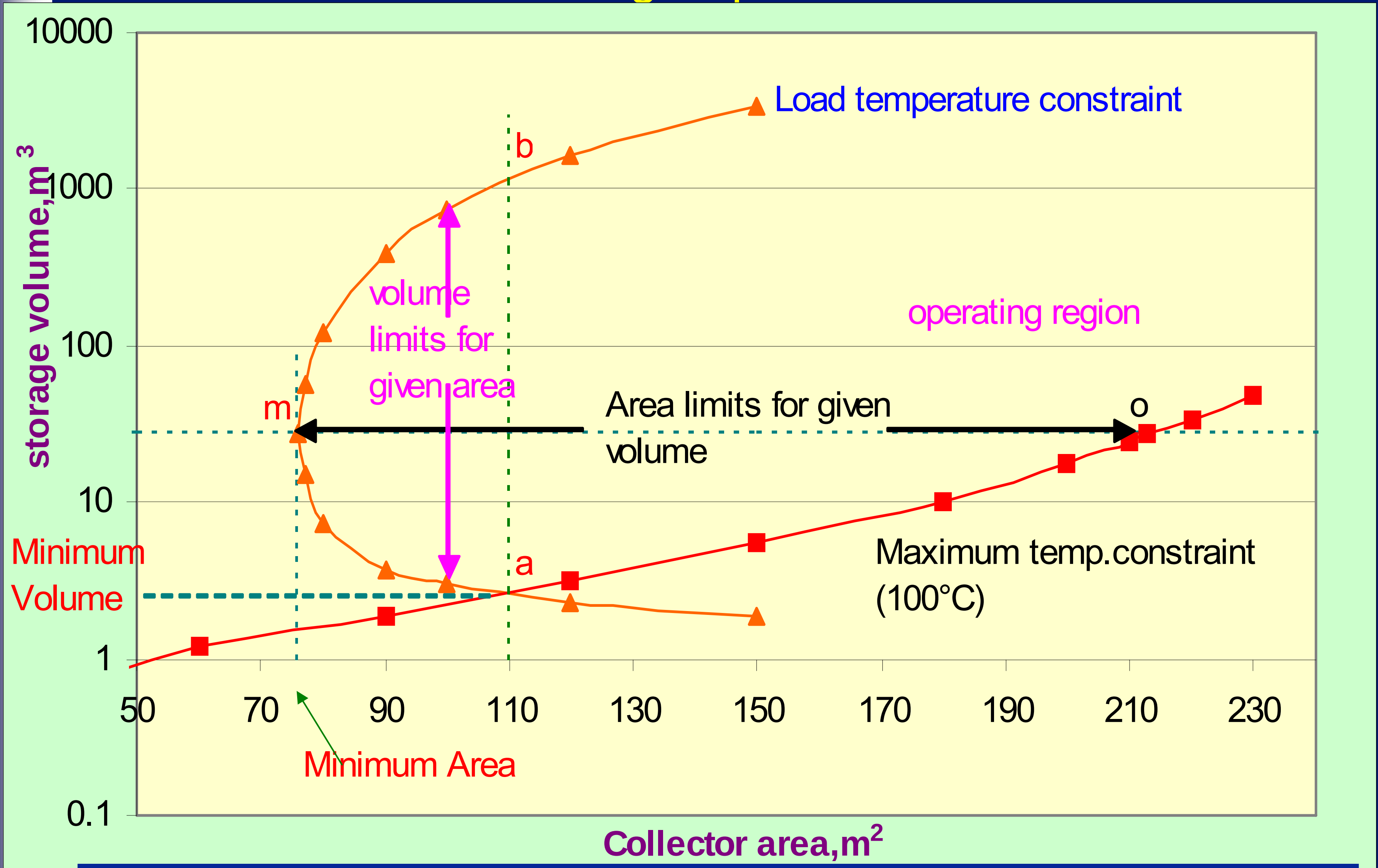
Design Space



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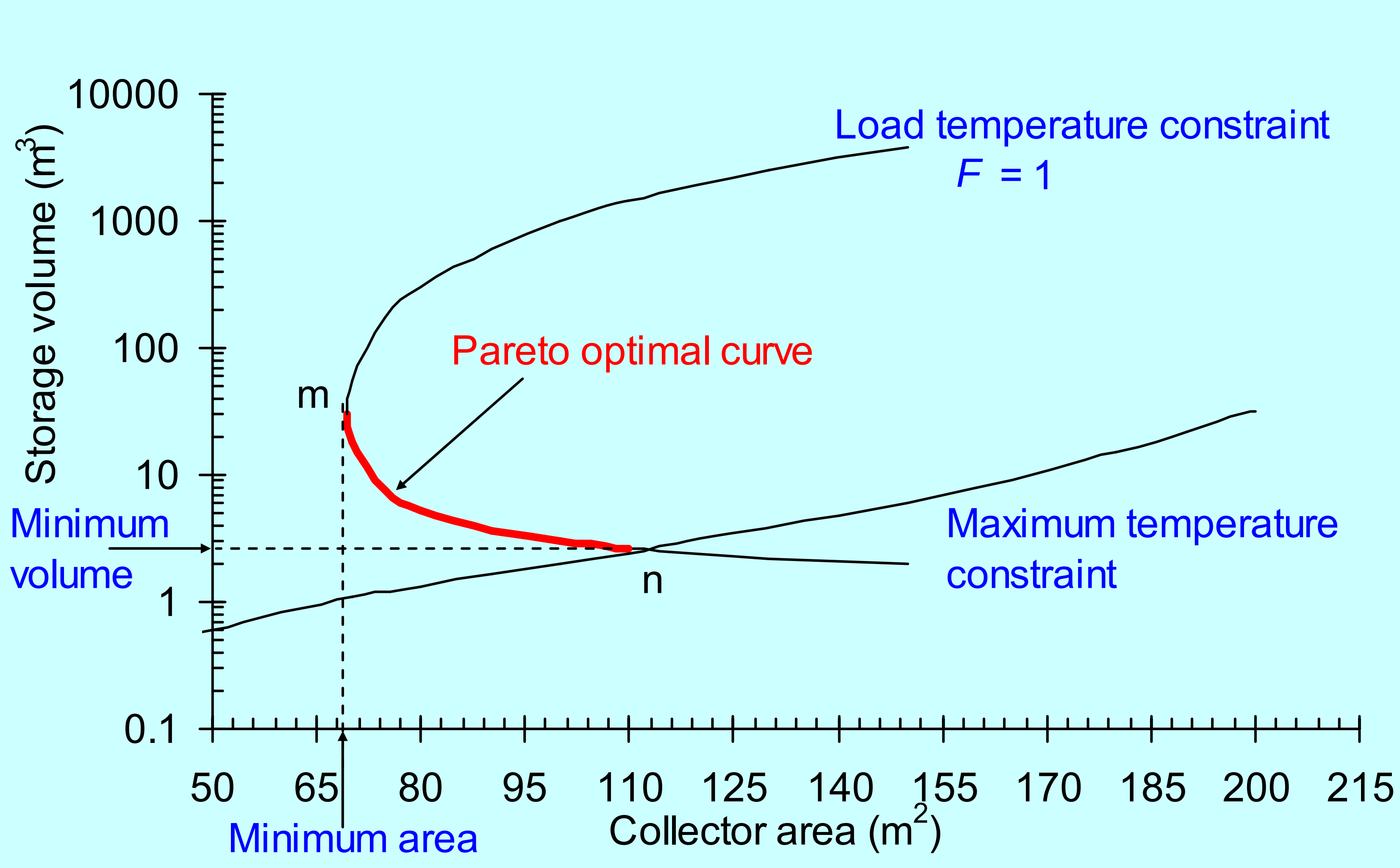
Pareto Optimal Curve



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Conclusion

- The concept of design space approach for synthesis, analysis, and optimization of solar thermal system has been developed
- Design space approach helps in clear understanding of the behavior of the system with different storage volumes and collector areas supplying a specified load, thus revealing constraints and flexibilities.
- Constraints such as existing collector area, limitations on available floor spacing, existing storage volume, or maximum allowable storage volume due to structural restriction, etc. can easily be incorporated in this approach.