Numerical method: demand side

Target domains

Building

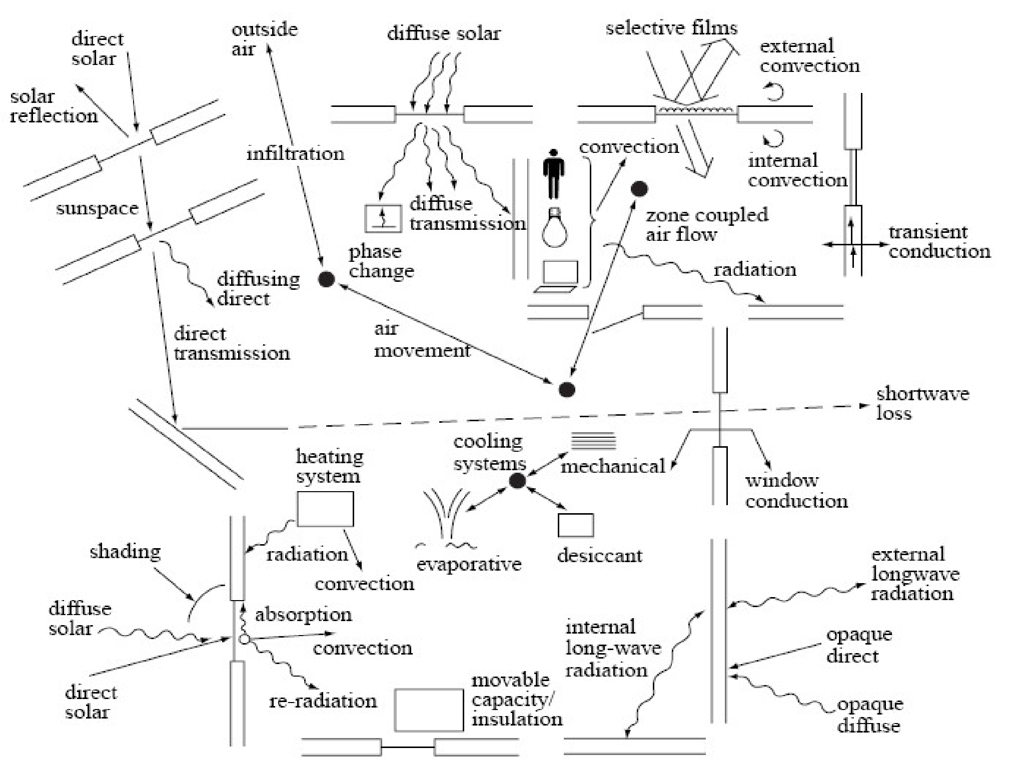


Figure 3.4: Building energy flowpaths.

Systems

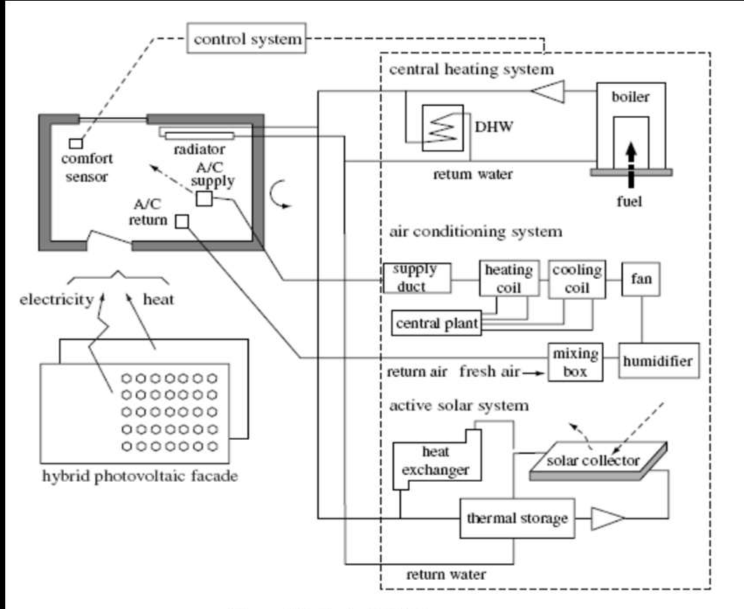


Figure 1.2: Typical HVAC systems.

Technical integration

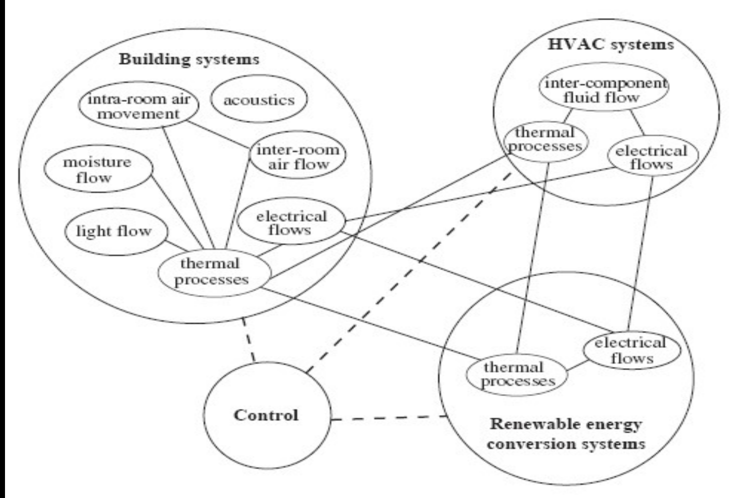
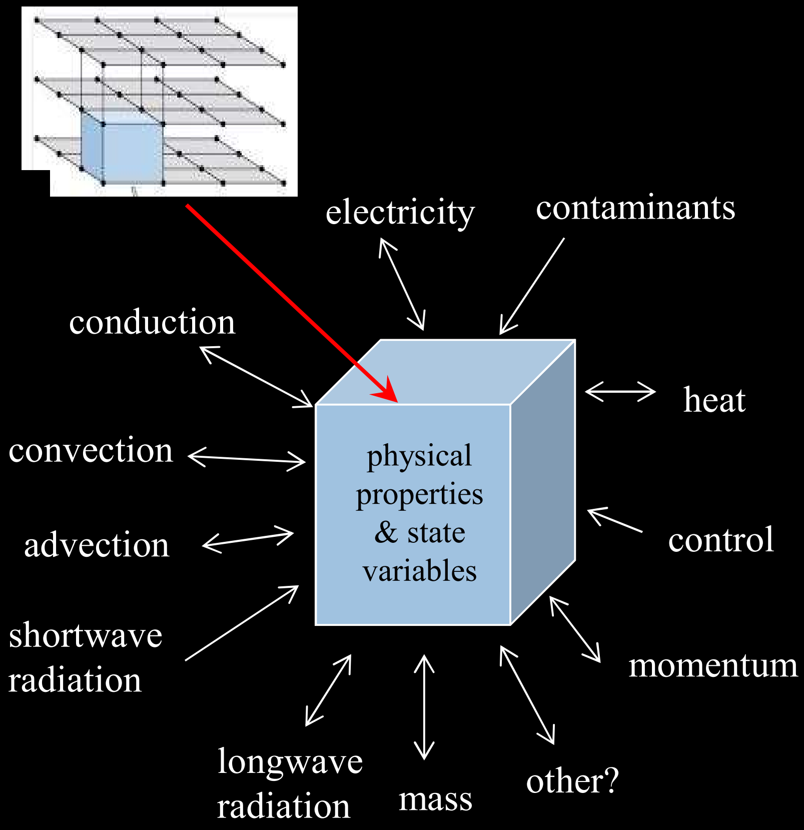


Figure 2.12: Examples of coupled domains.

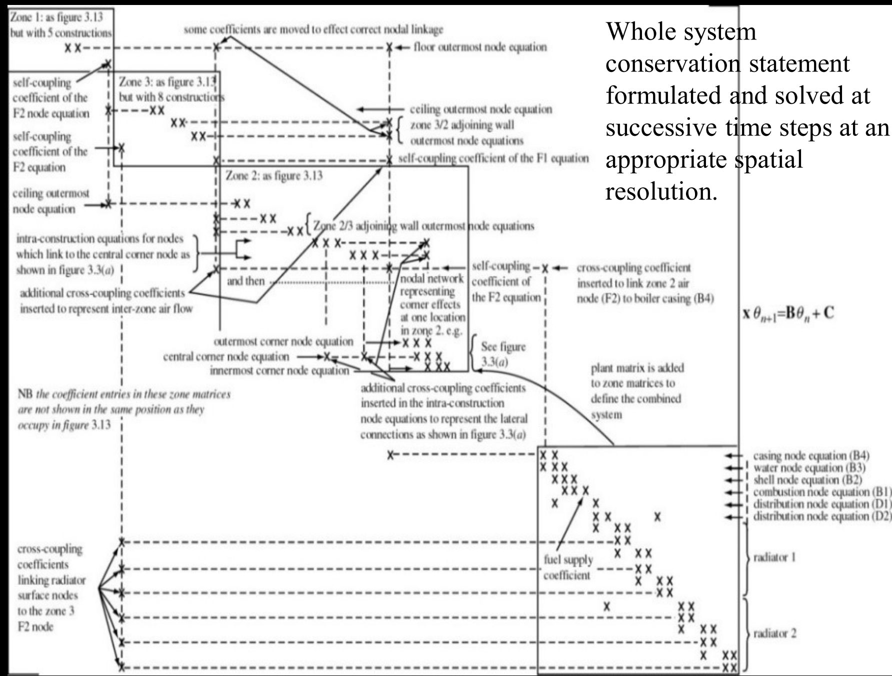
Target domains

Discretised system



$$\frac{\partial}{\partial t}(\rho\phi) = \frac{\partial}{\partial x_i}\left(\Gamma_\phi \frac{\partial \phi}{\partial x_i} - \rho U_i \phi\right) + S_\phi$$

The rate of increase of φ within a fluid element = the rate of increase of φ due to diffusion - the net rate of flow of φ out of the element + the rate of increase of φ due to sources.



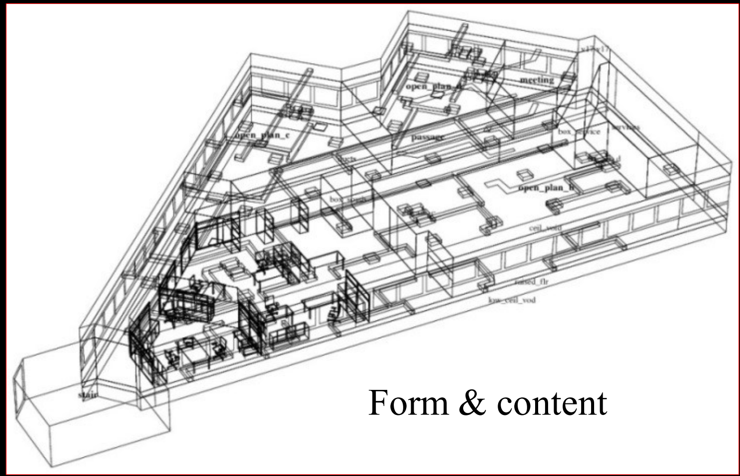
Whole system conservation statement formulated and solved at successive time steps at an appropriate spatial resolution.

It is hubristic to suggest that the future can be predicted, only emulated to ensure resilience.

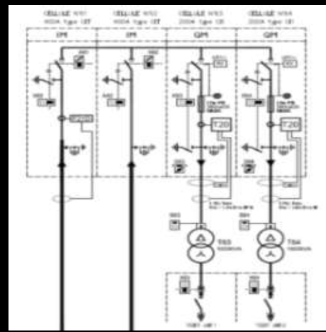
High resolution commercial building models

Renewable energy

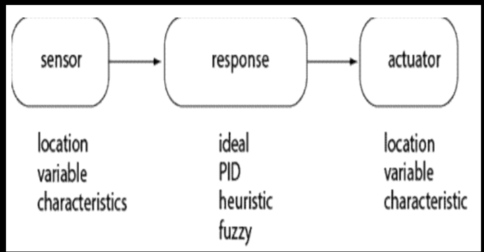
Occupants



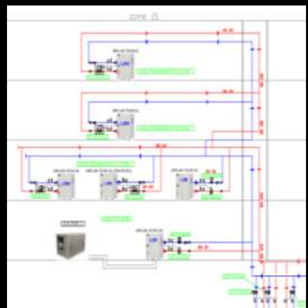
Electrical network



Control systems



HVAC systems



Lighting systems

PDE approximation

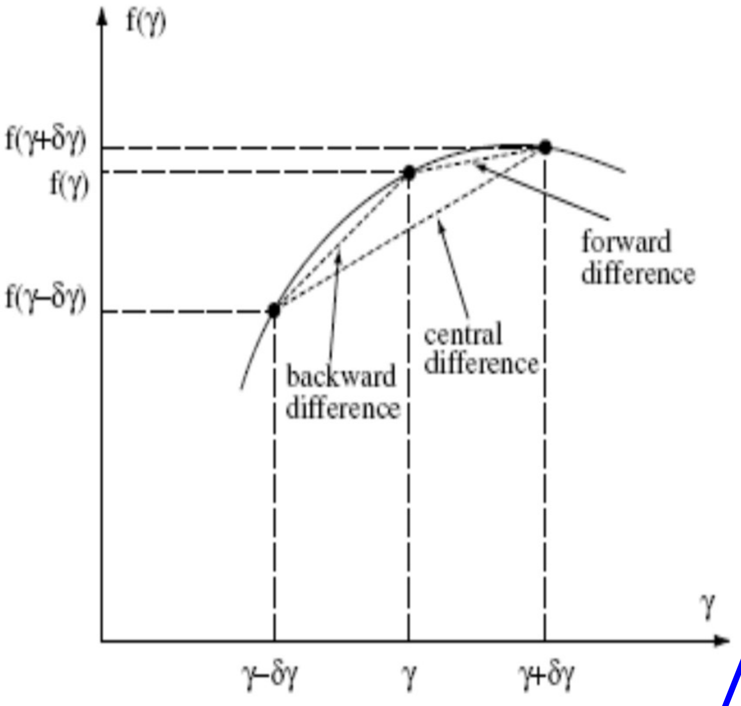


Figure 2.13: A continuous function of γ.

Taylor series expansion:

$$f(\gamma + \delta\gamma) = f(\gamma) + \delta\gamma f^1(\gamma) + \frac{(\delta\gamma)^2}{2} f^2(\gamma) + \frac{(\delta\gamma)^3}{6} f^3(\gamma) + \cdots$$

$$f(\gamma - \delta\gamma) = f(\gamma) - \delta\gamma f^1(\gamma) + \frac{(\delta\gamma)^2}{2} f^2(\gamma) - \frac{(\delta\gamma)^3}{6} f^3(\gamma) + \cdots$$

Add eqns:

$$f^2(\gamma) = \frac{f(\gamma + \delta\gamma) - 2f(\gamma) + f(\gamma - \delta\gamma)}{(\delta\gamma)^2} + \varepsilon[(\delta\gamma)^2]$$

Subtract eqns:

$$f^1(\gamma) = \frac{f(\gamma + \delta\gamma) - f(\gamma - \delta\gamma)}{2\delta\gamma} + \varepsilon[(\delta\gamma)^2].$$

Central difference approximations

Truncate eqn 1:

$$f^1(\gamma) = \frac{f(\gamma + \delta\gamma) - f(\gamma)}{\delta\gamma} + \varepsilon[(\delta\gamma)]$$

First forward difference approx.

Truncate eqn 2:

$$f^1(\gamma) = \frac{f(\gamma) - f(\gamma - \delta\gamma)}{\delta\gamma} + \varepsilon[(\delta\gamma)] .$$

First backward difference approx.

$$\frac{\partial^2 \theta(x,t)}{\partial x^2} = \frac{1}{\alpha}\frac{\partial \theta(x,t)}{\partial t} - \frac{q}{k}\,.$$

Fourier conduction eqn.

$$\frac{\theta(I+1,t) - 2\theta(I,t) + \theta(I-1,t)}{(\delta x)^2} = \frac{1}{\alpha}\frac{\theta(I,t+\delta t) - \theta(I,t)}{\delta t} - \frac{q(I,t)}{k}$$

Explicit formulation
(central and first forward)

$$\theta(I,t+\delta t) = \frac{k\delta t}{\rho C(\delta x)^2}\theta(I+1,t) + \left(1 - \frac{2k\delta t}{\rho C(\delta x)^2}\right)\theta(I,t) + \frac{k\delta t}{\rho C(\delta x)^2}\theta(I-1,t) + \frac{q(I,t)\delta t}{\rho C}\,.$$

$$1 - \frac{2k\delta t}{\rho C(\delta x)^2} < 0$$

$$\frac{\alpha\delta t}{(\delta x)^2} \le \tfrac{1}{2} \quad \text{or} \quad F \le \tfrac{1}{2}$$

$$\frac{\theta(I+1,t+\delta t) - 2\theta(I,t+\delta t) + \theta(I-1,t+\delta t)}{(\delta x)^2} = \frac{1}{\alpha}\frac{\theta(I,t+\delta t) - \theta(I,t)}{\delta t} - \frac{q(I,t+\delta t)}{k}$$

Implicit formulation (central and first backward)

$$\left(1 + \frac{2k\delta t}{\rho C(\delta x)^2}\right)\theta(I,t+\delta t) = \theta(I,t) + \frac{k\delta t}{\rho C(\delta x)^2}[\theta(I+1,t+\delta t) + \theta(I-1,t+\delta t)] + \frac{q(I,t+\delta t)\delta t}{\rho C}\,.$$

$$(1 + 2WF)\theta(I,t+\delta t) = WF[\theta(I+1,t+\delta t) + \theta(I-1,t+\delta t)] + [1 - 2F(1-W)]\theta(I,t) + (1-W)F[\theta(I+1,t) + \theta(I-1,t)] + \frac{\delta t}{\rho C}[Wq(I,t+\delta t) + (1-W)q(I,t)]\,.$$

Weighted average scheme

$$F \le \tfrac{1}{2}\left(\frac{1}{1-W}\right)$$

W < 0.5 explicit
W >= 0.5 implicit

Application issues

- Complications to differencing by Taylor series expansion:
  - simultaneous presence of multiple heat transfer processes;
  - time and positional dependency of heat generation due to solar radiation, mechanical plant etc.;
  - discretisation leading to non-homogeneous, anisotropic finite volumes;
  - presence of multi-dimensional effects.

- Alternative approach: directly apply conservation principles to small control volumes.

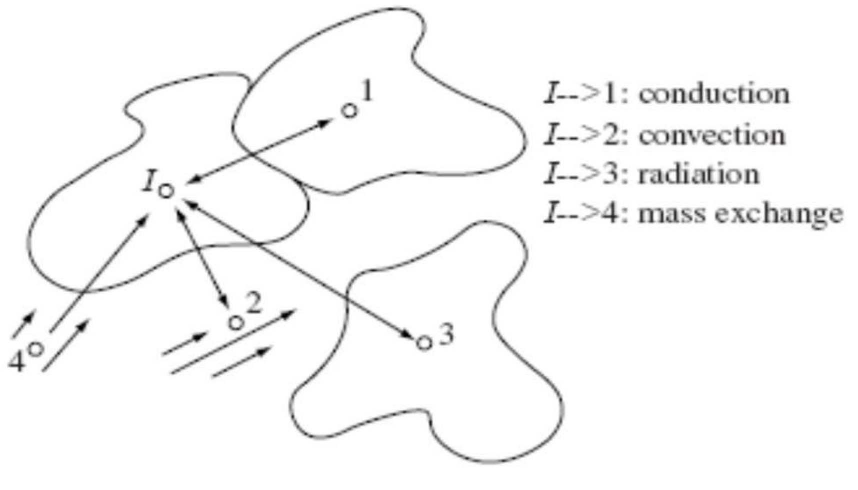


Figure 2.15: Heat exchanges in a physical system.

Control volume method – heat balance

$$\frac{\partial^2 \theta(x,t)}{\partial x^2} = \frac{1}{\alpha}\frac{\partial \theta(x,t)}{\partial t} - \frac{q}{k}\,.$$

in the limit

Heat flux: $Q_{J,I} = K_{J,I}(\theta_J - \theta_I)\ ;\ J = 1, 2, 3, 4$

Heat storage: $Q_s = \dfrac{\rho_I(\xi) C_I(\xi) \delta V_I(\xi)}{\delta t}\,[\theta(I, t+\delta t) - \theta(I, t)]$

Energy balance:

$$\frac{\rho_I(\xi) C_I(\xi) \delta V_I(\xi)}{\delta t}\,[\theta(I, t+\delta t) - \theta(I, t)] = \sum_{j=1}^{N} K_{j,I}(\theta_j - \theta_I)\Big|_{t=\xi} + q_I\Big|_{t=\xi}$$

General form:

$$C_s(t+\delta t)\theta(I, t+\delta t) - \sum_{i=1}^{N} C_{ci}(t+\delta t)\theta(i, t+\delta t) - \frac{\delta t\, q_I(t+\delta t)}{\delta V_I}$$
$$= C_s(t)\theta(I,t) + \sum_{i=1}^{N} C_{ci}(t)\theta(i,t) + \frac{\delta t\, q_I(t)}{\delta V_I} + \varepsilon$$

Always the same!

Note:
- ❑ equation can be applied to building and plant components;
- ❑ number of coefficients will vary;
- ❑ analogous considerations for mass and momentum balance.

Formulating a numerical model

- Continuous system made discrete by the placement of nodes at points of interest:
  - nodes represent homogeneous or non-homogeneous physical volumes (comprising fluids, opaque and transparent surfaces, constructional elements, plant component parts, room contents *etc.*).

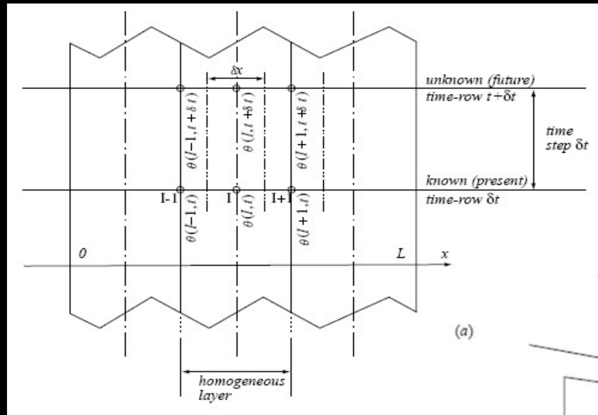


Figure 2.14: Homogeneous layer: space and time no

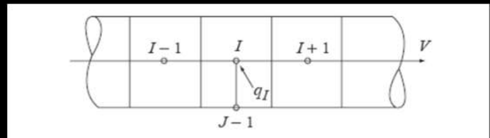
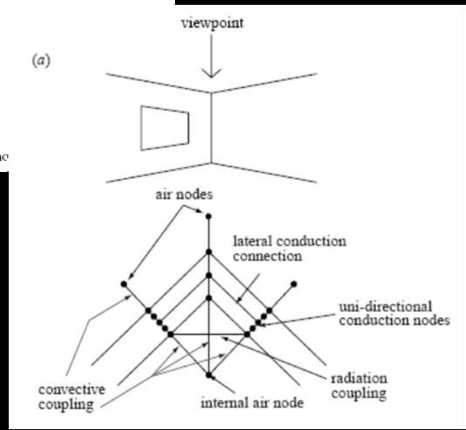


Figure 3.11: Nodal scheme for fluid flow in ducts and pipes.



- For each node, and in terms of all surrounding nodes representing regions deemed to be in thermodynamic contact, conservation equations are developed:
  - represents the nodal condition and the inter-nodal transfers of energy, mass and momentum.

- The entire equation-set is solved simultaneously for successive time steps:
  - gives the future time-row nodal state variables as a function of present time-row states and prevailing boundary conditions at both time-rows.

Modelling issues

- Not possible to prescribe a spatial discretisation scheme in advance ─ depending on the problem, model parts may require high resolution (many nodes) or low resolution (few nodes).

- Discretised conservation equations will have a variable number of coefficients depending on the node type. This will require a carefully designed matrix coefficient indexing scheme to facilitate efficient equation solution.

- Because different system parts will have different time constants and coupling strengths, equation processing must be structured to allow these effects to be reconciled whilst not enforcing a lowest common denominator processing frequency.

- Since different domain equations possess different characteristics (e.g. some are highly non-linear ─ an approach that depends on several co-operating solvers will be more computationally efficient than an approach that attempts to coerce the disparate equation-sets into a single solver type.

Numerical errors

Two sources of error associated with finite differencing schemes:

- ❑ Rounding - where computations include an insufficient number of significant figures. Can be minimised by careful design of the numerical scheme and by operating in double precision.

- ❑ Discretisation - resulting from the replacement of derivatives by finite differences. Error minimised by reducing space and time increments.
  - not possible to prescribe space and time increments because they depend on modelling objectives;
  - implicit formulation attractive because it is unconditionally stable;
  - discretisation depends on factors such as surface insolation, local convection, corner effects/thermal bridges, and the shape of the capacity/insulation system.

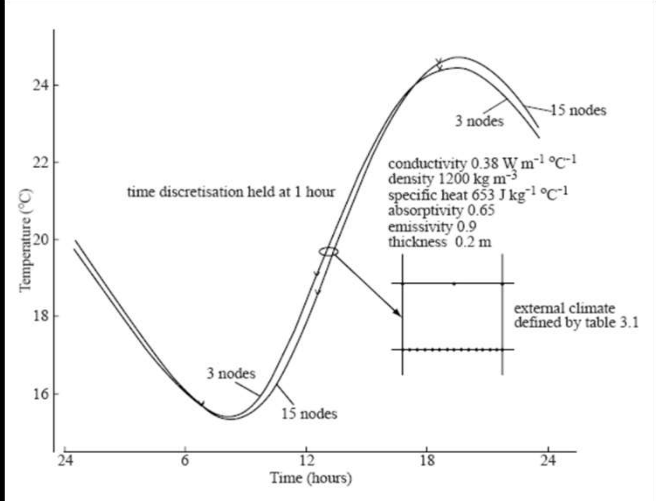


Figure 3.1: Effect of space discretisation.

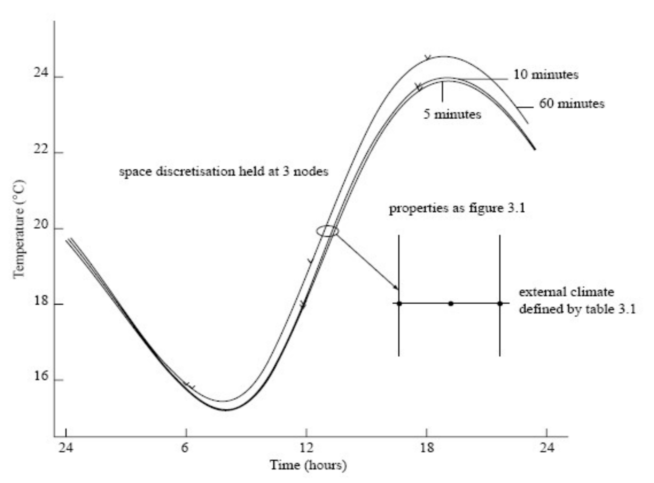


Figure 3.2: Effect of time discretisation.

System discretisation

- By prescription: e.g. at least 3 nodes per homogeneous element with a time step less than 1 hour.

- Using thermal criteria:
  - Biot Number << 1 use lumped parameter;
  - else, equal thermal capacity divisions using the dwell time.

- Mixed node schemes often required.

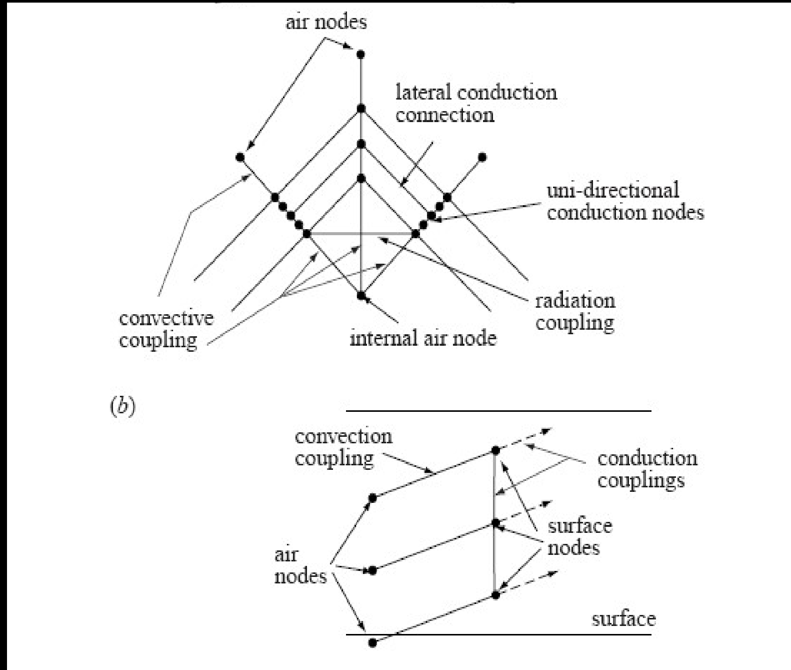


Figure 3.3: Some mixed nodal schemes and their typical applications. (a) Corner effects—a combined one- and two-dimensional scheme. (b) Surface temperature gradient—a two-dimensional scheme.

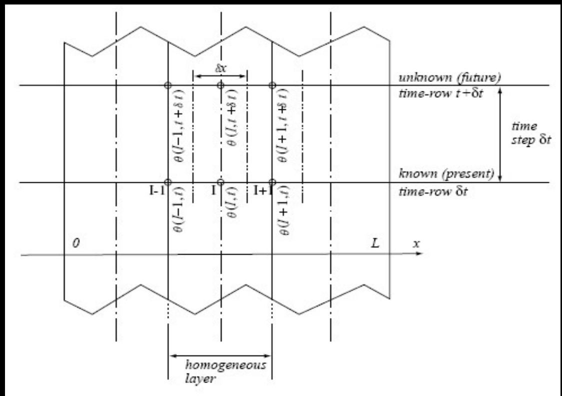


Figure 2.14: Homogeneous layer: space and time nodal scheme.

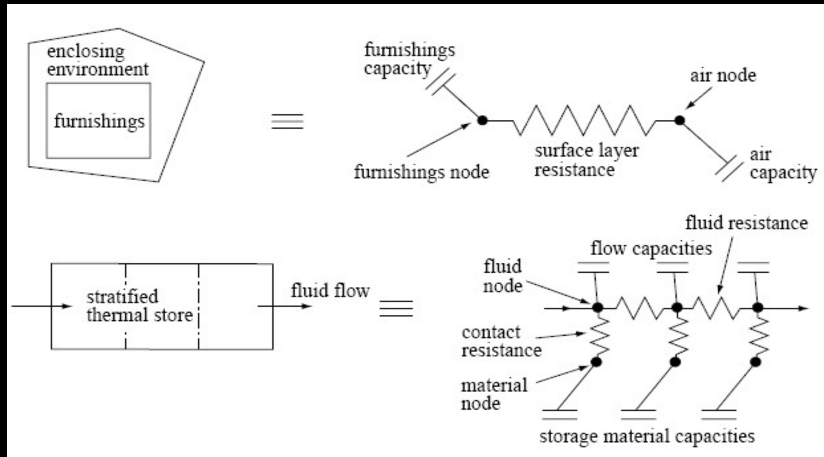
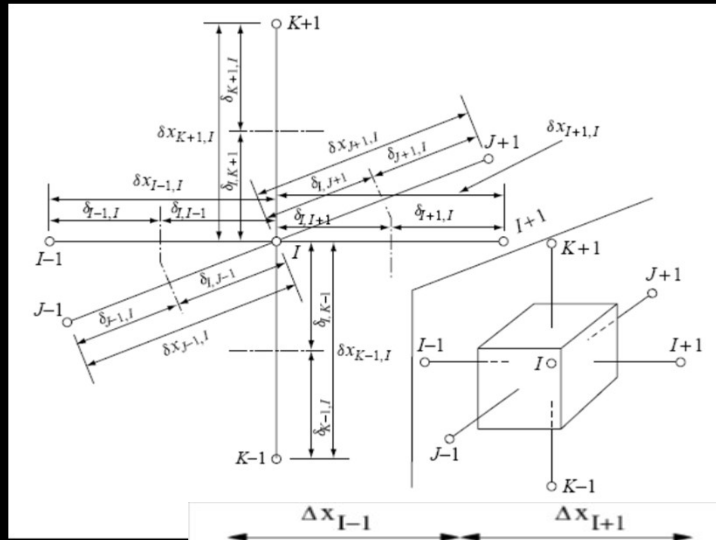


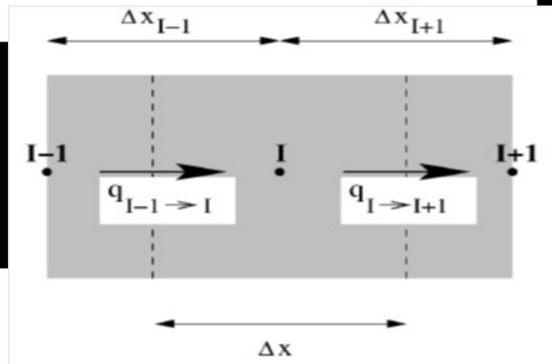
Figure 3.8: Nodal schemes for furnishings and thermal storage.

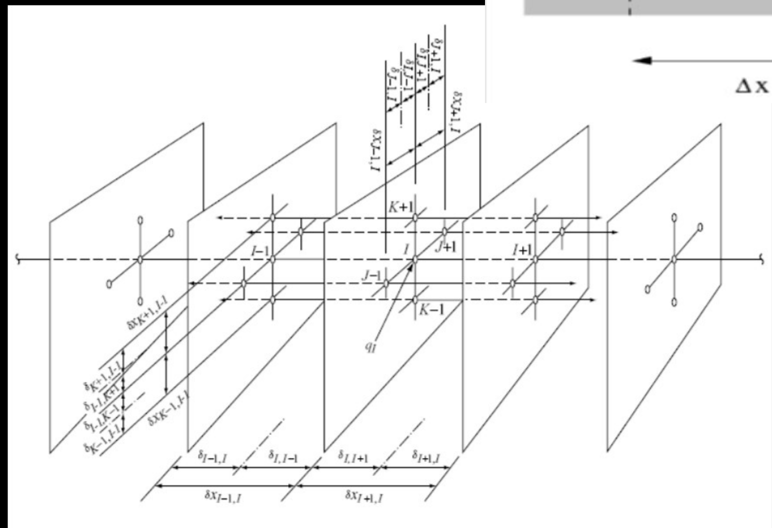
Material energy conservation equation

$$
\begin{aligned}
&\left(2\rho_I(t+\delta t)C_I(t+\delta t) + \frac{2\delta t\, k(t+\delta t)}{\delta x_I^2}\right)\theta(I, t+\delta t) \\
&- \frac{\delta t\, k(t+\delta t)}{\delta x_I^2}\theta(I-1, t+\delta t) - \frac{\delta t\, k(t+\delta t)}{\delta x_I^2}\theta(I+1, t+\delta t) - \frac{\delta t\, q_I(t+\delta t)}{\delta x_I \delta x_J \delta x_K} \\
&= \left(2\rho_I(t)C_I(t) - \frac{2\delta t\, k(t)}{\delta x_I^2}\right)\theta(I, t) \\
&+ \frac{\delta t\, k(t)}{\delta x_I^2}\theta(I-1, t) + \frac{\delta t\, k(t)}{\delta x_I^2}\theta(I+1, t) + \frac{\delta t\, q_I(t)}{\delta x_I \delta x_J \delta x_K}.
\end{aligned}
$$

$$
\begin{aligned}
&C_s(t+\delta t)\theta(I, t+\delta t) - \sum_{i=1}^{N} C_{ci}(t+\delta t)\theta(i, t+\delta t) - \frac{\delta t\, q_I(t+\delta t)}{\delta V_I} \\
&= C_s(t)\theta(I, t) + \sum_{i=1}^{N} C_{ci}(t)\theta(i, t) + \frac{\delta t\, q_I(t)}{\delta V_I} + \varepsilon
\end{aligned}
$$







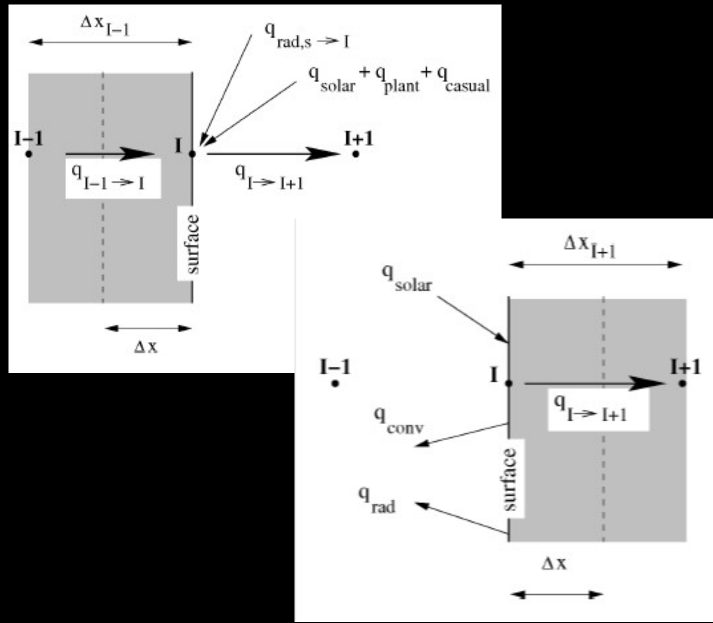
Material node types:

- ❑ opaque intra-construction;
- ❑ transparent intra-construction;
- ❑ phase change;
- ❑ boundary between elements;
- ❑ lumped.

Surface energy conservation equation

$$
\begin{aligned}
&\left(2W_I(t+\delta t) + \frac{\delta t\, k'_{I-1,I}(t+\delta t)}{\delta x_{I-1,I}\,\delta_{I,I-1}} + \frac{\delta t\, h_{cI+1,I}(t+\delta t)}{\delta_{I,I-1}} + \frac{\delta t \sum_{s=1}^{N} h_{rs,I}(t+\delta t)}{\delta_{I,I-1}}\right)\theta(I, t+\delta t) \\
&- \frac{\delta t\, k'_{I-1,I}(t+\delta t)}{\delta x_{I-1,I}\,\delta_{I,I-1}}\,\theta(I-1, t+\delta t) - \frac{\delta t\, h_{cI+1,I}(t+\delta t)}{\delta_{I,I-1}}\,\theta(I+1, t+\delta t) \\
&- \frac{\delta t \sum_{s=1}^{N} h_{rs,I}(t+\delta t)\theta(s, t+\delta t)}{\delta_{I,I-1}} - \frac{\delta t\, q_{PI}(t+\delta t)}{\delta_{I,I-1}\,\delta_{J-1,J+1}\,\delta_{K-1,K+1}} \\
&= \left(2W_I(t) - \frac{\delta t\, k'_{I-1,I}(t)}{\delta x_{I-1,I}\,\delta_{I,I-1}} - \frac{\delta t\, h_{cI+1,I}(t)}{\delta_{I,I-1}} - \frac{\delta t \sum_{s=1}^{N} h_{rs,I}(t)}{\delta_{I,I-1}}\right)\theta(I, t) \\
&+ \frac{\delta t\, k'_{I-1,I}(t)}{\delta x_{I-1,I}\,\delta_{I,I-1}}\,\theta(I-1, t) + \frac{\delta t\, h_{cI+1,I}(t)}{\delta_{I,I-1}}\,\theta(I+1, t) + \frac{\delta t \sum_{s=1}^{N} h_{rs,I}(t)\theta(s, t)}{\delta_{I,I-1}} \\
&+ \frac{\delta t[q_{PI}(t) + q_{SI}(t) + q_{RI}(t) + q_{SI}(t+\delta t) + q_{RI}(t+\delta t)]}{\delta_{I,I-1}\,\delta_{J-1,J+1}\,\delta_{K-1,K+1}} + \varepsilon\ .
\end{aligned}
$$

$$
\begin{aligned}
&C_s(t+\delta t)\theta(I, t+\delta t) - \sum_{i=1}^{N} C_{ci}(t+\delta t)\theta(i, t+\delta t) - \frac{\delta t\, q_I(t+\delta t)}{\delta V_I} \\
&= C_s(t)\theta(I, t) + \sum_{i=1}^{N} C_{ci}(t)\theta(i, t) + \frac{\delta t\, q_I(t)}{\delta V_I} + \varepsilon
\end{aligned}
$$



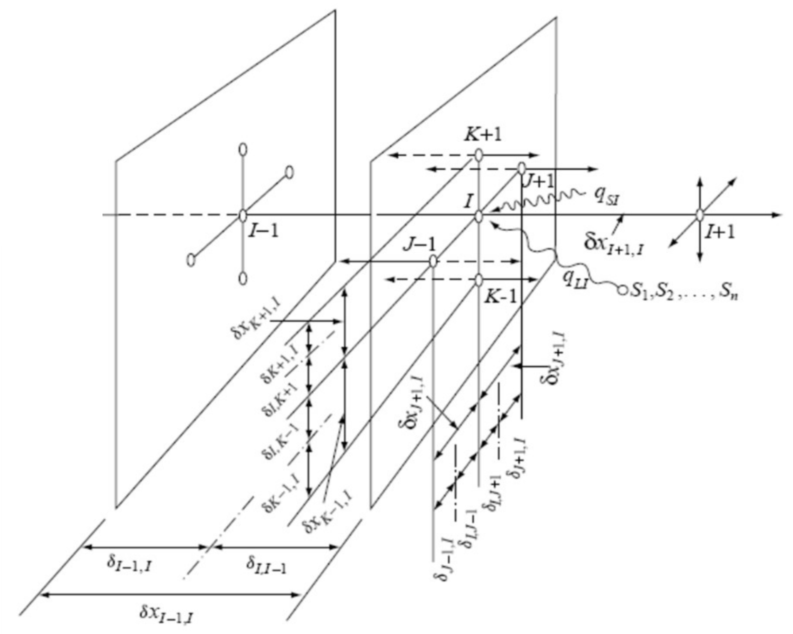


Figure 3.9: Surface energy balance nodal scheme.

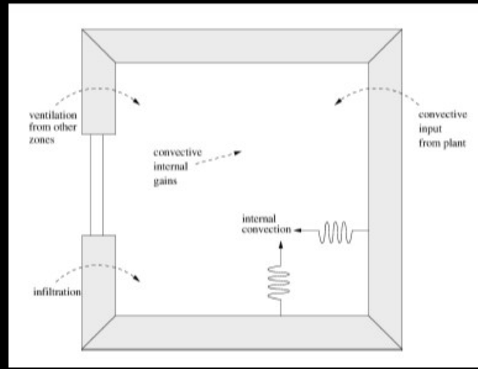
Surface node types:

- ❑ room surfaces;
- ❑ plant component surfaces;
- ❑ ground.

Fluid energy conservation equation

$$\left(2W_I(t+\delta t) + \frac{\delta t \sum_{i=1}^{N} h_{ci,I}(t+\delta t)\delta A_{i,I}}{\delta V_I} + \frac{\delta t \sum_{j=1}^{M} v_{j,I}(t+\delta t)\bar{\rho}_{j,I}(t+\delta t)\bar{C}_{j,I}(t+\delta t)}{\delta V_I}\right)\theta(I,t+\delta t)$$
$$- \frac{\delta t \sum_{i=1}^{N} h_{ci,I}(t+\delta t)\delta A_{i,I}\theta(i,t+\delta t)}{\delta V_I} - \frac{\delta t \sum_{j=1}^{M} v_{j,I}(t+\delta t)\bar{\rho}_{j,I}(t+\delta t)\bar{C}_{j,I}(t+\delta t)\theta(j,t+\delta t)}{\delta V_I}$$
$$- \frac{\delta t\, q_I(t+\delta t)}{\delta V_I} = \left(2W_I(t) - \frac{\delta t \sum_{i=1}^{N} h_{ci,I}(t)\delta A_{i,I}}{\delta V_I} - \frac{\delta t \sum_{j=1}^{M} v_{j,I}(t)\bar{\rho}_{j,I}(t)\bar{C}_{j,I}(t)}{\delta V_I}\right)\theta(I,t)$$
$$+ \frac{\delta t \sum_{i=1}^{N} h_{ci,I}(t)\delta A_{i,I}\theta(i,t)}{\delta V_I} + \frac{\delta t \sum_{j=1}^{M} v_{j,I}(t)\bar{\rho}_{j,I}(t)\bar{C}_{j,I}(t)\theta(j,t)}{\delta V_I} + \frac{\delta t\, q_I(t)}{\delta V_I} + \varepsilon$$

$$C_s(t+\delta t)\theta(I,t+\delta t) - \sum_{i=1}^{N} C_{ci}(t+\delta t)\theta(i,t+\delta t) - \frac{\delta t\, q_I(t+\delta t)}{\delta V_I}$$
$$= C_s(t)\theta(I,t) + \sum_{i=1}^{N} C_{ci}(t)\theta(i,t) + \frac{\delta t\, q_I(t)}{\delta V_I} + \varepsilon$$



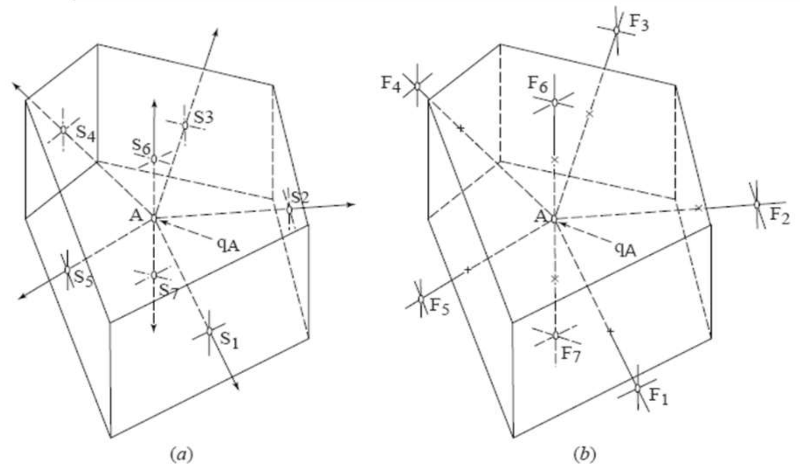


Figure 3.10: Fluid volume energy balance nodal scheme. (a) Fluid volume contained by real surfaces; convective heat transfer. (b) Fluid volumes contained by fictitious surfaces; advective heat transfer.

Surface node types:

- room air;
- construction air gaps;
- plant component fluids.

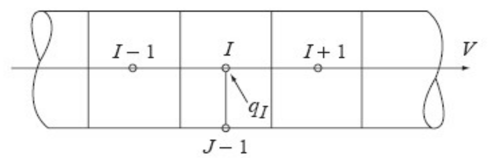


Figure 3.11: Nodal scheme for fluid flow in ducts and pipes.

Equation structuring – building zone + contents + radiator

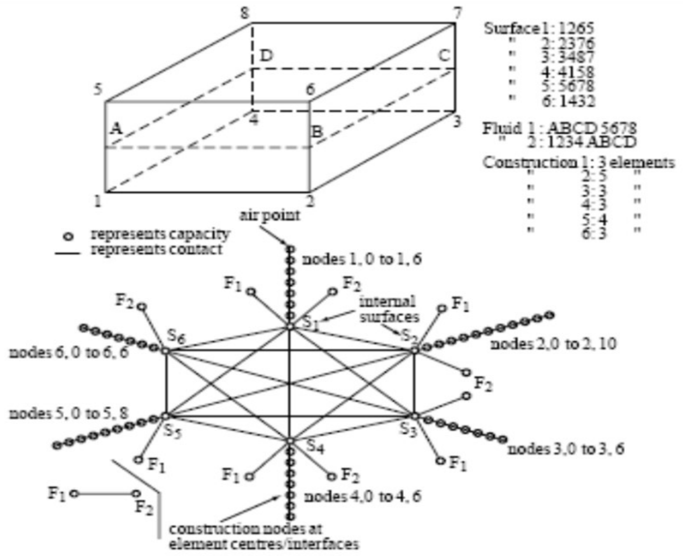


Figure 3.12: A single zone system and equivalent nodal scheme.

$$\mathbf{A}\theta_{n+1} = \mathbf{B}\theta_n + \mathbf{C}.$$

$$\mathbf{Z} = \mathbf{B}\theta_n + \mathbf{C}$$

$$\theta_{n+1} = \mathbf{A}^{-1}\mathbf{Z}.$$

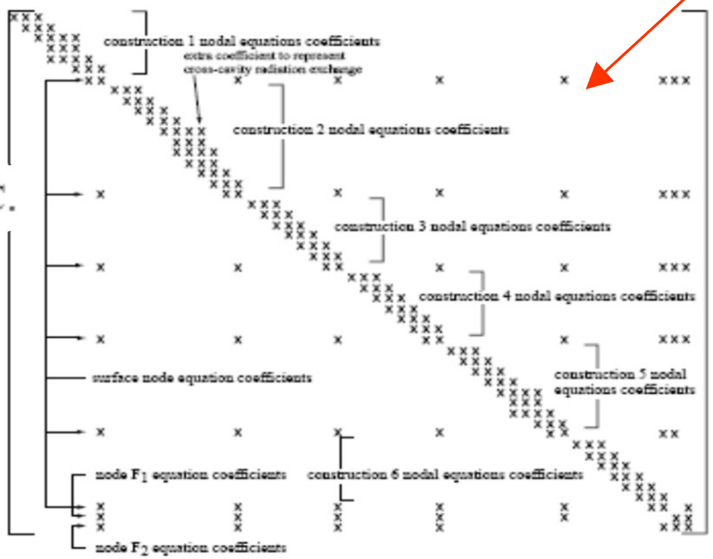


Figure 3.13: The future time-row coefficients matrix (A) of the single zone matrix equation $\mathbf{A}\theta_{n+1} = \mathbf{B}\theta_n + \mathbf{C}$.

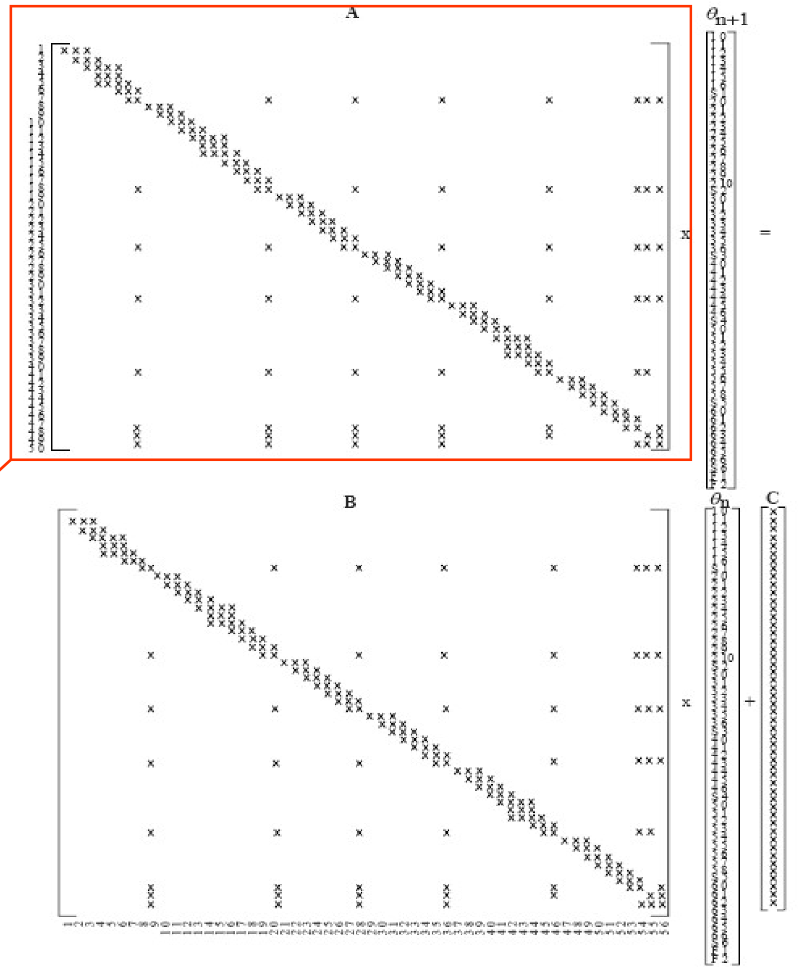


Figure 3.20: The single zone matrix equation $\mathbf{A}\theta_{n+1} = \mathbf{B}\theta_n + \mathbf{C}$.

outputs support: energy and comfort, impact of infiltration & ventilation, short- & longwave radiation, casual gains etc.

Equation structuring - passive/active solar system

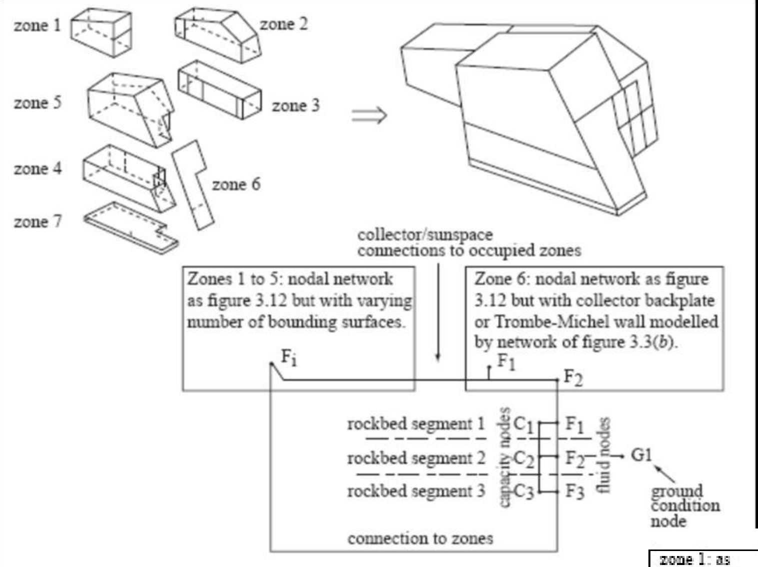


Figure 3.18: An passive/ active solar system.

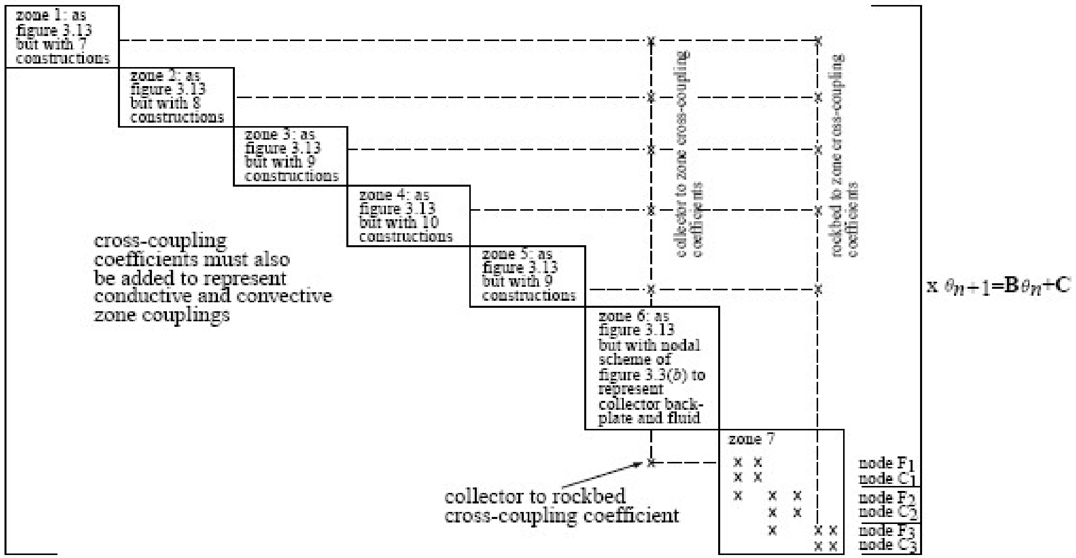
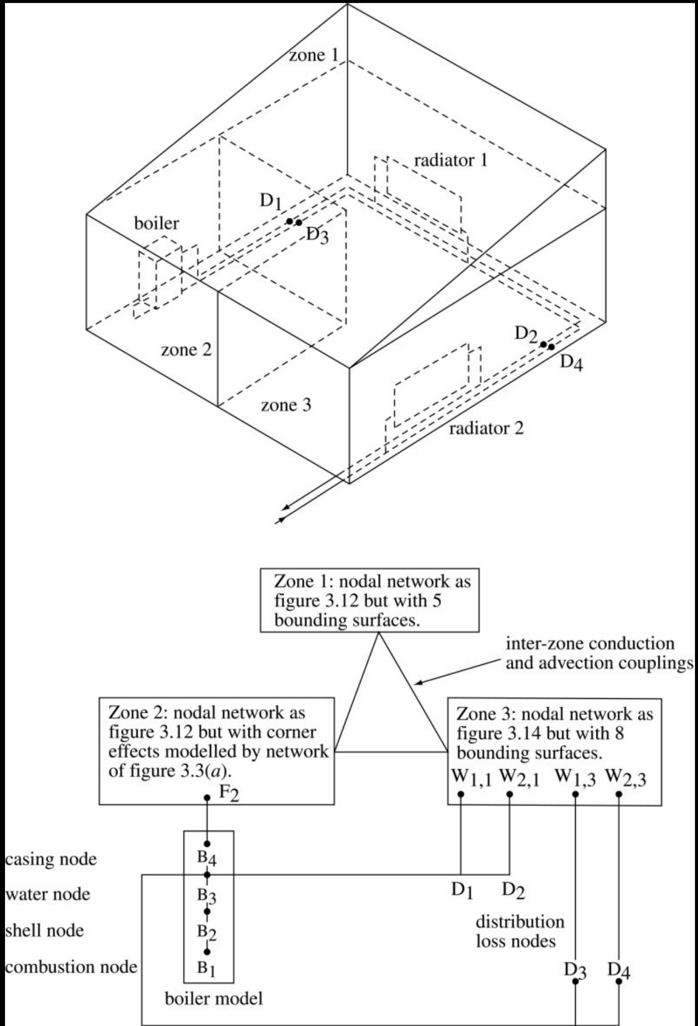
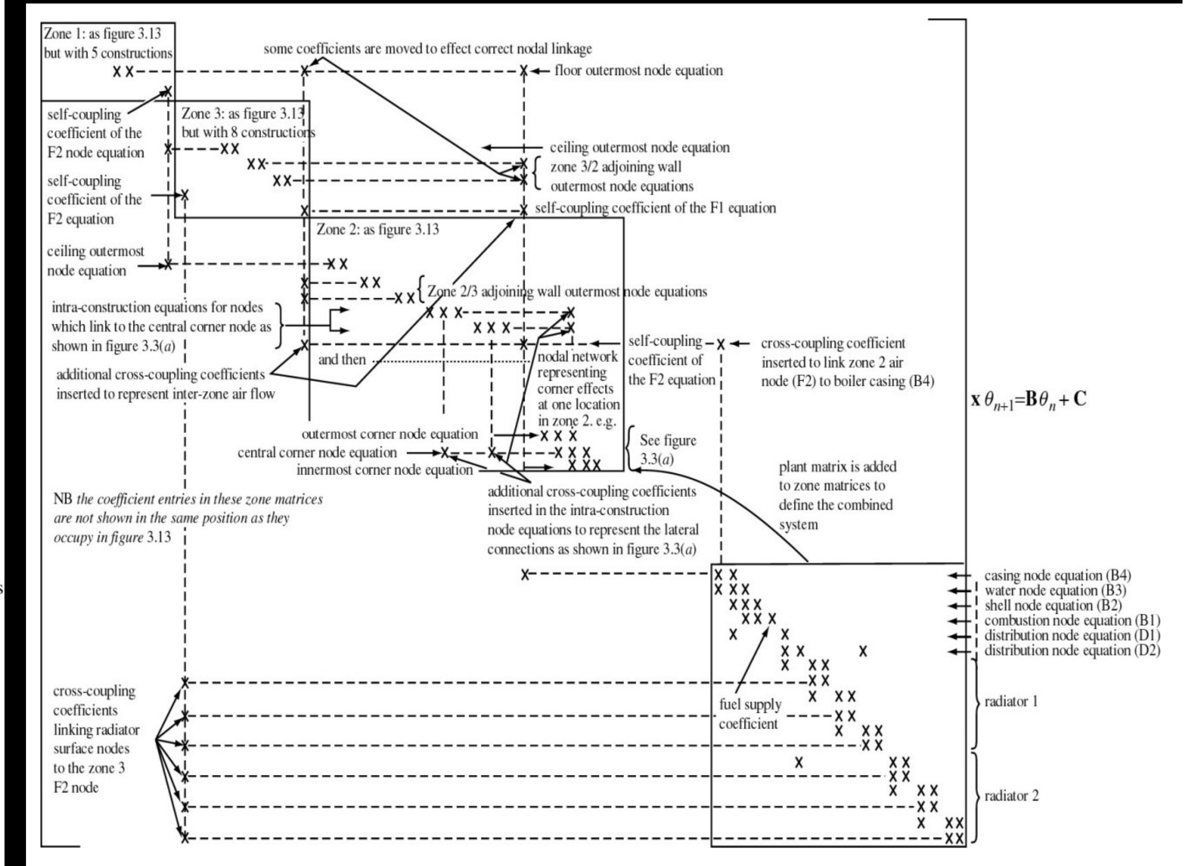


Figure 3.19: The energy balance matrix equation for the system of figure 3.18.

Equation structuring - central heating system





Outputs support: energy and comfort; building/plant zoning strategies; control, system efficiency, distribution losses etc.

Calculating equation coefficients

Construction Conservation Equation

$$
\left(2\rho_I(t+\delta t)C_I(t+\delta t)+\frac{2\delta t\,k(t+\delta t)}{\delta x_I^2}\right)\theta(I,t+\delta t)
-\frac{\delta t\,k(t+\delta t)}{\delta x_I^2}\theta(I-1,t+\delta t)-\frac{\delta t\,k(t+\delta t)}{\delta x_I^2}\theta(I+1,t+\delta t)-\frac{\delta t\,q_I(t+\delta t)}{\delta x_I\delta x_J\delta x_K}
$$
$$
=\left(2\rho_I(t)C_I(t)-\frac{2\delta t\,k(t)}{\delta x_I^2}\right)\theta(I,t)
+\frac{\delta t\,k(t)}{\delta x_I^2}\theta(I-1,t)+\frac{\delta t\,k(t)}{\delta x_I^2}\theta(I+1,t)+\frac{\delta t\,q_I(t)}{\delta x_I\delta x_J\delta x_K}.
$$

Surface Conservation Equation

$$
\left(2W_I(t+\delta t)+\frac{\delta t\,k'_{I-1,I}(t+\delta t)}{\delta x_{I-1,I}\delta_{I,I-1}}+\frac{\delta t\,h_{cI+1,I}(t+\delta t)}{\delta_{I,I-1}}+\frac{\delta t\sum_{s=1}^{N}h_{rs,I}(t+\delta t)}{\delta_{I,I-1}}\right)\theta(I,t+\delta t)
$$
$$
-\frac{\delta t\,k'_{I-1,I}(t+\delta t)}{\delta x_{I-1,I}\delta_{I,I-1}}\theta(I-1,t+\delta t)-\frac{\delta t\,h_{cI+1,I}(t+\delta t)}{\delta_{I,I-1}}\theta(I+1,t+\delta t)
$$
$$
-\frac{\delta t\sum_{s=1}^{N}h_{rs,I}(t+\delta t)\theta(s,t+\delta t)}{\delta_{I,I-1}}-\frac{\delta t\,q_{PI}(t+\delta t)}{\delta_{I,I-1}\delta_{J-1,J+1}\delta_{K-1,K+1}}
$$
$$
=\left(2W_I(t)-\frac{\delta t\,k'_{I-1,I}(t)}{\delta x_{I-1,I}\delta_{I,I-1}}-\frac{\delta t\,h_{cI+1,I}(t)}{\delta_{I,I-1}}-\frac{\delta t\sum_{s=1}^{N}h_{rs,I}(t)}{\delta_{I,I-1}}\right)\theta(I,t)
$$
$$
+\frac{\delta t\,k'_{I-1,I}(t)}{\delta x_{I-1,I}\delta_{I,I-1}}\theta(I-1,t)+\frac{\delta t\,h_{cI+1,I}(t)}{\delta_{I,I-1}}\theta(I+1,t)+\frac{\delta t\sum_{s=1}^{N}h_{rs,I}(t)\theta(s,t)}{\delta_{I,I-1}}
$$
$$
+\frac{\delta t[q_{PI}(t)+q_{SI}(t)+q_{RI}(t)+q_{SI}(t+\delta t)+q_{RI}(t+\delta t)]}{\delta_{I,I-1}\delta_{J-1,J+1}\delta_{K-1,K+1}}+\varepsilon.
$$

Fluid Conservation Equation

$$
\left(2W_I(t+\delta t)+\frac{\delta t\sum_{i=1}^{N}h_{ci,I}(t+\delta t)\delta A_{i,I}}{\delta V_I}+\frac{\delta t\sum_{j=1}^{M}v_{j,I}(t+\delta t)\bar{\rho}_{j,I}(t+\delta t)\bar{C}_{j,I}(t+\delta t)}{\delta V_I}\right)\theta(I,t+\delta t)
$$
$$
-\frac{\delta t\sum_{i=1}^{N}h_{ci,I}(t+\delta t)\delta A_{i,I}\theta(i,t+\delta t)}{\delta V_I}-\frac{\delta t\sum_{j=1}^{M}v_{j,I}(t+\delta t)\bar{\rho}_{j,I}(t+\delta t)\bar{C}_{j,I}(t+\delta t)\theta(j,t+\delta t)}{\delta V_I}
$$
$$
-\frac{\delta t\,q_I(t+\delta t)}{\delta V_I}=\left(2W_I(t)-\frac{\delta t\sum_{i=1}^{N}h_{ci,I}(t)\delta A_{i,I}}{\delta V_I}-\frac{\delta t\sum_{j=1}^{M}v_{j,I}(t)\bar{\rho}_{j,I}(t)\bar{C}_{j,I}(t)}{\delta V_I}\right)\theta(I,t)
$$
$$
+\frac{\delta t\sum_{i=1}^{N}h_{ci,I}(t)\delta A_{i,I}\theta(i,t)}{\delta V_I}+\frac{\delta t\sum_{j=1}^{M}v_{j,I}(t)\bar{\rho}_{j,I}(t)\bar{C}_{j,I}(t)\theta(j,t)}{\delta V_I}+\frac{\delta t\,q_I(t)}{\delta V_I}+\varepsilon
$$

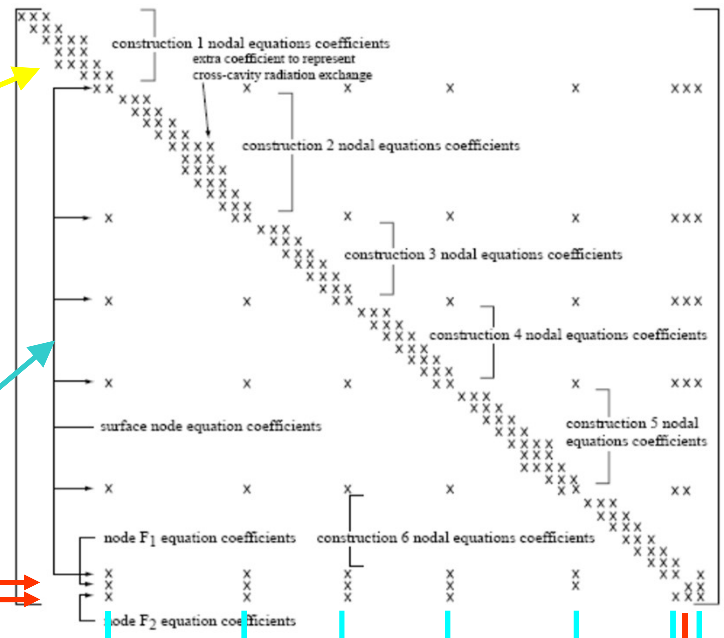


Figure 3.13: The future time-row coefficients matrix (**A**) of the single zone matrix equation $\mathbf{A}\theta_{n+1} = \mathbf{B}\theta_n + \mathbf{C}$.

needs flow estimation

needs radiation and convection estimation

Imposing control

Figure 6.15: Elements of a control loop.

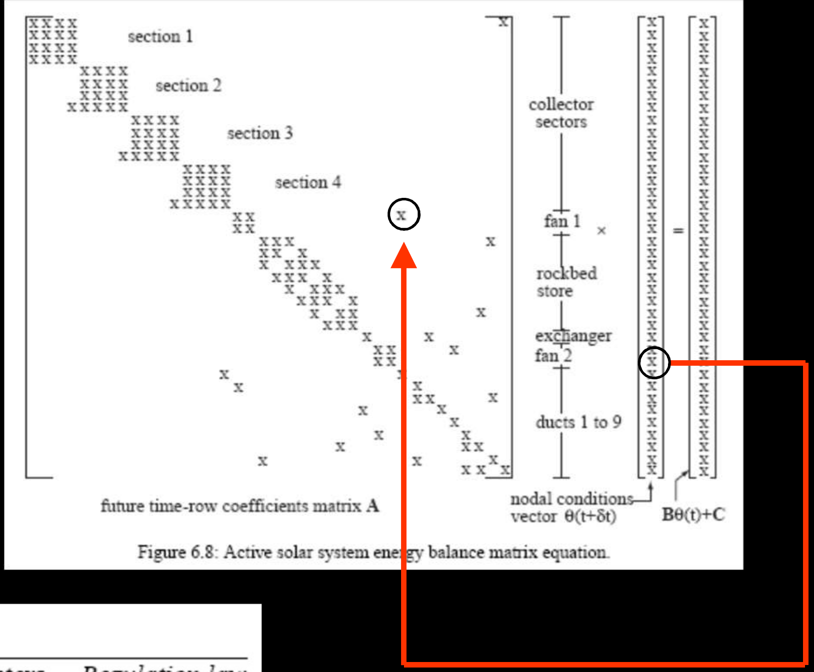


Figure 6.8: Active solar system energy balance matrix equation.

Table 6.8: Examples of control loop elements.

Sensed/actuated parameters	*Regulation law*	*Sensed/actuated parameters*	*Regulation law*
time of day/year	ideal	CO_2 level	duty cycling
climate	PID combinations	ventilation rate	load shedding
various temperatures	optimum start/stop	room air velocity	adaptive
glare and illuminance	weather compensation	hygro-thermal properties	fuzzy logic
luminaire status	cascade	humidity	neural network
occupancy	enthalpy cycle		

Table 6.9: Some examples of simulation-assisted control.

Control focus	*Optimised parameter*	*Control focus*	*Optimised parameter*
HVAC operation	start/stop time	district heating	match to load
night cooling	hours of operation	under-floor heating	period of operation
night set-back	set-back temperature	mixed ventilation	avoid overheating
boiler sequencing	heating system eff.	ice store charging	hours of operation
load shedding	energy consumption	ground heat pump	thermal storage
CHP	hours of operation		

Equation-set solution

- Equations are linked => simultaneous solution required.
- Equation-set is sparse and populated by clusters of equations relating to components with different time constants => special solver required to minimise the computational effort.
- Partitioning techniques often used allowing different clusters to be processed at different frequencies depending on the related time constant.
- This allows control decisions to be made, and problem parameters recomputed, more frequently for an item of plant requiring a computational time-step of, say, 1 minute, than for a heavyweight construction requiring, say, 60 minutes.
- Two main equation solving approaches: iterative and direct.

Equation-set extension

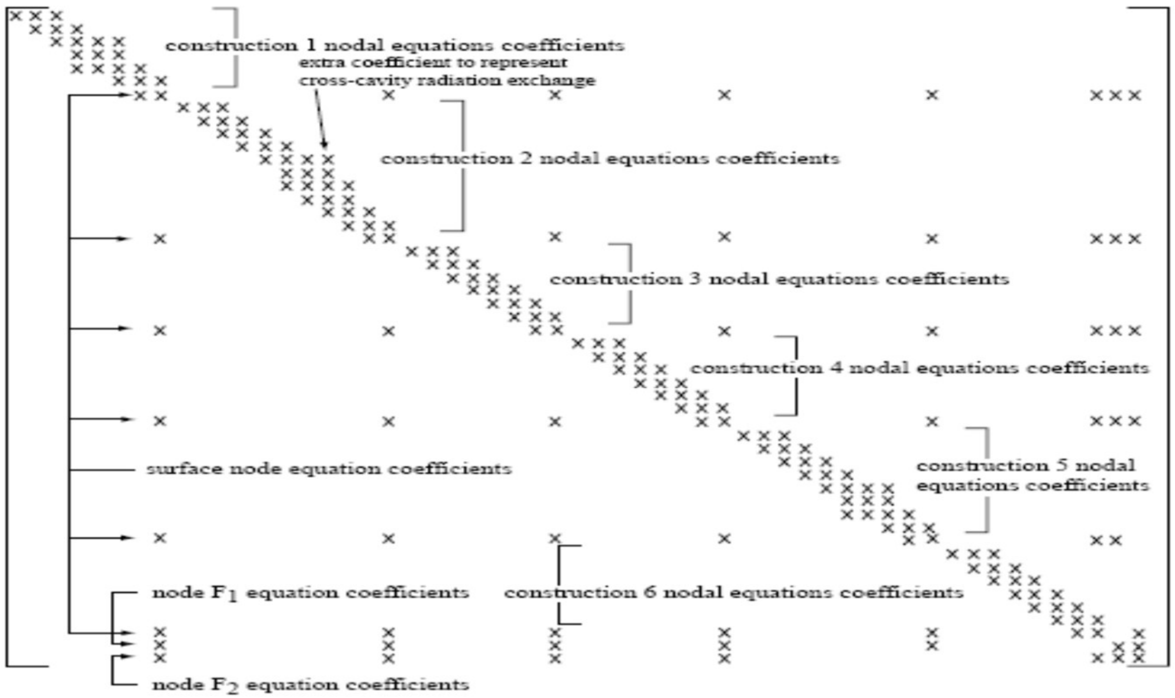


Figure 3.13: The future time-row coefficients matrix (**A**) of the single zone matrix equation $\mathbf{A}\theta_{n+1} = \mathbf{B}\theta_n + \mathbf{C}$.

Equation coefficients can be extended to improve the modelling resolution in relation to:

- short-wave and long-wave radiation;
- air movement;
- casual gains;
- surface convection;
- variation in fundamental parameters.

Technique can be similarly applied to all energy systems.