CENTER FOR ENERGY AND PROCESSES

Thermal model of an earth-to-air heat exchanger for passive cooling of buildings

Modélisation thermique d'un échangeur air-sol pour le rafraîchissement de bâtiments

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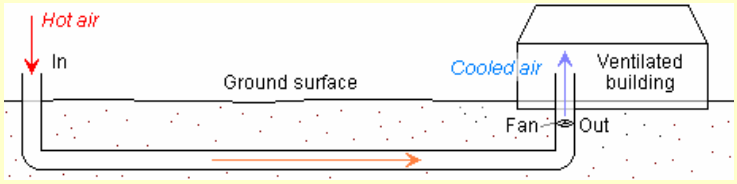
25 avril 2007, Aix-les-Bains
Journée thématique SFT-IBPSA
Froid solaire et confort d'été

1. The earth-to-air heat exchanger (ETAHE)
2. Modelling
3. Implementation
4. Validation

1. The earth-to-air heat exchanger

1. The earth-to-air heat exchanger

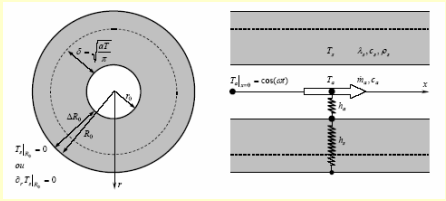
- Basic technology
- Complex dynamics (thermal inertia of the soil)
- Soil temperature uneasy to evaluate

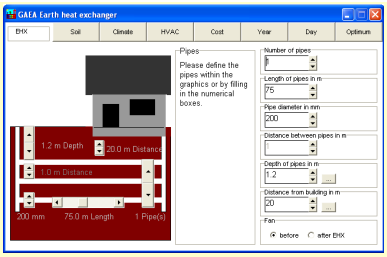


- Complete model is needed for integration within a dynamic building model

1. The earth-to-air heat exchanger

- Litterature review
  - Analytic study of soil-air exchange in ducts
    (PhD. thesis of P. Hollmuller)
  - GAEA software + PhD. Thesis of G. Dibowski
    (Groupe AG Solar NRW)
  - Several ground thermal models
    (INSA de Toulouse)





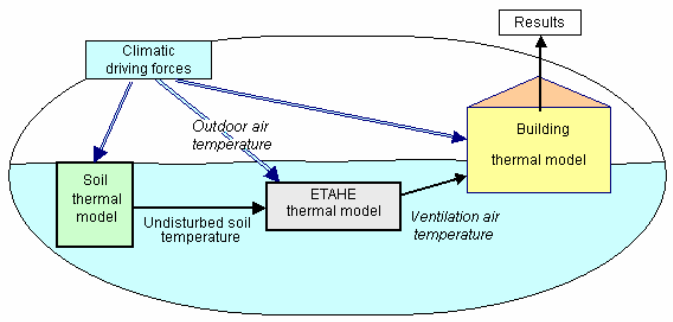
These ETAHE models are not coupled with a detailed building model.

1. The earth-to-air heat exchanger

- Main phenomena
  - Convection in ducts
  - Conduction through duct and soil
  - Water flowing in soil
  - Influence of a nearby building
- Main parameters
  - Exchanger geometry and dimensions (length, diameter, etc.)
  - Ducts depth in soil
  - Air flow in ducts
  - Soil physical features (nature, humidity)
- Driving forces
  - Outside air temperature
  - Soil temperature
  - Other climatic data such as solar radiation
- The model developed is
  - coupled with a detailed building model
  - a compromise between acuracy and user-friendliness
  - 60 nodes only

2. Model

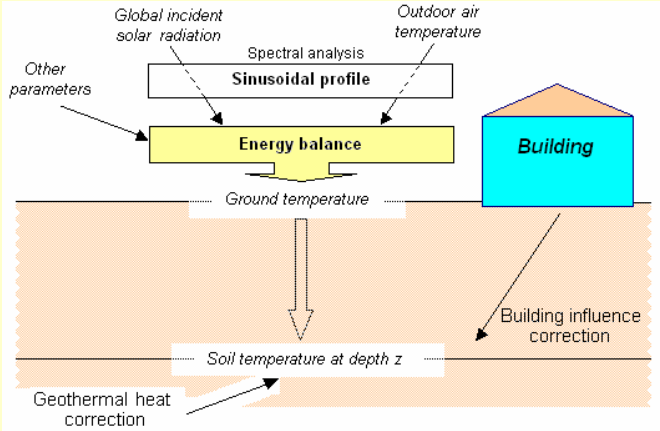
2.1 Model structure



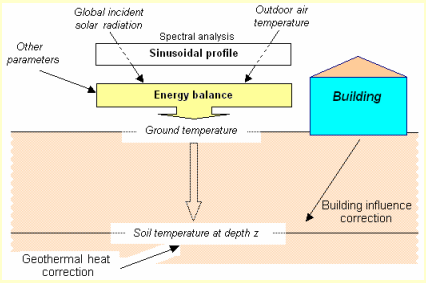
- Two linked models
  - Soil thermal model → boundary value
  - Earth-to-air heat exchanger model

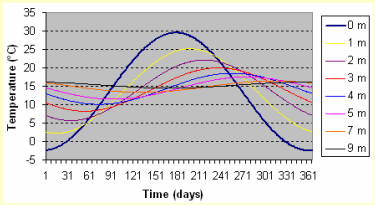
2.2 Ground thermal model

- Structure



2.2 Ground thermal model



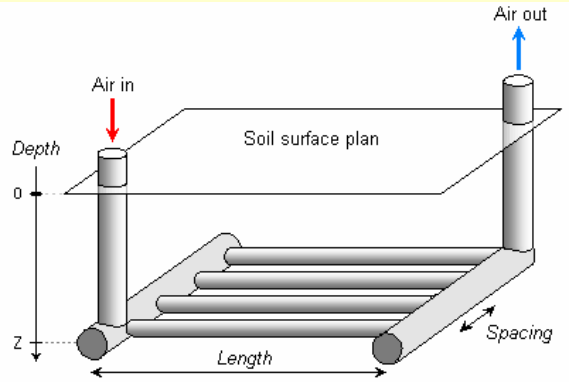


$$T(r,z,t)=\overline{T_s}+Geo(z)+\sigma(r,z)\left(T_{surf\_bat}-\overline{T_s}\right)+\left(1-\sigma(r,z)\right)\sum_{n=1}^{N_h}\left[A_{surf\_sol,n}\cdot\exp\left(\frac{z}{\delta(n\cdot\omega)}\right)\cdot\sin\left(n\cdot\omega\cdot t-\varphi_{surf\_sol,n}-\frac{z}{\delta(n\cdot\omega)}\right)\right]$$

- $\overline{T_s}$: Mean annual temperature
- $Geo(z)$: Geothermal flow
- $\sigma(r,z)$: Building influence factor
- $\sum_{n=1}^{N_h}\left[A_{surf\_sol,n}\cdot\exp\left(\frac{z}{\delta(n\cdot\omega)}\right)\cdot\sin\left(n\cdot\omega\cdot t-\varphi_{surf\_sol,n}-\frac{z}{\delta(n\cdot\omega)}\right)\right]$: Propagation of the ground surface temperature in the soil

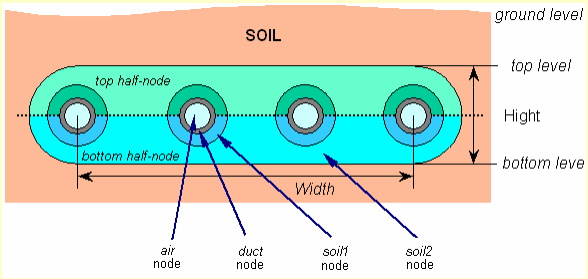
2.3 Earth-to-air heat exchanger thermal model

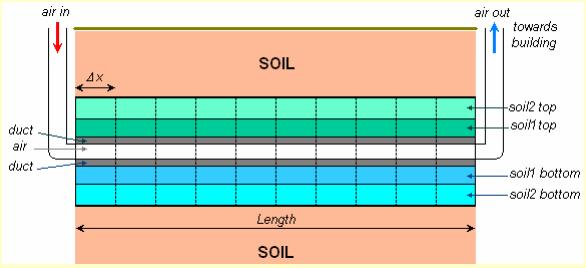
- Structure



2.3 Earth-to-air heat exchanger thermal model

- Finite volume model





2.3 Earth-to-air heat exchanger thermal model

- Equating
  - Energy balance for each volume
- Differential equation in a matrix form

$$C \cdot \frac{dT}{dt} = A \cdot T + E \cdot U$$

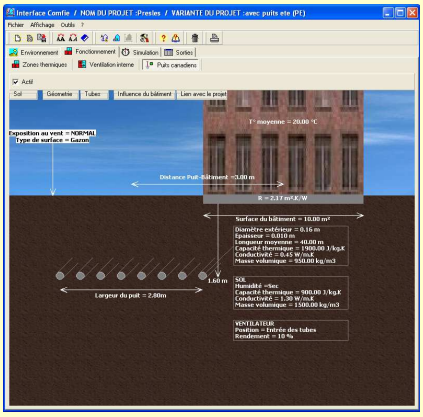
C : diagonal matrix of thermal capacities (J/K)
T : vector of the temperatures (K)
A : matrix of thermal exchanges between volumes (W/K)
E : matrix of thermal exchanges between volumes and driving forces (W/K)
U : vector of the driving forces (K)

- Solving by modal analysis
  - enables a line by line resolving (by matrix inversion)
  - No modal reduction needed (6 equations only)

3. Implementation

3. Implementation

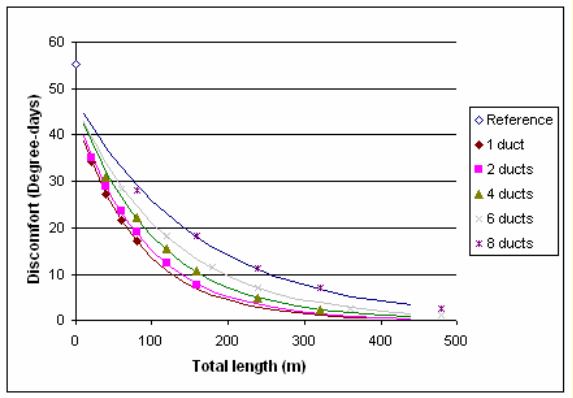
- Integration of the model as a module in Pléiades + COMFIE software
- Graphic user interface realized by *Izuba Energies*



4. Validation

4.1 Sensitivity study

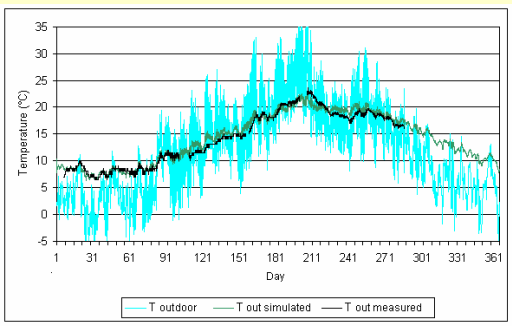
- The selection of the most important parametres has been checked.

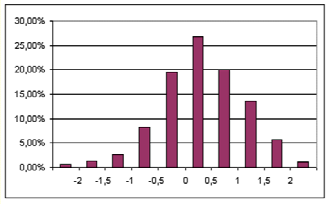


Example : Discomfort reduction in function of the total exchanger length and the number of ducts at constant air flow

4.2 Validations

- Living-room of an elderly people's home in Presles (95)
  ETAHE installed by *Canada Clim*

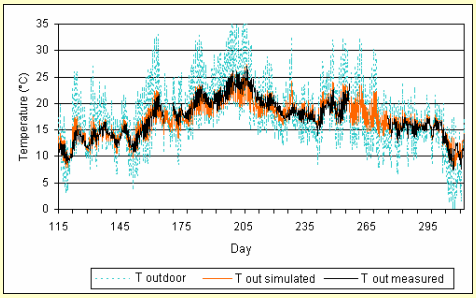


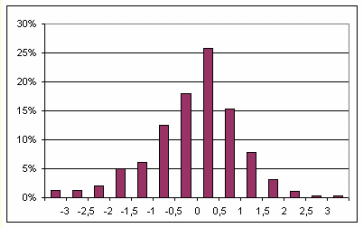


Error statistic distribution →
Mean : + 0,3 °C
< 2 °C during 98 % of time

4.2 Validations

- Office part of a tertiary building in Montigny-lès-Cormeilles (95). ETAHE installed by *Canada Clim*





Error statistic distribution →

Mean : 0°C

< 2 °C during 94 % of time

Conclusions

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- Model including the main phenomena and the main corresponding parametres
- Limited complexity of finite volume model
- Accurate results, same accuracy as GAEA

Limits

- The soil thermal model complete validation and calibration is needed.
- Soil regeneration by water infiltration is not considered
- Future improvement : coupling with regulation and heat recovery ventilation (HRV) unit

- Model released in the last version (2.7.1) of Pléiades+COMFIE software

Thank you for your attention

Merci de votre attention