International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 4 Issue 10 ǁ October. 2016 ǁ PP. 22-30

Moisture Transfer in Buildings

Md Sadiqul Hasan Talukder
B.Sc. In Mechanical Engineer Department Of Mechanical Engineering Rajshahi University Of Engineering & Technology, Bangladesh.

Abstract: This research work deals with the implication of modern retailing at not only in Dhaka, Bangladesh but also the whole district in Bangladesh with main objectives to find out technological activity, impact on modern welfare..
Key words: Accurate, Perimeter, Darcy's Law, Thermal Conductivity, Heat-conduction

I. INTRODUCTION

The objective of this work is to evaluate the possibility of ensuring indoor temperature and relative humidity in an acceptable range by controlling heating and ventilation associated with minimising the energy consumption or cost by the use of a numerical simulation program. An acceptable indoor range means that indoor temperature is 20 °C with small fluctuation and relative humidity is in the range of 20–70%. A simple heating and ventilation control regulation is proposed. Simulation examples are conducted for different types of buildings based on energy consumption or cost factor. Simulations demonstrate that the indoor condition is much more improved and significant energy consumption or cost can be reduced by using the control regulation developed in this paper.

II. HEADINGS

The overall objective of this work is to develop an accurate model for predicting heat and moisture transfer in buildings including building envelopes and indoor air. The model is based on the fundamental thermodynamic relations. Darcy's law, Fick's law and Fourier's law are used in describing the transfer equations. The resultant nonlinear system of partial differential equations is discretised in space by the finite element method. The time marching scheme, Crank–Nicolson scheme, is used to advance the solution in time. The final numerical solution provides transient temperature and moisture distributions in building envelopes as well as temperature and moisture content for building's indoor air subject to outdoor weather conditions described as temperature, relative humidity, solar radiation and wind speed. A series measurements were conducted in order to investigate the model performance. The simulated values were compared against the actual measured values. A good agreement was obtained.

III. INDENTATIONS

Some of the earliest detailed heat transfer measurements from a basement were performed by Houghten et al. (1942) . They measured soil temperatures and wall and floor heat fluxes for a buried structure over a period of one year. These measurements proved that the simple conduction calculations used at that time vastly over-predicted the heat loss. Bareither et al. (1948) measured temperatures and heat loss from nine slab-on-grade constructions and showed the existence of two-dimensional flow for a 3-foot strip along the edge and one-dimensional flow for the central region of the floor. They also derived two methods to estimate the heat loss, q (W) from slab-on-grade floors based on heat-loss factors, F_1 and F_2.

$$q = F_1 P(T_{in} - T_{out}) + 2(A_{totalfloor} - A_{perimeter}) \quad (2.1)$$

$$q = F_2 P(T_{in} - T_{out}) \quad (2.2)$$

The perimeter of the floor is P (m), the indoor-outdoor air temperature difference is ($T_{in} - T_{out}$) (C), and $A_{perimeter}$ (m^2) is the floor area of a 3-foot border along the exposed edge. Bareither et al. believed that Eq. (2.1) would provide better estimates of floor heat loss for all constructions,

ESpecially for floors with an A/P ratio greater than 12 m. The values for the F_2 heat loss factor from this research were used in the *ASHRAE Handbook of Fundamentals* for many years until they were replaced by numerically derived values.

For his Ph.D. thesis, Shipp (1979) compiled experimental data on a large, earth-sheltered building on the University of Minnesota campus. Wall heat fluxes, soil temperatures, and moisture contents were measured to depths of 9.3 m in grass-covered, asphalt-covered, and concrete-covered areas around the building. On the north side of the building, three different soil types were used as backfill. The ground surface conditions were determined to be the most important factor controlling the heat transfer between the building and the ground. The boundary conditions at the surface affect not only the heat flow into the ground but also the moisture content of the soil, which affects the soil thermal properties. This suggests that a detailed treatment of the ground surface moisture and energy balances is important.

Bligh et al. (1982) and Bligh and Knoth (1983) completed detailed measurements of the soil and structure temperatures, heat flows, energy use, and indoor and outdoor conditions for an earth- sheltered house near Boston, Massachusetts. They demonstrated that the heat-flow paths from the buried walls change from the surface in the winter to the deep ground in the spring. They also showed that ground surface temperatures under damp grass were as much as 20°C cooler than the temperatures of bare ground, showing the importance of ground cover.

Yoshino et al. (1992) completed a 5-year study of the thermal performance of a semi - underground test house in Sendai, Japan. The house was divided into identical sides, C and D, except that D also included horizontal insulation 0.3 m beneath the ground surface around the perimeter extending out 1.35 m from the building. They measured soil and inside air temperatures and heating energy consumption for the two sides. The side with horizontal insulation had slightly lower temperature variations and slightly lower heating loads. The use of horizontal insulation was only moderately effective in this case.

Trethowen and Delsante (1998) measured heat flows, temperatures, and soil thermal conductivities for two houses over a 4-year period in New Zealand. Both houses used uninsulated slab-on-grade construction and were occupied throughout the experiment. The water-table depth for the houses varied between 0.4 m and 1.0 m and maintained a high soil moisture content throughout the year. One significant result of the work is that it took approximately 2 years for the perimeter regions to reach a quasi-steady state and 3 years for the core region to reach a quasi-steady state. In addition, the presence of the houses did not seem to affect the depths of the water tables. Trethowen and Delsante calculated whole- floor R -values and compared these with calculations from simple methods from the ASHRAE (1997) and CIBSE Handbooks (1986), Delsante (1990), and Davies (1993). The calculated values were off by as much as + 50% for one house and -25% for the other house. The disagreements in these comparisons were caused by underestimating the soil thermal conductivity and by not including the width of the exterior wall. They estimate that approximately 10% of the floor heat loss could be through vertical conduction to the masonry exterior wall above the floor.

Thomas and Rees (1999) completed a one-and-a-half-year study of floor heat flows, soil temperature, and moisture levels of a new building at the Cardiff School of Engineering. The experiments showed that a lightweight concrete floor performed better thermally, with an overall thermal transmittance of 0.20 $W/m^2{\cdot}K$, when compared to 0.26 W/m^2 K for a normal-weight concrete floor. The measurements also showed that, for an uninsulated floor, approximately 60% of the winter floor heat loss to the ground occurs in a 1.5-m-wide strip around the perimeter of the building. Soil moisture levels in the first 2 m beneath the slab were relatively constant, but a rising water table did increase the moisture at a depth of 3 m. The soil moisture levels measured 1 m outside of the building foundation showed significant seasonal variation, suggesting strong effects of coupled heat and moisture transfer.

The first analytic two-dimensional model of ground-heat transfer to be widely recognized was developed by Macey (1949), who considered the problem of an infinitely long floor with correction factors for rectangular floors and wall thickness. This method is still used as the basis for heat -loss calculations in the *CIBSE Guide* (1986) . The first well-known transient solution method was developed by Lachenbruch (1957), who solved the differential heat-conduction equation using Green's functions. Lachenbruch used this method to study the three-dimensional heat conduction in permafrost beneath heated buildings and found that it takes 3 years for the temperature field to reach an annual steady periodic behavior. This solution method was later used as the basis of a computer program to calculate monthly heat loss values and ground temperature data used by the building energy simulation programs DOE-2 and BLAST (Kusuda et al. 1982 and Kusuda and Bean 1984). Both of these models assume uniform and constant thermal properties.

Fourier series solutions to the ground-heat-conduction equation were developed by Muncey and Spencer (1978), Shen and Ramsey (1983), and Delsante and Stokes (1983). Muncey and Spencer studied the shape of the slab floor and found that there is a linear relationship between a resistance parameter defined as thermal resistance of a slab shape/thermal resistance of a square of equal perimeter, and an area parameter defined as area/(perimeter/4)^2. Shen and Ramsey developed a transient thermal-analysis program for earth-sheltered buildings based on their solution method. Delsante was able to derive a closed-form solution to the two-dimensional heat conduction problem and an approximate solution to the three -dimensional problem. This model was later extended to approximate the heat loss through core and perimeter regions of insulated floors (Delsante 1988 and 1989), which was shown to compare well with measured data (Delsante 1990).

Claesson and Hagentoft (1991a and 1991b) applied superposition and dimensional analysis to combine numerical and analytical solutions of the problem of heat loss from slab-on-grade floors. The heat-conduction equation is solved for a steady state problem, for a periodic outdoor temperature, and for a unit step in outdoor temperature. The three solutions are combined by superposition to obtain the final solutions for specific problems. They discovered that the effects of groundwater are small unless the water level is high, that the effects of freezing are small, and that the insulating effects of snow cover should be considered. Hagentoft (1996a and 1996b) later investigated using a constant-temperature water table as a lower boundary condition. The effect of the water table depends on the heat-conduction ratio through the soil to the convection of heat carried away by the groundwater.

Krarti uses a clever approach called the Interzone Temperature Profile Estimation (ITPE) technique, which combines numerical and analytical approaches to solve the heat-conduction problem (Krarti et al. 1988a, 1988b, 1990, and 1994). If steady-periodic conditions are assumed, the transient heat-conduction equation can be transformed into a time-independent Helmholtz-type equation. The temperature is represented by a mean value, amplitude, frequency, and a phase shift. The ITPE technique divides the problem domain into zones, where the heat-conduction equation can be easily solved, and requires estimates of the temperature profile along the surfaces between the zones. Two- and three-dimensional models were developed that compare favorably with the results of Mitalas and Bahnfleth (Krarti 1995b) in predicting annual heat -loss values. One important conclusion from this work is the fact that the heat transfer from a slab floor can be divided into one-, two-, and three-dimensional regions (Krarti 1990) . A frequency-response analysis of this problem by Krarti, Claridge, and Kreider (1995a) showed that uninsulated slab floors and basement walls respond to ground-surface temperature variations in a few hours and insulated floors and walls respond to temperature variations in a few days. Limitations of this model include the need to know (or estimate) the temperature profiles between zones, constant soil properties, and a simplified treatment of the ground-surface boundary condition.

There are many simple methods available to determine the seasonal or annual ground-coupled heat loss from buildings. Most of these methods are based on the results of massive amounts of numerical simulations. While they can provide guidelines, the potential errors are large.

MacDonald et al. (1985) found that the predictions between models could vary by more than a factor of two.

Probably the most widely used methods are presented in the *ASHRAE Handbook of Fundamentals* (1997) for slab-on- grade floors and basements. The heat conduction from a slab-on- grade floor is approximated as a function of a heat-loss coefficient, F_2, the slab perimeter, and the temperature difference between the indoor and outdoor air as given in Eq. (2.2). The heat-loss coefficients were determined using the results of a two-dimensional, finite-element program for four foundation types with and without insulation in three climates (Wang 1979) . As pointed out by Bahnfleth (1989), this method neglects the heat transfer from the core region of the floor, which can be important for medium or large buildings. The method for basements, based on the work of Latta and Boileau (1969), assumes circular heat-conduction paths from the basement walls and floor to the ground surface. The walls are divided into strips at different depths with effective path lengths through the soil to the ground surface. This method does not take into account the vertical heat flow in the walls, which can be dramatically altered by insulation configurations and surface conditions. In addition, this model does not directly account for heat transfer to the deep ground, which can be significant when the surface is warm or when there is high groundwater. Both of these methods were based on calculations that assumed a single soil thermal conductivity and, they are limited in the geometries that can be modeled.

Another well-known method derived by Mitalas (1982 and 1987) is based on the results of hundreds of two- and three-dimensional simulations with a finite element method **(**FEM) code. This method uses shape factors called Basement Heat Loss Factors (BHLF) to estimate the monthly heat loss values for various geometries, insulation configurations, and soil thermal properties. Corner allowance factors for the three-dimensional corner effects were derived from the three-dimensional model. This simplified method is limited to a few specified geometries, insulation configurations, soil thermal conductivities, and heating degree days. In addition, no information is given on the ground surface boundary conditions used in the numerical simulations. Other methods are presented by Yard et al. (1984), the *CIBSE guide* (1986), Bahnfleth (1989), and Krarti and Choi (1996).

Changes were made to the DOE-2 building energy simulation program to improve its ground-coupled heat transfer calculations (Huang et al. 1988 and Shen et al. 1988). Shen et al. completed an annual numerical analysis of the ground-coupled heat transfer for 88 configurations of deep basements, shallow basements, crawl spaces, and slabs-on-grade in 13 U.S. cities. Using superposition of a steady-state solution and a periodic solution, they showed that the periodic solution could be completed once and then scaled to any climate. Many simplifying assumptions had to be made, such as neglecting the solar input and using a fixed heat-transfer coefficient at the ground surface. Huang et al. combined these results with DOE-2.1C to complete whole - building simulations and to provide guidance on insulation placement and amounts, which were published in the *Builder's Foundation Handbook* (Carmody et al. 1991). Winkelmann (1998) used these results to develop a simplified method of modeling underground surfaces using DOE-2.1E.

Using fully numeric solutions has been limited mainly to the researchers who developed them to perform parametric analysis and to develop correlation-based methods (e.g., the Mitalas method). The main reason for their limited use is the large amount of computer time and memory required to run them; they also tend to be complex programs. However, personal computers are now becoming fast enough, and the speed will continue to rise rapidly, making full numerical models practical. Most of the methods use either the finite-difference method (FDM) or the FEM method.

One of the earliest models was a three-dimensional FDM developed by Kusuda and Achenbach (1963). The program was used to study the temperature and humidity conditions in fallout shelters. One significant feature of this work is that they used different values of soil thermal conductivity for summer and winter to account for the seasonal changes in soil moisture content.

Wang (1979) developed a two-dimensional FEM model, which, as mentioned above, is the basis for the present F_2 coefficients in the *ASHRAE Handbook of Fundamentals* (1997) . This program includes the effects of the soil freezing and thawing. The results were reported as the heat loss per linear foot of the floor cross-section and not for the entire floor. The translation of these results to real floor geometry was not reported.

Speltz (1980) developed a complete program for the energy simulation of underground structures that includes a two- dimensional FEM routine for ground- coupled heat transfer. The most notable feature of this work is the detailed energy balance for the ground-surface-boundary condition.

The model includes short- and long-wave radiation exchange, conduction to the ground, convection, and evapotranspiration.

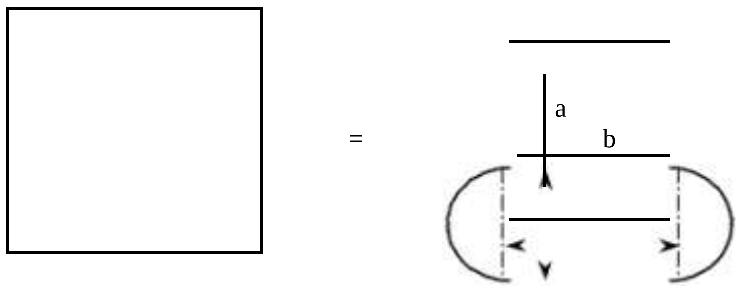
One of the most thorough works in this area was completed by Mitalas (1982, 1987), who completed hundreds of computer runs for slab-on-grade floors, shallow basements, and deep basements using two- and three-dimensional FEM codes. Mitalas noted that the heat loss can be significantly affected by groundwater, changes in soil thermal conductivity caused by moisture and temperature variation, and variations in ground surface temperature caused by solar radiation, adjacent buildings, and snow cover. This work was used as the basis for another two-dimensional program called BASECALC that simulates the three-dimensional heat transfer at the corners with the *corner correction method* (Beausoleil-Morrison et al. 1995). The *corner factor* is defined as

$$F_C = \frac{q_{corner\ zones} / P_{corner\ zones}}{q_{central\ zone} / P_{central\ zone}} \qquad (2.3)$$

The heat loss is q and the zone perimeter is P. A total of 1512 corner factors were determined for different combinations of the insulation placement, insulation resistance, basement depth, basement width, soil thermal conductivity, and water table depth. The heat loss for the central zone is calculated by BASECALC .

Bligh and Willard (1985) used the FEM thermal analysis program ADINAT to study the thermal performance of earth-sheltered buildings. This model used hourly weather data and included the effects of snow cover, cloud cover, and soil moisture phase changes from liquid to vapor and from liquid to solid. The most significant result of this work is that the heat loss varied nearly linearly with soil conductivity. Also, the solution took nearly 3 years to reach a quasi-steady state when initialized at zero and only a month when using a more realistic initialization from the results of a 3-year run, confirming the results of Lachenbruch.

Walton (1987) investigated the possibility of using two-dimensional calculations to approximate the three-dimensional heat flow to reduce the computation time. He transformed rectangular-shaped floors into rectangles with round ends, keeping the area and the perimeter the same as shown in Figure 2.1. The heat transfer is then calculated using two -dimensional Cartesian coordinates for the center section and two-dimensional cylindrical coordinates for the end sections. This method, called the “rounded rectangle” or RR method, estimates the steady-state heat transfer from various simple basement and slab-on-grade floor geometries to within 1.5% and 1.7% of the results from the three-dimensional model. Year -long transient calculations also produced similar results. This shows the possibility of reducing the computation time by using two-dimensional calculations; however, the RR technique is limited to simple slab-on-grade geometries where axis-symmetric conditions exist.



Same area, A and perimeter P

$$a = P - \sqrt{P^2 - 4\pi A}\ /\ \pi$$

$$b = (P - \pi a)/2$$

Figure 2.1. Geometry transformation used by Walton to reduce the three-dimensional problem to a two-dimensional problem.

Another comprehensive model is presented by Bahnfleth (1989) and Bahnfleth and Pedersen (1990). He developed a detailed three-dimensional FDM model for heat conduction from slab-on-grade floors. Significant features of this model include the detailed ground-surface energy balance that handles everything the Speltz model does plus the ground-shading effects. Bahnfleth performed many parametric runs to study the dominant influences on ground-heat loss. He determined that the primary factors in determining the heat loss are the weather conditions affecting the ground- surface temperatures, the floor-area-to-perimeter ratio, soil thermal conductivity, and the insulation configuration. He showed that when the annual mean heat loss, q, is plotted against the floor area-to-perimeter ratio, A/P, the data can be approximated by

$$q = c(A/P)^d \qquad (2.5)$$

The parameters c and d are functions of the annual average indoor-outdoor temperature difference, soil properties, domain geometry, foundation design, and other factors. A parametric study of soil thermal conductivity and diffusivity showed that a factor of four increase in conductivity produced a three-fold increase in annual mean heat loss, while the diffusivity had very little effect on the mean or periodic heat loss. The ground-surface temperature was also shown to have a large influence on heat loss; therefore, it is not surprising that evapotranspiration and shading can significantly affect the ground-heat transfer. Runs with potential (maximum) evapotranspiration reduced the annual mean heat loss by 18.7% in Minneapolis and by 170% in Phoenix. The real effect of this will be less because the maximum evapotranspiration rarely occurs. The shading of the building on the ground decreased the annual mean heat loss by 27% in Phoenix.

Despite the thoroughness of the model, there are some weaknesses. One shortcoming is the assumption of constant soil thermal properties, which does not allow for different soil layers, moisture effects, or freezing and thawing. Another limitation is that partial insulation of the slab and footing walls, which are common methods of construction, cannot be modeled. Bahnfleth et al. (1998) extended this work to a three-dimensional model for the heat loss from basements. This new model is more flexible with the insulation configurations, and the temperature of an unconditioned basement can be calculated to simulate interior conditions more accurately.

One glaring omission from the area of building ground-coupled heat transfer models is the lack of validation with experimental data. This is because of the size, complexity, and length of time required to monitor ground-coupled heat and moisture transfer. Rees et al. (1995) and Rees and Thomas (1997) compared the results of an FEM program with long-term experimental data.

Some of the comparisons are very good, while others are not. Rees attributes this to the estimation of the soil properties. It could also be caused by the approximation of the surface boundary conditions and by the fact that the soil properties were kept constant.

Adjali et al. (1998b) compared results from a finite volume ground heat transfer model added to the building energy simulation code, APACHE, with experimental data on a partial underground test room at the University of Minnesota. The results compared favorably for the summer, but not very well in the winter. They concluded that neglecting the effects of snow cover and rain can significantly affect the predicted temperatures. A sensitivity study showed that the soil thermal conductivity is the most important parameter and that the simulated results are more sensitive in the winter than the summer.

The only researcher found by the author to model the coupled heat and moisture transfer in soils around buildings was Shen (1986), who developed a two -dimensional fully implicit FDM program to analyze soil heat and moisture transfer. Shen validated the model well with published analytic solutions and with experimental data from heat and moisture transfer in a 1-m cylinder of Mississippi River sand. This model was then used to study the effects of rain on the heat transfer from a basement wall with both a clay soil and a sandy soil (Shen 1986; Shen and Ramsey 1988). The simulations were completed with the heat and moisture equations coupled and uncoupled. In the uncoupled simulation, the heat transfer by moisture movement was not considered; however, the soil's thermal properties were calculated as a function of the moisture content from the moisture transfer solution. The sandy soil showed a 9% increase in heat transfer for winter conditions and a 40% increase for summer conditions when the equations were coupled. The differences were much smaller for the clay soil. These results must be regarded with care because uncoupling the equations increases the thermal resistance since the heat flow by moisture transfer is not included. The main effect of moisture on the heat transfer in soils is on the thermal conductivity, which was not tested by this case.

Gold (1967) measured the ground temperatures under two parking lots. One was cleared of snow in the winter, and the other was a grass-covered area. He estimated that for the grass-covered area in the summer, about 48% of the net solar radiation was dissipated by evapotranspiration, 42% by long-wave radiation, 7% by convection, and 3% by conduction into the ground. For the parking lot areas, the net solar radiation was split between convection and long-wave radiation losses with about 50% for each. Apparently, the conduction to the ground was very small. The snow-covered parking lot maintained an average surface temperature approximately 10°C warmer than the coldest monthly average air temperature.

Kusuda (1975) investigated the effect of ground surface cover by measuring the temperatures under black asphalt, asphalt painted white, bare dirt, short grass, and long grass. He found that the average monthly temperatures near the surface under the black asphalt were about 15°F hotter than under the long grass, even at a depth of one foot. In the winter, all of the temperatures at one foot were similar. At a depth of 30 feet, the soil temperatures under the black asphalt were higher in the winter, but similar to the others in the summer.

Gilpin and Wong (1976) discussed the "heat-valve" effect of snow cover. They argued that prolonged snow cover in the winter acts as an insulating layer and can raise the annual mean ground-surface temperatures. They also showed that a phase change in the ground amplifies this effect.

Ground- coupled heat transfer is an important term in a building's energy balance; however, the tools for detailed analyses of the problem are not available. The most widely used analysis methods are quite crude and can easily produce inaccurate results. Most models are severely limited in the geometries, insulation configurations, boundary conditions, and the soil properties that can be analyzed. For a first approximation, these models can produce reasonable results; however, answers that are more accurate are difficult to come by. Questions such as the distribution of soil moisture around buildings, the interaction of the ground surface with the atmosphere, and the effects of phase change on ground-coupled heat transfer have not been answered with enough detail to provide good design advice. The behavior of heated floors and basements is also not well understood. Using the ground for cooling in warm climates has not been mentioned, but is also a very important topic. The aim of this research was to gain some insight into these issues and provide the necessary tools for further research.

Heat transfer in soil occurs through many different paths, including conduction through the soil grains, liquid, and gases; latent heat transfer through evaporation-condensation cycles; sensible heat transfer by vapor and liquid diffusion and convection; and radiation in the gas -filled pores.

Conduction through the solid soil particles is the dominant heat-transfer mode under most circumstances (de Vries 1958) . The contact resistance between the soil grains is the limiting factor; therefore, anything that reduces this resistance increases the thermal conductivity. Increasing the dry density promotes better contact between soil grains, and adding colloidal clay particles to a coarse soil can reduce the contact resistance by filling in the voids as long as the larger grains are not pushed apart. Adding moisture to a dry soil forms liquid islands around the contact points, which provides another path for heat flow (Farouki 1981). When moisture levels approach saturation, the lower thermally conductive gases are replaced with higher thermally conductive moisture.

In the gas -filled pores of unsaturated soils, liquid water evaporates on the warm side, absorbing the latent heat of vaporization and reducing the radius of the meniscus (dotted lines in Figure 3.1). Diffusion occurs because of the vapor pressure gradient, and the vapor condenses on the other side of the pore, releasing the latent heat of vaporization and increasing the meniscus radius. The sensible heat carried by the vapor is negligible because of the vapor's low volumetric heat capacity. At steady state, the imbalance in menisci radii induces capillary liquid flow between the soil grains to balance the vapor flow (Philip and de Vries 1957) . This process is significant to the overall thermal conductivity because the effective thermal conductivity of the vapor distillation cycles is larger than the thermal conductivity of the gas-filled pores alone (deVries 1958).

Forced convection arises from potential gradients. One example of forced convection in soils is the infiltration of liquid at the ground surface, which can be significant for a short time after a large rain or irrigation. This heat transfer mode is included in this model. Groundwater flow, which is usually parallel to the ground surface, affects the vertical heat transfer by entraining moisture and by dispersion effects. This is only significant in coarse sands and gravel (Farouki1981) and is not considered in this analysis. The presence of groundwater does affect soil heat transfer by providing a large heat sink and a source of moisture, which can be adsorbed by the soil above. This effect is included in this analysis.

The following three heat transfer modes are small for the soils and the conditions encountered in the ground around buildings. Free convection arising from temperature gradients is only significant in soils having particle sizes larger than 8 mm (Farouki 1981). Sensible heat transfer by vapor convection or diffusion is negligible because of the vapor's low volumetric heat capacity. Radiation heat transfer contributes less than 1% of the total heat transfer in sands at normal atmospheric temperatures and is much less in finer-grained soils (Farouki 1981).

The movement of water in soil is determined by the water's relative potential energy state. Hillel (1998) defines soil water potential "as the difference in partial specific free energy between soil water and standard water." Standard water is water at a free surface, which is exposed to atmospheric pressure at a specified height. Water in saturated soil under hydrostatic pressure greater than atmospheric pressure has a positive potential energy. Water in unsaturated soil is at pressures less than atmospheric and has a negative potential energy. To extract water from an unsaturated soil, the capillary and adsorptive forces holding on to the water must be overcome. The attractive force of the capillary and adsorptive actions of the soil matrix is called the soil matric potential. The total potential is assumed to be the gravitational and matric potentials as presented in Eq. (3.1), where z is taken as positive upwards. Osmotic potential arises from solute concentration gradients and is usually much smaller than the gravitational and matric potentials, and is neglected in this work. The potential is often expressed as an equivalent head of water and, therefore, has the dimension of length.

$$\Phi = \psi + z \qquad (3.1)$$

In the absence of osmotic forces, the matric potential can be used to determine the soil's moisture content. The relationship between the matric potential and the soil moisture is shown graphically by the soil-moisture-retention curve (also called the soil water characteristic curve). Figure 3.2 shows an approximation of the soil-moisture-retention curve for loamy sand reported by Noborio et al. (1996) and Yolo light clay (Moore 1939). The flatness of the sandy soil curve shows that the moisture drains quickly and the steeper slope for the clay shows that this soil has a higher attraction to moisture.

The behavior of the soil moisture retention typically exhibits a hysteresis between wetting and drying. The process of drying a moist soil (desorption) takes more energy than is released during the wetting (adsorption) process; therefore, the drying curve is usually higher than the wetting curve (Case 1994). This hysteresis is not modeled in this work, and the soil moisture retention curves are based on the drying behavior because this was the measurement method used for the soils in this research.

To simulate the soil moisture transfer in a soil, a continuous or piece-wise continuous correlation for the matric potential must be obtained. One of the most widely accepted methods for doing this is presented by van Genuchten (1980). The form of the correlation is

$$\Theta = \left[\frac{1}{1+\alpha|\psi|^{n}}\right]^{m} \qquad (3.2)$$

$$\Theta \equiv \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (3.3)$$

The degree of saturation is Θ; θ_r and θ_s are the residual and saturated water contents; α, m, and n are parameters set to fit the measured data; and $m = 1 - 1/n$. Van Genuchten presents a graphical method of determining these parameters to fit the measured data

The flow of water through unsaturated soil can be approximated by Richards' version of Darcy's law relating the flow to the gradient of the hydraulic head or the total potential (Hillel 1998). The parameter relating the flow to the pressure gradient is the hydraulic conductivity, K (m/s).

$$u_l = -K(\psi)\nabla\Phi \qquad (3.4)$$

The hydraulic conductivity in unsaturated soil is a function of soil and fluid properties, moisture content, and temperature. The soil liquid is assumed to be relatively pure water; therefore, the effects of the liquid on the hydraulic conductivity are neglected. If measured data are known for the range of moisture contents under consideration, a good approximation can be fitted to the data by a least-squares technique (Haverkamp et al. 1977). If hydraulic conductivity values are not known over the range of moisture contents, a satisfactory approximation can be developed using the hydraulic conductivity at saturation and the same parameters as determined from the soil-moisture-retention curve using van Genuchten's method (1980).

$$K(\Theta) = K_{sat}\,\Theta^{1/2}\left[1-\left(1-\Theta^{1/m}\right)^{m}\right]^{2} \qquad (3.5)$$

or in terms of the matric potential

$$K(\psi) = K_{sat}\,\frac{\left\{1-\left|\alpha\psi\right|^{n-1}\left[1+\left|\alpha\psi\right|^{n}\right]^{-m}\right\}^{2}}{\left[1+\left|\alpha\psi\right|^{n}\right]^{m/2}} \qquad (3.6)$$

The hydraulic conductivity curves of a loamy sand (Norborio et al. 1996) and of Yolo light clay using van Genuchten's method are shown in Figure 3.3.

If only pore ice exists in partially frozen soil, the movement of the unfrozen water content can be approximated by a Darcy's Law approach similar to that used in unfrozen soil (Kay and Perfect 1988). The hydraulic conductivity of partially frozen soil is a function of the unfrozen water content, which is a function of the temperature (Hoekstra 1966 and Harlan 1973). Measurements show that the hydraulic conductivity falls from values in the range of 10^{-8} m/s to between 10^{-12} m/s and 10^{-14} m/s over the temperature range from 0.0 to –1.0°C (Horiguchi and Miller 1983). Because no correlations for the hydraulic conductivity of frozen soil were found, it is assumed to follow the unfrozen relation using the unfrozen water content and corresponding matric potential. A small amount of water corresponding to the residual water content from the soil-moisture-retention curve remains unfrozen below the freezing point, but is not allowed to move once the soil temperature is below 0.0°C.

The correlations presented for the matric potential and the hydraulic conductivity are based on measurements taken in the lab at a constant temperature; however, soil temperatures in the field are constantly changing, which affects the values of these properties. This temperature effect is much smaller than that of moisture and is often neglected. For hydraulic conductivity, the viscous flow model of Miller and Miller (1956) points to a correction by the ratio of the kinematic viscosities of water at the reference temperature T_r and the actual temperature T. This method is generally accepted to produce accurate results (Milly 1982 from Eagleson 1970).

$$K_l(T,\theta) = \frac{\nu(T_r)}{\nu(T)}\,K_l(T_r,\theta) \qquad (3.7)$$

A temperature correction for the matric potential relationship can be derived by noting that the equilibrium of the air-water interface in a soil pore requires (Milly 1982)

$$\psi = \frac{2\sigma}{\rho_l\, g\, r_c} \qquad (3.8)$$

The harmonic mean radius is r_c, and the surface tension of the liquid is σ. From this, a temperature correction can be formed as

$$\psi(\theta, T) = \psi(\theta, T_r)\frac{\sigma(T)\,\rho_l(T_r)}{\sigma(T_r)\,\rho_l(T)} \qquad (3.9)$$

The density ratio is usually dropped from this equation. Using these temperature corrections from Eqs. (3.7) and (3.9) is often called the surface-tension viscous-flow (STVF) approach. Milly (1984 from Milly and Eagleson 1980) suggests another formulation for the matric potential

$$\psi(\theta, T) = \psi(\theta, T_r)e^{-C_\psi (T-T_r)} \qquad (3.10)$$

where

$$C_\psi = \frac{1}{\psi}\frac{\partial \psi}{\partial T}\bigg|_\theta \qquad (3.11)$$

is taken as a constant, $C\psi = 0.0068\ K^{-1}$.

Another approach is the gain factor method from Nimmo and Miller (1986). The gain factor G for the matric potential relationship is defined as

$$G_\psi(\theta) = \frac{\psi(T,\theta)/\psi(T_r,\theta) - 1}{\sigma(T)/\sigma(T_r) - 1} \qquad (3.12)$$

This method requires knowledge of the matric potential at two temperatures to determine the gain factor. Giakoumakis and Tsakiris (1991) showed that the gain-factor method works better than the STVF method for fine-textured soils, but the STVF method works well for coarse-textured soils.

The temperature correction factors with T_r = 20.0°C for the STVF method and the Milly-Eagleson method are shown in Figure 3.4. Notice that the surface-tension model with the density ratio is very similar to the value without the density ratio. Because the STVF model is the most widely used, it was chosen for this work.

IV. CONCLUSION

Limitation:

1. Only three-dimensional FEM codes acceptable.
2. The correlations presented for the matric potential is not so easy.

Though it has limitations but modern era is very dependable on these. Specially in industrial sector these are very effective. Hence, all kinds safety for human is possible by this system. So, this system is absolutely welcome for modern era.