Computational techniques applied to design ventilation system for the preservation of the tombs of the valley of Kings, Luxor

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Abstract: The cultural heritage left by the Egyptian Pharaohs in the tombs of the Valley of the Kings represents some of the key elements of the Egyptian cultural and tourism wealth and standing monuments demonstrating the wealth and technology of the pharaohs. These tombs were prepared to bury the Kings' mummies and artifacts for eternal life. Many of the wall paintings identifying the various ancient rituals and life style are in good conditions as the tombs were only recently opened to the public and resulted, in many instances, to dramatic deterioration of the wall paintings due in part to excessive humidity. Basically, ventilation air design systems are considered here for the tomb passage of King Ramsis VII, Ramsis IV, Siti II and Bay including different visitors (obstacles) alternative positioning to adequately predict the actual air flow, thermal and moisture patterns in the tombs and hence to provide energy efficient design of ventilation system and reduce the adverse effect of excessive humidity.

Keywords: archeology, CFD, Ventilation

1   Introduction

The present work made use of packaged Computational Fluid Dynamics (CFD) programs. For the present work, following similar work of AbdelAziz et al (2005) and Khalil (2006), a numerical study is carried out to define the optimum airside design of the tombs air ventilation and conditioning systems, which provides the optimum comfort and healthy conditions with optimum energy utilization. Basically, airside design types are considered here for the tomb passage of King Ramsis VII, Ramsis IV, Siti II and Bay, including different visitors (obstacles) alternative positioning to introduce the capability of the design to provide the optimum characteristics. The primary objective of the present work is to assess the airflow

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characteristics, thermal pattern and moisture distribution in the different tombs ventilation configurations in view of basic known flow characteristics. Tombs consist, typically of three gently sloping corridors. The free air supply and mechanically extracted ducted air play an important role in shaping the main flow pattern where the internal obstacles can distort the airflow pattern by increasing the recirculation zones or by deflecting the main airflow pattern.

2   Numerical Investigations

2.1   Governing Equations

The different governing partial differential equations are typically expressed in a general form, (Khalil; 2000 and Kameel; 2002) in 3D configurations under steady conditions, as:

$$\frac{\partial}{\partial x}\rho U \Phi + \frac{\partial}{\partial y}\rho V \Phi + \frac{\partial}{\partial z}\rho W \Phi =$$
$$\frac{\partial}{\partial x}\left(\Gamma_{\Phi,eff}\frac{\partial \Phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Gamma_{\Phi,eff}\frac{\partial \Phi}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Gamma_{\Phi,eff}\frac{\partial \Phi}{\partial z}\right) + S_{\Phi} \quad (1)$$

Where: ρ = Air density, kg/m^3 Φ = Dependent variable, S$_{\Phi}$ = Source term of Φ
U, V, W = Velocity vectors . $\Gamma_{\Phi,eff}$ = Effective diffusion coefficient.

The diffusion coefficients and source terms for the differential equations can be found in reference by Khalil (2008).

2.2   Boundary Conditions and assumptions

Four different tomb configurations were investigated; these outline the design development over the years from being merely single corridor with dead end as in tomb of Ramses VII, termed KV1 shown in figure 1 to more complicated designs of tombs KV2, KV13 and KV15. The sky-open entrance zone is excluded from the tomb structure. The proposed ventilation floor-mounted air extract grilles locations are clearly identified in figure 1. The tomb of Ramsis VII is simple in construction in a single axis; the vertical cross section clearly identified three zones, figure 1a. The entrance zone that extended to over 12 m with door locking the second zone of 20 m length that descended with steps down to another door locking the burial zone of 12 m length where the sarcophagus is located. The tomb height is 3.6 m on average and the width around 4 m on average, (Khalil; 2006).

Over 600000 computational cells were used to map the tomb total volume .More than 500 iterations were necessary to achieve the convergence criteria of residuals

being less than 10^{-3}in computational time just under three hours. Measured averaged wall temperatures of 295 K were used as boundary conditions, Khalil (2008). The inlet air conditions are taken as the average day max of 40^oC (313 k) and 30% relative humidity (humidity ratio =0.0138), representing August conditions which are the worst over the year. When air is admitted freely to the tomb, the turbulence intensity could be assumed to be 6% and the length scale is assumed to be 1 m. Using the Psychrometric chart one can find that the outside air wet bulb temperature is 25^oC; at the walls zero species, water vapour, diffusive flux are assumed with standard wall function for near wall treatment. The visitors' bodies are kept at the human skin temperature of 37^oC due to the light clothing of visitors. The visitors' faces are considered as isothermal walls kept at the human skin temperature of 37^oC as well. Species mass fraction of 0.0411 kg_w/ $kg_{d.a}$ is assumed in order to take into account the sweat effect in moisture gain to the tomb airflow.

3   Results and Discussions

In peruse of the appropriate ventilation system designs, simulation of actual air flow patterns and heat transfer behavior was carried out with the above computational scheme with simulation of visitors as shown in figures 6 to 17 in the following paragraphs. The proposed simulated design is to extract air through floor-mounted ports each 1.0x0.15 m at different locations as shown in Figures 1 to 4, with air freely entering the tomb. Figure 6 depicted the predicted velocity vectors distribution at a middle plane showing 24 visitors located along KV1 tomb.

The isotherms contours of Figure 7 clearly demonstrate the extent of the ambient outside warm air penetrating the tomb environment up to 50% of the length where temperatures are 313 K. The corresponding relative humidity contours are shown in Figure 8, identifying dangerously high levels to the artifacts and paintings preservation particularly at the end of the tomb with only 24 visitors, Osama (2008). The second example is that of KV2, the tomb of Ramsis IV, it had the same geometrical configurations as KV1, but with a length of 88 m. Figures 9 and 10 demonstrate the predicted temperature and relative humidity contours for KV2 with 27 visitors, 11 extraction grilles were utilized in the centre of the tomb along its axis.

KV13 is the tomb and burial place of the noble Bay of the Nineteenth Dynasty. The tomb was later reused by Amenherkhepshef and Mentuherkhepsef of the Twentieth Dynasty. The tomb design is different than that of KV1 and KV2 as it is longer with many intermediate chambers as was shown earlier in Figure 3.The corresponding temperature and relative humidity contours are shown in Figures 11 to 12 respectively, with 9 floor-mounted extraction grilles .For further details of the effect of using side grilles, reference should be made to Osama (2008). The fourth tomb is that of King Siti II, known as KV15, the tomb had intermediate hall with columns
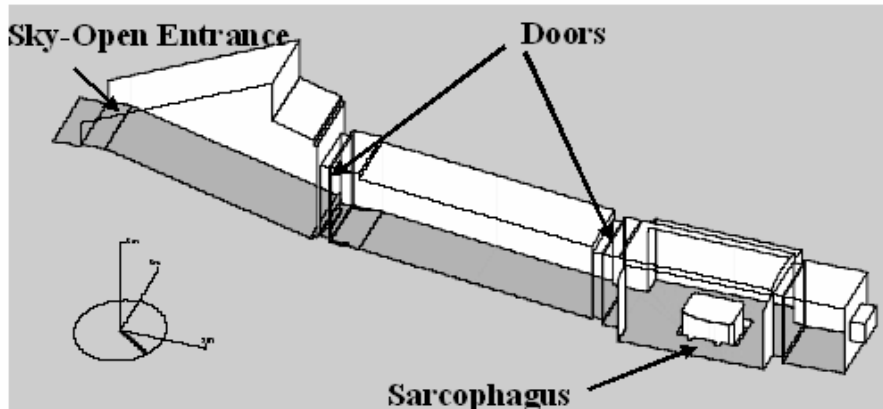
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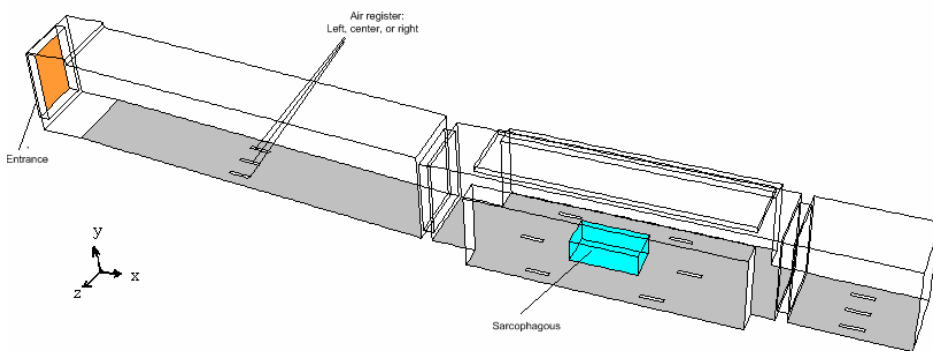
b

Figure 1: a. KV1 with sky-open entrance; b. KV1 ventilation grilles locations

followed by a sloped ramp to the sarcophagus. The complexity of the tomb necessitated the typical use of larger number of about 700000 tetrahedral cells. The obtained computations were based on the above assumptions with a base case of 26 visitors distributed in the tomb as shown in Figures 13 and 14.

The corresponding isothermal lines are shown in Figure 13 for a wall temperature of 295 K. The effect of the fresh incoming hot air of 40 ^{0} C was dominant to almost 25% of the tomb length in the core area. Temperatures generally cools off to nearly 29 ^{0}C. Away from the centre plane temperatures cool down to near 300 K as shown in Figure 13. Predicted relative humidity contours shown in Figure 14 that indicated that excessive humidity towards the dead end of the tomb which can be easily attributed to the produced water vapor from human activities and not outside air relative humidity that is only 30% during August.
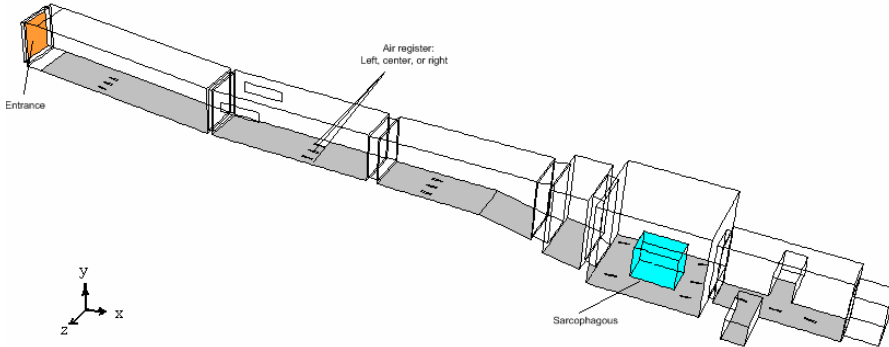
Figure 2: KV2 structure details
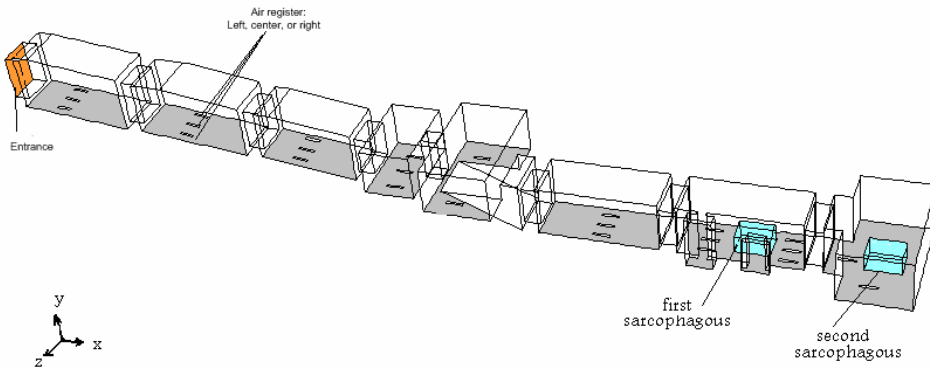
Figure 3: KV13 structure details

4 Discussion and Conclusions

The main flow pattern of the free supplied air and floor mounted extracts is slightly influenced by the extraction ports locations, for KV1 and KV2. For each visitor group location, a corresponding proper airside design was suggested to provide the optimum utilization of the supplied air. The influence of the recirculation zones on the visitors' occupancy zone and also on the fresh supplied air was investigated and low velocity values were observed and were well below the ASHRAE (2005) recommended values. The influence of the number of visitors on production of excessive relative humidity near the walls was significant. More numerical results can be seen in the work of (AbdelAziz et al 2005, Khalil; 2008 and Salama; 2008).
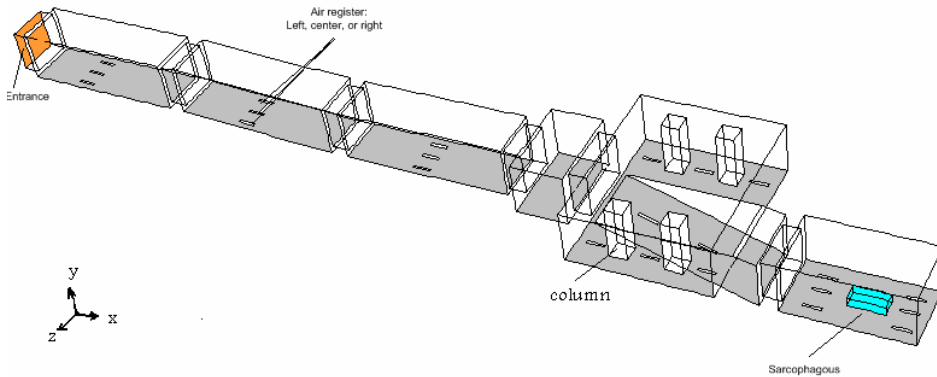
Figure 4: KV15 structure details

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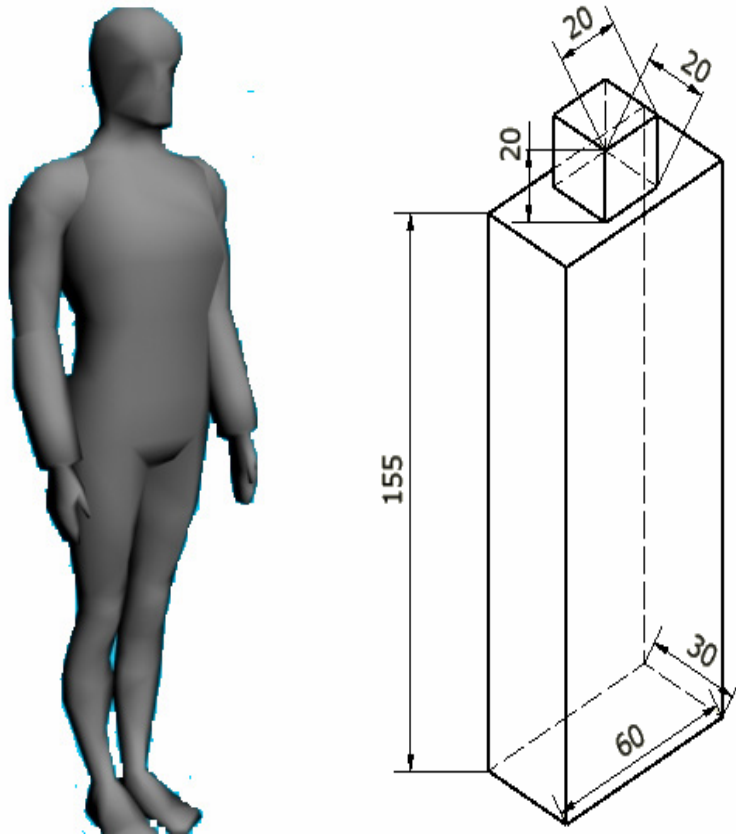
Figure 5: Visitors Modelling
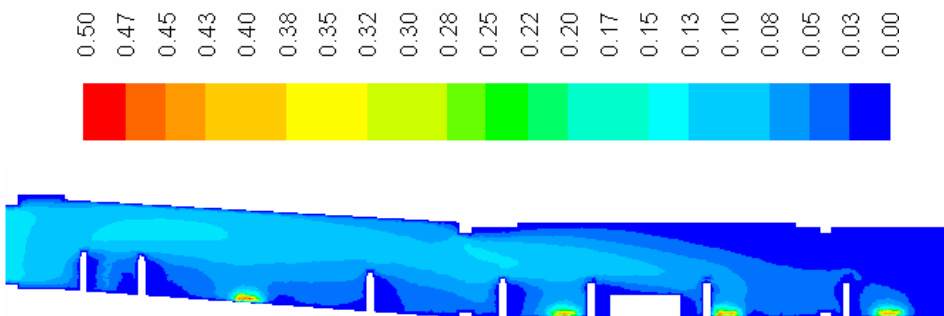
Figure 6: Predicted velocity contours, m/s
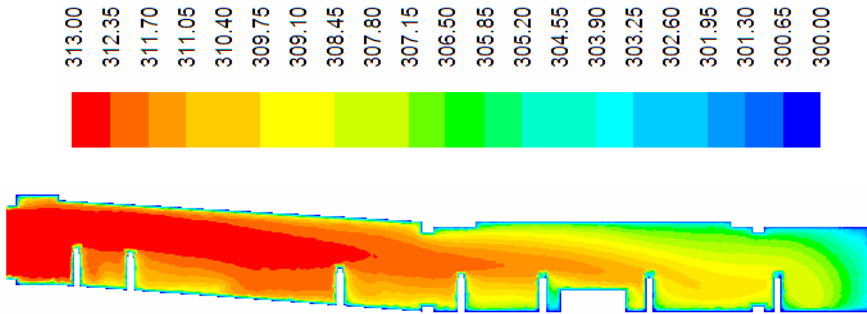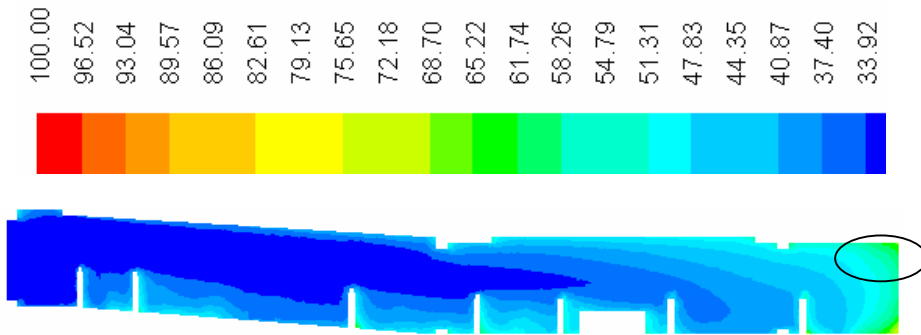
Figure 7: Predicted temperature contours, K

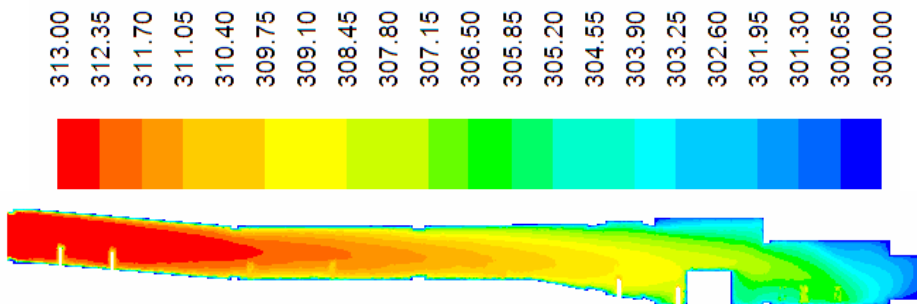Figure 8: Predicted Relative Humidity, %, KV1

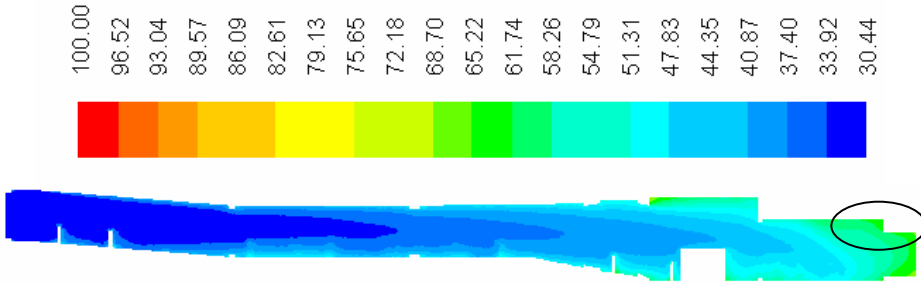Figure 9: Predicted Temperature Contours, K, KV2
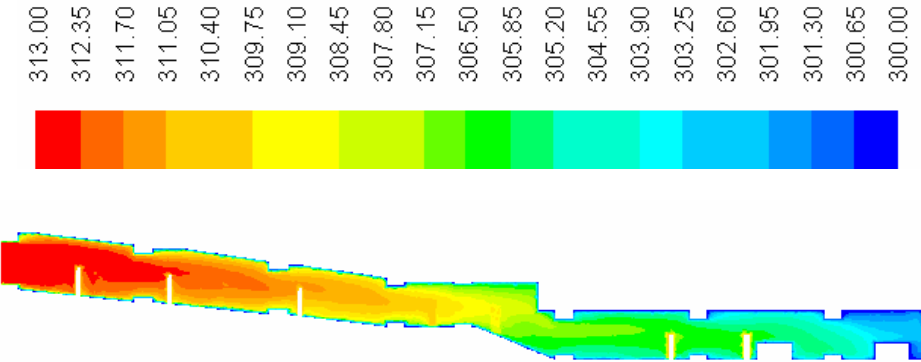
Figure 10: Predicted Relative Humidity, %, KV2
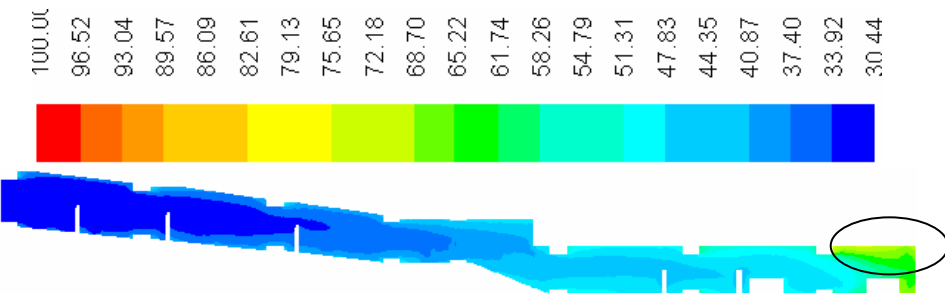

Figure 11: Predicted temperature Contours, K
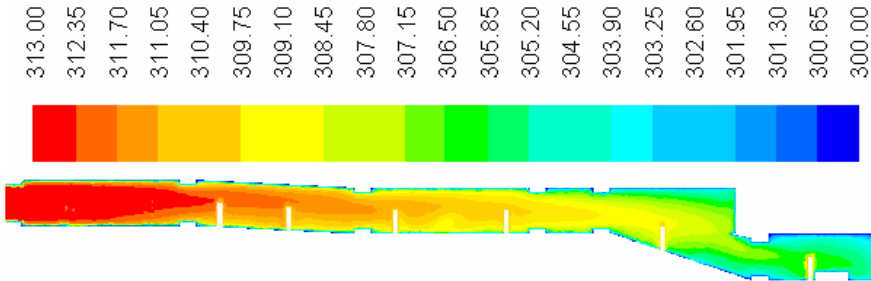

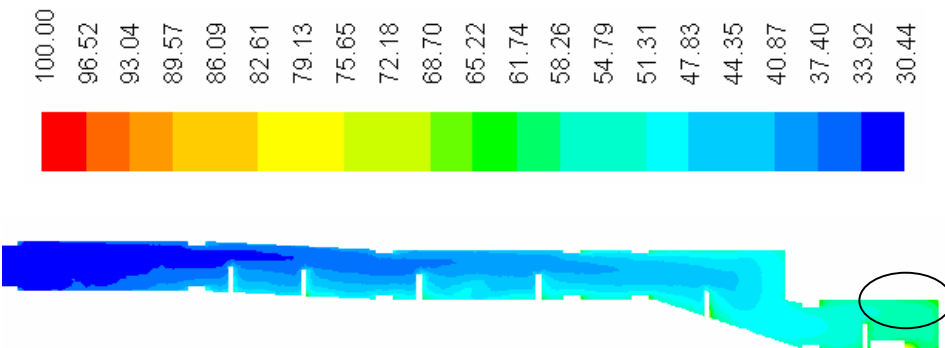Figure 12: Predicted Relative Humidity, %, KV13

Figure 13: Predicted temperature Contours, K

Figure 14: Predicted Relative Humidity, %Rh, KV15