# Sensitivity Analysis of Ventilation Parameters and Site Input Properties

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**Abstract**

*The sensitivity of temperatures and relative humidities is studied to the variation of selected input properties and ventilation parameters at Yucca Mountain (YM). The perturbed site input properties are: rock heat conductivity (k), thermal diffusivity (a), and heat transfer coefficient (h) on the drift surface. The ventilation Air Flow Rate (AFR), input air temperature, areal thermal heat load, and the average water percolation rate due to precipitation are also varied as input parameters. The temperatures and heat removal rates by ventilation were found to be most sensitive to the thermal conductivity, exceeding 100 % at low ventilation rate. This finding underlines the importance of the thermal conductivity values and modes for YM, since any input percentage error in conductivity may affect the predicted temperature fields by a higher percentage error. High sensitivities were also obtained to the intake air temperature, underlining the importance of studying seasonal temperature and possible future climate changes in the repository design.*

## I. INTRODUCTION

It is difficult to determine the precision requirements of the main ventilation input parameters for temperature and humidity calculation at Yucca Mountain (YM) based on judgment and experience since the heat load is relatively high when compared to deep, underground mines, and the decay heat characteristics are specific to nuclear waste. Lack of adequate analysis even for common mine climate simulations hampers correct assessment of needed accuracy of input data. This problem is addressed only in a few publications; however, none have been related to a high-level nuclear waste storage arrangement.

A few computer "experiments" with different mine climate simulation programs, published by Szabo et. al[1]., showed good agreement with the analytical results for zero wetness factor, however, for wet surfaces, the simulated percentage sensitivities were different and non-conclusive. It was recognized that the sensitivity was generally high at the beginning of the ventilating time, and became lower with protracted ventilation. The cumulative effect, however, which may average sensitivities over time, was not included in their work. To be able to handle cumulative effects, the heat conduction history of the rock was modeled by Danko et.al[2]. describing a continuous air temperature variation with time at each roadway cross section, instead of using a step-change function, represented by the age function G (Bi, Fo) solution common in mine climate/heat flow simulation models. For a completely dry roadway and for short periods of time, the sensitivity of the dry bulb temperature to thermal conductivity was found to be slightly higher than to thermal diffusivity and to the heat transfer coefficient. It was found that for increasing periods of time, after passing peak values, the thermal diffusivity kept constant, and the heat transfer coefficient decreased its influence, while the thermal conductivity became gradually more important. It was concluded that different precision requirements should be used for the thermophysical properties in different types of calculations e.g., for construction/development and blast cooling during potential retrieval, or during continuous and long ventilation periods. For short periods of time in slightly wet roadways, the influence of the thermal conductivity increased, while that of the heat transfer coefficient strongly decreased regarding the air dry-bulb temperatures. It was suggested that the sensitivity in the wet bulb temperature should be used for increased significance.

The proposed paper follows the method of numerical sensitivity analysis used in the previous publications. The selected input properties are: rock heat conductivity (k), thermal diffusivity ($\alpha$), and heat transfer coefficient (h) on the drift surface. One main ventilation input parameter, that is, ventilation Air Flow Rate (AFR) , and another main heat load parameter, the average Areal Thermal Load (ATL) are also varied to understand their implications in the sensitivity to the precision of k, $\alpha$, and h., as well the sensitivity of the resulting temperature histories to their control precision. In addition, the ventilation Air Flow Rate (AFR), input air temperature, areal thermal heat load, and the average water percolation rate due to precipitation are also varied as input parameters.

## II. WORK DESCRIPTION

The hydrothermal-ventilation/heat flow model and software MULTIFLUX[3] (MF), Version 3.0 developed at the University of Nevada, Reno (UNR) with non-linear processing capabilities, is used for the numerical sensitivity analysis. A base case is defined according to the latest, Bechtel SAIC, Inc. numerical study used in the Analysis/Model Report[4] (AMR) Rev. 01, assuming 56 MTU/Acre for the ATL and 15 $m^3/s$ for the AFR. To be comparable, 600 m emplacement tunnel and 300 years ventilation period were assumed. The base case input values for the k, a, and h are used according to the AMR Rev01 values. Deviations from the base case in the sensitivity study are selected according to expected variations at Yucca Mountain. Lithophysal rock formation may decrease k, therefore, k is reduced from the base case of 2 to 1.6 and 1.2 $W/m^2/K$. For a similar reason, the rock density, ρ is also reduced by 25 %. The resultant values for thermal diffusivity can be determined from the $\alpha = k * (\rho c)$ formula, where ρ is density and c is specific heat. Since MF applies NUFT[5] as a module for simulating heat and moisture flows in the rock domain and it does not require the explicit value of α as an input parameter, α is back-calculated. The AFR is varied to be lower than the base case to 5 and 1 $m^3/s$, while the ATL is varied to be lower and higher, representing a cold design with 37 and a hot design with 85 MTU/Acre. The surface heat transfer coefficient was varied between 1.89 to 4 based on AMR input and MF3.0 CFD calculations respectively.

Drift wall temperature, container surface temperature, drift wall relative humidity, and relative cumulative heat removal by ventilation are considered as selected result parameters for sensitivity calculation. The measure of sensitivity is calculated as the ratio of the relative change in the selected result parameter to the relative variation of selected input parameter.

## III. RESULTS AND DISCUSSIONS

An interesting and surprising finding was that the ATL values showed a negligible effect on the output sensitivities. Approximately the same sensitivity variation was obtained for different, but fixed ATL values. The phenomenon may be explained by an approximately linear behavior of the heat and moisture transport processes in the study cases. Consequently, the ATL values were selected by convenience between 5 MTU/Acre and 85MTU/Acre, in order to keep the output maximum wall temperature at the end of the emplacement drift below 200 $^oC$ in the various study cases. Since not used as an independent input parameter, the ATL sensitivities are not processed in separate graphs.

Another interesting, but not so surprising finding, was that the ventilation rates strongly affected relative sensitivities. This can be seen from sensitivity results for the high, medium, and low ventilation flow rates that are given in Figures 1, 2 and 3 respectively. The input, perturbed parameters of k, h, and ρ for the simulations are given in the legends of the figures. As shown, the AMR Rev 0l case is carried as the base case at zero percent. The drift and waste container wall temperature variations relative to the base case due to input parameter perturbations are calculated and plotted in Figures 1, 2 and 3. Each figure has two curves for k, two curves for h, and one curve for ρ perturbations. The results must be considered percentage change in the output as a response to a 100 % (positive) change in the input. Only partial changes are made, but the figures can be used to evaluate percentage combinations. The sensitivity of heat removal rate by ventilation to the input perturbations is also given in Figures 1-3. The temperatures and especially the heat removal rates by ventilation were found to be most sensitive to the thermal conductivity, exceeding 100 % at low ventilation rate. This finding underlines the importance of the thermal conductivity values and modes for YM, since any input percentage error in conductivity may affect the predicted temperature fields by an even higher percentage error. High sensitivities were also obtained to the intake air temperature, underlining the importance of studying seasonal temperature and possible future climate changes in the repository design. At high ventilation rates, the importance of the heat transport coefficient can be seen in Figure 1 (a) and (b), especially at longer ventilation time periods.

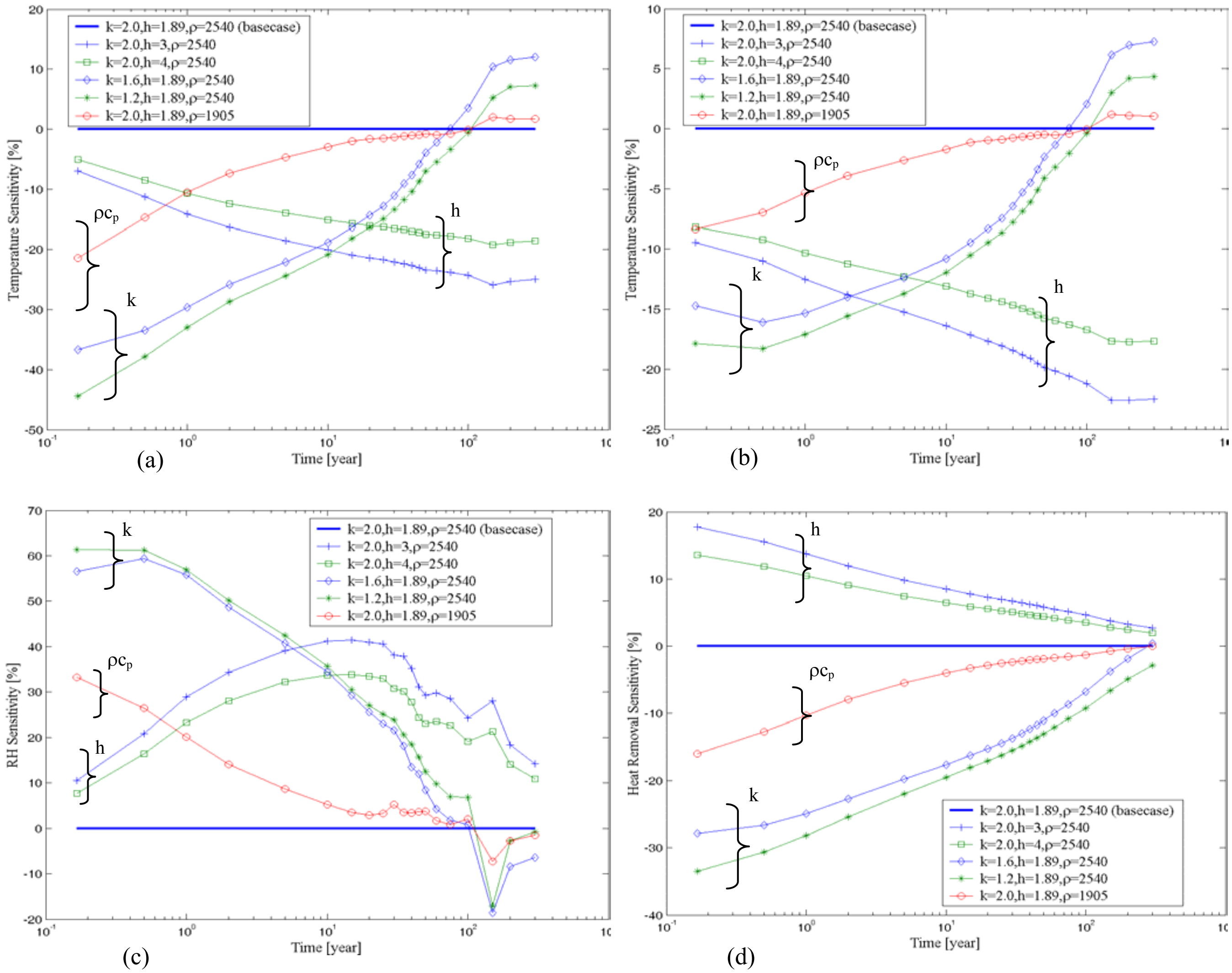


Figure 1. Sensitivity results , (a)wall temperature, (b)container temperature, (c)wall Relative Humidity, and (d)cumulative heat removal; Airflow rate: 15 $m^3/s$.

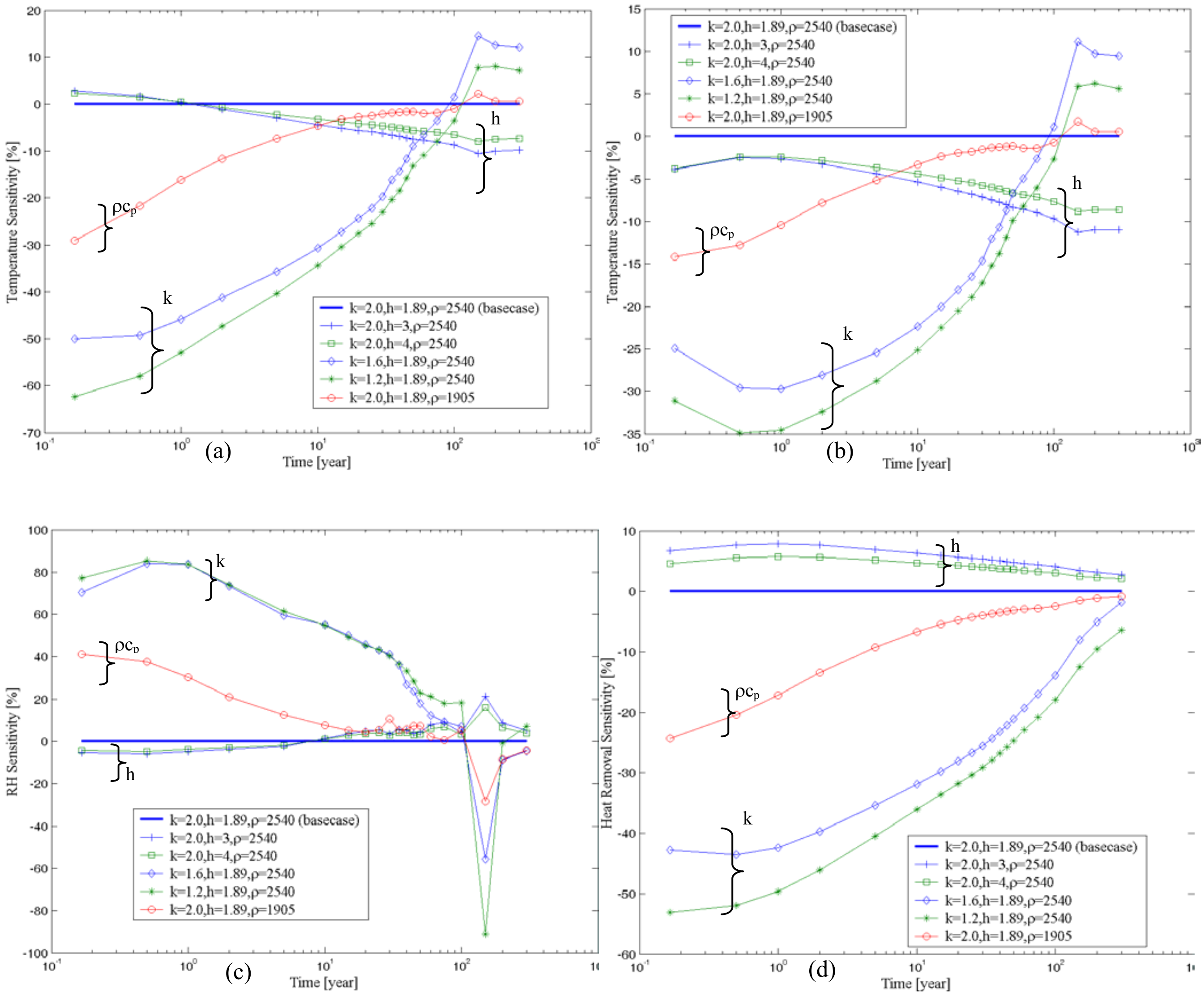


Figure 2. Sensitivity results , (a)wall temperature, (b)container temperature, (c)wall Relative Humidity, and (d)cumulative heat removal; Airflow rate: 5 $m^3$/s.

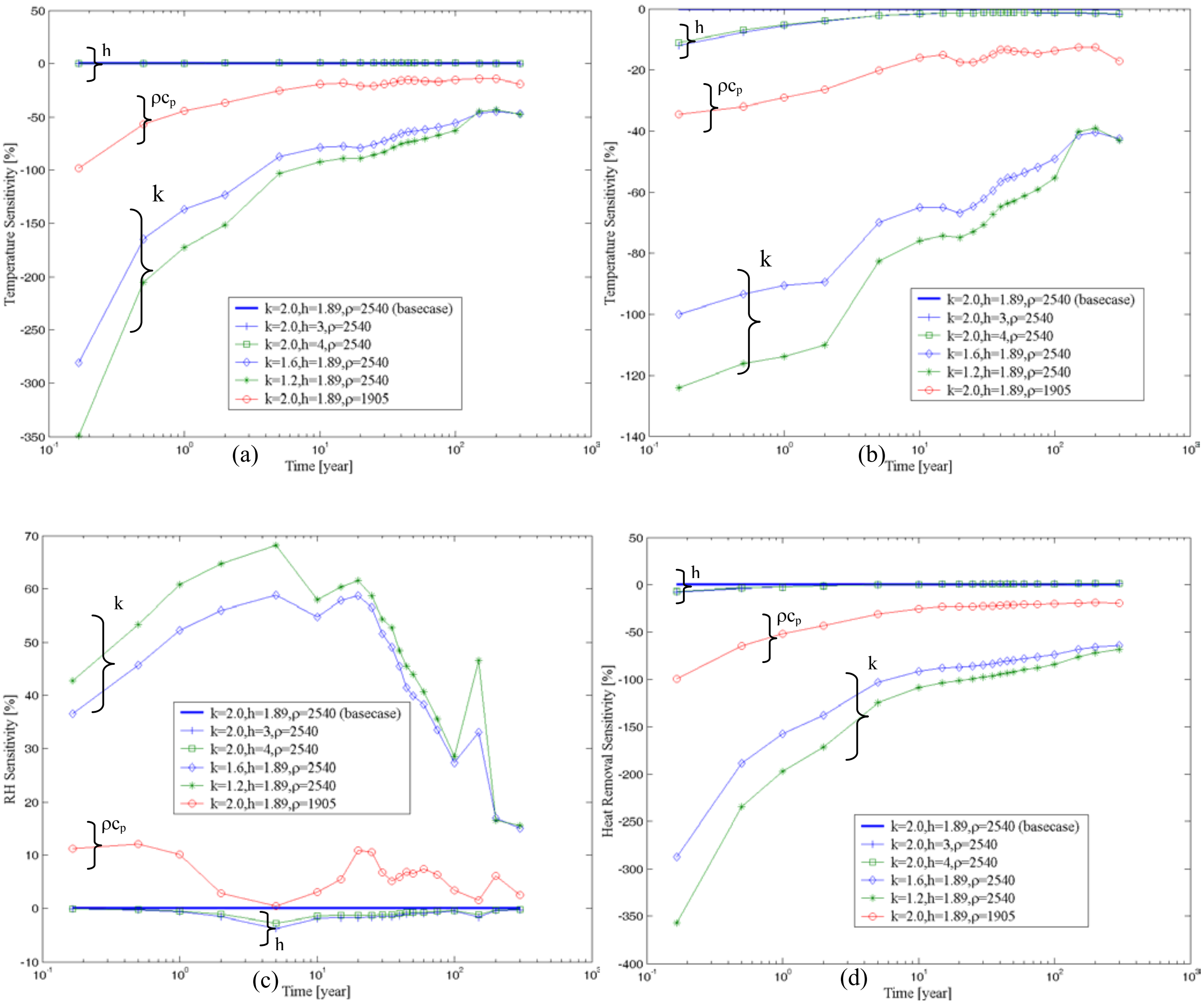


Figure 3. Sensitivity results , (a)wall temperature, (b)container temperature, (c)wall Relative Humidity, and (d)cumulative heat removal; Airflow rate: 1 $m^3$/s.

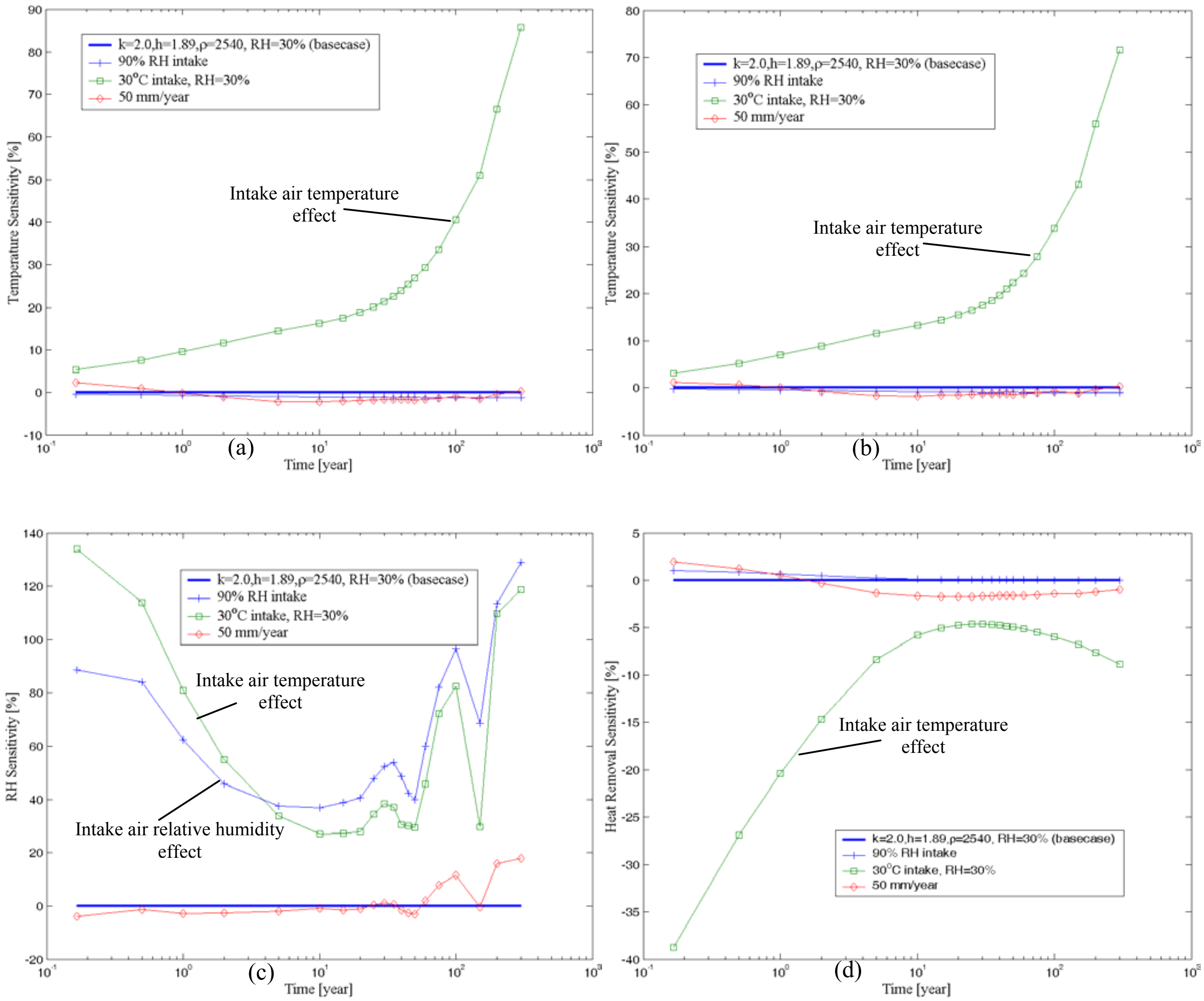


Figure 4. Sensitivity results with the variation in intake air and ground precipitation, (a)wall temperature, (b)container temperature, (c)wall Relative Humidity, and (d)cumulative heat removal; Airflow rate: 5 $m^3$/s.

## IV. CONCLUSIONS

The thermal conductivity is a very important input parameter, especially with low ventilation which will be naturally the case at YM after closure. This finding underlines the importance of evaluating lithophysal thermophysical properties at YM, since uncertainties in the bulk lithophysal conductivity may be as high as 50-100%. The high sensitivities in Figures 2a, b, and d, as well as in Figures 3a, b, and d indicate that 50-100% error may occur in the predicted temperature and heat removal rates at YM due to input data uncertainties. Decrease in effective rock density increases temperatures, further aggravating the effect of conductivity decrease due to lithophysae upon temperature.

Significant sensitivity to the surface heat transfer coefficient was found for strongly ventilated scenarios. This parameter was thought to be much less important in previous studies[2] involving ordinary mine climate simulation applications for long periods of time. A recent study[6] showed the importance of modeling heat transfer coefficient variations accurately, and that conclusion is consistent with the new sensitivity results. More precise and cost-effective design can be supported using new ventilation experimental results with the correct annulus geometry between the drift and waste packages. Alternatively, numerical, Computational Fluid Dynamics model calculations can be incorporated that have been successfully integrated with MF in ventilation model calculations[6].

## V. ACKNOWLEDGMENTS

The editorial review comments by Dr. John Walton, Professor at the University of Texas at El Paso, are highly appreciated.

## VI. REFERENCES

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