Evaluation of Comsol as a tool for pinpointing moisture entering locations from inside surface moisture

A.W.M. (Jos) van Schijndel, Eindhoven University of Technology
Eindhoven, Netherlands

Abstract: The location and nature of the moisture leakages are sometimes difficult to detect. Moreover, the relation between observed inside surface moisture patterns and where the moisture enters the construction is often not clear. The objective of this paper is to investigate inverse modeling techniques as a tool for the detection of moisture leakage locations in building constructions from inside surface moisture patterns. It is concluded that although the presented methodology is promising, more research is needed to confirm its usability.

Keywords: Moisture, leakage, modeling, Comsol

1. Introduction

Hunting Lodge St. Hubertus is one of the most prominent buildings from the beginning of the twentieth century and is noted in the top 100 list of Dutch monuments. The conservation of the building and its interior are of great importance. The Dutch Government Building Department, which takes care of the maintenance of the building, has expressed their concern about the observed damage due to high moisture levels by the rain that finds its way to the interior at places of inadequate detailing and therefore causes damage mainly near openings in the façade and on the inside of the façade below balconies. The main problem is that the location and nature of the moisture leakages are not easily detectable. We often don't know the relation between the observed inside surface moisture patterns and where the moisture enters the construction. The objective is to investigate inverse modeling techniques as a tool for the detection of moisture leakage locations in building constructions, i.e. we want to investigate the (in)possibilities of pinpointing moisture leakages from inside surface moisture patterns using inverse modeling techniques. The research approach was as follows: First, a study and evaluation of previous work. Second, the implementation of three dimensional moisture models of building constructions in COMSOL. Third, the simulation of scenarios with different moisture source load characteristics including surface load sources at different locations. Fourth, the inverse determination of moisture source characteristics from 'fingerprints' of typical leakages. Fifth, the application of the approach to a real building with moisture leakage problems, i.e. the Hunting Lodge St. Hubertus. Sixth, the testing of the method with laboratory experiments. Seventh, the evaluation of the approach as instrument for pinpointing the location of leakages. This paper presents the preliminary results of the first five steps. Currently we also are working on the last two steps. The results will be available in due time.

2. Summary of the observed moisture problems at the hunting lodge St. Hubertus

Hunting Lodge St. Hubertus is located on the northern side of the Dutch National Park 'De Hoge Veluwe'. The Hunting Lodge is built as a guesthouse between 1916 and 1922, by Holland's most well known architect from that time, H.P. Berlage. The building consists of a low rise rectangular volume with wings that stretch out diagonally and with a characteristic high tower of over 30 meters height in the middle of the building (see figure 1). A large pond is situated south-west of the building and the building is surrounded by forest in all other directions.

Figure 1. Hunting Lodge St. Hubertus.

The damage that occurs in the tower were systematically inspected to enable a thorough assessment of the possible causes of the moisture problems by Briggen et al. (2009). The damage on the inside of the tower, and where possible also on the outside, is systematically inspected. The location and type of each moisture problem are documented in a table, illustrated with a picture of the damage. The moisture problems that manifest themselves in the tower of the Hunting Lodge can be divided in the following categories: efflorescence, cracking, soiling, moist spots, mechanical damage and biological growth. A few pictures of the moisture damage that occurs in the tower are shown in figure 2 (Briggen et al. (2009)).

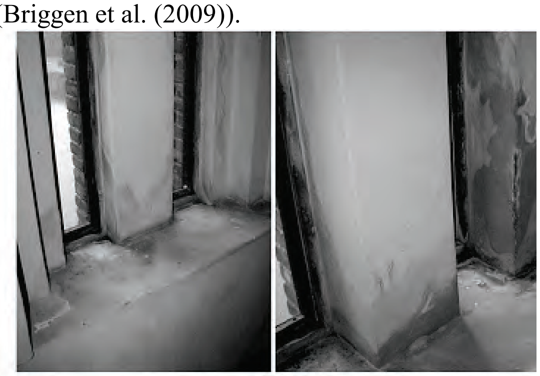


Figure 2. Observed moisture damage in the tower of the building: moist spots and efflorescence

Regarding the location of the damage it can be concluded from the inspection that most damage occurs on the interior surface of the south-west facade of the tower. Since the prevailing wind direction in the Netherlands is south-west, which means that the south-west facade of the tower is subjected to wind-driven rain the most, there appears to be a connection between the rain load of the facade and the damage on the inside. There are no clear differences between the damage on lower or higher floors or between the damage on the middle and on the sides of the facade. Most damage occurs near openings in the facade and on the interior surface of the facade below balconies.

3. Measurements

The data set is part of the measurement program at the Hunting Lodge St. Hubertus site, performed during 2006-2007 by Briggen (2007). Details of this project can be found in Briggen et al (2009). One of problems seemed to be high moisture contents at the inside surface of the façade of the tower. The construction of this façade is shown in figure 3.

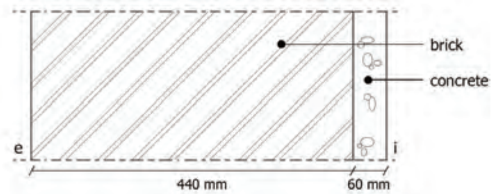


Figure 3. The building façade

The outside climate conditions were measured by a weather station within 50m from the building. The inside air temperature and relative humidity were measured using standard equipment (see figure 3). A representation of inside surface conditions were obtained by placing a small box (5cm x 5cm x 1cm) against the wall and measure the air temperature and relative humidity inside.

Figure 4. Measurement of the surface temperature and relative humidity using a box

The data consists of the measured time series of the indoor and outdoor climate as presented in figures 5 and 6.

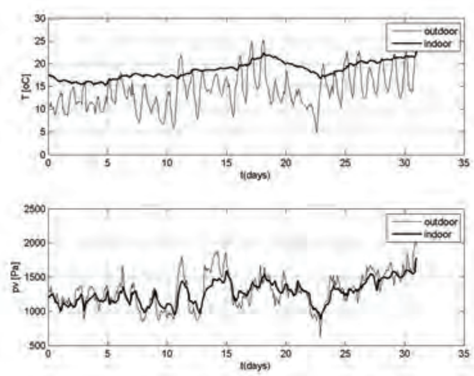


Figure 5. The measured air temperatures (top) and calculated vapour pressures (bottom, from measured T/RH)

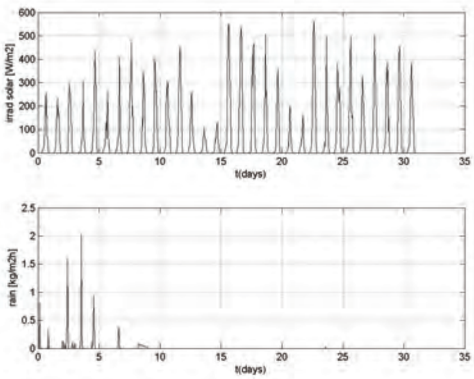


Figure 6. The measured solar irradiance (top) and rain intensity (bottom)

4. Modeling

The Multiphysics modeling approach of van Schijndel (2007) is used. The heat and moisture transport can be described by the following PDEs:

$$C_T \frac{\partial T}{\partial t} = \nabla \cdot (K_{11} \nabla T + K_{12} \nabla LPc)$$
$$C_{LPc} \frac{\partial LPc}{\partial t} = \nabla \cdot (K_{21} \nabla T + K_{22} \nabla LPc) \qquad (1)$$

With

$$LPc = {}^{10}\log(Pc)$$
$$C_T = \rho \cdot c$$
$$K_{11} = \lambda$$
$$K_{12} = -l_{lv} \cdot \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT}, \qquad (2)$$
$$C_{LPc} = \frac{\partial w}{\partial Pc} \cdot \frac{\partial Pc}{\partial LPc}$$
$$K_{22} = -K \cdot \frac{\partial Pc}{\partial LPc} - \delta_p \cdot \phi \cdot \frac{\partial Pc}{\partial LPc} \cdot Psat \cdot \frac{M_w}{\rho_a RT},$$
$$K_{21} = \delta_p \cdot \phi \cdot \frac{\partial Psat}{\partial T},$$

Where t is time [s]; T is temperature [oC]; Pc is capillary pressure [Pa]; ρ is material density [kg/m3]; c is specific heat capacity [J/kgK]; λ is thermal conductivity [W/mK]; llv is specific latent heat of evaporation [J/kg]; δp vapour permeability [s]; φ is relative humidity [-]; Psat is saturation pressure [Pa]; Mw = 0.018 [kg/mol]; R = 8.314 [J/molK]; ρa is air density [kg/m3]; w is moisture content [kg/m3];K is liquid water permeability [s].

MatLab is used for the implementation of material and boundary properties. These functions are used to convert measurable material properties such as K, φ, δp and λ which are dependent on the moisture content into PDE coefficients which are dependent on the LPc and T. This is schematically shown in figure 7.

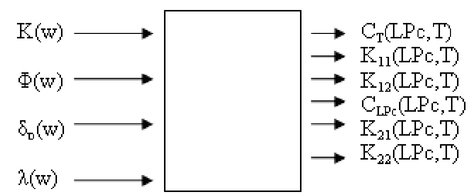


Figure 7. The conversion from measurable material properties into PDE coefficients

The material database of DELPHIN (2010) is used to provide material properties for the first guess. For brick, the Brick material properties of DELPHIN are used with constant ρ= 1700; c = 840; λ = 0.85 and variable moisture properties using the tables. For concrete, the Lime plaster properties of DELPHIN (ρ= 1800; c = 840; λ = 1.05) are used in the same way. From these data, the PDE coefficients were determined together with the boundary conditions implemented using the COMSOL model of Section 3. Figure 8 and 9 show the results.

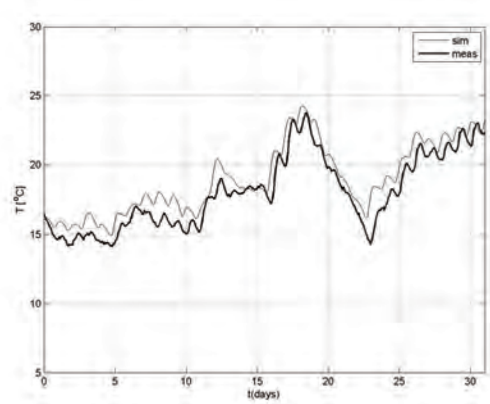


Figure 8. The measured and simulated inside surface temperature.

Figure 8 shows that the simulated inside surface temperature is already quite close to the measured one.

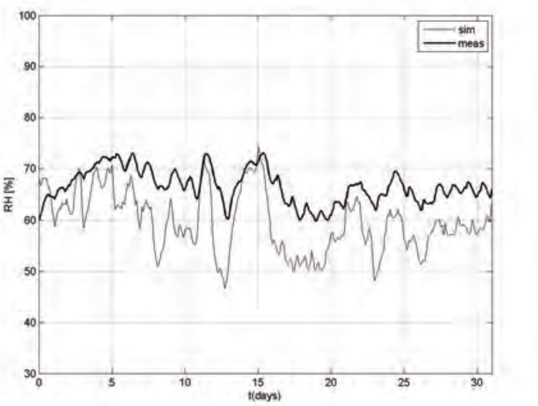


Figure 9. The measured and simulated relative humidity at the surface.

The simulated relative humidity at the inside surface of figure 9 seems to be less close to the measured one compared to the previous figure. This gives also rise to the just mentioned questions. For each material and at each point the vapour pressure can be calculated using a similar corresponding function.

5. Determination of moisture source characteristics

In this Section we try to reproduce the following observed moisture spots (see figure 10).

Figure 10. Observed moisture spots at the inner surface near the windows

The modeling approach of the previous section was used. The mesh of (simplified) geometry is presented in figure 11.

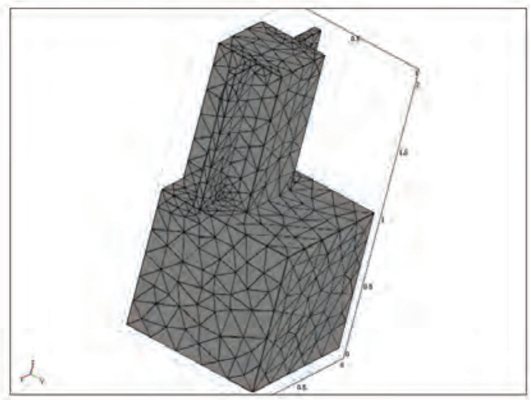


Figure 11. The mesh

The first step of the inverse modeling procedure is to switch one or more boundary conditions from dry into wet and then investigate it's effect on the inside surface moisture print. For example, Figure 13 shows the simulated profile at the inner surface by switching the location provided in Figure 12 from dry into wet.

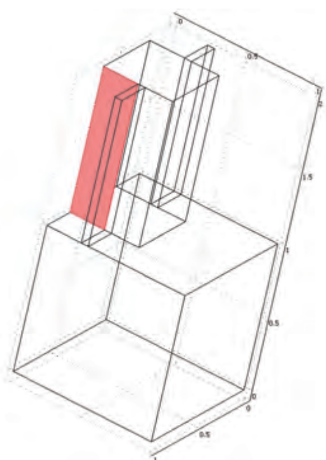


Figure 12. The location of the wet surface condition.

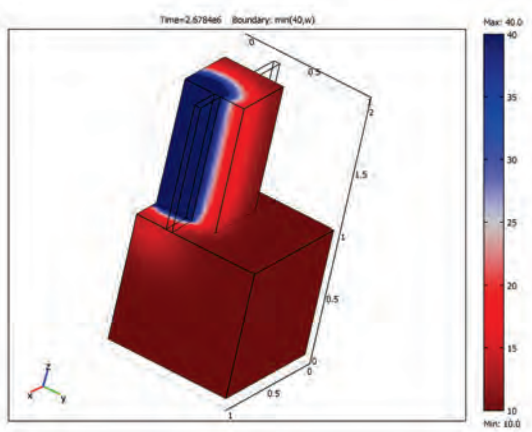


Figure 13. The steady state moisture spot at the inner surface.

There is no match between the simulated profile at the inner surface of figure 13 with the observed profile of figure 10. Therefore it is concluded that the location of figure 12 is not a possible candidate that causes the observed moisture spots. In the Appendix an overview is provided of nine more moisture profiles caused by corresponding possible wet locations. From these results, the best candidate for the moisture leakage location seems to be at the bottom of the window.

6. Discussion and conclusions

This paper investigates the (in)possibilities of pinpointing moisture leakages from inside surface moisture patterns using inverse modeling techniques. It is concluded that although the presented methodology is promising, more research is needed to confirm its usability.

The current inverse modeling technique is still rather basic by manipulating the boundary conditions by hand. A more sophisticated method, where the boundary conditions are manipulated by a computer algorithm is under investigation. Other future research include the testing of the method with laboratory experiments and a thoroughly evaluation of the approach as instrument for pinpointing the location of leakages.

REFERENCES

Briggen, P.M. (2007), A study on the moisture problems at Hunting Lodge St. Hubertus. MSc thesis, Technische Universiteit Eindhoven 120 pages (in Dutch)

Briggen, P.M., Blocken, B.J.E., Schijndel, A.W.M. van & Schellen, H.L. (2009a). Wind-driven rain and related moisture problems at the tower of a monumental building. In 4th International Building Physics Conference, 15-18 June 2009, Istanbul, Turkey.

Briggen, P.M., Blocken, B.J.E., Schellen, H.L. (2009b). Wind-driven rain on the facade of a monumental tower: numerical simulation, full-scale validation and sensitivity analysis. Building and Environment, 44(8), 1675-1690.

Schijndel, A.W.M. van (2007). Integrated heat air and moisture modeling and simulation. PhD thesis, Technische Universiteit Eindhoven 200 pages

Schijndel, A.W.M. van (2009). Integrated modeling of dynamic heat, air and moisture processes in buildings and systems using SimuLink and COMSOL. Building Simulation: An International Journal, 2, 143-155.

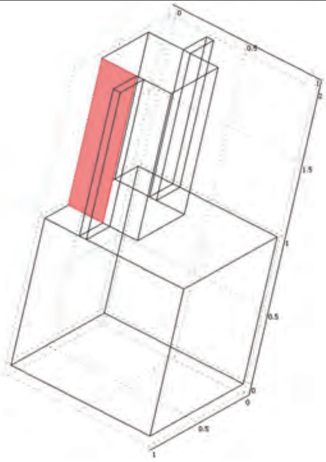
Schijndel, A.W.M. van (2009). The Exploration of an Inverse Problem Technique to Obtain Material Properties of a Building Construction. In 4th International Building Physics Conference Istanbul, 91-98.

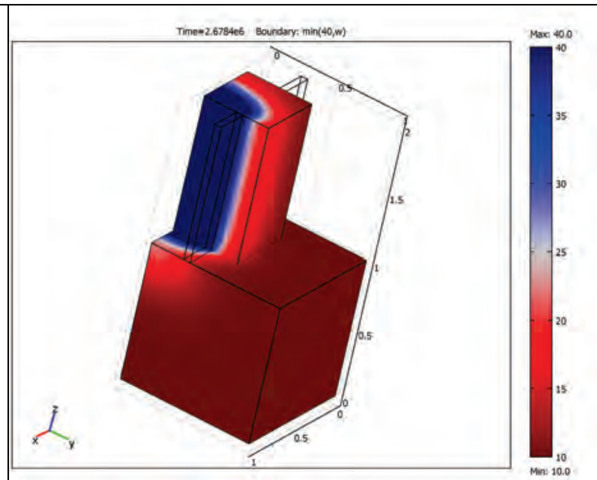
DELPHIN http://de.wikipedia.org/wiki/Delphin_(Software)

HAMLab http://archbps1.campus.tue.nl/bpswiki/index.php/Hamlab

COMSOL http://en.wikipedia.org/wiki/COMSOL

APPENDIX

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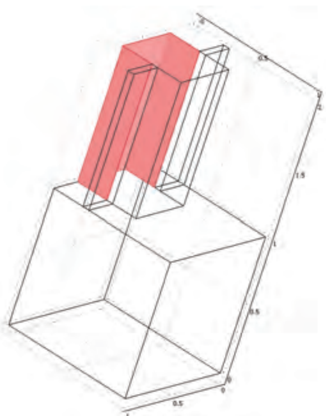

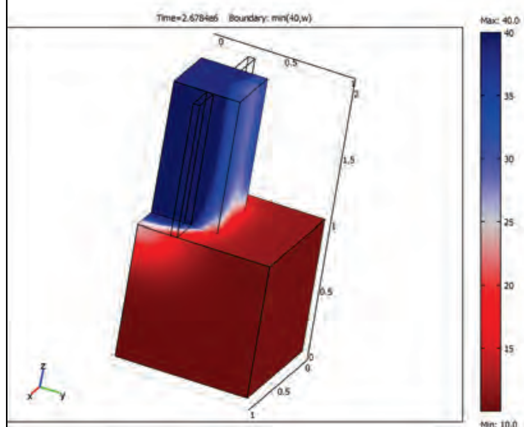
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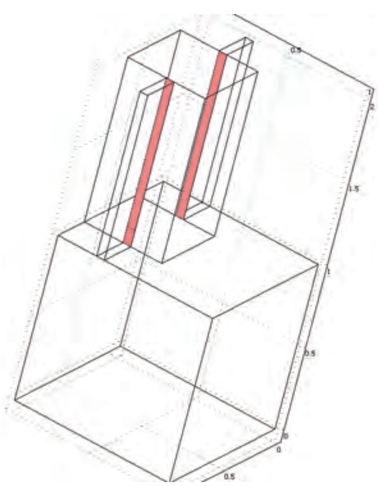

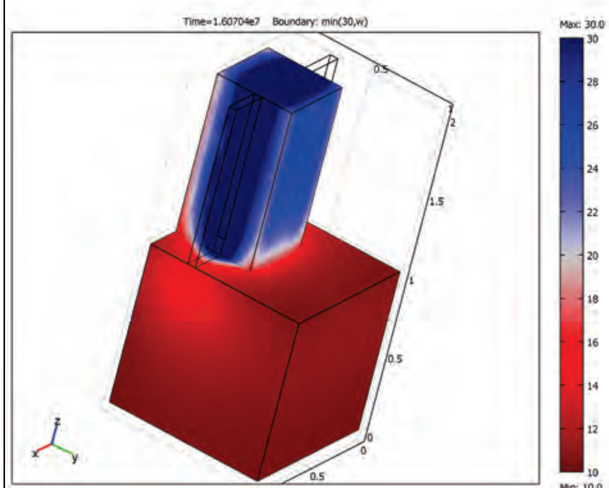
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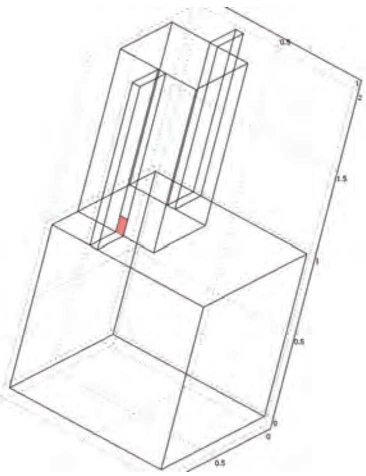

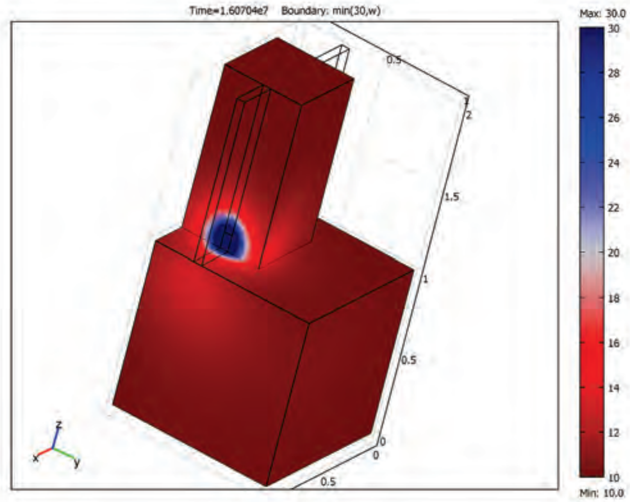

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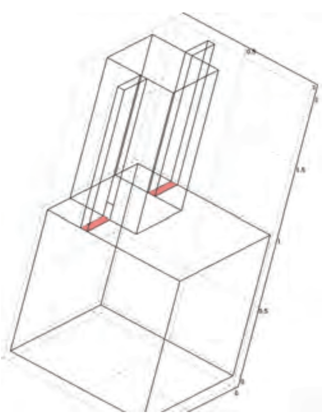

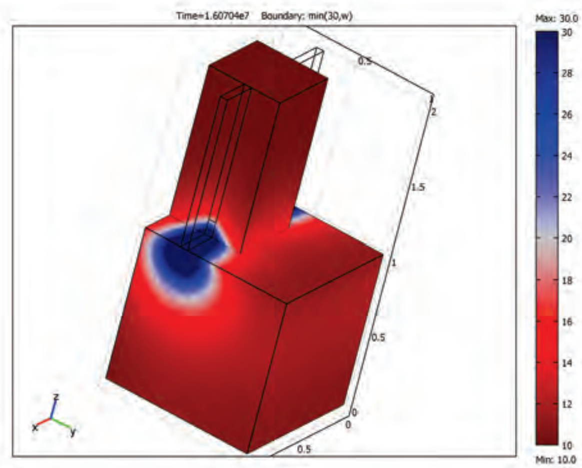

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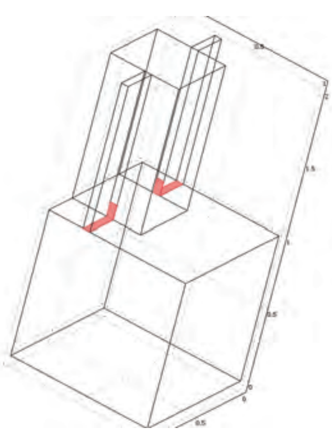

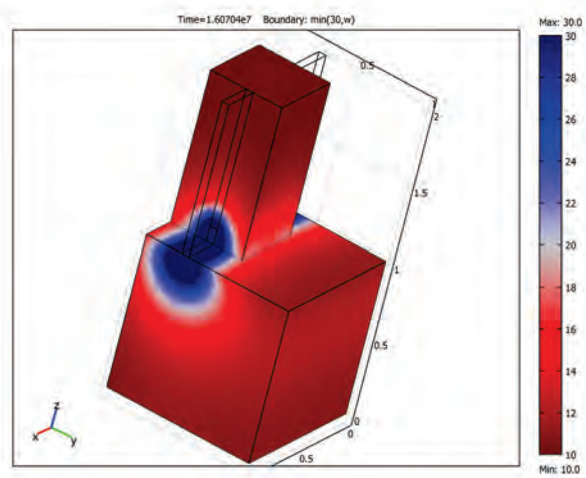

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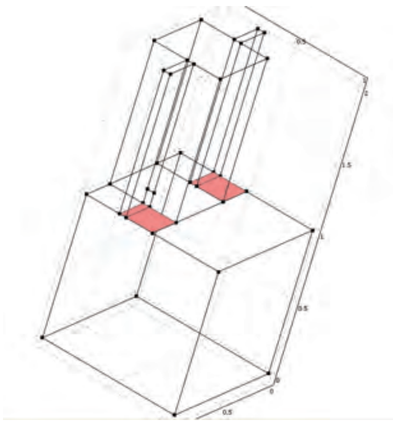

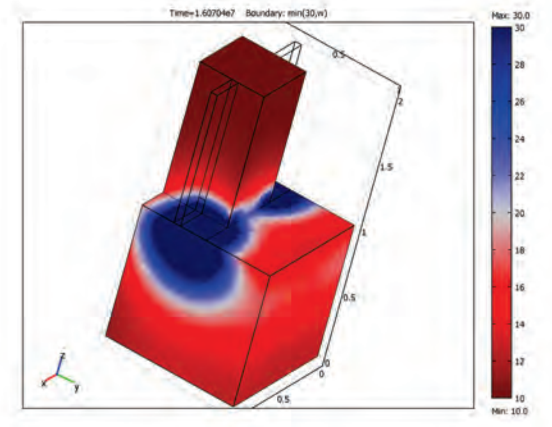
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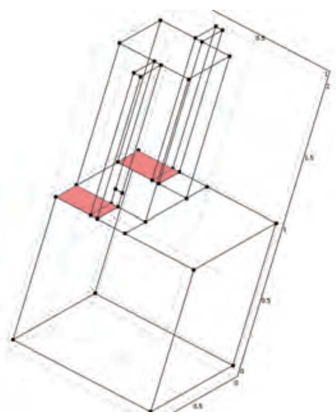

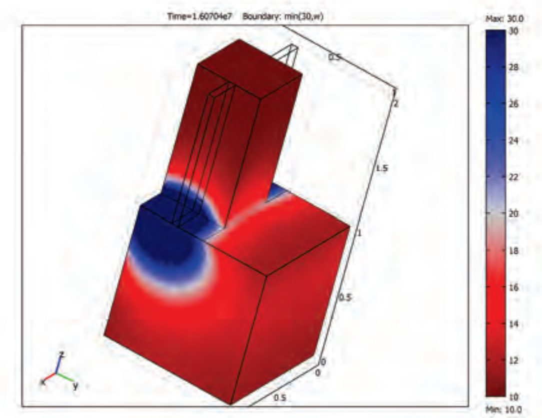
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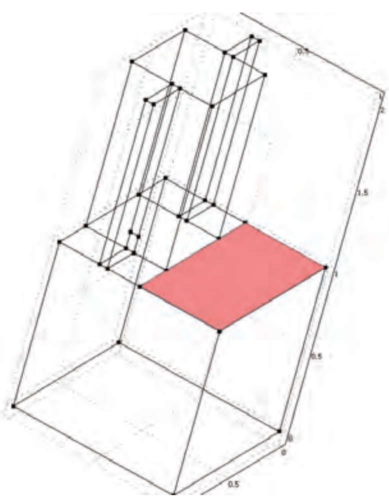

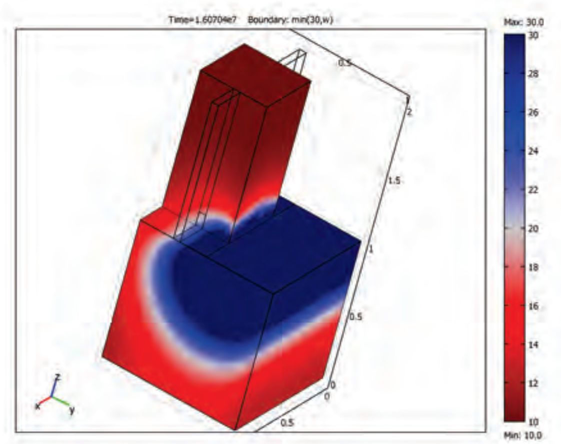
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