# ESTIMATION OF TEMPERING EFFECTS ON OPTICAL SPECTRA OF LOW-E GLASS COATINGS WITH ARTIFICIAL NEURAL NETWORKS


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## Background

- Since the major application areas of the low-E glass coatings are the construction and automotive fields the coated glass is tempered after coating, in order to increase strength and safety.

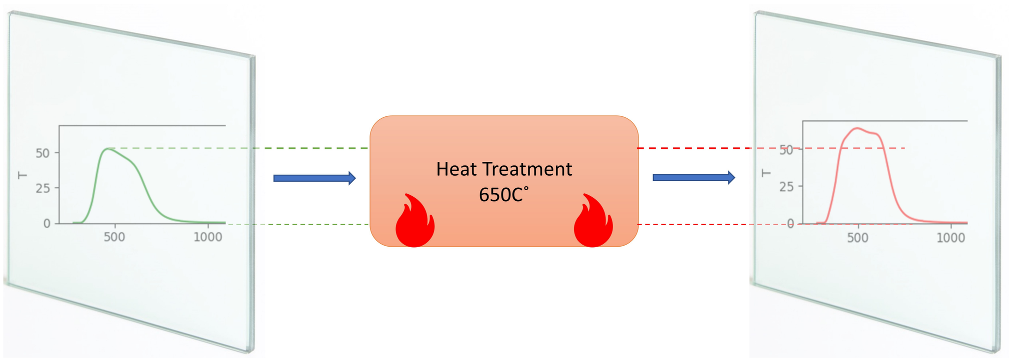


Figure 1. Heat treatment process.

- However, once the glass is tempered, the optical properties deviate from the targeted spectra due to the heat treatment process. The unforeseen changes in the optical spectra cause changes in the color and thermal performance of the glass.

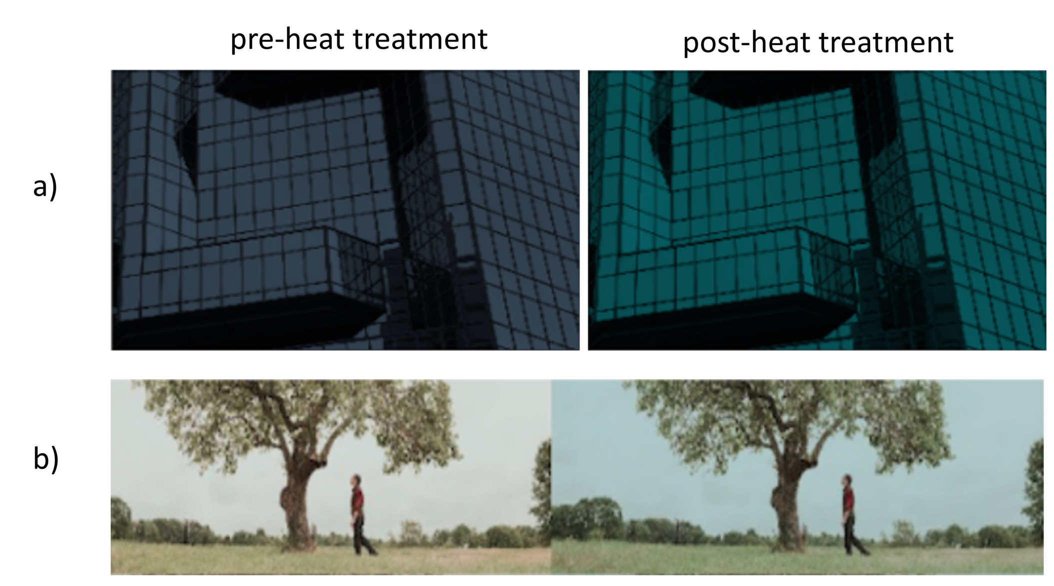


Figure 2. Effects of heat treatment on optical spectra: (a) The reflectance spectra change ($R_c$) is used to demonstrate the color change in the reflected surface, (b) The transmittance spectra change ($T$) is used to demonstrate the color change as seen through a coated glass.

- Researchers are currently using the trial and error method during design, in order to obtain the desired optical behavior of the coated glass after heat treatment, since there is no known analytical/numerical approach for a post-treatment optical behavior calculation.

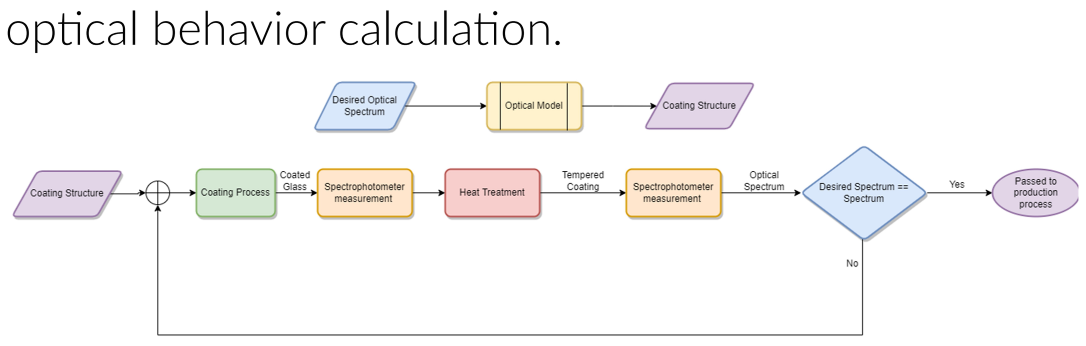

Figure 3. Tempered low-E coating research and development process.

- **Dataset**:
- Glasses were coated with low-E technology in Şişecam Science and Technology Center R & D laboratories.
- Transmittance ($T$), the reflectance of coated surface ($Rc$), and the reflectance of uncoated surface ($Ru$) were obtained by spectrophotometer in the $280nm - 2500nm$ range and $5nm$ resolution.

## A Deep Learning Based Ensemble Model - HeatNET

- Instead of trial and error method during the design process. We propose modeling the heat treatment process using artificial neural networks by utilizing data obtained during past experiments
- Coated glass's optical properties can be represented by reflection and transmittance optical spectra, as well as by descriptive optical features ($DOF$), which contains some sort of summary information of these spectra. $DOF$ values, also called characteristic parameters, are determined by ISO 9050:2003 [1].
- We have three sub-models under HeatNET Model and we use ensemble learning methodology to get the final post-heat treatment $DOF$ predictions.

## Training Methodology

1. **Spectral learning model**,
   This model conceptually treats spectral data on the basis of wavelength. The model is for estimating optical values for a specific wavelength rather than optical values for the whole spectrum of the glass piece.

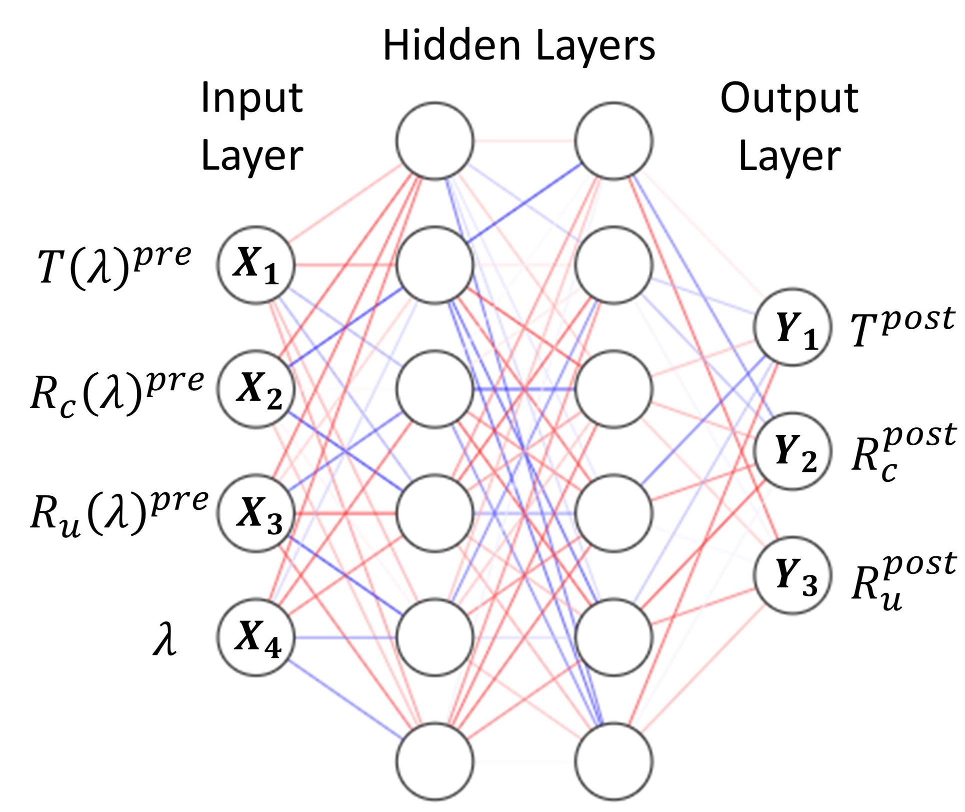


Figure 4. Spectral HeatNET Model

2. **Physics-informed HeatNet Model**,
   This model is using descriptive optical features as input of the ANN model. Since the $DOF$ values were formulated by domain experts to summarize the optical characteristics of glasses and standardized with ISO 9050:2003 they can be used as the input features of the heat treatment model instead of the whole spectra.

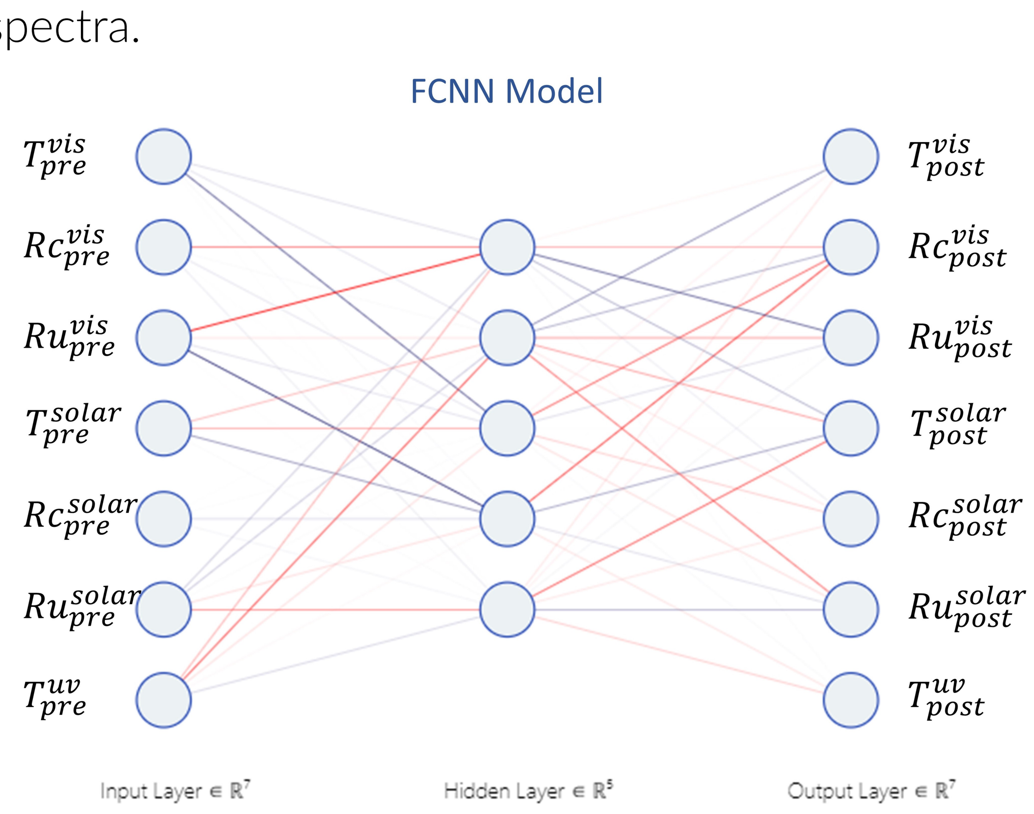


Figure 5. Physics-informed HeatNet Model

3. **ConvHeatNet Model**,
   This model is based on convolutional neural network (CNN), has optical spectrums as inputs and DOF values as outputs. The model has advantages such as sparse interactions and parameter sharing that allow it to use fewer training parameters compared to FCNNs and provides different feature extractions at the different spectrum ranges of given data.

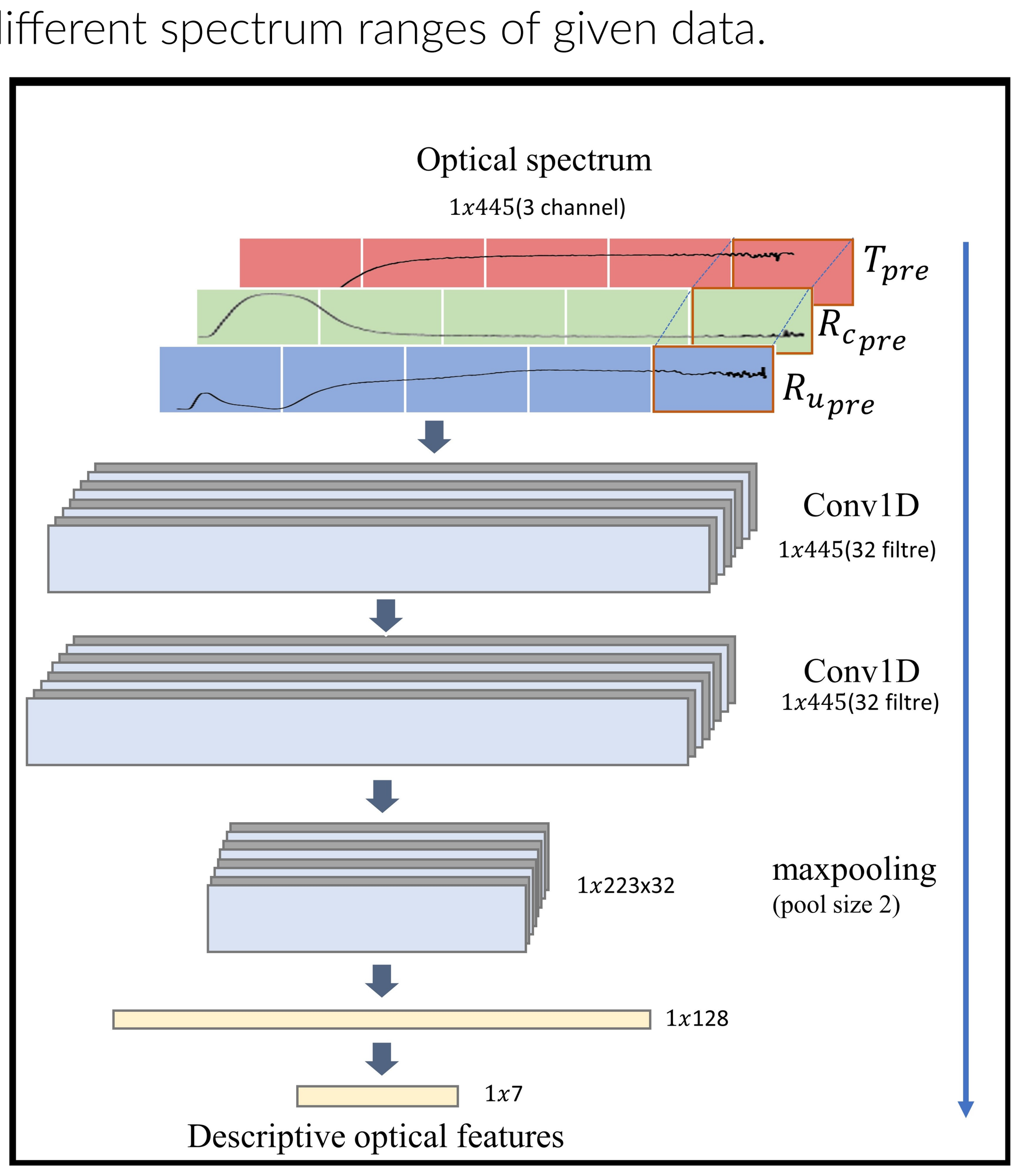


Figure 6. ConvHeatNet Model

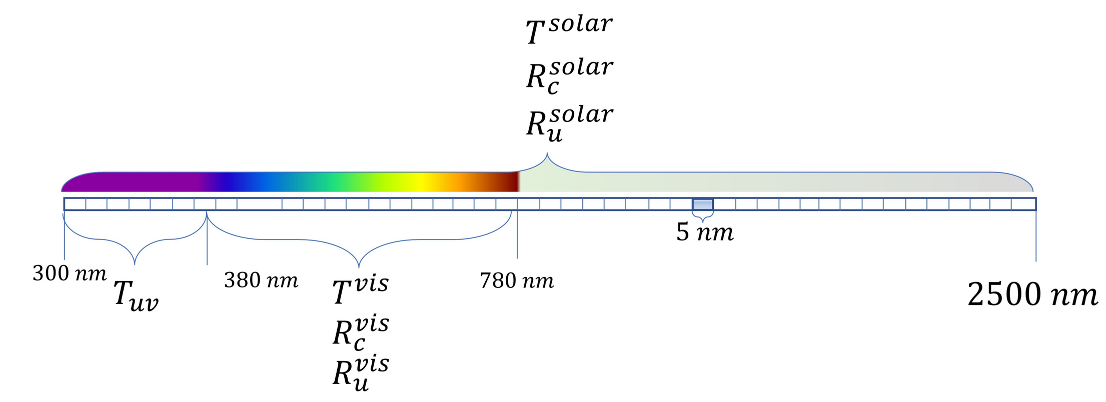


Figure 7. $DOF$ values represents three spectral regions:
UV spectrum ($300 - 380nm$)
visible spectrum ($380 - 780nm$)
solar spectrum ($300 - 2500nm$).

## Evaluation Methodology

- **Model-1**,
  We predict $T, R_c, R_u$ values for each wave-length value to represent a glass sample's optical characteristics between $280 - 2500nm$ for $5nm$ resolution. After prediction, we transform $3 \times 445$ wave-length predictions into $7$ $DOF$ values using ISO 9050:2003 standard calculations[1].
- **Model-2 and Model-3**,
  We predict directly $7$ $DOF$ values.
- **Ensamble Learning**,
  The weighted average of the three model's predictions was used to get the final estimate of optical properties.
- We split the dataset into a training set, evaluation set, and test set.
- Evaluation process consists of calculating the mean absolute error ($MAE$) and the error standard deviation ($\sigma$) of the error distribution for each $DOF$ value.

## Results

| | $T$ visible | $Rc$ visible | $Ru$ visible | $T$ solar | $Rc$ solar | $Ru$ solar | $T$ UV |
|---|---|---|---|---|---|---|---|
| $MAE$ | 0.612 | 0.407 | 0.417 | 0.460 | 0.538 | 0.400 | 0.812 |
| $\sigma$ | 0.462 | 0.406 | 0.438 | 0.364 | 0.434 | 0.285 | 0.670 |

Figure 8. Mean absolute error of the post heat treatment $DOF$ values. $DOF$ values represent the optical properties of special ranges of the spectra, which can take values in the range of $0 - 100$.

## Conclusion

- This model can be used to reliably estimate the post-heat treatment optical properties of low-E glass.

## Future Work

- Increasing the number of sample pairs used in training by collecting new data,
- Using thin film stack order, thin film thickness, and material type as a new input future in the training to reinforce the model,

will improve the accuracy of the HeatNET Model.

## Acknowledgment


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