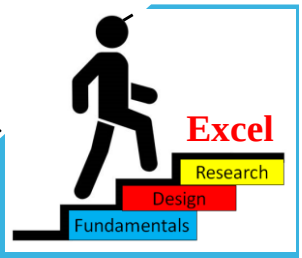
THERMAX 1-2-3
A MODELLING PLATFORM FOR OPTIMISATION ANALYSES OF FLUID-THERMAL SYSTEMS USING MS EXCEL



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Khartoum – December 19, 2024

Outlines

- Objective, method, and tools
- The Excel-based platform for thermo-fluid analyses
- Highlights
  - Examples of basic analyses
  - Examples of design optimisation analyses
  - Examples of research analyses
- About Thermax
- A Solver-TOPSIS technique for MOO analyses
- Course material

OBJECTIVE, METHOD, AND TOOLS

Objective, method, and tools

- To describe an effective learning/teaching method for energy-related undergraduate subjects:
  - Thermodynamics
  - Fluid-dynamics
  - Heat-transfer
- Method and tools:
  - Encourage computer-aided analytical methods
  - Enable design analyses of fluid-thermal systems
  - Adopt problem and project-based learning (PBL)
  - Facilitate student research

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THE EXCEL-BASED PLATFORM FOR THERMO-FLUID ANALYSES

Excel's Built-in capabilities

- Graphical display of data and analyses results
- Numerous built-in mathematical functions, e.g. statistical, financial, etc.
- Solution of linear systems of equations by the matrix inversion method (**MMULT, MINVERSE**)
- Iterative solutions and solution of non-linear equations:
  - **Internal solver (the iterative calculations option)**
  - **Goal-Seek**

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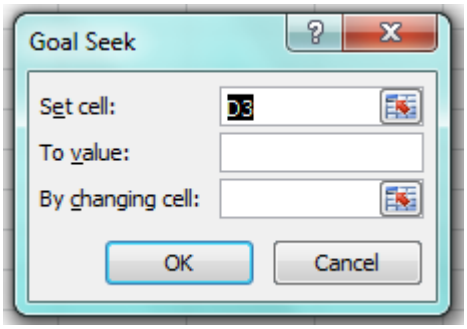
Goal Seek



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Tools for thermo-fluid analyses

- Single-objective optimisation (**Solver**)
- Multi-objective optimisation (**Solver+TOPSIS**)
- Various add-ins for fluid properties (e.g. REFPROP, **Thermax**)
- Visual Basic for Applications (**VBA**) for the development of user-defined functions

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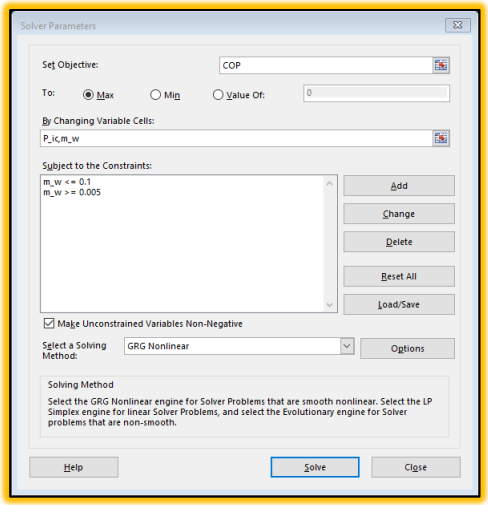
Solver for S-O and M-O optimisation



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Thermax

- Thermodynamic analyses require evaluation of the thermodynamic properties of working fluids at different phases, pressures and temperatures.
- Excel itself doesn't have built-in function for this purpose.
- Thermax has been developed for education purposes.

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Thermax functions for fluid properties

#	Substance(s) of the group	Prefix
1	Ideal gases (29)	Gas…
2	Water and steam	Wat…
3	Refrigerants (32)	Ref…
4	Water lithium-bromide solution	Lib…
5	Ammonia-water solution	Nh3...
6	Psychrometry	Psy
7	Fuels and reacting substances (18)	Chm…
8	Air at atmospheric pressure	Air…

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Visual Basic for Applications (VBA)

- VBA
- Availability and ease of use
- Development of user-defined functions, e.g. for fluid properties
- Development of Macros and user forms for user-friendliness of developed applications
- Examples:

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Function GWP(Ref$)

```
Function GWP(Ref$)
If Ref$ = "R23" Then
GWP = 14800
ElseIf Ref$ = "R404A" Then
GWP = 3920
ElseIf Ref$ = "R4104A" Then
GWP = 89
ElseIf Ref$ = "R134a" Then
GWP = 1300
ElseIf Ref$ = "R744" Then
GWP = 1
ElseIf Ref$ = "R152a" Then
GWP = 140
ElseIf Ref$ = "R290" Then
GWP = 5
ElseIf Ref$ = "R717" Then
GWP = 0
End If
End Function
```

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Function Schedule40(Diam, index)

```
Function Schedule40(Diam, index)
'Dim A, B, C, D, E, F
a = Array(0.405, 1.029, 0.02242, 0.683, 0.0003947, 0.3664)
b = Array(0.54, 1.372, 0.03033, 0.924, 0.0007227, 0.6706)
c = Array(0.675, 1.714, 0.04108, 1.252, 0.001326, 1.233)
D = Array(0.84, 2.134, 0.05183, 1.58, 0.00211, 1.961)
e = Array(1.05, 2.667, 0.06867, 2.093, 0.003703, 3.441)
F = Array(1.315, 3.34, 0.08742, 2.664, 0.006002, 5.574)
G = Array(1.66, 4.216, 0.115, 3.504, 0.01039, 9.643)
h = Array(1.9, 4.826, 0.1342, 4.09, 0.01414, 13.13)
.
.
If (Diam <= a(index)) Then
Schedule40 = a(index)
ElseIf Diam <= b(index) Then
.
.
End If
End Function
```

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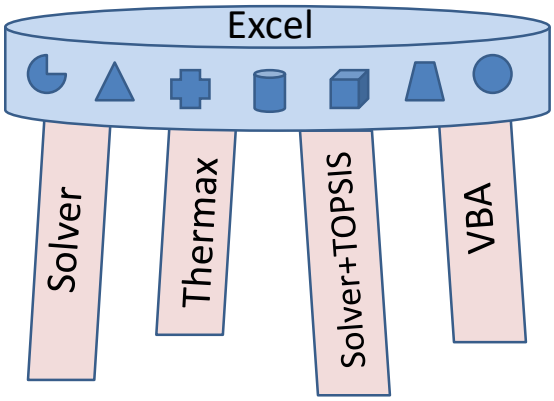
The Excel-based modelling platform



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Features

- An Excel add-in for fluid properties that is adequate for most thermo-fluid analyses (Thermax)
- A technique for using Solver and TOPSIS for multi-objective optimisation analyses
- Three books that can be used at three levels:
  - Thermodynamic analyses of energy utilisation systems using Excel (3rd year - Thermodynamics II, Applied thermodynamics)
  - Computer-aided analyses of fluid-thermal systems using Excel (4th year – Computer applications, Elective subject)
  - Optimisation analyses of fluid-thermal systems using Excel (5th year - Elective subject)

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References

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2. M. Hofmann, F. Witte, M. Fritz, J. Freissmann, l Tuschy, G. Tsatsaronis. *Free and Open-Source Teaching: Understanding Exergy using Thermal Engineering Systems in Python (TESPy),* Proceedings of ECOS 2023 - the 36th International Conference on **E**fficiency, **C**ost, **O**ptimization, **S**imulation and **E**nvironmental impact of energy systems, 25-30 June, 2023, Las Palmas de Gran Canaria, Spain

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End of part 1

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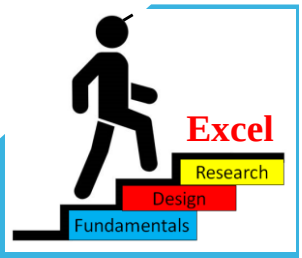
THERMAX 1-2-3: A MODELLING PLATFORM FOR OPTIMIZATION ANALYSES OF FLUID-THERMAL SYSTEMS USING MS EXCEL



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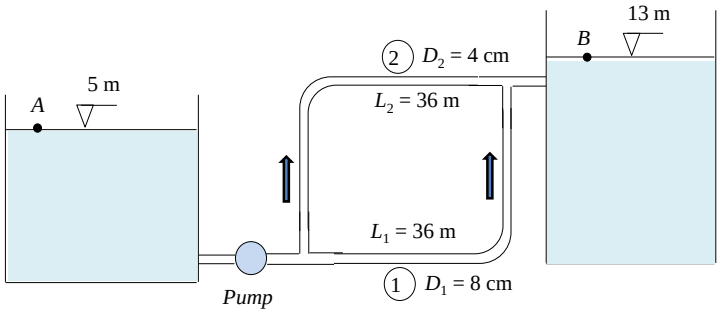
Khartoum – February 19, 2024

Highlights

- Examples of basic analyses
- Examples of design optimisation analyses
- Examples of research analyses

EXAMPLES OF BASIC ANALYSES

Pumping water through two parallel pipes: Type-II & III flow analyses [1]



Excel sheet basic analyses

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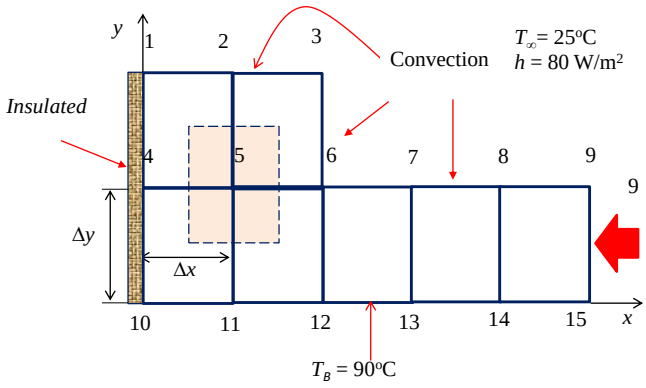
F.D. analysis of transient 2D heat-conduction with heat-generation [2,3]



Excel sheet basic analyses

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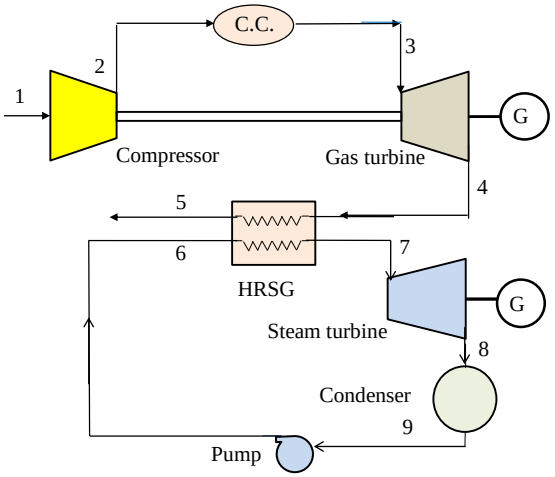
The combined-cycle power plant [4]



Excel sheet basic analyses

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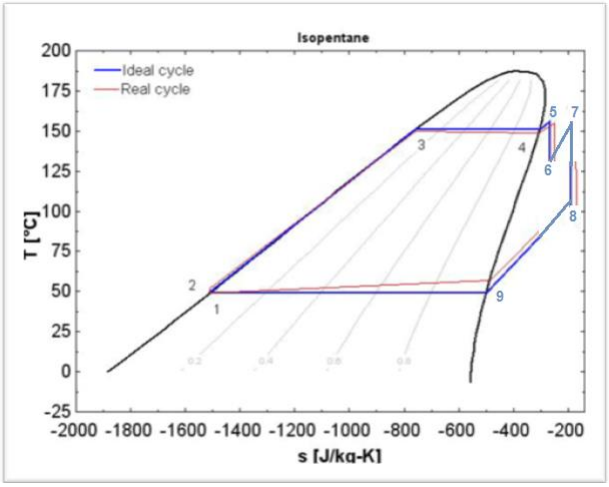
Organic Rankine cycle



Excel sheet basic analyses

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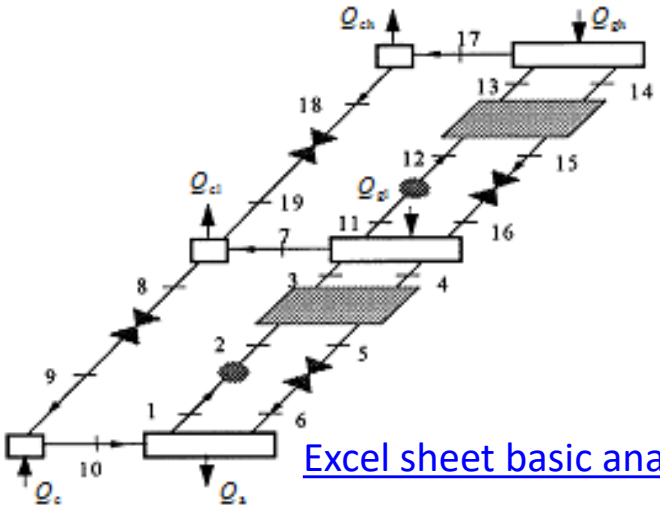
Single and double-effect VAR systems



Excel sheet basic analyses

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EXAMPLES OF DESIGN ANALYSES

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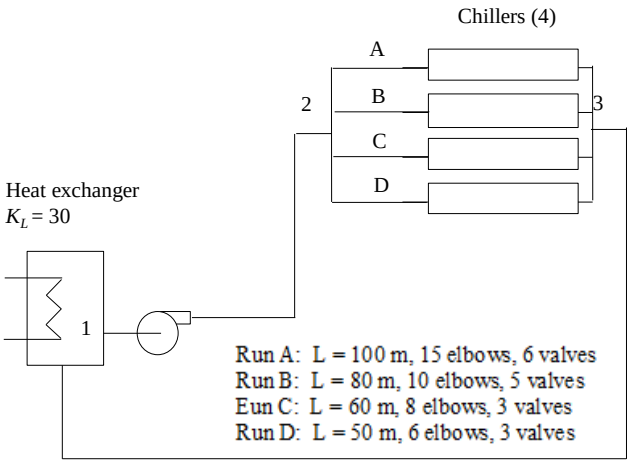
Design of pump-pipe systems [5]



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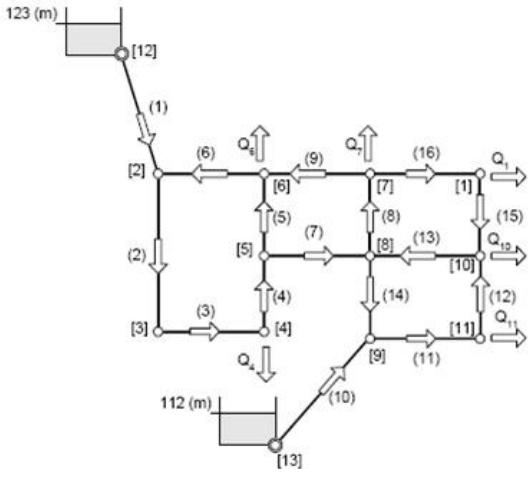
Pipe-network analyses [6]



Excel sheet design analyses

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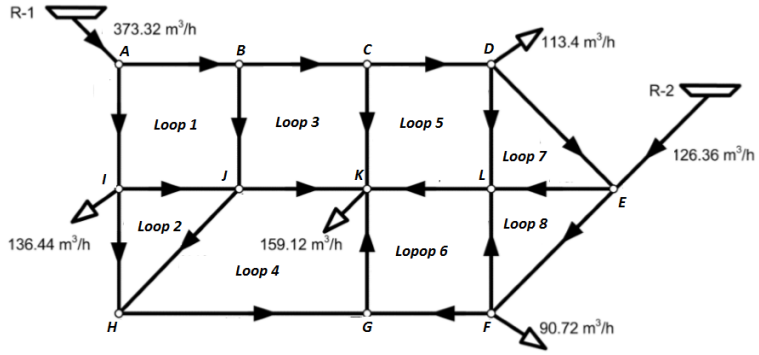
Pipe-network analyses [7]



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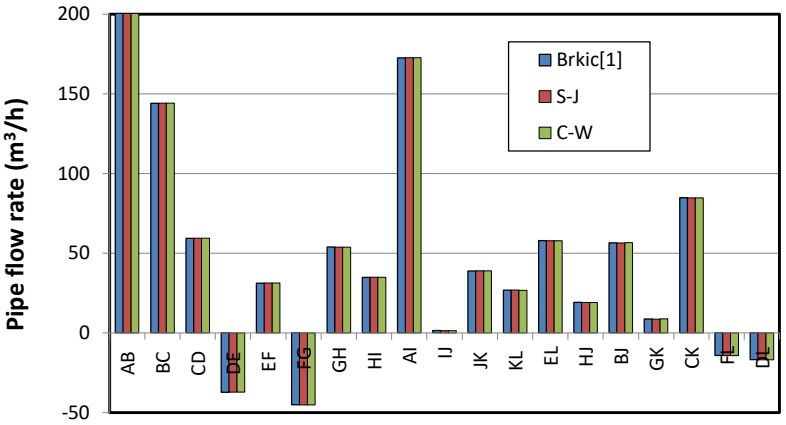
Pipe-network analyses



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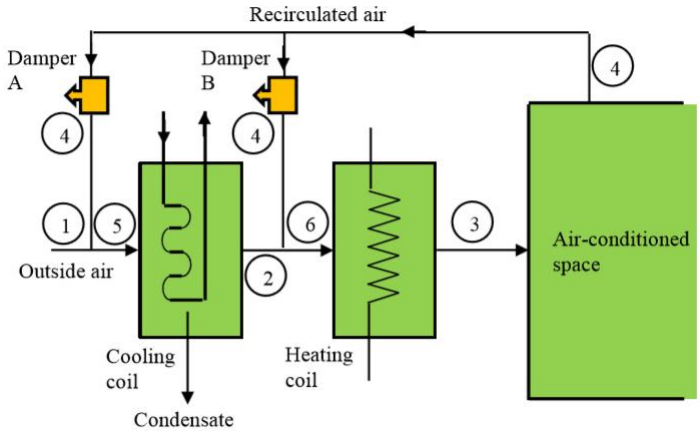
Design analysis of an air-conditioning system [8]



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Design analysis of an air-conditioning system

It is required to evaluate the effect of mixing part of the discharged air with the fresh incoming air. Dampers A and B can be set to give three alternative operating modes:

(a) Both dampers closed (zero recirculated air).
(b) Damper A open and damper B closed. One-third of the conditioned air comes from outside air.
(c) Both dampers open. One-third of the conditioned air comes from outside air. One-third of the recirculated air bypasses the dehumidifier via open damper B, and the rest flows through the damper A.

Which of the three operating modes gives the minimum cooling and heating loads?

Table 7.5. Cooling and heating capacities for the three options

Option	Cooling capacity [kJ/min]	Heating capacity [kJ/min]	Total load [kJ/min]	Saving [%]
(a)	112,696.7	20,227.4	132,924.10	-
(b)	63,575.2	20,227.4	83,802.60	36.95
(c)	50,570.1	7,7173.1	57,743.20	56.56

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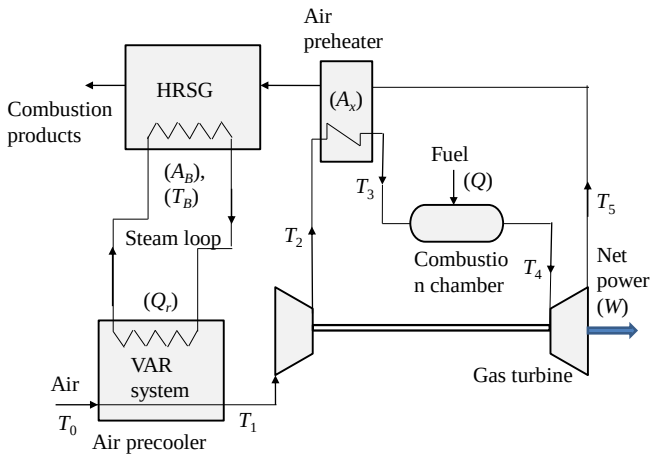
Optimisation analysis of a GT inlet-air cooling system [9]



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EXAMPLES OF RESEARCH ANALYSES

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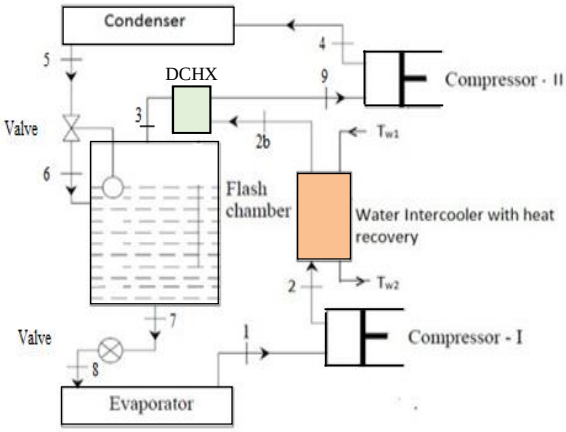
Multi-objective optimisation of innovative multi-stage VCR systems [10]



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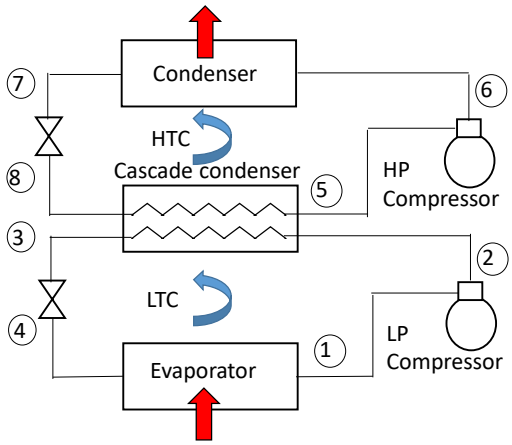
Multi-objective analyses of cascade refrigeration systems using refrigerants with low GWP [11]



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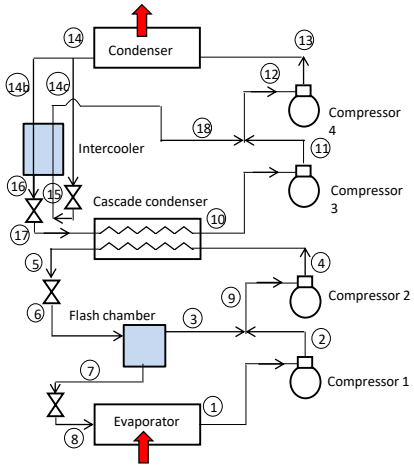
4E optimisation analyses of innovative cascade VCR systems [12]



Excel sheet research analyses

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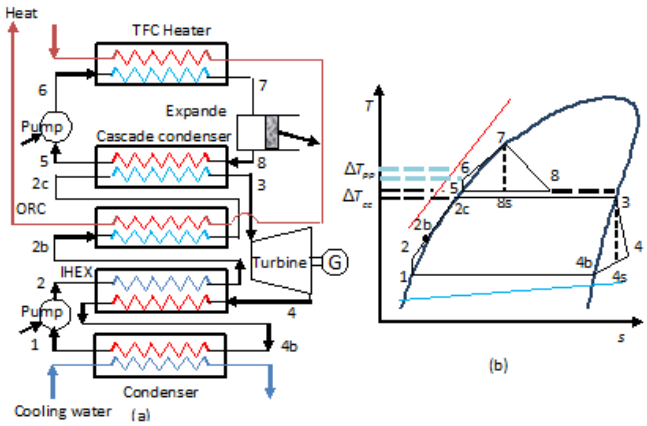
Thermodynamic Evaluation of a Combined ORC-TFC Cycle for Low-Temperature Power Generation by using Microsoft Excel



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12. M. M. El-Awad, M.S. Al-Saidi S. A. Abdalla, Multi-objective optimisation analyses of an innovative cascade refrigeration system with various low GWP refrigerants using Microsoft Excel, submitted to AUT Journal of Modelling and Simulation, Jan 2024.

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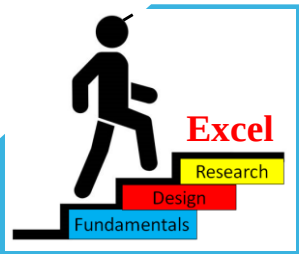

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Khartoum – December 19, 2024

- About Thermax
- A Solver-TOPSIS technique for MOO analyses
- Course material and suggested courses
- Experience matters: Past R&D

ABOUT THERMAX

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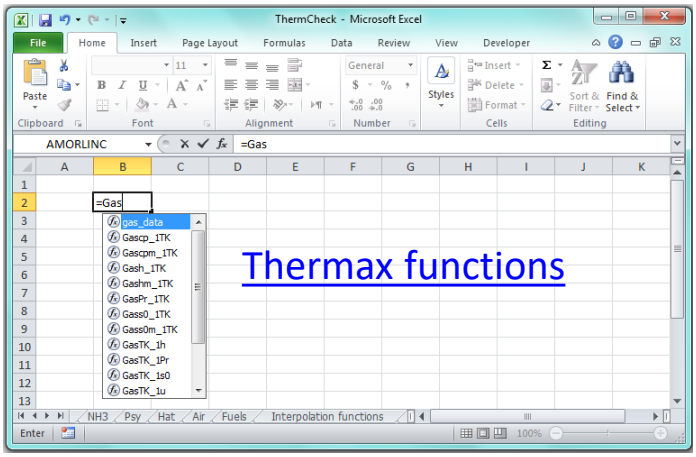
Thermax functions



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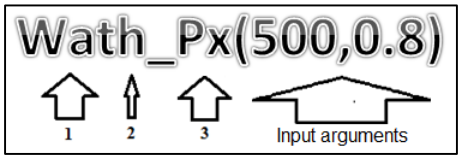
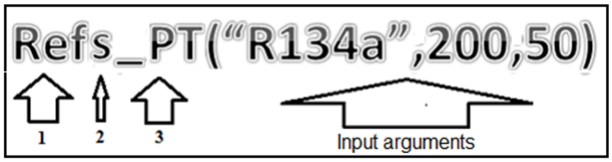
Name style





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Validation

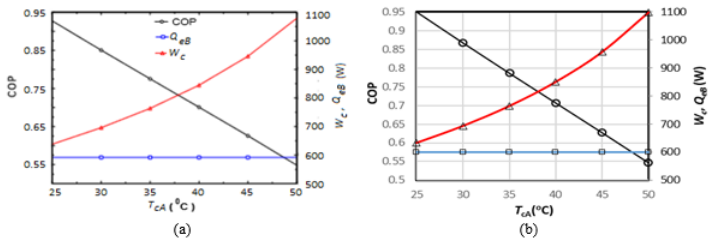
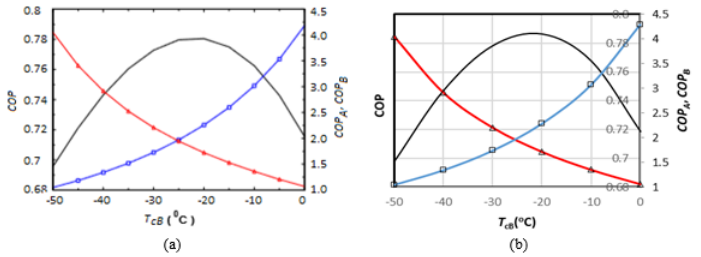


Figure 8. Effect of the high-temperature stage condensing temperature on COP, Q_{eB} and W_c
(a) adapted from Parekh and Tailor [12], (b) present results



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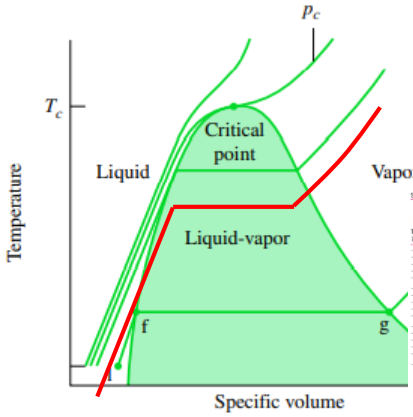
Needed improvement for refrigerants



Saturated refrigerant-134a—Temperature table

Temp., T, °C	Sat. press., P_{sat}, kPa	Specific volume, m³/kg: Sat. liquid, v_f	Specific volume, m³/kg: Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Internal energy, kJ/kg: Evap., u_{fg}	Internal energy, kJ/kg: Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Enthalpy, kJ/kg: Evap., h_{fg}	Enthalpy, kJ/kg: Sat. vapor, h_g	Entropy, kJ/kg · K: Sat. liquid, s_f	Entropy, kJ/kg · K: Evap., s_{fg}	Entropy, kJ/kg · K: Sat. vapor, s_g
−40	51.25	0.0007054	0.36081	−0.036	207.40	207.37	0.000	225.86	225.86	0.00000	0.96866	0.96866
−38	56.86	0.0007083	0.32732	2.475	206.04	208.51	2.515	224.61	227.12	0.01072	0.95511	0.96584
−36	62.95	0.0007112	0.29751	4.992	204.67	209.66	5.037	223.35	228.39	0.02138	0.94156	0.96315
−34	69.56	0.0007142	0.27090	7.517	203.29	210.81	7.566	222.09	229.65	0.03199	0.92859	0.96058
−32	76.71	0.0007172	0.24711	10.05	201.91	211.96	10.10	220.81	230.91	0.04253	0.91560	0.95813
−30	84.43	0.0007203	0.22580	12.59	200.52	213.11	12.65	219.52	232.17	0.05301	0.90278	0.95579
−28	92.76	0.0007234	0.20666	15.13	199.12	214.25	15.20	218.22	233.43	0.06344	0.89012	0.95356
−26	101.73	0.0007265	0.18946	17.69	197.72	215.40	17.76	216.92	234.68	0.07382	0.87762	0.95144
−24	111.37	0.0007297	0.17395	20.25	196.30	216.55	20.33	215.59	235.92	0.08414	0.86527	0.94941
−22	121.72	0.0007329	0.15995	22.82	194.88	217.70	22.91	214.26	≥237.17	0.09441	0.85307	0.94748
−20	132.82	0.0007362	0.14729	25.39	193.45	218.84	25.49	212.91	238.41	0.10463	0.84101	0.94564
−18	144.69	0.0007396	0.13583	27.98	192.01	219.98	28.09	211.55	239.64	0.11481	0.82908	0.94389
−16	157.38	0.0007430	0.12542	30.57	190.56	221.13	30.69	210.18	240.87	0.12493	0.81729	0.94222
−14	170.93	0.0007464	0.11597	33.17	189.09	222.27	33.30	208.79	242.09	0.13501	0.80561	0.94063
−12	185.37	0.0007499	0.10736	35.78	187.62	223.40	35.92	207.38	243.30	0.14504	0.79406	0.93911
−10	200.74	0.0007535	0.099516	38.40	186.14	224.54	38.55	205.96	244.51	0.15504	0.78263	0.93766
−8	217.08	0.0007571	0.092352	41.03	184.64	225.67	41.19	204.52	245.72	0.16498	0.77130	0.93629
−6	234.44	0.0007608	0.085810	43.66	183.13	226.80	43.84	203.07	246.91	0.17489	0.76008	0.93497
−4	252.85	0.0007646	0.079804	46.31	181.61	227.92	46.50	201.60	248.10	0.18476	0.74896	0.93372
−2	272.36	0.0007684	0.074304	48.96	180.08	229.04	49.17	200.11	249.28	0.19459	0.73794	0.93253

- The properties of superheated refrigerants are obtained by extending the compressibility-factor concept to enthalpy and entropy
- Expanding the scope of analyses to cover new material such as nano refrigerants

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A SOLVER-TOPSIS TECHNIQUE FOR MULTI-OBJECTIVE OPTIMISATION

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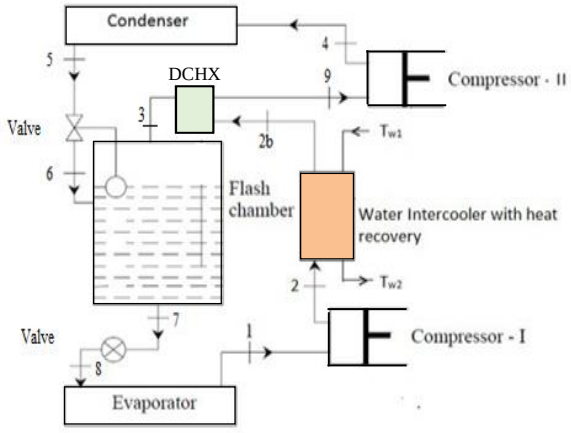
Multi-objective optimisation by using Solver and TOPSIS

- Developing a method for using Excel's Solver for MOO analyses of fluid-thermal systems with multiple design parameters by utilising the TOPSIS technique.
- Draft paper 1:
  - https://www.academia.edu/113799908/Multi_objective_optimisation_of_VCR_systems_by_applying_TOPSIS_to_the_single_objective_solutions_obtained_with_Excel_Solver
- Draft paper 2:
  - https://www.academia.edu/113901794/A_Solver_TOPSIS_technique_for_multi_objective_optimisation_of_two_stage_compression_VCR_systems_using_Microsoft_Excel
- Book 3 Chapter 14:
  - https://www.academia.edu/113901794/A_Solver_TOPSIS_technique_for_multi_objective_optimisation_of_two_stage_compression_VCR_systems_using_Microsoft_Excel

47

Multi-objective optimisation of innovative multi-stage VCR systems



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Multi-objective optimisation of innovative multi-stage VCR systems

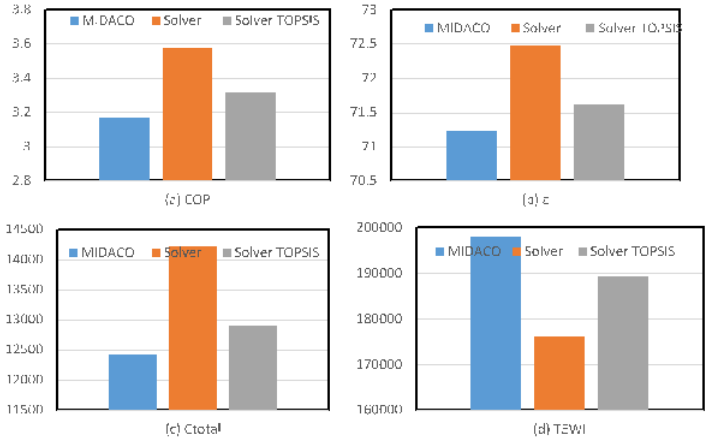


Fig.13 *Comparison of the four key performance indicators obtained by MIDACO, the SOO solution of Solver, and the MOO solution of Solver-TOPSIS technique*

Multi-objective optimisation of innovative multi-stage VCR systems

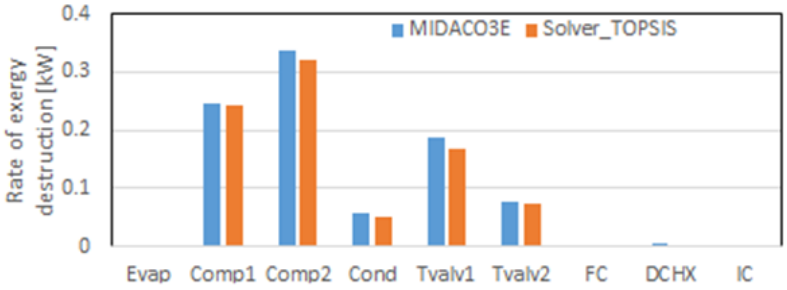
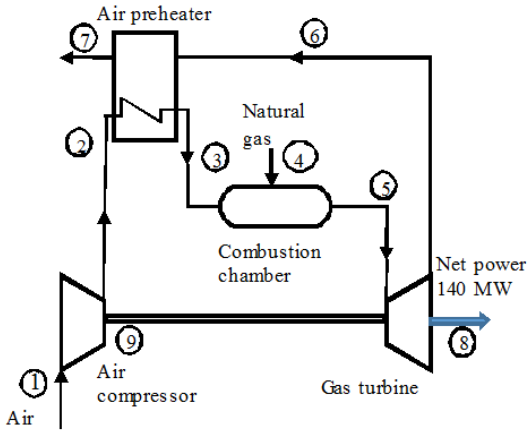


Fig.14 *Exergy destruction rates at optimal solutions obtained with MIDACO and Solver-TOPSIS*

Multi-objective optimisation of a regenerative gas turbine



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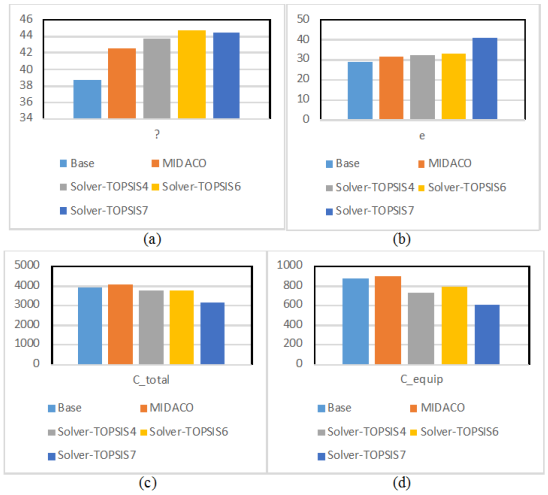
Multi-objective optimisation of a regenerative gas turbine



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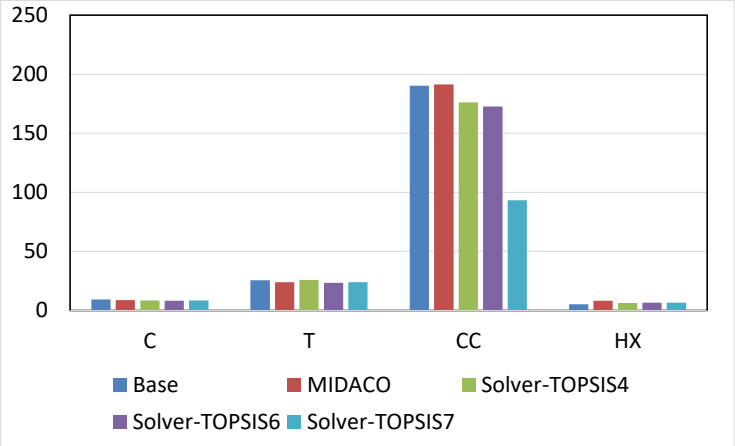
Multi-objective optimisation of a regenerative gas turbine



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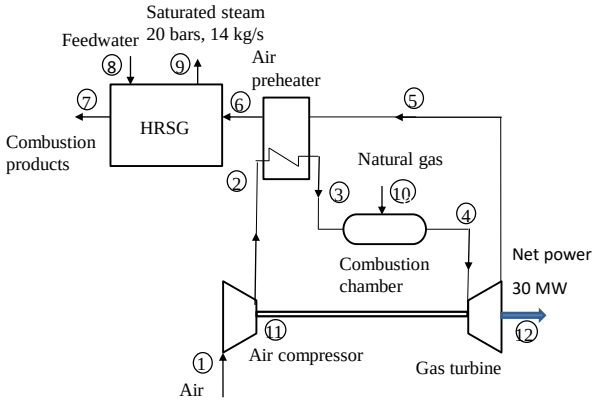
3E optimisation of a gas-turbine co-generation system



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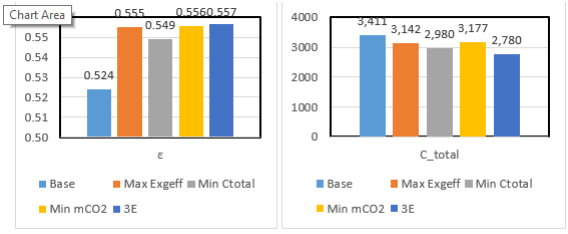
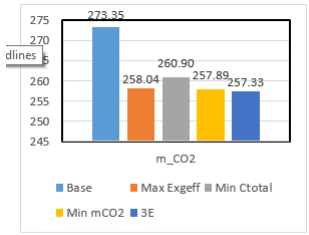
3E optimisation of a gas-turbine co-generation system





(c) m_CO2

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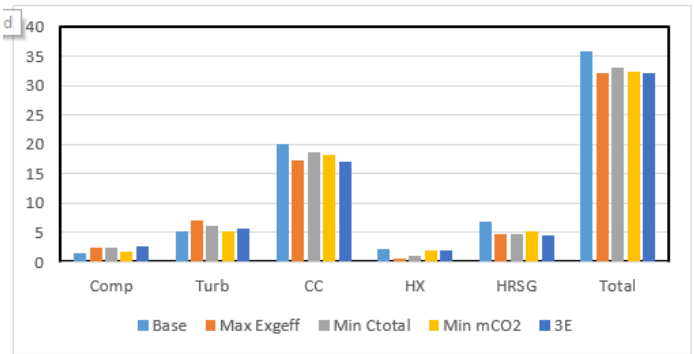
3E optimisation of a gas-turbine co-generation system



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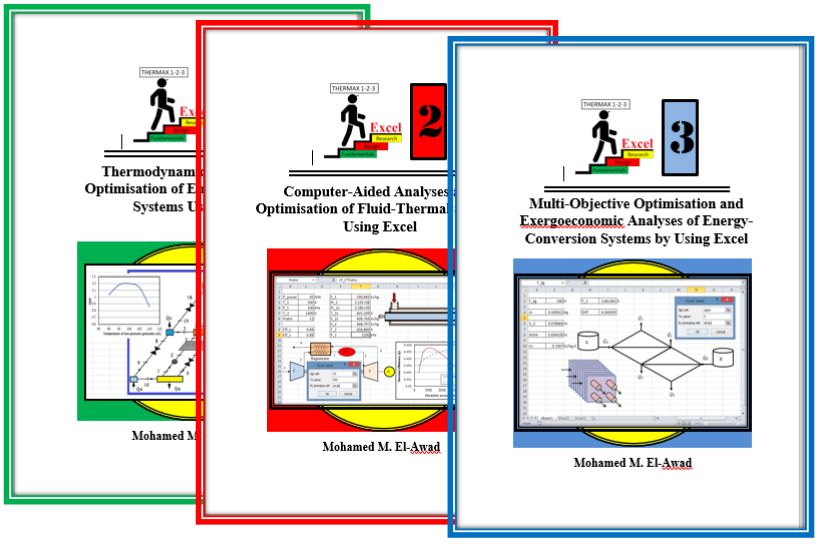
COURSE MATERIAL AND SUGGESTED COURSES

Three books *(unpublished)*



Three books (*unpublished)*

- Thermodynamic Analyses and Optimisation of Energy-Conversion Systems using Excel -

  https://www.academia.edu/24381392/Thermodynamic_Analyses_and_Optimisation_of_Energy_Conversion_Systems_Using_Excel?email_work_card=view-paper
- Computer–Aided Analyses and Optimisation of Fluid-Thermal Systems using Excel

  https://www.academia.edu/40015718/Computer_Aided_Analyses_and_Optimisation_of_Fluid_Thermal_Systems_using_Excel?auto=download&email_work_card=download-paper
- Multi-Objective Optimisation and Exergoeconomic Analyses of Energy-Conversion Systems by Using Excel –

  https://www.academia.edu/41316679/Multi_Objective_Optimisation_and_Exergoeconomic_Analyses_of_Energy_Conversion_Systems_by_Using_Excel?auto=download&email_work_card=download-paper

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More

- The development of Thermax123: An educational Excel-based modelling platform for thermo-fluid analyses
- https://www.academia.edu/124075030/The_development_of_Thermax123_An_educational_Excel_based_modelling_platform_for_thermo_fluid_analyses
- The development of computer-aided thermofluid software: a personal perspective
- https://www.academia.edu/42748397/The_development_of_computer_aided_thermofluid_software_CATs_a_personal_perspective
- Video
- https://www.academia.edu/video/kVeVJl

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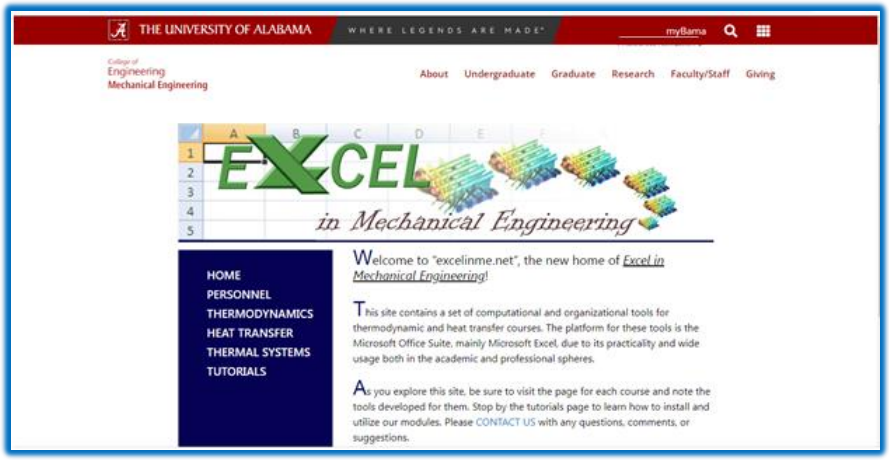
A special acknowledgement



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- Linkedin:
  - https://www.linkedin.com/in/dr-musadag-el-awad-11103464/
- Facebook:
  - https://web.facebook.com/profile.php?id=100049820741529
- Youtube:
  - https://web.facebook.com/profile.php?id=100049820741529

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