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APPENDICES

Appendix A Heat Accumulate in Interval of Hot Streams for Constructing Composite Curve

Table A1 Heat accumulate in interval of hot streams

Temperature Intervals		ΔT (°C)	I1	I2	I3	I4	I5
360	350	10	624.42	223.9	114.45	48.29	107.54
350	330	20					
330	324	6					
324	304.9	19.1					
304.9	290	14.9					
290	289.6	0.4					
289.6	287.64	1.96					
287.64	285.4	2.24					
285.4	284.581	0.819					
284.581	282.98	1.601					
282.98	281.6	1.38					
281.6	280.342	1.258					
280.342	276.7	3.642					
276.7	259.54	17.16					
259.54	258.9	0.64					
258.9	256.6	2.3					
256.6	254.65	1.95					
254.65	253	1.65					
253	242.067	10.93					
242.067	236	6.067					
236	233	3					
233	227.41	5.59					
227.41	223.1	4.31					
223.1	222.3	0.8				38.632	
222.3	220.4	1.9				91.751	
220.4	217.732	2.668				128.837	
217.732	217.3	0.432				20.8612	
217.3	216.9	0.4				19.316	
216.9	216.7	0.2				9.658	21.508
216.7	215.972	0.728			83.3196	35.1551	78.2891
215.972	213.5	2.472			282.920	119.372	265.838
213.5	212.71	0.79		176.881	90.4155	38.1491	84.9566
212.71	206.88	5.83		1305.33	667.243	281.530	626.958
206.88	205	1.88		420.932	215.166	90.7852	202.175
205	192.95	12.05		2697.99	1379.12	581.894	1295.85
192.95	175.106	17.84		3995.27	2042.24	861.686	1918.94
175.106	165.104	10.00		2239.44	1144.72	482.996	1075.61
165.104	163.027	2.077		465.040	237.712	100.298	
163.027	162.786	0.241		53.9599	27.5824		
162.786	158.665	4.121		922.691	471.648		
158.665	140.463	18.20			2083.21		
140.463	128.5	11.96					
128.5	105.3	23.2	14486.5				
105.3	90.3	15					

Table A1 (Continued)

Temperature Intervals		ΔT (°C)	I6	I7	I8	I9	I10
360	350	10	247.68	79.7564	350.141	137.343	262.96
350	330	20					
330	324	6					
324	304.9	19.1					
304.9	290	14.9					
290	289.6	0.4					
289.6	287.64	1.96					
287.64	285.4	2.24					
285.4	284.581	0.819					
284.581	282.98	1.601					
282.98	281.6	1.38					
281.6	280.342	1.258				172.777	
280.342	276.7	3.642				500.203	
276.7	259.54	17.16				2356.80	
259.54	258.9	0.64				87.8995	
258.9	256.6	2.3				315.888	604.808
256.6	254.65	1.95				267.818	512.772
254.65	253	1.65				226.616	433.884
253	242.067	10.93				1501.57	2874.94
242.067	236	6.067				833.26	1595.37
236	233	3				412.029	788.88
233	227.41	5.59		445.838		767.747	1469.94
227.41	223.1	4.31		343.750		591.948	1133.35
223.1	222.3	0.8		63.8051		109.874	210.368
222.3	220.4	1.9		151.537		260.951	499.624
220.4	217.732	2.668		212.790	934.176	366.431	701.577
217.732	217.3	0.432		34.4547	151.260	59.3321	
217.3	216.9	0.4	99.072	31.9025	140.056	54.9372	
216.9	216.7	0.2	49.536	15.9512	70.0282	27.4686	
216.7	215.972	0.728	180.311	58.0626	254.902	99.9857	
215.972	213.5	2.472	612.265	197.157	865.548	339.511	
213.5	212.71	0.79	195.667	63.0075	276.611	108.501	
212.71	206.88	5.83	1443.97	464.979	2041.32	800.709	
206.88	205	1.88	465.638	149.942	658.265	258.204	
205	192.95	12.05	2984.54	961.064	4219.19		
192.95	175.106	17.84	4419.60	1423.17			
175.106	165.104	10.00		797.723			
165.104	163.027	2.077		165.654			
163.027	162.786	0.241		19.2212			
162.786	158.665	4.121					
158.665	140.463	18.20					
140.463	128.5	11.96					
128.5	105.3	23.2					
105.3	90.3	15					
90.3							

Table A1 (Continued)

Temperature Intervals		ΔT (°C)	I11	I12	I13	I14	I15
360	350	10	376.482	118.26	52.149	26.98	402.217
350	330	20					
330	324	6					
324	304.9	19.1					
304.9	290	14.9					5993.03
290	289.6	0.4					160.886
289.6	287.64	1.96					788.345
287.64	285.4	2.24					900.966
285.4	284.581	0.819				22.0966	329.415
284.581	282.98	1.601				43.1949	643.949
282.98	281.6	1.38				37.2324	555.059
281.6	280.342	1.258				33.9408	505.989
280.342	276.7	3.642				98.2611	1464.87
276.7	259.54	17.16			894.876	462.976	6902.04
259.54	258.9	0.64			33.3753	17.2672	
258.9	256.6	2.3			119.942	62.054	
256.6	254.65	1.95	734.139		101.690	52.611	
254.65	253	1.65	621.195		86.0458	44.517	
253	242.067	10.93	4116.07	1292.93	570.145	294.972	
242.067	236	6.067	2284.11	717.483	316.388		
236	233	3	1129.44	354.78	156.447		
233	227.41	5.59	2104.53	661.073	291.512		
227.41	223.1	4.31	1622.63	509.700	224.762		
223.1	222.3	0.8	301.185	94.608	41.7192		
222.3	220.4	1.9	715.315	224.694			
220.4	217.732	2.668	1004.45	315.517			
217.732	217.3	0.432	162.640	51.0883			
217.3	216.9	0.4	150.592	47.304			
216.9	216.7	0.2	75.2964	23.652			
216.7	215.972	0.728	274.078	86.0932			
215.972	213.5	2.472	930.663				
213.5	212.71	0.79	297.420				
212.71	206.88	5.83					
206.88	205	1.88					
205	192.95	12.05					
192.95	175.106	17.84					
175.106	165.104	10.00					
165.104	163.027	2.077					
163.027	162.786	0.241					
162.786	158.665	4.121					
158.665	140.463	18.20					
140.463	128.5	11.96					
128.5	105.3	23.2					
105.3	90.3	15					
90.3							

Table A1 (Continued)

Temperature Intervals		ΔT (°C)	I16	I17	I18	I19	I20
360	350	10	47.8872	28.4187	153.373	83.755	654.512
350	330	20				837.55	
330	324	6			3067.46	1675.1	
324	304.9	19.1		170.512	920.238	502.53	
304.9	290	14.9	914.645	542.797	2929.42	1599.72	
290	289.6	0.4	713.519	423.438	2285.25	1247.95	
289.6	287.64	1.96	19.1548	11.3674	61.3492	33.502	
287.64	285.4	2.24	93.8589	55.7006	300.611	164.159	
285.4	284.581	0.819	107.267		343.555	187.611	
284.581	282.98	1.601	39.2196		125.612	68.5953	
282.98	281.6	1.38	76.6674			134.091	
281.6	280.342	1.258				115.581	
280.342	276.7	3.642				105.363	
276.7	259.54	17.16					
259.54	258.9	0.64					
258.9	256.6	2.3					
256.6	254.65	1.95					
254.65	253	1.65					
253	242.067	10.93					
242.067	236	6.067					
236	233	3					
233	227.41	5.59					
227.41	223.1	4.31					
223.1	222.3	0.8					
222.3	220.4	1.9					
220.4	217.732	2.668					
217.732	217.3	0.432					
217.3	216.9	0.4					
216.9	216.7	0.2					
216.7	215.972	0.728					
215.972	213.5	2.472					
213.5	212.71	0.79					
212.71	206.88	5.83					
206.88	205	1.88					
205	192.95	12.05					
192.95	175.106	17.84					
175.106	165.104	10.00					
165.104	163.027	2.077					
163.027	162.786	0.241					
162.786	158.665	4.121					
158.665	140.463	18.20					
140.463	128.5	11.96					
128.5	105.3	23.2					
105.3	90.3	15					9817.68
90.3							

Table A1 (Continued)

Temperature Intervals		ΔT (°C)	I21	I22	I23
360	350	10	287.257	103.292	164.428
350	330	20			
330	324	6			
324	304.9	19.1			
304.9	290	14.9			
290	289.6	0.4			65.7713
289.6	287.64	1.96		202.452	322.279
287.64	285.4	2.24		231.374	368.319
285.4	284.581	0.819		84.5961	134.666
284.581	282.98	1.601		165.370	263.249
282.98	281.6	1.38		142.543	226.911
281.6	280.342	1.258		129.941	206.850
280.342	276.7	3.642		376.189	598.847
276.7	259.54	17.16		1772.49	2821.58
259.54	258.9	0.64		66.1068	105.234
258.9	256.6	2.3		237.571	378.185
256.6	254.65	1.95		201.419	320.635
254.65	253	1.65		170.431	
253	242.067	10.93		1129.29	
242.067	236	6.067		626.672	
236	233	3	861.771	309.876	
233	227.41	5.59	1605.76	577.402	
227.41	223.1	4.31	1238.07		
223.1	222.3	0.8	229.805		
222.3	220.4	1.9	545.788		
220.4	217.732	2.668	766.402		
217.732	217.3	0.432	124.095		
217.3	216.9	0.4	114.902		
216.9	216.7	0.2	57.4514		
216.7	215.972	0.728	209.123		
215.972	213.5	2.472	710.1		
213.5	212.71	0.79	226.933		
212.71	206.88	5.83	1674.71		
206.88	205	1.88			
205	192.95	12.05			
192.95	175.106	17.84			
175.106	165.104	10.00			
165.104	163.027	2.077			
163.027	162.786	0.241			
162.786	158.665	4.121			
158.665	140.463	18.20			
140.463	128.5	11.96			
128.5	105.3	23.2			
105.3	90.3	15			
90.3					

Appendix B Heat Accumulate in Interval of Cold Streams for Constructing Composite Curve

Table B1 Heat accumulate in interval of cold streams

Temperature Intervals		ΔT (°C)
360	295.7	64.3
295.7	290	5.7
290	289.36	0.64
289.36	265.42	23.94
265.42	265.25	0.17
265.25	260.48	4.77
260.48	235.33	25.15
235.33	231.13	4.2
231.13	230.85	0.28
230.85	230.81	0.04
230.81	222.48	8.33
222.48	206.3	16.18
206.3	204.84	1.46
204.84	201.31	3.53
201.31	183.24	18.07
183.24	182	1.24
182	167.1	14.9
167.1	165.24	1.86
165.24	151.76	13.48
151.76	148.44	3.32
148.44	138.62	9.82
138.62	124.6	14.02
124.6	123.57	1.03
123.57	119.62	3.95
119.62	118.09	1.53
118.09	103.37	14.72
103.37	86.597	16.77
86.597	61.71	24.88
61.71	30	31.71
30		

J1	J2	J3	J4	J5
456.92	493.34	520.24	143.59	378.533
			567.180	
			219.692	
			2113.64	5572.00
		8725.98		
	12277.7			
14488.9				

Table B1 (Continued)

Temperature Intervals		ΔT (°C)
360	295.7	64.3
295.7	290	5.7
290	289.36	0.64
289.36	265.42	23.94
265.42	265.25	0.17
265.25	260.48	4.77
260.48	235.33	25.15
235.33	231.13	4.2
231.13	230.85	0.28
230.85	230.81	0.04
230.81	222.48	8.33
222.48	206.3	16.18
206.3	204.84	1.46
204.84	201.31	3.53
201.31	183.24	18.07
183.24	182	1.24
182	167.1	14.9
167.1	165.24	1.86
165.24	151.76	13.48
151.76	148.44	3.32
148.44	138.62	9.82
138.62	124.6	14.02
124.6	123.57	1.03
123.57	119.62	3.95
119.62	118.09	1.53
118.09	103.37	14.72
103.37	86.597	16.77
86.597	61.71	24.88
61.71	30	31.71
30		

J6	J7	J8	J9	J10
550	570.41	572.09	580.84	169.077
				47.3415
				6.76308
				1408.41
				2735.66
				246.852
				596.841
				3055.22
			720.241	209.655
			8654.51	2519.24
			1080.36	
		7711.77		
		1899.33		
	5601.42			
7711				
566.5				
2172.5				

Table B1 (Continued)

Temperature Intervals		ΔT (°C)
360	295.7	64.3
295.7	290	5.7
290	289.36	0.64
289.36	265.42	23.94
265.42	265.25	0.17
265.25	260.48	4.77
260.48	235.33	25.15
235.33	231.13	4.2
231.13	230.85	0.28
230.85	230.81	0.04
230.81	222.48	8.33
222.48	206.3	16.18
206.3	204.84	1.46
204.84	201.31	3.53
201.31	183.24	18.07
183.24	182	1.24
182	167.1	14.9
167.1	165.24	1.86
165.24	151.76	13.48
151.76	148.44	3.32
148.44	138.62	9.82
138.62	124.6	14.02
124.6	123.57	1.03
123.57	119.62	3.95
119.62	118.09	1.53
118.09	103.37	14.72
103.37	86.597	16.77
86.597	61.71	24.88
61.71	30	31.71
30		

J11	J12	J13	J14	J15
259.33	128.02	134.02	139.62	615.79
				15487.1
				2586.31
				172.421
			5.5848	
2160.21			1163.03	
4195.95		2168.44		
378.621		195.669		
915.434		473.090		
4686.09	2313.32			
321.569	158.744			
3864.01	1907.49			

Table B1 (Continued)

Temperature Intervals		ΔT (°C)	J16	J17	J18	J19	J20
360	295.7	64.3	412.096	222.36	416.1	220.35	307.923
295.7	290	5.7					
290	289.36	0.64				1255.99	
289.36	265.42	23.94				141.024	
265.42	265.25	0.17			9961.43	5275.17	
265.25	260.48	4.77		37.8012	70.737		
260.48	235.33	25.15	1965.69	1060.65			
235.33	231.13	4.2					
231.13	230.85	0.28					
230.85	230.81	0.04					
230.81	222.48	8.33					
222.48	206.3	16.18					
206.3	204.84	1.46					
204.84	201.31	3.53					
201.31	183.24	18.07					
183.24	182	1.24					
182	167.1	14.9					
167.1	165.24	1.86					
165.24	151.76	13.48					
151.76	148.44	3.32					1022.30
148.44	138.62	9.82					3023.80
138.62	124.6	14.02					4317.08
124.6	123.57	1.03					
123.57	119.62	3.95					
119.62	118.09	1.53					
118.09	103.37	14.72					
103.37	86.597	16.77					
86.597	61.71	24.88					
61.71	30	31.71					
30							

Table B1 (Continued)

Temperature Intervals		ΔT (°C)	J21	J22	J23
			221.267	254.14	967.3
360	295.7	64.3			62197.3
295.7	290	5.7			5513.61
290	289.36	0.64			
289.36	265.42	23.94			
265.42	265.25	0.17			
265.25	260.48	4.77			
260.48	235.33	25.15			
235.33	231.13	4.2	929.321		
231.13	230.85	0.28	61.9547		
230.85	230.81	0.04	8.85068		
230.81	222.48	8.33	1843.15		
222.48	206.3	16.18	3580.1		
206.3	204.84	1.46			
204.84	201.31	3.53		897.114	
201.31	183.24	18.07		4592.31	
183.24	182	1.24		315.133	
182	167.1	14.9			
167.1	165.24	1.86			
165.24	151.76	13.48			
151.76	148.44	3.32			
148.44	138.62	9.82			
138.62	124.6	14.02			
124.6	123.57	1.03			
123.57	119.62	3.95			
119.62	118.09	1.53			
118.09	103.37	14.72			
103.37	86.597	16.77			
86.597	61.71	24.88			
61.71	30	31.71			
30					

Appendix C The Data Parameter and Source Code in Grassroots Model

```
$TITLE  HEN design- Automatic parameter calculation
$OFFUPPER

$ONTEXT
*NM-4S1-FINAL-
*****************************************************************************
INSTRUCTIONS: YOU NEED TO DEFINE
SETS:
     -ZONES (UNLESS YOU HAVE COMPELLING REASONS FOR MORE, WE
      RECOMMEND ONE)
     -HOT, COLD AND UTILITY STREAMS
     -NUMBER OF INTERVALS
     -NUMBER OF SCENARIOS (LEAVE IT ONE FOR THE TIME BEING)
     -NUMBER OF EXCHANGERS PER PAIR OF STREAMS.
     -SETS OF HOT AND COLD STREAMS THAT ARE INCLUDED IN THIS
      RUN

PARAMETERS:
     -NUMBER OF INTERVALS DESIRED FOR HOT AND COLD STREAMS
     -HEAT TRANSFER COEFFICIENT FOR HOT AND COLD STREAMS
     -SUPPLY(INITIAL) AND TARGET(FINAL) TEMPERATURES FOR HOT
      AND COLD STREAMS
     -SUPPLY(INITIAL) AND TARGET(FINAL) TEMPERATURES FOR HOT
      AND COLD STREAMS IN EACH ZONE
     -FCp (FLOW*HEAT CAPACITY) FOR HOT AND COLD STREAMS
      USE THE MAX FCp FOR THE UTILITIES
     -PARAMETER THAT ALLOWS MORE THAN ONE EXCHANGER PER PAIR OF STREAMS
     -PARAMETERS TO ALLOW SPLITS IN HOT AND COLD STREAMS
     -PARAMETERS TO ALLOW NONISOTHERMAL MIXING IN HOT AND
      COLD STREAMS
     -MAXIMUM NUMBER OF MATCHES PER PAIR WHEN MORE THAN
      ONE IS ALLOWED
     -CHANGE OF TEMPERATURE FOR UTILITIES
     -MAXIMUM FLOW*Cp FOR HOT AND COLD UTILITIES
     -COST OF HOT AND COLD UTILITY
     -FIXED COST PER SHELL
     -AREA VARIABLE COST ($/AREA) UNITS NEED TO BE CONSISTENT
      WITH FCP, TEMPERATURES AND HEAT TRANSFER COEFFICIENTS
     -MINIMUM HEAT THAT CAN BE TRANSFERRED IN AN INTERVAL
      PER MATCH
     -MAXIMUM AREA PER EXCHANGER
     -MAXIMUM AREA PER SHELL
     -MAXIMUM AND MINIMUM NUMBER OF EXCHANGERS (TOTAL)
```

-MINUMUM DELTA T (HRAT)
-PARAMETER THAT DEFINES WHICH EQUATIONS RUN:
GRASSROOTS, RETROFIT OR RELOCATION (OPT)
-PARAMETERS FOR THE RETROFIT EQUATIONS (AEX, AEX_B, NHE0)

WHEN ALL VALUES ARE ZERO, DEFINE AT LEAST ONE. OMMISSION MEANS ZERO BY DEFAULT

MORE INSTRUCTIONS ARE GIVEN IN EACH INSTANCE

Notes for development: NEED TO be able to ENTER CP PER INTERVAL SOMEHOW...

```
*******************************************************************************
$OFFTEXT
* NOTES ON DEVELOPMENT- THIS MODEL AS IS DOES NOT SEEM TO WORK WELL FOR BIF=1.
* IN ADDITION, THE CONSTRAINTS ON TEMPERATURE FEASIBILITY DO NOT WORK WELL
* THEY GIVE AS FEASIBLE SOMETHING THAT IS NOT.

*******************************************************************************
*******************************************************************************
* INPUT SETS
*******************************************************************************
*******************************************************************************

SETS
 Z transfer zones       /Z1/
*_____________________________________________
*ALWAYS DEFINE THE HOT STREAMS FIRST, AND THEN THE COLD STREAMS
 I Hot streams          /I1*I24/
 J cold streams         /J1*J24/
*ALWAYS DEFINE THE UTILITIES WITH THE HIGHEST INDEX
 HU(I) Heating utilities /I24/
 CU(J) Cooling utilities /J24/
*_____________________________________________
 M temperature intervals /M1*M96/
*MODEL IS NOT PREPARED TO RUN FOR MANY SCENARIOS YET.
 S SCENARIO             /S1/
 K exchangers per pair of stremas in each zone /K1*K1/
 FREEH(I)  HOT STREAMS INCLUDED IN THIS RUN /I1*I24/
 FREEC(J)  COLD STREAMS INCLUDED IN THIS RUN /J1*J24/

 ALIAS (M,N,L,O)
 ALIAS (I,II)
 ALIAS (J,JJ)
 ALIAS (K,KK)
 ALIAS (Z,ZZ);

*******************************************************************************
```

```
*******************************************************************************
* INPUT PARAMETERS
*******************************************************************************
*******************************************************************************
PARAMETERS
NIZ(S,Z,I) NUMBER OF INTERVALS DESIRED FOR HOT STREAMS IN EACH ZONE
/
S1.Z1.I1   2
S1.Z1.I2   2
S1.Z1.I3   2
S1.Z1.I4   2
S1.Z1.I5   2
S1.Z1.I6   2
S1.Z1.I7   2
S1.Z1.I8   2
S1.Z1.I9   2
S1.Z1.I10  2
S1.Z1.I11  2
S1.Z1.I12  2
S1.Z1.I13  2
S1.Z1.I14  2
S1.Z1.I15  2
S1.Z1.I16  2
S1.Z1.I17  2
S1.Z1.I18  2
S1.Z1.I19  2
S1.Z1.I20  2
S1.Z1.I21  2
S1.Z1.I22  2
S1.Z1.I23  2
S1.Z1.I24  2
/
NJZ(S,Z,J) NUMBER OF INTERVALS DESIRED FOR COLD STREAMS IN EACH ZONE
/
S1.Z1.J1       2
S1.Z1.J2       2
S1.Z1.J3       2
S1.Z1.J4       2
S1.Z1.J5       2
S1.Z1.J6       2
S1.Z1.J7       2
S1.Z1.J8       2
S1.Z1.J9       2
S1.Z1.J10      2
S1.Z1.J11      2
S1.Z1.J12      2
```

```
S1.Z1.J13     2
S1.Z1.J14     2
S1.Z1.J15     2
S1.Z1.J16     2
S1.Z1.J17     2
S1.Z1.J18     2
S1.Z1.J19     2
S1.Z1.J20     2
S1.Z1.J21     2
S1.Z1.J22     2
S1.Z1.J23     2
S1.Z1.J24     2
/
HI(S,I) HEAT TRANSFER COEFFICIENT FOR HOT STREAMS
/
S1.I1    0.928
S1.I2    0.968
S1.I3    0.68
S1.I4    1.064
S1.I5    0.968
S1.I6    1.012
S1.I7    0.952
S1.I8    0.878
S1.I9    0.342
S1.I10   0.948
S1.I11   0.626
S1.I12   0.952
S1.I13   1
S1.I14   0.466
S1.I15   0.738
S1.I16   0.832
S1.I17   0.57
S1.I18   0.39
S1.I19   0.384
S1.I20   0.928
S1.I21   0.648
S1.I22   1.154
S1.I23   0.805
S1.I24   2
/
HJ(S,J)  HEAT TRANSFER COEFFICIENT FOR COLD STREAMS
/
S1.J1    0.928
S1.J2    0.968
S1.J3    0.68
S1.J4    1.064
```

S1.J5 0.968
S1.J6 1.012
S1.J7 0.952
S1.J8 0.878
S1.J9 0.342
S1.J10 0.948
S1.J11 0.626
S1.J12 0.952
S1.J13 1
S1.J14 0.466
S1.J15 0.738
S1.J16 0.832
S1.J17 0.57
S1.J18 0.39
S1.J19 0.384
*S1.J20 0.
S1.J20 0.684
S1.J21 1.154
S1.J22 1.01
S1.J23 2
S1.J24 0.5
/
TIH(S,I) SUPPLY (INLET) TEMPERATURE FOR HOT STREAMS
/
S1.I1 128.5
S1.I2 213.5
S1.I3 216.7
S1.I4 223.1
S1.I5 216.9
S1.I6 217.3
S1.I7 233
S1.I8 220.4
S1.I9 281.6
S1.I10 258.9
S1.I11 256.6
S1.I12 253
S1.I13 276.7
S1.I14 285.4
S1.I15 304.9
S1.I16 324
S1.I17 330
S1.I18 350
S1.I19 360
S1.I20 105.3
S1.I21 236
S1.I22 289.6

S1.I23 290
S1.I24 500
/
TOH(S,I) TARGET (FINAL) TEMPERATURE FOR HOT STREAMS
/
S1.I1 105.3
S1.I2 158.665
S1.I3 140.463
S1.I4 163.027
S1.I5 165.104
S1.I6 175.106
S1.I7 162.786
S1.I8 192.95
S1.I9 205.486
S1.I10 217.732
S1.I11 212.71
S1.I12 215.972
S1.I13 222.3
S1.I14 242.067
S1.I15 259.54
S1.I16 282.98
S1.I17 287.64
S1.I18 284.581
S1.I19 280.342
S1.I20 90.3
S1.I21 206.88
S1.I22 227.41
S1.I23 254.65
S1.I24 480
/
TIC(S,J) SUPPLY (INLET) TEMPERATURE FOR COLD STREAMS
/
S1.J1 30
S1.J2 61.71
S1.J3 86.597
S1.J4 103.37
S1.J5 103.37
S1.J6 119.62
S1.J7 138.62
S1.J8 148.44
S1.J9 165.24
S1.J10 167.1
S1.J11 167.1
S1.J12 167.1
S1.J13 201.31
S1.J14 222.48

```
S1.J15    230.85
S1.J16    260.48
S1.J17    260.48
S1.J18    265.25
S1.J19    265.42
*S1.J20    0.
S1.J20    124.6
S1.J21    206.3
S1.J22    182
S1.J23    290
S1.J24    35
/
TOC(S,J)  TARGET (FINAL) TEMPERATURE FOR COLD STREAMS
/
S1.J1     61.71
S1.J2     86.597
S1.J3     103.37
S1.J4     123.57
S1.J5     118.09
S1.J6     138.62
S1.J7     148.44
S1.J8     165.24
S1.J9     183.24
S1.J10    231.13
S1.J11    230.81
S1.J12    201.31
S1.J13    222.48
S1.J14    230.85
S1.J15    260.48
S1.J16    265.25
S1.J17    265.42
S1.J18    289.36
S1.J19    295.7
*S1.J20    0.
S1.J20    151.76
S1.J21    235.33
S1.J22    204.84
S1.J23    360
S1.J24    50
/
TIHZ(S,Z,I) SUPPLY (INLET) TEMPERATURE FOR HOT STREAMS IN EACH ZONE
/
S1.Z1.I1   128.5
S1.Z1.I2   213.5
S1.Z1.I3   216.7
S1.Z1.I4   223.1
```

S1.Z1.I5 216.9
S1.Z1.I6 217.3
S1.Z1.I7 233
S1.Z1.I8 220.4
S1.Z1.I9 281.6
S1.Z1.I10 258.9
S1.Z1.I11 256.6
S1.Z1.I12 253
S1.Z1.I13 276.7
S1.Z1.I14 285.4
S1.Z1.I15 304.9
S1.Z1.I16 324
S1.Z1.I17 330
S1.Z1.I18 350
S1.Z1.I19 360
S1.Z1.I20 105.3
S1.Z1.I21 236
S1.Z1.I22 289.6
S1.Z1.I23 290
S1.Z1.I24 500
/
TOHZ(S,Z,I) TARGET (FINAL) TEMPERATURE FOR HOT STREAMS IN EACH ZONE
/
S1.Z1.I1 105.3
S1.Z1.I2 158.665
S1.Z1.I3 140.463
S1.Z1.I4 163.027
S1.Z1.I5 165.104
S1.Z1.I6 175.106
S1.Z1.I7 162.786
S1.Z1.I8 192.95
S1.Z1.I9 205.486
S1.Z1.I10 217.732
S1.Z1.I11 212.71
S1.Z1.I12 215.972
S1.Z1.I13 222.3
S1.Z1.I14 242.067
S1.Z1.I15 259.54
S1.Z1.I16 282.98
S1.Z1.I17 287.64
S1.Z1.I18 284.581
S1.Z1.I19 280.342
S1.Z1.I20 90.3
S1.Z1.I21 206.88
S1.Z1.I22 227.41
S1.Z1.I23 254.65

S1.Z1.I24 480

/

TICZ(S,Z,J) SUPPLY (INLET) TEMPERATURE FOR COLD STREAMS IN EACH ZONE

/

S1.Z1.J1 30

S1.Z1.J2 61.71

S1.Z1.J3 86.597

S1.Z1.J4 103.37

S1.Z1.J5 103.37

S1.Z1.J6 119.62

S1.Z1.J7 138.62

S1.Z1.J8 148.44

S1.Z1.J9 165.24

S1.Z1.J10 167.1

S1.Z1.J11 167.1

S1.Z1.J12 167.1

S1.Z1.J13 201.31

S1.Z1.J14 222.48

S1.Z1.J15 230.85

S1.Z1.J16 260.48

S1.Z1.J17 260.48

S1.Z1.J18 265.25

S1.Z1.J19 265.42

*S1.J20 0.

S1.Z1.J20 124.6

S1.Z1.J21 206.3

S1.Z1.J22 182

S1.Z1.J23 290

S1.Z1.J24 35

/

TOCZ(S,Z,J) TARGET (FINAL) TEMPERATURE FOR COLD STREAMS IN EACH ZONE

/

S1.Z1.J1 61.71

S1.Z1.J2 86.597

S1.Z1.J3 103.37

S1.Z1.J4 123.57

S1.Z1.J5 118.09

S1.Z1.J6 138.62

S1.Z1.J7 148.44

S1.Z1.J8 165.24

S1.Z1.J9 183.24

S1.Z1.J10 231.13

S1.Z1.J11 230.81

S1.Z1.J12 201.31

S1.Z1.J13 222.48

S1.Z1.J14 230.85

```
S1.Z1.J15    260.48
S1.Z1.J16    265.25
S1.Z1.J17    265.42
S1.Z1.J18    289.36
S1.Z1.J19    295.7
*S1.J20    0.
S1.Z1.J20    151.76
S1.Z1.J21    235.33
S1.Z1.J22    204.84
S1.Z1.J23    360
S1.Z1.J24    50
/
FH(S,I)    FCp (FLOW*Cp) FOR HOT STREAMS.
*USE THE MAXIMUM FCp FOR THE UTILITIES
/
S1.I1    624.42
S1.I2    223.9
S1.I3    114.45
S1.I4    48.29
S1.I5    107.54
S1.I6    247.68
S1.I7    79.76
S1.I8    350.14
S1.I9    137.34
S1.I10    262.96
S1.I11    376.48
S1.I12    118.26
S1.I13    52.15
S1.I14    26.98
S1.I15    402.2166
S1.I16    47.88
S1.I17    28.42
S1.I18    153.37
S1.I19    83.76
S1.I20    654.512
S1.I21    287.26
S1.I22    103.292
S1.I23    164.23
*S1.I24
/
FC(S,J)    FCp (FLOW*Cp) FOR COLD STREAMS
*USE THE MAXIMUM FCp FOR THE UTILITIES
/
S1.J1    456.92
S1.J2    493.34
S1.J3    520.24
```

```
S1.J4     143.59
S1.J5     378.533
S1.J6     550
S1.J7     570.41
S1.J8     572.09
S1.J9     580.84
S1.J10    169.077
S1.J11    259.33
S1.J12    128.02
S1.J13    134.02
S1.J14    139.62
S1.J15    615.79
S1.J16    412.096
S1.J17    222.36
S1.J18    416.1
S1.J19    220.35
*S1.J20    0.
S1.J20    307.923
S1.J21    221.267
S1.J22    254.14
S1.J23    967.3
*S1.J24
/
BIF(Z,I,J)  ALLOW MORE THAN ONE EXCHANGER IN EACH ZONE
/
Z1.I1.J1     0
*Z1.(I1*I24).(J1*J7)    0
/
SPH(I)  ALLOW SPLITTING FOR HOT STREAMS (SH in paper)
/
I1      0
I2      0
I3      0
I4      0
I5      0
I6      0
I7      0
I8      0
I9      0
I10     0
I11     0
I12     0
I13     0
I14     0
I15     0
I16     0
```

I17 0
I18 0
I19 0
I20 0
I21 0
I22 0
I23 0
I24 0
/
SPC(J) ALLOW SPLITTING FOR COLD STREAMS (SC in paper)
/
J1 0
J2 0
J3 0
J4 0
J5 0
J6 0
J7 0
J8 0
J9 0
J10 0
J11 0
J12 0
J3 0
J14 0
J15 0
J16 0
J17 0
J18 0
J19 0
J20 0
J21 0
J22 0
J23 0
J24 0
/
NIH(I) NON ISOTHERMAL MIXING FOR HOT STREAMS
/
I1 0
I1 0
I2 0
I3 0
I4 0
I5 0
I6 0
I7 0

I8 0
I9 0
I10 0
I11 0
I12 0
I13 0
I14 0
I15 0
I16 0
I17 0
I18 0
I19 0
I20 0
I21 0
I22 0
I23 0
I24 0
/
NIC(J) NON ISOTHERMAL MIXING FOR COLD STREAMS
/
J1 0
J2 0
J3 0
J4 0
J5 0
J6 0
J7 0
J8 0
J9 0
J10 0
J11 0
J12 0
J3 0
J14 0
J15 0
J16 0
J17 0
J18 0
J19 0
J20 0
J21 0
J22 0
J23 0
J24 0
/
DTVIO(I,J) SET TO ZERO IF TEMPERATURE FEASIBILITY CHECKING IS NOT NEEDED

```
* THAT IS, WHEN STREAM TEMPERATURES DO NOT OVERLAP.
/
I1.(J1*J24)  1
I2.(J1*J24)  1
I3.(J1*J24)  1
I4.(J1*J24)  1
I5.(J1*J24)  1
I6.(J1*J24)  1
I7.(J1*J24)  1
I8.(J1*J24)  1
I9.(J1*J24)  1
I10.(J1*J24) 1
I11.(J1*J24) 1
I12.(J1*J24) 1
I13.(J1*J24) 1
I14.(J1*J24) 1
I15.(J1*J24) 1
I16.(J1*J24) 1
I17.(J1*J24) 1
I18.(J1*J24) 1
I19.(J1*J24) 1
I20.(J1*J24) 1
I21.(J1*J24) 1
I22.(J1*J24) 1
I23.(J1*J24) 1
I24.(J1*J23)     1
*I24.J7      1
/
KMAX(Z,I,J) MAXIMUM NUMBER OF EXCHANGERS PER MATCH WHEN ALLOWED (BIF=1)
/
Z1.I1.J1        1
*Z1.(I1*I24).(J1*J24)    1
/
DTHU(I)    TEMPERATURE CHANGE OF HOT UTILITY
/
I24     20
/
DTCU(J)    TEMPERATURE CHANGE OF COLD UTILITY
/
J24     15
/
FMAX_HU(I)  MAXIMUM FLOW OF HOT UTILITY
/
I24    3000
/
FMAX_CU(J)  MAXIMUM FLOW OF COLD UTILITY
```

```
/
J24  1000
/
CHU(I)  COST OF HOT UTILITY (PER UNIT FLOW)
/
I24     71.1
/
CCU(J) COST OF COLD UTILITY (PER UNIT FLOW)
/
J24      6.7
/
CFU FIXED COST PER SHELL
/1/
CFE FIXED COST PER EXCHANGER
/0/
CAE COST PER UNIT AREA
/1/

QLHMIN   MINIMUM HEAT THAT CAN BE TRANSFERRED IN EACH HOT STREAM INTERVAL
/0.00/

QLCMIN MINIMUM HEAT THAT CAN BE TRANSFERRED IN EACH COLD STREAM INTERVAL
/0.00/

AMAX  MAXIMUM AREA PER EXCHANGER
/20000/

ASHELLMAX  MAXIMUM AREA PER SHELL
/5000/

USHELLMAX  MAXIMUM NUMBER OF SHELL  PER EXCHANGER
/2/

TOTNEXCHMAX  MAXIMUM NUMBER OF EXCHANGERS IN THE NETWORK (ALL ZONES)
/900/

TOTNEXCHMIN  MINIMUM NUMBER OF EXCHANGERS IN THE NETWORK (ALL ZONES)
/0/

DTMIN  MINUMUM APPROACH TEMPERATURE IN ALL MATCHES (HRAT)
/0/

*-------------------------------------------------------------------------
OPT DEFINES WHICH EQUATIONS RUN OPT=0 GRASSROOTS OPT=1 RETROFIT OPT=2 RELOCATION
/0/
```

```
****************************** ADD FOR RETROFIT ********************************

AEX(Z,I,J) AREA OF EXISTING HEAT EXCHANGERS
/
Z1.I1.J2  48.4

/
AEX_B(K,Z,I,J)  AREA OF EXISTING HEAT EXCHANGERS (BIF=1)
/
K1.Z1.I1.J2  48.4

/
NHE0(S,Z,I,J)  NUMBER OF EXISTING HEAT EXCHANGERS
/
S1.Z1.I1.J2 1

/
USHELL0(Z,I,J)
/
Z1.I1.J2 1

/
USHELL0_B(K,Z,I,J)
/
K1.Z1.I1.J2 1

/
NHE_ADD(Z,I,J)
/
Z1.I1.J1  1

/
D_AEX_MAX(Z,I,J)  MAXIMUM AREA TO ADD TO EXCHANGERS
/
Z1.I1.J2  4.84
/
D_AEX_MAX_B(K,Z,I,J)  MAXIMUM AREA TO ADD TO EXCHANGERS (BIF=1)
/
K1.Z1.I1.J2  4.84
/

CAE_ADD   COST OF AREA ADDED
/77.788/

CFAE_ADD   FIXED COST OF AREA ADDED
```

```
/7./

CAE_RED   COST OF AREA reduction
/10./

CFAE_RED   FIXED COST OF AREA reduction
/7./
NOTALLOW_H_ORD(Z,I,J,JJ)
/
Z1.I1.J1.J2 0
/
NOTALLOW_C_ORD(Z,J,I,II)
/
Z1.J1.I1.I2 0
/;

SCALARS Si, Zi, Mi, Ic, Ji

* WE FIRST CALCULATE THE STARTING INTERVALS FOR EACH STREAM FOR EACH
* SCENARIO IN EACH ZONE: IHminZ(S,Z,I)

PARAMETERS IHminZ(S,Z,I),IHmaxZ(S,Z,I),IHmax(S,I),IHmin(S,I),
        HOT(S,I,M), HOT2(S,M), HOTZ(S,Z,I,M),ICminZ(S,Z,J),ICmaxZ(S,Z,J),
        ICmin(S,J),ICmax(S,J),COLD(S,J,M),COLD2(S,M), COLDZ(S,Z,J,M),
        H_I(S,I,M), H_J(S,J,M)

* WE FIRST CALCULATE THE STARTING INTERVALS FOR EACH STREAM FOR EACH
* SCENARIO IN EACH ZONE: IHminZ(S,Z,I)
```

```
FOR(Si=1 TO CARD(S),
  FOR(Zi=1 TO CARD(Z),
    FOR(Ic=1 TO CARD(I),
      IHminZ(S,Z,I)$[ORD(S)=Si AND ORD(I)=1 AND ORD(Z)=1]=
                                  0+ 1$[NIZ(S,Z,I)>=1];
      IHminZ(S,Z,I)$[ORD(S)=Si AND ORD(I)>1 AND ORD(Z)=1]=
       0+ {SUM((ZZ,II)$[ORD(II)<ORD(I)],NIZ(S,ZZ,II))+1}$[NIZ(S,Z,I)>=1];
      IHminZ(S,Z,I)$[ORD(S)=Si AND ORD(Z)>1]=
       0+ {SUM((ZZ,II)$[ORD(II)<ORD(I)],NIZ(S,ZZ,II))+
          SUM(ZZ$[ORD(ZZ)< Zi],NIZ(S,ZZ,I))+1}$[NIZ(S,Z,I)>=1];
      IHmaxZ(S,Z,I)$[ORD(S)=Si AND ORD(I)=Ic AND ORD(Z)=Zi]=
       0+ {IHminZ(S,Z,I)+NIZ(S,Z,I)-1}$[NIZ(S,Z,I)>=1];
      IHmin(S,I)$[ORD(S)=Si AND ORD(I)=Ic]=
        SUM[Z$(SUM(ZZ$[ORD(ZZ)<=ORD(Z)-1],NIZ(S,ZZ,I))=0},IHminZ(S,Z,I)];
      IHmax(S,I)$[ORD(S)=Si AND ORD(I)=Ic]=
        SUM[Z$(SUM(ZZ$[ORD(ZZ)>=ORD(Z)+1],NIZ(S,ZZ,I))=0},IHmaxZ(S,Z,I)];

      FOR(Mi=1 TO CARD(M),
        HOT(S,I,M)$[ORD(S)=Si AND ORD(I)=Ic AND ORD(M)=Mi]=
              0+ 1$[ORD(M)>= IHmin(S,I) AND ORD(M)<=IHmax(S,I)];
        HOT2(S,M)$[ORD(S)=Si AND ORD(M)=Mi]=
              0+ 1$[ORD(M)<= SUM(I$(ORD(I)=CARD(I)),IHmax(S,I))];
        HOTZ(S,Z,I,M)$[ORD(S)=Si AND ORD(I)=Ic AND ORD(M)=Mi
                                  AND ORD(Z)=Zi]=
            0+ 1$[ORD(M)>= IHminZ(S,Z,I) AND ORD(M)<=IHmaxZ(S,Z,I)];
        H_I(S,I,M)$[ORD(S)=Si AND ORD(I)=Ic AND ORD(M)=Mi
                          AND HOT(S,I,M)=1] = HI(S,I) ;
      ));
    FOR(Ji=1 TO CARD(J),
      ICminZ(S,Z,J)$[ORD(S)=Si AND ORD(J)=1AND ORD(Z)=1]=
        0+ {SUM(I$[ORD(I)=CARD(I)],IHmax(S,I))+1}$[NJZ(S,Z,J)>=1];
      ICminZ(S,Z,J)$[ORD(S)=Si AND ORD(J)>1AND ORD(Z)=1]=
        0+ {SUM{I$[ORD(I)=CARD(I)],IHmax(S,I)}
         +SUM((ZZ,JJ)$[ORD(JJ)<ORD(J)],NJZ(S,ZZ,JJ))+1}$[NJZ(S,Z,J)>=1];
      ICminZ(S,Z,J)$[ORD(S)=Si AND ORD(Z)>1]=
        0+ {SUM{I$[ORD(I)=CARD(I)],IHmax(S,I)}
         + SUM((ZZ,JJ)$[ORD(JJ)<ORD(J)],NJZ(S,ZZ,JJ))
         + SUM(ZZ$[ORD(ZZ)< Zi],NJZ(S,ZZ,J))+1}$[NJZ(S,Z,J)>=1];
      ICmaxZ(S,Z,J)$[ORD(S)=Si AND ORD(J)=Ji AND ORD(Z)=Zi]=
        0+ {ICminZ(S,Z,J)+NJZ(S,Z,J)-1}$[NJZ(S,Z,J)>=1];
      ICmin(S,J)$[ORD(S)=Si AND ORD(J)=Ji]=
        SUM[Z$(SUM(ZZ$[ORD(ZZ)<=ORD(Z)-1],NJZ(S,ZZ,J))=0},ICminZ(S,Z,J)];
      ICmax(S,J)$[ORD(S)=Si AND ORD(J)=Ji]=
        SUM[Z$(SUM(ZZ$[ORD(ZZ)>=ORD(Z)+1],NJZ(S,ZZ,J))=0},ICmaxZ(S,Z,J)];
```

```
        FOR(Mi=1 TO CARD(M),
          COLD(S,J,M)$[ORD(S)=Si AND ORD(J)=Ji AND ORD(M)=Mi]=
              0+ 1$[ORD(M)>= ICmin(S,J) AND ORD(M)<=ICmax(S,J)];
          COLD2(S,M)$[ORD(S)=Si AND ORD(M)=Mi]=
              0+ 1$[ORD(M)>SUM(I$(ORD(I)=CARD(I)),IHmax(S,I))
                    AND ORD(M)<= SUM(J$(ORD(J)=CARD(J)),ICmax(S,J))];
          COLDZ(S,Z,J,M)$[ORD(S)=Si AND ORD(J)=Ji AND ORD(M)=Mi
              AND ORD(Z)=Zi]= 0+ 1$[ORD(M)>= ICminZ(S,Z,J)
                                    AND ORD(M)<=ICmaxZ(S,Z,J)];
          H_J(S,J,M)$[ORD(S)=Si AND ORD(J)=Ji AND ORD(M)=Mi
                                    AND COLD(S,J,M)=1] = HJ(S,J) ;
  ));

PARAMETERS DT(S,M),TU(S,M),TL(S,M),CPH(S,I,M),CPC(S,J,M),DHH(S,I,M),DHC(S,J,M) ;

*WE ALWAYS DEFINE Cp AS 1; USER IS TOLD TO ENTER F*Cp

 CPH(S,I,M)$[HOT(S,I,M)=1] = 1;
 CPC(S,J,M)$[COLD(S,J,M)=1] = 1;

DT(S,M) = SUM((Z,I)$[HOTZ(S,Z,I,M)=1],
            {[TIHZ(S,Z,I)-TOHZ(S,Z,I)]/[IHmaxZ(S,Z,I)-IHminZ(S,Z,I)+1]})
                                    $[HOT2(S,M)=1]+
       SUM((Z,J)$[COLDZ(S,Z,J,M)=1],
            {[TOCZ(S,Z,J)-TICZ(S,Z,J)]/[ICmaxZ(S,Z,J)-ICminZ(S,Z,J)+1]})
                                    $[COLD2(S,M)=1];
* Here, we shift TU for cold streams. Change introduced in 2007

FOR(Si= 1 TO CARD(S),
   FOR (Mi=1 TO CARD(M),
      TU(S,M)$[ORD(S)=Si AND ORD(M)=Mi]=
            {SUM((Z,I)$[HOTZ(S,Z,I,M)=1 AND ORD(M)=
                 IHminZ(S,Z,I)],TIHZ(S,Z,I)$[ORD(M)=IHminZ(S,Z,I)])
            + SUM((Z,I)$[HOTZ(S,Z,I,M)=1 AND ORD(M)>IHminZ(S,Z,I)
                                AND ORD(M)<=IHmaxZ(S,Z,I)],
                [TIHZ(S,Z,I)-(ORD(M)-IHminZ(S,Z,I))*DT(S,M)]
                    $[ORD(M)>IHminZ(S,Z,I) AND ORD(M)<=
                        IHmaxZ(S,Z,I)])}$[HOT2(S,M)=1]
            +{SUM((Z,J)$[COLDZ(S,Z,J,M)=1 AND ORD(M)=ICminZ(S,Z,J)],
                  (TOCZ(S,Z,J)+DTMIN)$[ORD(M)=ICminZ(S,Z,J)])
            + SUM((Z,J)$[COLDZ(S,Z,J,M)=1 AND ORD(M)>ICminZ(S,Z,J)
                                AND ORD(M)<=ICmaxZ(S,Z,J)],
                [TOCZ(S,Z,J)-(ORD(M)-ICminZ(S,Z,J))*DT(S,M)
                                    +DTMIN ]
                    $[ORD(M)>ICminZ(S,Z,J) AND ORD(M)<=
                        ICmaxZ(S,Z,J)])}$[COLD2(S,M)=1];
```

```
TL(S,M)$[ORD(S)=Si AND ORD(M)=Mi]=
    {SUM((Z,I)$[HOTZ(S,Z,I,M)=1 AND ORD(M)=
        IHmaxZ(S,Z,I)],TOHZ(S,Z,I)$[ORD(M)=IHmaxZ(S,Z,I)])
    + SUM((Z,I)$[HOTZ(S,Z,I,M)=1 AND ORD(M)<IHmaxZ(S,Z,I)
                AND ORD(M)>=IHminZ(S,Z,I)],
        [TOHZ(S,Z,I)+(IHmaxZ(S,Z,I)-ORD(M))*DT(S,M)]
            $[ORD(M)<IHmaxZ(S,Z,I)AND ORD(M)>=
                IHminZ(S,Z,I)])}$[HOT2(S,M)=1]
    +{SUM((Z,J)$[COLDZ(S,Z,J,M)=1 AND ORD(M)=ICmaxZ(S,Z,J)],
            (TICZ(S,Z,J)+DTMIN)$[ORD(M)=ICmaxZ(S,Z,J)])
    + SUM((Z,J)$[COLDZ(S,Z,J,M)=1 AND ORD(M)<ICmaxZ(S,Z,J)
                AND ORD(M)>=ICminZ(S,Z,J)],
            [TICZ(S,Z,J)+(ICmaxZ(S,Z,J)-ORD(M))*DT(S,M)
                +DTMIN ]
            $[ORD(M)<ICmaxZ(S,Z,J)AND ORD(M)>=
                ICminZ(S,Z,J)])}$[COLD2(S,M)=1];

FOR(Ic=1 TO CARD(I),
    DHH(S,I,M)$[ORD(S)=Si AND ORD(M)=Mi AND ORD(I)=Ic
                AND HOT(S,I,M)=1]=
            FH(S,I)*CPH(S,I,M)*[TU(S,M)-TL(S,M)] ;
    );
  FOR(Ji=1 TO CARD(J),
    DHC(S,J,M)$[ORD(S)=Si AND ORD(M)=Mi AND ORD(J)=Ji
                AND COLD(S,J,M)=1]=
            FC(S,J)*CPC(S,J,M)*[TU(S,M)-TL(S,M)] ;
    )));


PARAMETER HHEAD(S,M,N),CHEAD(S,M,N),LMTD(S,M,N),D(S,Z,M,N),
    ALLOW(S,Z,I,J), ALLOW_H(S,Z,I,M,J),ALLOW_C(S,Z,J,M,I), ALLOW_2(Z,I,J);

*D(S,Z,M,N)=1 MATCH BETWEEN INTERVALS M AND N ALLOWED BASED ON LMTD
* The temperature differences in each interval are calculated for the nonshifted
* cold streams, that is using  TU(S,N)-DTMIN, because TU is shifted.

HHEAD(S,M,N) = {TU(S,M)-TU(S,N) + DTmin }$[HOT2(S,M) AND COLD2(S,N)];
CHEAD(S,M,N) = {TL(S,M)-TL(S,N) + DTmin}$[HOT2(S,M) AND COLD2(S,N)];

* the addition of 0.000000000001, helps sort out the case of
*  HHEAD(S,M,N)=CHEAD(S,M,N). Indeed, there is no qualifier for the equal case.
* Thus, (HHEAD(S,M,N)> CHEAD(S,M,N)+0.000000000001
*      OR HHEAD(S,M,N)< CHEAD(S,M,N)-0.000000000001)  identifies when they
* are different. Notice that the presence of the "OR".
* When they are close we use
* HHEAD(S,M,N)< CHEAD(S,M,N)+0.000000000001 AND HHEAD(S,M,N)>
```

```
*            CHEAD(S,M,N)-0.000000000001]
* we require both to hold, so that only the = case will be identified.

LMTD(S,M,N)= {[HHEAD(S,M,N)-CHEAD(S,M,N)]/LOG[HHEAD(S,M,N)/CHEAD(S,M,N)]}
      $[HHEAD(S,M,N)> 0 AND CHEAD(S,M,N)>0
        AND (HHEAD(S,M,N)> CHEAD(S,M,N)+0.000000000001
        OR HHEAD(S,M,N)< CHEAD(S,M,N)-0.000000000001 )]
      + {[HHEAD(S,M,N)+CHEAD(S,M,N)]/2}$[HHEAD(S,M,N)>0 AND CHEAD(S,M,N)>0
        AND HHEAD(S,M,N)< CHEAD(S,M,N)+0.000000000001 AND HHEAD(S,M,N)>
        CHEAD(S,M,N)-0.000000000001];

D(S,Z,M,N)= 1$[  {HOT2(S,M)=1 AND HOT2(S,N)=1 AND SUM[I$(HOT(S,I,M)=1
        AND HOT(S,I,N)=1),HOTZ(S,Z,I,M)]=1 AND SUM[I$(HOT(S,I,N)=1
        AND HOT(S,I,M)=1),HOTZ(S,Z,I,N)]=1}
      OR {COLD2(S,M)=1 AND COLD2(S,N)=1 AND SUM[J$(COLD(S,J,M)=1
        AND COLD(S,J,N)=1),COLDZ(S,Z,J,M)]=1 AND SUM[J$(COLD(S,J,N)=1
        AND COLD(S,J,M)=1),COLDZ(S,Z,J,N)]=1}
      OR {(HHEAD(S,M,N)>=0.0001 AND CHEAD(S,M,N)>=0.0001)
        AND SUM[I$(HOT(S,I,M)=1),HOTZ(S,Z,I,M)]=1
        AND SUM[J$(COLD(S,J,N)=1),COLDZ(S,Z,J,N)]=1}];

FOR(Si= 1 TO CARD(S),
  FOR(Zi=1 TO CARD(Z),
    FOR(Ic=1 TO CARD(I),
      FOR(Ji=1 TO CARD(J),
        ALLOW(S,Z,I,J)$[ORD(S)=Si AND ORD(Z)=Zi AND ORD(I)=Ic
              AND ORD(J)=Ji]= 0+ 1${SUM[(M,N)$[HOT(S,I,M)=1
              AND COLD(S,J,N)=1],D(S,Z,M,N)] >0
              AND NOT[HU(I) AND CU(J)]};
        FOR (Mi=1 TO CARD(M),
          ALLOW_H(S,Z,I,M,J)$[ORD(S)=Si AND ORD(Z)=Zi AND ORD(I)=Ic
                AND ORD(J)=Ji AND ORD(M)=Mi
                AND HOT(S,I,M)=1]=
            0+ 1${SUM[N$[COLD(S,J,N)=1],D(S,Z,M,N)] >0
                  AND NOT[HU(I)AND CU(J)]};
          ALLOW_C(S,Z,J,M,I)$[ORD(S)=Si AND ORD(Z)=Zi AND ORD(I)=Ic
                AND ORD(J)=Ji AND ORD(M)=Mi
                AND COLD(S,J,M)=1]=
            0+ 1${SUM[N$[HOT(S,I,N)=1],D(S,Z,N,M)] >0
                  AND NOT[HU(I)AND CU(J)]};
          )))));
FOR(Zi=1 TO CARD(Z),
  FOR(Ic=1 TO CARD(I),
    FOR(Ji=1 TO CARD(J),
      ALLOW_2(Z,I,J)$[ORD(Z)=Zi AND ORD(I)=Ic AND ORD(J)=Ji]=
      0+ 1${SUM[S,ALLOW(S,Z,I,J)] >0 AND NOT[HU(I)AND CU(J)]};
```

)));

*---

VARIABLES

TCOST total cost
PAR(Z,I,J) area
Q(S,Z,I,M,J,N) heat load for process-process match
QNEW_M(S,Z,I,J,M) cumulative heat transfer from hot to cold stream q^ IN PAPER
QNEW_N(S,Z,I,J,N) cumulative heat transfer from cold to hot stream q^ IN PAPER

*Amount of heat transfered to the next heat exchanger
* (using the hot or the cold stream) THIS IS ACTIVATED WHEN BIF=1
QNEW2_M(S,Z,I,J,M)
QNEW2_N(S,Z,I,J,N)

*Variable that determines whether heat exchange takes place or not at
* that interval (BIF=0). BINARY
Y_M(S,Z,I,J,M)
Y_N(S,Z,I,J,N)
*Aariable that determines whether heat exchange takes place or not at
* that interval (BIF=1) POSITIVE VARIABLE
Y_M_B(S,Z,I,J,M)
Y_N_B(S,Z,I,J,N)

*Variable that indicates if a heat exchanger begins (BIF=0) POSITIVE
NHE_M0(S,Z,I,J,M) K IN PAPER
NHE_N0(S,Z,I,J,N)
*Variable that indicates if a heat exchanger begins (BIF=1) BINARY
NHE_M0_B(S,Z,I,J,M)
NHE_N0_B(S,Z,I,J,N)

*Variable that indicates if a heat exchanger ends (BIF=0) POSITIVE
NHE_M1(S,Z,I,J,M)
NHE_N1(S,Z,I,J,N)
*Variable that indicates if a heat exchanger ends (BIF=1) BINARY
NHE_M1_B(S,Z,I,J,M)
NHE_N1_B(S,Z,I,J,N)

* ALTHOUGH WE ARE BUILDING THIS FOR ONE SCENARIO ONLY, THE NUMBER OF EXCHANGERS
* USED IN DIFFERENT SCENARIOS MIGHT BE DIFFERENT, SO NHE IS SCENARIO DEPENDENT
* MORE SCENARIOS SHOULD NOT BE USED.

```
NHE(S,Z,I,J)   number of heat exchangers between hot stream i and cold stream j



*variable that distinguish wheter an interval is extreme (the first or
*         last interval of the exchanger) or not
ALFA_M(S,Z,I,J,M)
ALFA_N(S,Z,I,J,N)



FHU(I)         HOT UTILITY USAGE FCP (MJ_h_C)
FCU(J)         COLD UTILITY FCP (MJ_h_C)
B1(S,Z,I,M,J,N)  X(imjn) in the paper



*non-isothermal mixing of stream splits
QH(S,Z,I,M,N)    heat flow between intervals of the same hot stream
QC(S,Z,J,M,N)    heat flow between intervals of the same cold stream

$ONTEXT
* THESE HAS BEEN REMOVED FROM THE MODEL.
* CORRESPONDS TO AREA COUNTING FOR BIF=1,
* WHICH DOES NOT WORK EVEN WITHOUT THESE CONSTRAINTS

*Auxiliary variable utilized to compute the area of individual heat exchangers
Q2(S,Z,I,M,J,N)
X1_B(S,Z,I,J,M)  G(ijm) in the paper  (see equation (97)
*X_B(S,K,Z,I,J,M)


$OFFTEXT
PAR_B(K,Z,I,J)   used in bif=1
USHELL(Z,I,J)    number of shells in the heat exchanger
USHELL_B(K,Z,I,J) number of shells in the kth heat exchanger


*******************************NEW VARIABLES FOR FOR RETROFIT*********************

PAR_N(S,Z,I,J)
PAR_N_B(K,Z,I,J)
DPAR_E(Z,I,J)
DPAR_E_B(K,Z,I,J)
DELTA(Z,I,J,K,K)
DELTAPSIA(Z,I,J,KK,K)
```

```
PSIA(Z,I,J,K)
PHI(Z,I,J,K)
T(Z,I,J)    INDICATES THAT THERE IS ARE ADDITION TO EXISTING EXCHANGERS
T_B(K,Z,I,J) INDICATES THAT THERE IS ARE ADDITION TO EXISTING EXCHANGERS(BIF=1)
T2(Z,I,J)   INDICATES THAT THERE IS ARE REDUCTION
T2_B(Z,I,J)  INDICATES THAT THERE IS ARE REDUCTION (BIF=1)

POSITIVE VARIABLE Q,QNEW2_M,QNEW2_N,QC,QH,Q2,PAR,QNEW_M,QNEW_N , Y_M_B, Y_N_B
          ,NHE_M0,NHE_M1,NHE_N0,NHE_N1,ALFA_M,ALFA_N,NHE

BINARY VARIABLE NHE_M0_B, NHE_M1_B,NHE_N0_B,NHE_N1_B,Y_M,Y_N
*                          ,X1_B   USED IN EQUATIONS (97-102)

INTEGER VARIABLE USHELL,USHELL_B

*****************************NEW VARIABLES FOR FOR RETROFIT*******************

POSITIVE VARIABLE  PAR_N, PAR_N_B, DPAR_E, DPAR_E_B

BINARY VARIABLE PHI,T,T_B, T2, T2_B, DELTA, PSIA
*-------------------------------------------------------------------------------


*-------------------------------------------------------------------------------

EQUATIONS
HBHU(S,I,M)
HBCU(S,J,N)
HBHS(S,I,M)
HBCS(S,J,N)
TRANSFOR_M(S,Z,I,J,M)
TRANSFOR_N(S,Z,I,J,N)
HBHS_NI(S,I,M)
HBCS_NI(S,J,N)
NOISOH(S,I,M)
NOISOC(S,J,N)
BINARY_M1(S,Z,I,J,M)
BINARY_M2(S,Z,I,J,M)
BINARY_M1_B(S,Z,I,J,M)
BINARY_M2_B(S,Z,I,J,M)
BINARY_N1(S,Z,I,J,N)
BINARY_N2(S,Z,I,J,N)
BINARY_N1_B(S,Z,I,J,N)
BINARY_N2_B(S,Z,I,J,N)
BINARY_M5(S,Z,I,J,M)
BINARY_M5b(S,Z,I,J,M)
```

BINARY_M3(S,Z,I,J,M)
*BINARY_M4(S,Z,I,J,M)
BINARY_M8(S,Z,I,J,M)
BINARY_M9(S,Z,I,J,M)
BINARY_M6(S,Z,I,J,M)
*BINARY_M7(S,Z,I,J,M)
BINARY_M3_B(S,Z,I,J,M)
*BINARY_N4(S,Z,I,J,N)
BINARY_N5(S,Z,I,J,N)
BINARY_N5b(S,Z,I,J,N)
BINARY_N3(S,Z,I,J,N)
*BINARY_N4(S,Z,I,J,N)
BINARY_N8(S,Z,I,J,N)
BINARY_N9(S,Z,I,J,N)
BINARY_N6(S,Z,I,J,N)
*BINARY_N7(S,Z,I,J,N)
BINARY_N3_B(S,Z,I,J,N)
HE_COUNT_M0(S,Z,I,J)
HE_COUNT_M0_B(S,Z,I,J)
HE_COUNT_N0(S,Z,I,J)
HE_COUNT_N0_B(S,Z,I,J)
HE_COUNT_M1(S,Z,I,J)
HE_COUNT_M1_B(S,Z,I,J)
HE_COUNT_N1(S,Z,I,J)
HE_COUNT_N1_B(S,Z,I,J)
NEXCH(S,Z,I,J)
NEXCH_B(S,Z,I,J)

BIF_3(S,Z,I,J,M,N)
BIF_4(S,Z,I,J,M,N)
BIF_11(S,Z,I,J,M)
BIF_12(S,Z,I,J,N)
BIF_6(S,Z,I,J,M)
BIF_9(S,Z,I,J,M)
BIF_5(S,Z,I,J,M)
BIF_8(S,Z,I,J,N)
BIF_10(S,Z,I,J,N)
BIF_7(S,Z,I,J,N)
BIF_1(S,Z,I,J,M,N)
BIF_2(S,Z,I,J,M,N)

FEAS_M_01(S,Z,I,J,M)
FEAS_M_01_B(S,Z,I,J,M)
FEAS_M_02(S,Z,I,J,M)
FEAS_M_02_B(S,Z,I,J,M)
FEAS_M_03(S,Z,I,J,M)

FEAS_M_03_B(S,Z,I,J,M)
*FEAS_M_04(S,Z,I,J,M)
FEAS_M_2(S,Z,I,J,M)
FEAS_M_1(S,Z,I,J,M)
FEAS_M_3(S,Z,I,J,M)
FEAS_M_4(S,Z,I,J,M)
FEAS_M_3_B_2(S,Z,I,J,M)
FEAS_M_3_B_1(S,Z,I,J,M)
FEAS_M_4_B(S,Z,I,J,M)
FEAS_M_1_SP(S,Z,I,J,M)
FEAS_M_1_SP_B(S,Z,I,J,M)
FEAS_N_01(S,Z,I,J,N)
FEAS_N_01_B(S,Z,I,J,N)
FEAS_N_02(S,Z,I,J,N)
FEAS_N_02_B(S,Z,I,J,N)
FEAS_N_03(S,Z,I,J,N)
FEAS_N_03_B(S,Z,I,J,N)
*FEAS_N_04(S,Z,I,J,N)
FEAS_N_2(S,Z,I,J,N)
FEAS_N_1(S,Z,I,J,N)
FEAS_N_3(S,Z,I,J,N)
FEAS_N_4(S,Z,I,J,N)
FEAS_N_3_B_2(S,Z,I,J,N)
FEAS_N_3_B_1(S,Z,I,J,N)
FEAS_N_4_B(S,Z,I,J,N)
FEAS_N_1_SP(S,Z,I,J,N)
FEAS_N_1_SP_B(S,Z,I,J,N)
FEAS_BEG_SP(S,Z,I,J,M,N)
FEAS_BEG_B_SP(S,Z,I,J,M,N)
FEAS_END_SP(S,Z,I,J,M,N)
FEAS_END_B_SP(S,Z,I,J,M,N)
FEAS_BEG3(S,Z,I,J,M,N)
FEAS_BEG(S,Z,I,J,M,N)
FEAS_BEG2(S,Z,I,J,M,N)
FEAS_END3(S,Z,I,J,M,N)
FEAS_END(S,Z,I,J,M,N)
FEAS_END2(S,Z,I,J,M,N)
FEAS_BEG4_B(S,Z,I,J,M,N)
FEAS_BEG2_B(S,Z,I,J,M,N)
FEAS_BEG1_B(S,Z,I,J,M,N)
FEAS_BEG3_B(S,Z,I,J,M,N)
FEAS_END3_B(S,Z,I,J,M,N)
FEAS_END_B(S,Z,I,J,M,N)
FEAS_END2_B(S,Z,I,J,M,N)
PAREQ(S,Z,I,J)
*BIF_13_2(S,K,Z,I,J)

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*BIF_13_2(S,K,Z,I,J,M)
*BIF_13_1(S,K,Z,I,J)
*BIF_13_1(S,K,Z,I,J,M)
*BIF_14(S,K,Z,I,J)
*BIF_15(S,Z,I,J,M)
*BIF_16(S,Z,I,J,M)
*BIF_17(S,Z,I,J,M)
*BIF_18(S,Z,I,J,M,N)
SHELL(Z,I,J)
SHELL_B(K,Z,I,J)

TOTALCOST
* EXTRA EQUATIONS NOT IN PAPER
KMAX1(S,Z,I,J)
KMAX2(S,Z,I,J)
UMAX1(S,Z,I,J)    MAXIMUM NUMBER OF SHELLS
UMAX2(S,K,Z,I,J)
TOTNEXCH_MAX      MAXIMUM NUMBER OF EXCHANGERS
TOTNEXCH_MIN

**********ADD FOR RETROFIT**********
AREA_REST1(S,Z,I,J)
AREA_REST2(S,Z,I,J)
AREA_REST3(S,Z,I,J)
AREA_REST4(S,Z,I,J)
$ONTEXT
* BIF=1 DOES NOT WORK WELL
AREA_REST1_B(S,K,Z,I,J)
AREA_REST2_B(S,K,Z,I,J)
AREA_REST2_B1(S,K,KK,Z,I,J)
AREA_REST2_B2(S,K,KK,Z,I,J)
AREA_REST2_B3(S,K,KK,Z,I,J)
AREA_REST3_B(S,K,Z,I,J)
AREA_REST4_B(S,K,Z,I,J)
AREA_REST5_B(S,K,Z,I,J)
AREA_REST6_B(S,Z,I,J)
$OFFTEXT
ADD_REST7(S,Z,I,J)
ADD_REST8(S,Z,I,M,J,JJ)
ADD_REST9(S,Z,J,N,I,II) ;

*-------------------------------------------------------------------
*EQ (1)
HBHU(S,I,M)$(HOT(S,I,M)=1 AND HU(I) AND FREEH(I))..
* THE SUMMATION IS DONE OVER DIFFERENT ZONES (Z), WHEREAS IT IS NOT SUPPOSED TO
* BE LIKE THAT. THE PAPER SHOWS THIS EQUATION WRITTNE FOR EVERY ZONE.
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* HOWEVER, IT TURNS OUT THAT EVERY PAIR OF INTERVALS BELONGS TO ONLY ONE ZONE
* AND, IN ADDITION, D(S,Z,M,N) WILL NOT ALLOW HEAT EXCHANGE ACROSS ZONES.
* THUS, ONE CAN LEAVE THE SUMMATION- IT WOULD BE CLEAR IF IT THE EQUATION IS
* CONVERTED TO WHAT IT SHOULD BE.                    WE NEED TO FIX THIS
* THE SAME IS SAID FOR EQUATIONS (2) (3), (4), (7) AND (8)
* IN ADDITION, THERE ARE SOME REDUNDANCIES THAT CAN BE REMOVED. INDEED, WHEN
* D(S,Z,M,N)=1 IT IS BECAUSE HOT(S,I,M)=1 AND COLD(S,J,N)=1. THUS, ONE CAN
* REMOVE COLD(S,J,N). wE ALSO NEED TO TAKE A LOOK ABOVE AND SEE IF THE PARAMETER
* ALLOW IS NOT REDUNDANT AS WELL.                    WE NEED TO CHECK AND EVENTUALLY
FIX THIS
 FHU(I)*(TU(S,M)-TL(S,M)) =E=
       SUM((Z,N,J)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND COLD(S,J,N)=1
       AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1
                              AND FREEC(J)),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------
*EQ (2)
HBCU(S,J,N)$(COLD(S,J,N)=1 AND CU(J) AND FREEC(J))..
 FCU(J)*(TU(S,N)-TL(S,N)) =E=
       SUM((Z,M,I)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
       AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1
                              AND FREEH(I)),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------
*EQ (3)
HBHS(S,I,M)$(HOT(S,I,M)=1 AND NOT HU(I) AND FREEH(I) AND NIH(I)=0)..
 DHH(S,I,M)=E=SUM((Z,N,J)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND COLD(S,J,N)=1
        AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------
*EQ (4)
HBCS(S,J,N)$(COLD(S,J,N)=1 AND NOT CU(J) AND FREEC(J) AND NIC(J)=0)..
 DHC(S,J,N)=E=SUM((Z,M,I)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
        AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------
*EQ (5)
TRANSFOR_M(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND FREEH(I)
              AND FREEC(J))..
 QNEW_M(S,Z,I,J,M) =E=
           SUM(N$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND COLD(S,J,N)=1
              AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------
*EQ (6)
TRANSFOR_N(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND FREEH(I)
              AND FREEC(J))..
 QNEW_N(S,Z,I,J,N)=E=SUM(M$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
              AND ALLOW_H(S,Z,I,M,J)=1),Q(S,Z,I,M,J,N));

*-------------------------------------------------------------------------
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*EQ (7)
HBHS_NI(S,I,M)$(HOT(S,I,M)=1 AND NOT HU(I) AND FREEH(I) AND NIH(I)=1)..
 DHH(S,I,M)=E=
     SUM((Z,N,J)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND COLD(S,J,N)=1
         AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N))
   + SUM((Z,N)$(D(S,Z,M,N)=1 AND HOT(S,I,N)=1 AND ORD(N) GT ORD(M)),
                                        QH(S,Z,I,N,M))
   - SUM((Z,N)$(D(S,Z,M,N)=1 AND HOT(S,I,N)=1 AND ORD(N) LT ORD(M)),
                                        QH(S,Z,I,M,N));
*-------------------------------------------------------------------------------
*EQ (8)
HBCS_NI(S,J,N)$(COLD(S,J,N)=1 AND NOT CU(J) AND FREEC(J) AND NIC(J)=1)..
 DHC(S,J,N)=E=
     SUM((Z,M,I)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
         AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N))
   + SUM((Z,M)$(D(S,Z,M,N)=1 AND COLD(S,J,M)=1 AND ORD(M) LT ORD(N)),
                                        QC(S,Z,J,M,N))
   - SUM((Z,M)$(D(S,Z,M,N)=1 AND COLD(S,J,M)=1 AND ORD(M) GT ORD(N)),
                                        QC(S,Z,J,N,M));
*-------------------------------------------------------------------------------
*EQ (9)
NOISOH(S,I,M)$(HOT(S,I,M)=1 AND NOT HU(I) AND FREEH(I) AND NIH(I)=1)..
SUM((Z,N)$(D(S,Z,M,N)=1 AND HOT(S,I,N)=1 AND ORD(N) LT ORD(M)),QH(S,Z,I,M,N))=L=
 SUM((Z,N,J)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND COLD(S,J,N)=1
     AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------------
*EQ (10)
NOISOC(S,J,N)$(COLD(S,J,N)=1 AND NOT CU(J) AND FREEC(J) AND NIC(J)=1)..
SUM((Z,M)$(D(S,Z,M,N)=1 AND COLD(S,J,M)=1 AND ORD(M)GT ORD(N)),QC(S,Z,J,N,M))=L=
   SUM((Z,M,I)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
     AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N));
*-------------------------------------------------------------------------------
*EQ (11a and 13a)  Case of BIF(I,J)=0   (i,j) not belonging to set B.

BINARY_M1(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=0
             AND FREEH(I) AND FREEC(J))..
QNEW_M(S,Z,I,J,M)-Y_M(S,Z,I,J,M)*DHH(S,I,M)$(NOT HU(I))
             -Y_M(S,Z,I,J,M)*FMAX_HU(I)*DTHU(I)$(HU(I))=L=0;
*-------------------------------------------------------------------------------
*EQ (11b and 13b)       Case of BIF(I,J)=0  (i,j) not belonging to set B
BINARY_M2(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=0
   AND FREEH(I) AND FREEC(J)).. QNEW_M(S,Z,I,J,M)-Y_M(S,Z,I,J,M)*QLHMIN=G=0;

*-------------------------------------------------------------------------------
*EQ (11a and 13a) Case of BIF(I,J)=1    (i,j) belonging to set B
BINARY_M1_B(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
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                    AND FREEH(I) AND FREEC(J) )..
QNEW_M(S,Z,I,J,M)-Y_M_B(S,Z,I,J,M)*DHH(S,I,M)$(NOT HU(I))
          -Y_M_B(S,Z,I,J,M)*FMAX_HU(I)*DTHU(I)$(HU(I))=L=0;
*-------------------------------------------------------------------------
*EQ (11b and 13b) Case of BIF(I,J)=1   (i,j) belonging to set B
 BINARY_M2_B(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J)).. QNEW_M(S,Z,I,J,M)-Y_M_B(S,Z,I,J,M)*QLHMIN =G= 0;
*-------------------------------------------------------------------------
*EQ (12a and 14a) Case of BIF(I,J)=0   (i,j) not belonging to set B

BINARY_N1(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0
                    AND FREEH(I) AND FREEC(J)).
 QNEW_N(S,Z,I,J,N)-Y_N(S,Z,I,J,N)*DHC(S,J,N)$(NOT CU(J))
          -Y_N(S,Z,I,J,N)*FMAX_CU(J)*DTCU(J)$(CU(J))=L=0;
*-------------------------------------------------------------------------
*EQ (12b and 14b) Case of BIF(I,J)=0   (i,j) not belonging to set B
 BINARY_N2(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0
 AND FREEH(I) AND FREEC(J)).. QNEW_N(S,Z,I,J,N)-Y_N(S,Z,I,J,N)*QLCMIN=G=0;
*-------------------------------------------------------------------------
*EQ (12a and 14a) Case of BIF(I,J)=1   (i,j)  belonging to set B
BINARY_N1_B(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J) )..
    QNEW_N(S,Z,I,J,N)-Y_N_B(S,Z,I,J,N)*DHC(S,J,N)$(NOT CU(J))
        -Y_N_B(S,Z,I,J,N)*FMAX_CU(J)*DTCU(J)$(CU(J))=L=0;
*-------------------------------------------------------------------------
*EQ (12b and 14b) Case of BIF(I,J)=1   (i,j)  belonging to set B
BINARY_N2_B(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J)).. QNEW_N(S,Z,I,J,N)-Y_N_B(S,Z,I,J,N)*QLCMIN=G=0;
*-------------------------------------------------------------------------
*EQ (15) NOT NEEDED
*           GAMS WRITES IT AUTOMATICALLY WHEN IT WRITES EQUATION (18)
*-------------------------------------------------------------------------
*EQ (16)
BINARY_M5(S,Z,I,J,M)$(HOT(S,I,M)=1 AND HOT(S,I,M-1) AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J)).
                NHE_M0(S,Z,I,J,M)=L=2-Y_M(S,Z,I,J,M)-Y_M(S,Z,I,J,M-1);
*-------------------------------------------------------------------------
*EQ (17) IS IN REALITY NOT NEEDED, BUT WAS ADDED TO ENFORCE K=0 WHEN Y=0
*AND HOT(S,I,M-1) AND ALLOW_H(S,Z,I,M-1,J) AND ALLOW_H(S,Z,I,M,J)=1
*AND ALLOW_H(S,Z,I,M,J)=1

BINARY_M5b(S,Z,I,J,M)$(HOT(S,I,M)=1AND ALLOW_H(S,Z,I,M,J)=1AND BIF(Z,I,J)=0
            AND FREEH(I) AND FREEC(J)).
                    NHE_M0(S,Z,I,J,M) =L= Y_M(S,Z,I,J,M);

*   IT TURNS OUT THAT THIS EQUATION ONLY FORCES THE VALUES OF K TO BE ZERO
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*    WHEN Y=0, WHICH HAPPENS NATURALLY IF ONE IS MINIMIZING THE NUMBER OF
*    EXCHANGERS OR BECAUSE THE FIXED COSTS ARE BEING MINIMIZED.
*    EVEN IF NOT DRIVEN TO ZERO BY THE OBJECTIVE FUNCTION IT IS HARMELESS.
* HOWEVER, IT TURNS OUT THAT IT COULD MAKE EXTENSIONS OF THE MODEL HAVE
* PROBLEMS. SO, ALTHOUGH THE EQUATION IS NOT NEEDED, IT GIVES SOME EXTRA VALUES
* OF K WHEN THEY DO NOT REALLY MATTER.
*-------------------------------------------------------------------------
*EQ (18)
BINARY_M3(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=0
 AND FREEH(I) AND FREEC(J))..
 NHE_M0(S,Z,I,J,M) =G= Y_M(S,Z,I,J,M)-Y_M(S,Z,I,J,M-1)$(HOT(S,I,M-1)
                                AND ALLOW_H(S,Z,I,M-1,J)) ;
*-------------------------------------------------------------------------
*EQ (19)
* NOT NEEDED. THE VARIABLE IS ALREADY DECLARED POSITIVE
*BINARY_M4(S,Z,I,J,M)$(HOT(S,I,M)=1 AND HOT(S,I,M-1) AND ALLOW_H(S,Z,I,M,J)=1
* AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
*                                NHE_M0(S,Z,I,J,M)=G=0;
*-------------------------------------------------------------------------
*EQ (20) NOT NEEDED
*          GAMS WRITES IT AUTOMATICALLY WHEN IT WRITES EQUATION (18)
*-------------------------------------------------------------------------
*EQ (21)
BINARY_M8(S,Z,I,J,M)$(HOT(S,I,M)=1 AND HOT(S,I,M+1) AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M+1,J) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
            NHE_M1(S,Z,I,J,M)=L=2-Y_M(S,Z,I,J,M)-Y_M(S,Z,I,J,M+1);
*-------------------------------------------------------------------------
*EQ (22) : ORIGINALLY NOT NEEDED, BUT ADDED TO ENFORCE K=0 WHEN Y=0
*       AND HOT(S,I,M-1) AND ALLOW_H(S,Z,I,M-1,J)
BINARY_M9(S,Z,I,J,M)$(HOT(S,I,M)=1AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=0
          AND FREEH(I)AND FREEC(J))..
                    NHE_M1(S,Z,I,J,M) =L= Y_M(S,Z,I,J,M) ;

* SEE COMMENTS ON EQUATION (17)

*-------------------------------------------------------------------------
*EQ (23)
BINARY_M6(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=0
AND FREEH(I) AND FREEC(J)).. NHE_M1(S,Z,I,J,M)=G=Y_M(S,Z,I,J,M)-Y_M(S,Z,I,J,M+1)
                    $(HOT(S,I,M+1) AND ALLOW_H(S,Z,I,M+1,J)) ;
*-------------------------------------------------------------------------
*EQ (24)
* NOT NEEDED. THE VARIABLE IS ALREADY DECLARED POSITIVE
*BINARY_M7(S,Z,I,J,M)$(HOT(S,I,M)=1 AND HOT(S,I,M+1) AND ALLOW_H(S,Z,I,M,J)=1
* AND ALLOW_H(S,Z,I,M+1,J) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
*                                NHE_M1(S,Z,I,J,M)=G=0;
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*-------------------------------------------------------------------------

*EQ (25)
BINARY_M3_B(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
Y_M_B(S,Z,I,J,M) =E= SUM(O$(HOT(S,I,O)=1 AND ORD(O) LE ORD(M)
                  AND ALLOW_H(S,Z,I,O,J)=1),NHE_M0_B(S,Z,I,J,O))
               -SUM(O$(HOT(S,I,O)=1 AND ORD(O) LE [ORD(M)-1]
                  AND ALLOW_H(S,Z,I,O,J)=1),NHE_M1_B(S,Z,I,J,O));
*-------------------------------------------------------------------------
*EQ (26)
* IT TURNS OUT THAT I THOUGH GAMS WOULD WRITE IT AUTOMATICALLY SOMEWHERE, BUT
* I WAS WRONG. HOWEVER, WHEN INTRODUCED, THIS EQUATION GIVES INFEASIBLE.
* THE EQUATION MIGHT NOT BE NEEDED AFTER ALL (SEE NOTE IN EQUATION (17) ABOVE    WE NEED TO
ADRESS THIS.
*BINARY_N4(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
* AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
*                  NHE_N0(S,Z,I,J,N)=G=Y_N(S,Z,I,J,N);
*-------------------------------------------------------------------------
*EQ (27)
BINARY_N5(S,Z,I,J,N)$(COLD(S,J,N)=1 AND COLD(S,J,N-1) AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
               NHE_N0(S,Z,I,J,N)=L=2-Y_N(S,Z,I,J,N)-Y_N(S,Z,I,J,N-1);
*-------------------------------------------------------------------------
*EQ (28) NOT NEEDED, BUT ADDED TO ENFORCE K=0 WHEN Y=0
*       AND COLD(S,J,N-1) AND ALLOW_C(S,Z,J,N-1,I)
BINARY_N5b(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0
            AND FREEH(I) AND FREEC(J))..
                     NHE_N0(S,Z,I,J,N) =L= Y_N(S,Z,I,J,N);

* SEE COMMENTS ON EQUATION (17)
*-------------------------------------------------------------------------
*EQ (29)
BINARY_N3(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0
 AND FREEH(I) AND FREEC(J))..
               NHE_N0(S,Z,I,J,N) =G= Y_N(S,Z,I,J,N)-Y_N(S,Z,I,J,N-1)
                     $(COLD(S,J,N-1) AND ALLOW_C(S,Z,J,N-1,I));
*-------------------------------------------------------------------------
*EQ (30)
* NOT NEEDED. VARIABLE IS ALREADY DECLARED POSITIVE
*BINARY_N4(S,Z,I,J,N)$(COLD(S,J,N)=1 AND COLD(S,J,N-1) AND ALLOW_C(S,Z,J,N,I)=1
* AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
*                                 NHE_N0(S,Z,I,J,N)=G=0;
*-------------------------------------------------------------------------
*EQ (31) NOT NEEDED
*          GAMS WRITES IT AUTOMATICALLY WHEN IT WRITES EQUATION (18)
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*-------------------------------------------------------------------------
*EQ (32)
 BINARY_N8(S,Z,I,J,N)$(COLD(S,J,N)=1 AND COLD(S,J,N+1) AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
                NHE_N1(S,Z,I,J,N)=L=2-Y_N(S,Z,I,J,N)-Y_N(S,Z,I,J,N+1);
*-------------------------------------------------------------------------
*EQ (33) NOT NEEDED BUT ADDED TO ENFORCE K=0 WHEN Y=0
*       AND COLD(S,J,N-1)  AND ALLOW_C(S,Z,J,N-1,I)
BINARY_N9(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1AND BIF(Z,I,J)=0
            AND FREEH(I) AND FREEC(J))..
                        NHE_N1(S,Z,I,J,N) =L= Y_N(S,Z,I,J,N);

*  SEE COMMENTS ON EQUATION (17)
*-------------------------------------------------------------------------
*EQ (34)
BINARY_N6(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0
 AND FREEH(I) AND FREEC(J))..
                NHE_N1(S,Z,I,J,N)=G=Y_N(S,Z,I,J,N)-Y_N(S,Z,I,J,N+1)
                    $(COLD(S,J,N+1) AND ALLOW_C(S,Z,J,N+1,I));
*-------------------------------------------------------------------------
*EQ (35)
* NOT NEEDED. VARIABLE IS ALREADY DECLARED POSITIVE
*BINARY_N7(S,Z,I,J,N)$(COLD(S,J,N)=1 AND COLD(S,J,N+1) AND ALLOW_C(S,Z,J,N,I)=1
* AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=0 AND FREEH(I) AND FREEC(J))..
*                                   NHE_N1(S,Z,I,J,N)=G=0;
*-------------------------------------------------------------------------
*EQ (36)
BINARY_N3_B(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I)AND FREEC(J))..
 Y_N_B(S,Z,I,J,N)=E=SUM(O$(COLD(S,J,O) AND ORD(O) LE ORD(N)
 AND ALLOW_C(S,Z,J,O,I)),NHE_N0_B(S,Z,I,J,O)) - SUM(O$(COLD(S,J,O) AND ORD(O) LE
            ORD(N)-1 AND ALLOW_C(S,Z,J,O,I)),NHE_N1_B(S,Z,I,J,O));
*-------------------------------------------------------------------------
*EQ (37)
HE_COUNT_M0(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                            AND BIF(Z,I,J)=0)..
 NHE(S,Z,I,J)=E= SUM(M$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1  ),
                            NHE_M0(S,Z,I,J,M));
HE_COUNT_M0_B(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                            AND BIF(Z,I,J)=1)..
 NHE(S,Z,I,J)=E=SUM(M$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1),
                            NHE_M0_B(S,Z,I,J,M));
*
*-------------------------------------------------------------------------
*EQ (38)
 HE_COUNT_N0(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
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                                    AND BIF(Z,I,J)=0)..
 NHE(S,Z,I,J)=E= SUM(N$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1  )
                                    ,NHE_N0(S,Z,I,J,N));

 HE_COUNT_N0_B(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                                    AND BIF(Z,I,J)=1)..
 NHE(S,Z,I,J)=E=SUM(N$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 ),
                                    NHE_N0_B(S,Z,I,J,N)) ;
*
*---------------------------------------------------------------------------
*EQ (39)
HE_COUNT_M1(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                                    AND BIF(Z,I,J)=0)..
 NHE(S,Z,I,J)=E= SUM(M$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1),
                                    NHE_M1(S,Z,I,J,M));
HE_COUNT_M1_B(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                                    AND BIF(Z,I,J)=1)..
 NHE(S,Z,I,J)=E=SUM(M$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 ),
                                    NHE_M1_B(S,Z,I,J,M)) ;
*
*---------------------------------------------------------------------------
*EQ (40)
HE_COUNT_N1(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                                    AND BIF(Z,I,J)=0)..
 NHE(S,Z,I,J)=E= SUM(N$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1),
                                    NHE_N1(S,Z,I,J,N));
HE_COUNT_N1_B(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
                                    AND BIF(Z,I,J)=1)..
 NHE(S,Z,I,J)=E=SUM(N$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1),
 NHE_N1_B(S,Z,I,J,N)) ;
*
*---------------------------------------------------------------------------
*EQ (41)
NEXCH(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND BIF(Z,I,J)=0 AND FREEH(I)
  AND FREEC(J))..NHE(S,Z,I,J)=L=1;
*---------------------------------------------------------------------------
*EQ (42)
NEXCH_B(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND BIF(Z,I,J)=1 AND FREEH(I)
  AND FREEC(J))..NHE(S,Z,I,J)=L=KMAX(Z,I,J);
*---------------------------------------------------------------------------

*EQ (43)
BIF_1(S,Z,I,J,M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
  SUM(L$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M) AND HOT(S,I,L)=1
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```
                                    AND ALLOW_H(S,Z,I,L,J)=1),
    QNEW_M(S,Z,I,J,L)) - QNEW2_M(S,Z,I,J,M) =L=
 SUM(O$(D(S,Z,M,O)=1 AND ORD(O) LE ORD(N) AND COLD(S,J,O)
                                    AND ALLOW_C(S,Z,J,O,I)),
    QNEW_N(S,Z,I,J,O)) - QNEW2_N(S,Z,I,J,N)
 + B1(S,Z,I,M,J,N) *4* max(SUM(L$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M)
                    AND HOT(S,I,L)=1 AND ALLOW_H(S,Z,I,L,J)=1),
                DHH(S,I,L)),SUM(O$(D(S,Z,M,O)=1 AND ORD(O) LE ORD(N)
                AND COLD(S,J,O) AND ALLOW_C(S,Z,J,O,I)),DHC(S,J,O)));
*-------------------------------------------------------------------------------
*EQ (44)
BIF_2(S,Z,I,J,M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
    AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1
    AND BIF(Z,I,J)=1 AND FREEH(I)AND FREEC(J))..
 SUM(L$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M) AND HOT(S,I,L)=1
      AND ALLOW_H(S,Z,I,L,J)=1),
    QNEW_M(S,Z,I,J,L)) - QNEW2_M(S,Z,I,J,M) =G=
 SUM(O$(D(S,Z,M,O)=1 AND ORD(O) LE ORD(N) AND COLD(S,J,O)
                                    AND ALLOW_C(S,Z,J,O,I)),
    QNEW_N(S,Z,I,J,O)) - QNEW2_N(S,Z,I,J,N)
 -B1(S,Z,I,M,J,N) *4*  max(SUM(L$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M)
                    AND HOT(S,I,L)=1 AND ALLOW_H(S,Z,I,L,J)=1),
                DHH(S,I,L)),SUM(O$(D(S,Z,M,O)=1 AND ORD(O) LE ORD(N)
                AND COLD(S,J,O) AND ALLOW_C(S,Z,J,O,I)),DHC(S,J,O)));
*-------------------------------------------------------------------------------
*EQ (45)
BIF_3(S,Z,I,J,M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
    AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1
    AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
 B1(S,Z,I,M,J,N) =E= 2- 0.25* SUM(L$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M)
                    AND HOT(S,I,L)=1 AND ALLOW_H(S,Z,I,L,J)=1),
          NHE_M1_B(S,Z,I,J,L))
        + 0.25 *SUM(O$(D(S,Z,M,O)=1 AND ORD(O) LE ORD(N) AND COLD(S,J,O)
                    AND ALLOW_C(S,Z,J,O,I)),NHE_N1_B(S,Z,I,J,O))
                    -NHE_M1_B(S,Z,I,J,M)-NHE_N1_B(S,Z,I,J,N);
*-------------------------------------------------------------------------------
*EQ (46)
BIF_4(S,Z,I,J,M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND TL(S,N) GE TL(S,M)
 AND HOT(S,I,M)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
   SUM(L$(HOT(S,I,L)=1 AND ORD(L) LE ORD(M) AND ALLOW_H(S,Z,I,L,J)=1),
          NHE_M1_B(S,Z,I,J,L)) -SUM(O$(COLD(S,J,O) AND ORD(O) LE ORD(N)
                AND ALLOW_C(S,Z,J,O,I)),NHE_N1_B(S,Z,I,J,O))=G=0;

*-------------------------------------------------------------------------------
*EQ (47)
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BIF_11(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
    SUM(O$(HOT(S,I,O)=1 AND ORD(O) LE ORD(M) AND ALLOW_H(S,Z,I,O,J)=1),
                NHE_M0_B(S,Z,I,J,O)-NHE_M1_B(S,Z,I,J,O))=L=1 ;
*-------------------------------------------------------------------------
*EQ (48)
BIF_12(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
        SUM(O$(COLD(S,J,O) AND ORD(O) LE ORD(N) AND ALLOW_C(S,Z,J,O,I)),
                NHE_N0_B(S,Z,I,J,O)-NHE_N1_B(S,Z,I,J,O))=L=1;
*-------------------------------------------------------------------------
*EQ (49)
BIF_6(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
                QNEW2_M(S,Z,I,J,M) =L= QNEW_M(S,Z,I,J,M);
*-------------------------------------------------------------------------
*EQ (50)
BIF_9(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
            QNEW2_M(S,Z,I,J,M) =L= NHE_M0_B(S,Z,I,J,M)*DHH(S,I,M);
*-------------------------------------------------------------------------
*EQ (51)
BIF_5(S,Z,I,J,M)$(HOT(S,I,M)=1AND ALLOW_H(S,Z,I,M,J)=1AND BIF(Z,I,J)=1
 AND FREEH(I)AND FREEC(J))..
            QNEW2_M(S,Z,I,J,M) =L= NHE_M1_B(S,Z,I,J,M)*DHH(S,I,M);
*-------------------------------------------------------------------------
*EQ (52)      NOT NEEDED. THE VARIABLE IS DECLARED POSITIVE
*-------------------------------------------------------------------------
*EQ (53)
BIF_8(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
                QNEW2_N(S,Z,I,J,N) =L= QNEW_N(S,Z,I,J,N);
*-------------------------------------------------------------------------
*EQ (54)
BIF_10(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
            QNEW2_N(S,Z,I,J,N) =L= NHE_N0_B(S,Z,I,J,N)*DHC(S,J,N);
*-------------------------------------------------------------------------
*EQ (55)
BIF_7(S,Z,I,J,N)$(COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
            QNEW2_N(S,Z,I,J,N) =L= NHE_N1_B(S,Z,I,J,N)*DHC(S,J,N);
*-------------------------------------------------------------------------
*EQ (56)      NOT NEEDED. THE VARIABLE IS DECLARED POSITIVE
*-------------------------------------------------------------------------
*EQ (57)
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FEAS_M_01(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND SPH(I)=1 AND FREEH(I)
AND FREEC(J))..
        ALFA_M(S,Z,I,J,M)=L=1-NHE_M0(S,Z,I,J,M-1)-NHE_M0(S,Z,I,J,M);

FEAS_M_01_B(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
        ALFA_M(S,Z,I,J,M)=L=1-NHE_M0_B(S,Z,I,J,M-1)-NHE_M0_B(S,Z,I,J,M);
*-------------------------------------------------------------------------
*EQ (58)
FEAS_M_02(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND SPH(I)=1 AND FREEH(I)
AND FREEC(J))..
        ALFA_M(S,Z,I,J,M)=L=1-NHE_M1(S,Z,I,J,M-1)-NHE_M1(S,Z,I,J,M);
FEAS_M_02_B(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
        ALFA_M(S,Z,I,J,M)=L=1-NHE_M1_B(S,Z,I,J,M-1)-NHE_M1_B(S,Z,I,J,M);
*-------------------------------------------------------------------------
*EQ (59)
FEAS_M_03(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND SPH(I)=1 AND FREEH(I)
AND FREEC(J))..
   ALFA_M(S,Z,I,J,M)=G=Y_M(S,Z,I,J,M)-NHE_M0(S,Z,I,J,M-1)-NHE_M0(S,Z,I,J,M) -
                NHE_M1(S,Z,I,J,M-1)-NHE_M1(S,Z,I,J,M);
FEAS_M_03_B(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
ALFA_M(S,Z,I,J,M)=G=Y_M_B(S,Z,I,J,M)-NHE_M0_B(S,Z,I,J,M-1)-NHE_M0_B(S,Z,I,J,M)
            - NHE_M1_B(S,Z,I,J,M-1)-NHE_M1_B(S,Z,I,J,M);
*-------------------------------------------------------------------------
*EQ (60)
* NOT NEEDED alpha IS DECLARED POSITIVE
*FEAS_M_04(S,Z,I,J,M)$(HOT(S,I,M-1)AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND
*ALLOW_H(S,Z,I,M-1,J) AND (BIF(Z,I,J)=1 OR SPH(I)=1) AND FREEH(I) AND FREEC(J))..
*                   ALFA_M(S,Z,I,J,M)=G=0;
*-------------------------------------------------------------------------
* change : Eq 61 and 62 will be applied for both cases : BIF = 0 and BIF = 1
*EQ (61)
FEAS_M_2(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
AND ALLOW_H(S,Z,I,M-1,J) AND SPH(I)=1 AND FREEH(I) AND FREEC(J))..
*                   AND BIF(Z,I,J)=1)..
QNEW_M(S,Z,I,J,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M))) =L=
        QNEW_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1)))
+(1-ALFA_M(S,Z,I,J,M))*DHH(S,I,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001;
*-------------------------------------------------------------------------
*EQ (62)
FEAS_M_1(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
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 AND ALLOW_H(S,Z,I,M-1,J) AND SPH(I)=1 AND FREEH(I) AND FREEC(J))..
*                                AND BIF(Z,I,J)=1)..
 QNEW_M(S,Z,I,J,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M))) =G=
          QNEW_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1)))
    -(1-ALFA_M(S,Z,I,J,M))*DHH(S,I,M) /(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001;
*-------------------------------------------------------------------------------
*EQ (63)
FEAS_M_3(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND SPH(I)=1 AND FREEH(I)
 AND FREEC(J))..
 -QNEW_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1)))
  + QNEW_M(S,Z,I,J,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))
  +(1+ NHE_M1(S,Z,I,J,M-1) + NHE_M1(S,Z,I,J,M) - NHE_M0(S,Z,I,J,M-1))
   *DHH(S,I,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001 =G= 0;
*-------------------------------------------------------------------------------
*EQ (64)
FEAS_M_4(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=0 AND SPH(I)=1 AND FREEH(I)
 AND FREEC(J))..
 - QNEW_M(S,Z,I,J,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))
 + QNEW_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1)))
 +(1+ NHE_M0(S,Z,I,J,M-1)+NHE_M0(S,Z,I,J,M)-NHE_M1(S,Z,I,J,M))
  *DHH(S,I,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001 =G= 0;
*-------------------------------------------------------------------------------
*EQ (65)
FEAS_M_3_B_2(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=1 AND SPH(I)=1 AND FREEH(I)
 AND FREEC(J))..
  QNEW_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1)))=L=
  QNEW_M(S,Z,I,J,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))
  +(1+NHE_M1_B(S,Z,I,J,M-1)+NHE_M1_B(S,Z,I,J,M)-NHE_M0_B(S,Z,I,J,M-1))
   *DHH(S,I,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001;
*-------------------------------------------------------------------------------
*EQ (66)
FEAS_M_3_B_1(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=1 AND SPH(I)=1 AND FREEH(I)
 AND FREEC(J))..
  QNEW2_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1))) =L=
  QNEW_M(S,Z,I,J,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))+ (2 + NHE_M1_B(S,Z,I,J,M)
  + NHE_M1_B(S,Z,I,J,M)-NHE_M0_B(S,Z,I,J,M-1)-Y_M_B(S,Z,I,J,M-1))
     *DHH(S,I,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001;
*-------------------------------------------------------------------------------
*EQ (67)
FEAS_M_4_B(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND BIF(Z,I,J)=1 AND SPH(I)=1 AND FREEH(I)
 AND FREEC(J))..
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```
 (QNEW_M(S,Z,I,J,M)-QNEW2_M(S,Z,I,J,M))/(CPH(S,I,M)*(TU(S,M)-TL(S,M))) =L=
  QNEW_M(S,Z,I,J,M-1)/(CPH(S,I,M-1)*(TU(S,M-1)-TL(S,M-1)))
 +(2 + NHE_M0_B(S,Z,I,J,M-1)
 + NHE_M0_B(S,Z,I,J,M)-NHE_M1_B(S,Z,I,J,M)-Y_M_B(S,Z,I,J,M))
  *DHH(S,I,M)/(CPH(S,I,M)*(TU(S,M)-TL(S,M)))*1.00001;
*-------------------------------------------------------------------------
* Change in equation 68
*EQ (68)
FEAS_M_1_SP(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND HOT(S,I,M+1)
 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M-1,J) AND ALLOW_H(S,Z,I,M+1,J)
 AND BIF(Z,I,J)=0 AND SPH(I)=0 AND FREEH(I) AND FREEC(J))..
 QNEW_M(S,Z,I,J,M)=G=(Y_M(S,Z,I,J,M)- NHE_M0(S,Z,I,J,M) - NHE_M1(S,Z,I,J,M))
                                *DHH(S,I,M);

FEAS_M_1_SP_B(S,Z,I,J,M)$(HOT(S,I,M-1) AND HOT(S,I,M)=1 AND HOT(S,I,M+1)
 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_H(S,Z,I,M-1,J) AND ALLOW_H(S,Z,I,M+1,J) AND BIF(Z,I,J)=1 AND SPH(I)=0
 AND FREEH(I) AND FREEC(J))..
 QNEW_M(S,Z,I,J,M)=G=
    (Y_M_B(S,Z,I,J,M) - NHE_M0_B(S,Z,I,J,M) - NHE_M0_B(S,Z,I,J,M))*DHH(S,I,M);
*-------------------------------------------------------------------------
*EQ (69)
FEAS_N_01(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND SPC(J)=1 AND FREEH(I)
 AND FREEC(J))..
          ALFA_N(S,Z,I,J,N) =L= 1-NHE_N0(S,Z,I,J,N)-NHE_N0(S,Z,I,J,N-1);
FEAS_N_01_B(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
          ALFA_N(S,Z,I,J,N)=L=1-NHE_N0_B(S,Z,I,J,N)-NHE_N0_B(S,Z,I,J,N-1);
*-------------------------------------------------------------------------
*EQ (70)
FEAS_N_02(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND SPC(J)=1 AND FREEH(I)
 AND FREEC(J))..
            ALFA_N(S,Z,I,J,N)=L=1-NHE_N1(S,Z,I,J,N)-NHE_N1(S,Z,I,J,N-1);
FEAS_N_02_B(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
          ALFA_N(S,Z,I,J,N)=L=1-NHE_N1_B(S,Z,I,J,N)-NHE_N1_B(S,Z,I,J,N-1);
*-------------------------------------------------------------------------
*EQ (71)
FEAS_N_03(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND SPC(J)=1 AND FREEH(I)
 AND FREEC(J))..
   ALFA_N(S,Z,I,J,N)=G=Y_N(S,Z,I,J,N)-NHE_N0(S,Z,I,J,N)-NHE_N0(S,Z,I,J,N-1)
                        - NHE_N1(S,Z,I,J,N)-NHE_N1(S,Z,I,J,N-1);
FEAS_N_03_B(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
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 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
  ALFA_N(S,Z,I,J,N)=G=Y_N_B(S,Z,I,J,N)-NHE_N0_B(S,Z,I,J,N)-NHE_N0_B(S,Z,I,J,N-1)
                        -NHE_N1_B(S,Z,I,J,N)-NHE_N1_B(S,Z,I,J,N-1);
*-------------------------------------------------------------------------------
*EQ (72)
*  NOT NEEDED. VARIABLE IS DECLARED POSITIVE
*FEAS_N_04(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
* AND ALLOW_C(S,Z,J,N-1,I) AND (BIF(Z,I,J)=1 OR SPC(J)=1)
* AND FREEH(I) AND FREEC(J))..
*                                       ALFA_N(S,Z,I,J,N)=G=0;
*-------------------------------------------------------------------------------
*EQ (73)
FEAS_N_2(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND SPC(J)=1 AND FREEH(I) AND FREEC(J))..
*                                       AND BIF(Z,I,J)=1)..
 QNEW_N(S,Z,I,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))=L=
     QNEW_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)))
    +(1-ALFA_N(S,Z,I,J,N))*DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.00001;
*-------------------------------------------------------------------------------
*EQ (74)
FEAS_N_1(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND SPC(J)=1 AND FREEH(I) AND FREEC(J))..
*                                       AND BIF(Z,I,J)=1)..
  QNEW_N(S,Z,I,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))
    +(1-ALFA_N(S,Z,I,J,N))*DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.0001=G=
          QNEW_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)));
*-------------------------------------------------------------------------------
*EQ (75)
FEAS_N_3(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND SPC(J)=1 AND FREEH(I)
 AND FREEC(J))..
 -QNEW_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)))
 +QNEW_N(S,Z,I,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))
   +(1+NHE_N1(S,Z,I,J,N-1)+NHE_N1(S,Z,I,J,N)
  -NHE_N0(S,Z,I,J,N-1))*DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.00001 =G= 0;
*-------------------------------------------------------------------------------
*EQ (76)
FEAS_N_4(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0 AND SPC(J)=1 AND FREEH(I)
 AND FREEC(J))..
 -QNEW_N(S,Z,I,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))
 +QNEW_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)))
 +(1+NHE_N0(S,Z,I,J,N-1)  + NHE_N0(S,Z,I,J,N)
 -NHE_N1(S,Z,I,J,N))*DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.00001=G=0;
*-------------------------------------------------------------------------------
*EQ (77)
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FEAS_N_3_B_2(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1 AND SPC(J)=1
 AND FREEH(I) AND FREEC(J))..
 -QNEW_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)))
 +QNEW_N(S,Z,I,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))
 +(1 + NHE_N1_B(S,Z,I,J,N-1)+ NHE_N1_B(S,Z,I,J,N)-NHE_N0_B(S,Z,I,J,N-1))
  *DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.00001=G=0;
*-------------------------------------------------------------------------
*EQ (78)
FEAS_N_3_B_1(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1 AND SPC(J)=1
 AND FREEH(I) AND FREEC(J))..
 -QNEW2_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)))
 +QNEW_N(S,Z,I,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))+(2 + NHE_N1_B(S,Z,I,J,N)
 + NHE_N1_B(S,Z,I,J,N-1)-NHE_N0_B(S,Z,I,J,N-1)-Y_N_B(S,Z,I,J,N-1))
  *DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.00001=G=0;
*-------------------------------------------------------------------------
*EQ (79)
FEAS_N_4_B(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1 AND SPC(J)=1 AND FREEH(I)
 AND FREEC(J))..
  -(QNEW_N(S,Z,I,J,N)-QNEW2_N(S,Z,I,J,N))/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))
  + QNEW_N(S,Z,I,J,N-1)/(CPC(S,J,N-1)*(TU(S,N-1)-TL(S,N-1)))
  +(2 + NHE_N0_B(S,Z,I,J,N-1)
  + NHE_N0_B(S,Z,I,J,N) -NHE_N1_B(S,Z,I,J,N)-Y_N_B(S,Z,I,J,N))
   *DHC(S,J,N)/(CPC(S,J,N)*(TU(S,N)-TL(S,N)))*1.00001=G=0;
*-------------------------------------------------------------------------
*EQ (80)
 FEAS_N_1_SP(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND COLD(S,J,N+1)AND
 ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N-1,I) AND ALLOW_C(S,Z,J,N+1,I)
 AND BIF(Z,I,J)=0 AND SPC(J)=0 AND FREEH(I) AND FREEC(J))..
    QNEW_N(S,Z,I,J,N) =G=
   (Y_N(S,Z,I,J,N)-NHE_N0(S,Z,I,J,N)-NHE_N1(S,Z,I,J,N))*DHC(S,J,N);

 FEAS_N_1_SP_B(S,Z,I,J,N)$(COLD(S,J,N-1) AND COLD(S,J,N)=1 AND COLD(S,J,N+1)
 AND ALLOW_C(S,Z,J,N,I)=1
 AND BIF(Z,I,J)=1 AND SPC(J)=0 AND FREEH(I) AND FREEC(J))..
    QNEW_N(S,Z,I,J,N) =G=
   (Y_N_B(S,Z,I,J,N)-NHE_N0_B(S,Z,I,J,N)-NHE_N1_B(S,Z,I,J,N))*DHC(S,J,N);
*-------------------------------------------------------------------------  AND  ALLOW_C(S,Z,J,N-1,I)  AND
ALLOW_C(S,Z,J,N+1,I)
*EQ (81)
FEAS_BEG_SP(S,Z,I,J,M,N)$(TL(S,N) LE TU(S,M) AND TU(S,N) GE TL(S,M)
 AND HOT(S,I,M)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0 AND SPH(I)=0 AND SPC(J)=0
 AND FREEH(I) AND FREEC(J))..
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  TL(S,M) - TL(S,N) - QNEW_N(S,Z,I,J,N)/(FC(S,J)*CPC(S,J,N))
 + QNEW_M(S,Z,I,J,M)/(FH(S,I)*CPH(S,I,M))
 + (2-NHE_M0(S,Z,I,J,M)-NHE_N0(S,Z,I,J,N))*TU(S,N)=G=0;

FEAS_BEG_B_SP(S,Z,I,J,M,N)$(TL(S,N) LE TU(S,M) AND TU(S,N) GE TL(S,M)
 AND HOT(S,I,M)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1 AND SPH(I)=0 AND SPC(J)=0
 AND FREEH(I) AND FREEC(J))..
  TL(S,M) - TL(S,N) -QNEW_N(S,Z,I,J,N)/(FC(S,J)*CPC(S,J,N))
 + QNEW_M(S,Z,I,J,M)/(FH(S,I)*CPH(S,I,M))
 + (2-NHE_M0_B(S,Z,I,J,M)-NHE_N0_B(S,Z,I,J,N))*TU(S,N)=G=0;
*-------------------------------------------------------------------------------
*EQ (82)
FEAS_END_SP(S,Z,I,J,M,N)$(TL(S,N) LE TU(S,M) AND TU(S,N) GE TL(S,M)
 AND HOT(S,I,M)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=0 AND SPH(I)=0 AND SPC(J)=0
 AND FREEH(I) AND FREEC(J))..
  TU(S,M)-TU(S,N)
 -QNEW_M(S,Z,I,J,M)/(FH(S,I)*CPH(S,I,M)) +QNEW_N(S,Z,I,J,N)/(FC(S,J)*CPC(S,J,N))
                 +(2-NHE_M1(S,Z,I,J,M)-NHE_N1(S,Z,I,J,N))*TU(S,N)=G=0;
FEAS_END_B_SP(S,Z,I,J,M,N)$(TL(S,N) LE TU(S,M) AND TU(S,N) GE TL(S,M)
 AND HOT(S,I,M)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND BIF(Z,I,J)=1 AND SPH(I)=0 AND SPC(J)=0
 AND FREEH(I) AND FREEC(J))..
  TU(S,M)-TU(S,N)
-QNEW_M(S,Z,I,J,M)/(FH(S,I)*CPH(S,I,M)) + QNEW_N(S,Z,I,J,N)/(FC(S,J)*CPC(S,J,N))
               +(2-NHE_M1_B(S,Z,I,J,M)-NHE_N1_B(S,Z,I,J,N))*TU(S,N)=G=0;
*-------------------------------------------------------------------------------
*EQ (83)
FEAS_BEG3(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M+1) AND COLD(S,J,N)=1
 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M+1,J)
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=0
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
          NHE_N1(S,Z,I,J,N)=L=(2-NHE_M0(S,Z,I,J,M)-NHE_N0(S,Z,I,J,N));
*-------------------------------------------------------------------------------
*EQ (84)
FEAS_BEG(S,Z,I,J,M,N)$(DTVIO(I,J)=1  AND D(S,Z,M,N)=1 AND D(S,Z,M,N)=1
 AND TL(S,N) LT TU(S,M) AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1
 AND COLD(S,J,N)=1 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1
  AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I)AND HOT(S,I,M+1)
  AND ALLOW_H(S,Z,I,M+1,J)
 AND BIF(Z,I,J)=0 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
   QNEW_N(S,Z,I,J,N)/(TU(S,M)-TL(S,N))=L=
     (QNEW_N(S,Z,I,J,N+1)/(TU(S,N+1)-TL(S,N+1)))* CPC(S,J,N)/CPC(S,J,N+1)
       +(2-NHE_M0(S,Z,I,J,M)-NHE_N0(S,Z,I,J,N))*DHC(S,J,N)/(TU(S,M)-TL(S,N));
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*-------------------------------------------------------------------------
*EQ (85)
FEAS_BEG2(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1  AND COLD(S,J,N)=1
 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=0
AND HOT(S,I,M+1) AND ALLOW_H(S,Z,I,M+1,J)
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
 QNEW_M(S,Z,I,J,M)/(MIN(TU(S,M),TU(S,N))-TL(S,M))=G=
    QNEW_M(S,Z,I,J,M+1)/(TU(S,M+1)-TL(S,M+1))
  *CPH(S,I,M)/CPH(S,I,M+1)-(2-NHE_M0(S,Z,I,J,M)-NHE_N0(S,Z,I,J,N))
  *DHH(S,I,M+1)/(TU(S,M+1)-TL(S,M+1));
*-------------------------------------------------------------------------
*EQ (86)
FEAS_END3(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1  AND COLD(S,J,N)=1
 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1  AND BIF(Z,I,J)=0
AND HOT(S,I,M-1) AND ALLOW_H(S,Z,I,M-1,J) AND COLD(S,J,N-1)
AND ALLOW_C(S,Z,J,N-1,I)
AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
          NHE_M0(S,Z,I,J,M)=L=(2-NHE_M1(S,Z,I,J,M)-NHE_N1(S,Z,I,J,N));
*-------------------------------------------------------------------------
*EQ (87)
FEAS_END(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1  AND COLD(S,J,N)=1
AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1  AND BIF(Z,I,J)=0
AND HOT(S,I,M-1)AND ALLOW_H(S,Z,I,M-1,J)
AND COLD(S,J,N-1) AND ALLOW_C(S,Z,J,N-1,I)
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
 QNEW_M(S,Z,I,J,M)/(TU(S,M)-TL(S,N))=L=
   QNEW_M(S,Z,I,J,M-1)/(TU(S,M-1)-TL(S,M-1))
     *CPH(S,I,M)/CPH(S,I,M-1)+(2-NHE_M1(S,Z,I,J,M)-NHE_N1(S,Z,I,J,N))
     *DHH(S,I,M)/(TU(S,M)-TL(S,N));
*-------------------------------------------------------------------------
*EQ (88)
FEAS_END2(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M-1) AND COLD(S,J,N)=1
 AND COLD(S,J,N-1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M-1,J)
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=0
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
 QNEW_N(S,Z,I,J,N)/(TU(S,N)-MAX(TL(S,M),TL(S,N)))=G=
   QNEW_N(S,Z,I,J,N-1)/(TU(S,N-1)-TL(S,N-1))
     *CPC(S,J,N)/CPC(S,J,N-1)-(2-NHE_M1(S,Z,I,J,M)-NHE_N1(S,Z,I,J,N))
     *DHC(S,J,N-1)/(TU(S,N-1)-TL(S,N-1));
*-------------------------------------------------------------------------
```

```
*EQ (89)
FEAS_BEG4_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M+1) AND COLD(S,J,N)=1
 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M+1,J)
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=1
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
    NHE_N1_B(S,Z,I,J,N) =L=
          (1+Y_N_B(S,Z,I,J,N)-NHE_M0_B(S,Z,I,J,M)-NHE_N0_B(S,Z,I,J,N));
*-------------------------------------------------------------------------
*EQ (90)
FEAS_BEG2_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M+1) AND COLD(S,J,N)=1
 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M+1,J)
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=1
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
 QNEW_N(S,Z,I,J,N)/(TU(S,M)-TL(S,N))=L=
   QNEW_N(S,Z,I,J,N+1)/(TU(S,N+1)-TL(S,N+1))
     *CPC(S,J,N)/CPC(S,J,N+1)+(1+Y_N_B(S,Z,I,J,N)
   -NHE_M0_B(S,Z,I,J,M)-NHE_N0_B(S,Z,I,J,N))*DHC(S,J,N)/(TU(S,M)-TL(S,N));
*-------------------------------------------------------------------------
*EQ (91)
FEAS_BEG1_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M+1) AND COLD(S,J,N)=1
 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M+1,J)
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=1
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
  QNEW2_N(S,Z,I,J,N)/(TU(S,M)-TL(S,N))=L=
     QNEW_N(S,Z,I,J,N+1)/(TU(S,N+1)-TL(S,N+1))
  *CPC(S,J,N)/CPC(S,J,N+1)+(2-NHE_M0_B(S,Z,I,J,M)-NHE_N0_B(S,Z,I,J,N))
  *DHC(S,J,N)/(TU(S,M)-TL(S,N));
*-------------------------------------------------------------------------
*EQ (92)
FEAS_BEG3_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M+1) AND COLD(S,J,N)=1
 AND COLD(S,J,N+1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M+1,J)
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N+1,I) AND BIF(Z,I,J)=1
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
 QNEW_M(S,Z,I,J,M)/(MIN(TU(S,M),TU(S,N))-TL(S,M))=G=
  QNEW_M(S,Z,I,J,M+1)/(TU(S,M+1)-TL(S,M+1))
 *CPH(S,I,M)/CPH(S,I,M+1)-(2-NHE_M0_B(S,Z,I,J,M)-NHE_N0_B(S,Z,I,J,N))
 *DHH(S,I,M+1)/(TU(S,M+1)-TL(S,M+1));
*-------------------------------------------------------------------------
*EQ (93)
FEAS_END3_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND HOT(S,I,M-1) AND COLD(S,J,N)=1
 AND COLD(S,J,N-1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M-1,J)
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```
 AND ALLOW_C(S,Z,J,N,I) AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
 NHE_M0_B(S,Z,I,J,M)=L=
          (1+Y_M_B(S,Z,I,J,M)-NHE_M1_B(S,Z,I,J,M)-NHE_N1_B(S,Z,I,J,N));
*-------------------------------------------------------------------------
*EQ (94)
FEAS_END_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M)  AND HOT(S,I,M)=1 AND HOT(S,I,M-1) AND COLD(S,J,N)=1
 AND COLD(S,J,N-1) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_H(S,Z,I,M-1,J)
 AND ALLOW_C(S,Z,J,N,I)=1  AND BIF(Z,I,J)=1
*                          AND ALLOW_C(S,Z,J,N-1,I)  WAS REMOVED
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
   (QNEW_M(S,Z,I,J,M)-QNEW2_M(S,Z,I,J,M))/(TU(S,M)-TL(S,N))=L=
     QNEW_M(S,Z,I,J,M-1)/(TU(S,M-1)-TL(S,M-1))*CPH(S,I,M)/CPH(S,I,M-1)+
   (2-NHE_M1_B(S,Z,I,J,M)-NHE_N1_B(S,Z,I,J,N))*DHH(S,I,M)/(TU(S,M)-TL(S,N));
*-------------------------------------------------------------------------
*EQ (95)
FEAS_END2_B(S,Z,I,J,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M)  AND HOT(S,I,M)=1 AND HOT(S,I,M-1) AND COLD(S,J,N)=1
 AND COLD(S,J,N-1) AND ALLOW_H(S,Z,I,M,J)=1
*                          AND ALLOW_H(S,Z,I,M-1,J)  WAS REMOVED
 AND ALLOW_C(S,Z,J,N,I)=1 AND ALLOW_C(S,Z,J,N-1,I) AND BIF(Z,I,J)=1
 AND (SPH(I)=1 OR SPC(J)=1) AND FREEH(I) AND FREEC(J))..
(QNEW_N(S,Z,I,J,N)-QNEW2_N(S,Z,I,J,N))/(TU(S,N)-MAX(TL(S,M),TL(S,N)))=G=
 QNEW_N(S,Z,I,J,N-1)/(TU(S,N-1)-TL(S,N-1))*CPC(S,J,N)/CPC(S,J,N-1)
-(2-NHE_M1_B(S,Z,I,J,M)-NHE_N1_B(S,Z,I,J,N))*DHC(S,J,N-1)/(TU(S,N-1)-TL(S,N-1));
*-------------------------------------------------------------------------
*EQ (96)
PAREQ(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
 PAR(Z,I,J)=E=SUM((M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),
          Q(S,Z,I,M,J,N)*(1/H_I(S,I,M)+1/H_J(S,J,N))/LMTD(S,M,N));
*-------------------------------------------------------------------------
$ONTEXT
EQUATION EXTRA1;
EXTRA1(S,I,J,Z,M,N)$(DTVIO(I,J)=1 AND D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M)
 AND TU(S,N) GT TL(S,M) AND HOT(S,I,M)=1 AND COLD(S,J,N)=1
 AND ALLOW_H(S,Z,I,M,J)=1
 AND ALLOW_C(S,Z,J,N,I)=1
 AND FREEH(I) AND FREEC(J))..
      Q(S,Z,I,M,J,N)/(TU(S,M)-TL(S,N)) =L= DHH(S,I,M)/(TU(S,M)-TL(S,M));
$OFFTEXT

$ontext
*EQ (97)  FOR K=1, THE LAST SUMMATION WILL NOT BE WRITTEN.
BIF_13_2(S,K,Z,I,J)$(HOT(S,I,'M1')=1
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 AND ALLOW_H(S,Z,I,'M1',J)=1 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
  PAR_B(K,Z,I,J)=L=
        SUM((L,N)$(D(S,Z,L,N)=1 AND ORD(L) LE 1 AND TL(S,N) LT TU(S,L)
  AND HOT(S,I,L)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,L,J)=1
  AND ALLOW_C(S,Z,J,N,I)=1),
  (Q(S,Z,I,L,J,N)-Q2(S,Z,I,L,J,N))*(1/H_I(S,I,L)+1/H_J(S,J,N))/LMTD(S,L,N))
             +AMAX*(2-NHE_M1_B(S,Z,I,J,'M1')-X1_B(S,Z,I,J,'M1'))-
        SUM(KK$(ORD(KK) LT ORD(K)),PAR_B(KK,Z,I,J));
*-------------------------------------------------------------------------
*EQ (98)   FOR K=1, THE LAST SUMMATION WIL NOT BE WRITTEN.
BIF_13_1(S,K,Z,I,J)$(HOT(S,I,'M1')=1
  AND ALLOW_H(S,Z,I,'M1',J)=1 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
  PAR_B(K,Z,I,J)=G=
        SUM((L,N)$(D(S,Z,L,N)=1 AND ORD(L) LE 1 AND TL(S,N) LT TU(S,L)
  AND HOT(S,I,L)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,L,J)=1
  AND ALLOW_C(S,Z,J,N,I)=1),
  (Q(S,Z,I,L,J,N)-Q2(S,Z,I,L,J,N))*(1/H_I(S,I,L)+1/H_J(S,J,N))/LMTD(S,L,N))
             -AMAX*(2-NHE_M1_B(S,Z,I,J,'M1')-X1_B(S,Z,I,J,'M1'))-
        SUM(KK$(ORD(KK) LT ORD(K)),PAR_B(KK,Z,I,J));
*-------------------------------------------------------------------------
 real ones
*EQ (97)  FOR K=1, THE LAST SUMMATION WILL NOT BE WRITTEN.
BIF_13_2(S,K,Z,I,J,M)$(ORD(K) LT KMAX(Z,I,J) AND HOT(S,I,M)=1
  AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
  PAR_B(K,Z,I,J)=L=
        SUM((L,N)$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M) AND TL(S,N) LT TU(S,L)
  AND HOT(S,I,L)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,L,J)=1
  AND ALLOW_C(S,Z,J,N,I)=1),
  (Q(S,Z,I,L,J,N)-Q2(S,Z,I,L,J,N))*(1/H_I(S,I,L)+1/H_J(S,J,N))/LMTD(S,L,N))
             +AMAX*(2-NHE_M1_B(S,Z,I,J,M)-X1_B(S,Z,I,J,M))-
        SUM(KK$(ORD(KK) LT ORD(K)),PAR_B(KK,Z,I,J));
*-------------------------------------------------------------------------


*EQ (98)   FOR K=1, THE LAST SUMMATION WIL NOT BE WRITTEN.
BIF_13_1(S,K,Z,I,J,M)$(ORD(K) LT KMAX(Z,I,J) AND HOT(S,I,M)=1
  AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
  PAR_B(K,Z,I,J)=G=
        SUM((L,N)$(D(S,Z,L,N)=1 AND ORD(L) LE ORD(M) AND TL(S,N) LT TU(S,L)
  AND HOT(S,I,L)=1 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,L,J)=1
  AND ALLOW_C(S,Z,J,N,I)=1),
  (Q(S,Z,I,L,J,N)-Q2(S,Z,I,L,J,N))*(1/H_I(S,I,L)+1/H_J(S,J,N))/LMTD(S,L,N))
             -AMAX*(2-NHE_M1_B(S,Z,I,J,M)-X1_B(S,Z,I,J,M))-
        SUM(KK$(ORD(KK) LT ORD(K)),PAR_B(KK,Z,I,J));
*-------------------------------------------------------------------------


*EQ (99)
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BIF_14(S,K,Z,I,J)$(ORD(K) EQ KMAX(Z,I,J) AND ALLOW(S,Z,I,J)=1 AND FREEH(I)
 AND FREEC(J) AND BIF(Z,I,J)=1)..
   PAR_B(K,Z,I,J)=G=PAR(Z,I,J)-SUM(KK$(ORD(KK) LT ORD(K)),PAR_B(KK,Z,I,J));
*-------------------------------------------------------------------------
*EQ (100)
BIF_15(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
    SUM(K$(ORD(K) LE KMAX(Z,I,J)),
    ORD(K)*X1_B(S,Z,I,J,M))=E= SUM(L$(HOT(S,I,L)=1 AND ORD(L) LE ORD(M) AND
    ALLOW_H(S,Z,I,L,J)=1),NHE_M0_B(S,Z,I,J,L))+1-Y_M_B(S,Z,I,J,M) ;
*-------------------------------------------------------------------------
*EQ (101)
BIF_17(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
 AND FREEH(I) AND FREEC(J))..
 SUM(N$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1 AND COLD(S,J,N)=1
      AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),
                        Q2(S,Z,I,M,J,N))=E=QNEW2_M(S,Z,I,J,M);
*-------------------------------------------------------------------------
*THIS EQUATION WAS HER IN AUG 2007. IT IS NOT NEEDED.  X1_B is binary
*  BIF_16(S,Z,I,J,M)$(HOT(S,I,M)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND BIF(Z,I,J)=1
*  AND FREEH(I) AND FREEC(J))..
*     X1_B(S,Z,I,J,M)=L=1;
*-------------------------------------------------------------------------
*EQ (102)
BIF_18(S,Z,I,J,M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
 AND COLD(S,J,N)=1 AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1
 AND BIF(Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
                        Q2(S,Z,I,M,J,N)=L=Q(S,Z,I,M,J,N);
$offtext
*-------------------------------------------------------------------------
*EQ (103)
SHELL(Z,I,J)$(SUM[S,ALLOW(S,Z,I,J)]>= 1 AND FREEH(I) AND FREEC(J)
AND   BIF(Z,I,J)=0 )..
                        PAR(Z,I,J)=L=ASHELLMAX*USHELL(Z,I,J);
*-------------------------------------------------------------------------
*EQ (104)
SHELL_B(K,Z,I,J)$(SUM[S,ALLOW(S,Z,I,J)]>= 1 AND FREEH(I) AND FREEC(J)
 AND BIF(Z,I,J)=1)..
                    PAR_B(K,Z,I,J)=L=ASHELLMAX*USHELL_B(K,Z,I,J);
*-------------------------------------------------------------------------
*EQ (105)
* THIS EQUATION WILL NEED FIXING WHEN MORE SCENARIOS ARE ADDED.

TOTALCOST.. TCOST =E=  SUM(I$(HU(I) AND FREEH(I)),CHU(I)*FHU(I)*DTHU(I))
            + SUM(J$(CU(J) AND FREEC(J)),CCU(J)*FCU(J)*DTCU(J))
 + SUM((Z,I,J) $(OPT=0 AND SUM[S,ALLOW(S,Z,I,J)]>= 1 AND FREEH(I) AND FREEC(J)
```

```
      AND BIF(Z,I,J)=0),
     CFU*USHELL(Z,I,J)+ CFE* SUM(S,NHE(S,Z,I,J)))
*
+ SUM((K,Z,I,J)$(OPT=0 AND SUM[S,ALLOW(S,Z,I,J)]>= 1 AND FREEH(I) AND FREEC(J)
      AND BIF(Z,I,J)=1),
      CFU*USHELL_B(K,Z,I,J)+ CFE* SUM(S,NHE(S,Z,I,J)))

 + SUM((Z,I,J)$(OPT=0 AND SUM[S,ALLOW(S,Z,I,J)]>= 1 AND FREEH(I) AND FREEC(J)),
      CAE*PAR(Z,I,J))

* RETROFIT PART
+SUM((S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
 AND BIF(Z,I,J)=0) ,CFU*(USHELL(Z,I,J)-USHELL0(Z,I,J))
          + CFE* (NHE(S,Z,I,J)-NHE0(S,Z,I,J)))

+SUM((S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
 AND BIF(Z,I,J)=0), CAE_ADD*DPAR_E(Z,I,J)+CAE*PAR_N(S,Z,I,J))


   +SUM((S,K,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J) AND ALLOW(S,Z,I,J)=1
   AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)
   ,CAE_ADD*DPAR_E_B(K,Z,I,J)+CAE*PAR_N_B(K,Z,I,J))

*a fixed cost for adding area to the existing units is added

    +SUM((S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1
   AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=0),
                        CFAE_ADD*T(Z,I,J)+CFAE_RED*T2(Z,I,J))
                                                ;

* A fixed cost to relocate is also added.    Change to make it in BIF=1 too

*-------------------------------------------------------------------------
*EQ (106a,b) CONSISTENCY: Number of exchangers smaller than the number of shells
* Probably not needed, but it does not hurt having them

KMAX1(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=0)..
 NHE(S,Z,I,J) =L= USHELL(Z,I,J) ;
*
KMAX2(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
NHE(S,Z,I,J) =L= SUM(K,USHELL_B(K,Z,I,J)) ;
*-------------------------------------------------------------------------
*EQ (107a,b) limits on the number of shells.

UMAX1(S,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=0)..
USHELL(Z,I,J) =L= USHELLMAX ;
```

```
UMAX2(S,K,Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
USHELL_B(K,Z,I,J) =L= USHELLMAX ;
*-------------------------------------------------------------------------
*EQ 108  LIMIT THE NUMBER OF EXCHANGERS
TOTNEXCH_MAX(S).. SUM((Z,I,J), NHE(S,Z,I,J))=L=TOTNEXCHMAX;
*-------------------------------------------------------------------------
*EQ 109   MINIMUM NUMBER OF EXCHANGERS
TOTNEXCH_MIN(S).. SUM((Z,I,J)$(ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)),
NHE(S,Z,I,J))=G=TOTNEXCHMIN;



**************************EquationS for Retrofit*******************************
*******************************************************************************
*-------------------------------------------------------------------------
*EQ(R1)
AREA_REST1(S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
            AND BIF(Z,I,J)=0)..
   PAR(Z,I,J)=L=AEX(Z,I,J)+DPAR_E(Z,I,J)+PAR_N(S,Z,I,J);
*-------------------------------------------------------------------------
*EQ(R2)  maximum area added to an existing shell

AREA_REST2(S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
            AND BIF(Z,I,J)=0)..
        DPAR_E(Z,I,J)=L=T(Z,I,J)*D_AEX_MAX(Z,I,J);

*-------------------------------------------------------------------------
*EQ(R5)
AREA_REST3(S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
            AND BIF(Z,I,J)=0)..
   PAR_N(S,Z,I,J)=L=ASHELLMAX*(USHELL(Z,I,J)-USHELL0(Z,I,J));
*-------------------------------------------------------------------------
*EQ(R6)
* ALREADY ACCOUNTED FOR IN ADDED EQUATIONS
*-------------------------------------------------------------------------
*EQ(R7)
AREA_REST4(S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J)
            AND BIF(Z,I,J)=0)..
   AEX(Z,I,J)-PAR(Z,I,J)=L=AEX(Z,I,J)*T2(Z,I,J);
*-------------------------------BIF=1-------------------------------------
$ONTEXT
*EQ(R9)
AREA_REST1_B(S,K,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J) AND ALLOW(S,Z,I,J)=1
            AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
```

```
   PAR_B(K,Z,I,J)=L=SUM(KK$(ORD(KK) LE NHE0(S,Z,I,J)),AEX_B(KK,Z,I,J)
            *DELTA(Z,I,J,KK,K))+DPAR_E_B(K,Z,I,J)+PAR_N_B(K,Z,I,J);
*-------------------------------------------------------------------------
*EQ(R10) maximum area added to an existing shell

AREA_REST2_B(S,K,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J) AND ALLOW(S,Z,I,J)=1
        AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
   DPAR_E_B(K,Z,I,J)=L=SUM(KK$(ORD(KK) LE NHE0(S,Z,I,J)),
            (AEX_B(KK,Z,I,J))*DELTAPSIA(Z,I,J,KK,K));
* THESE EQUATIONS ARE THE LINEARIZATION OF DELTA*PSIA
AREA_REST2_B1(S,K,KK,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J)
      AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
DELTAPSIA(Z,I,J,KK,K)=L=DELTA(Z,I,J,KK,K);
AREA_REST2_B2(S,K,KK,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J)
      AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
DELTAPSIA(Z,I,J,KK,K)=L=PSIA(Z,I,J,KK);
AREA_REST2_B3(S,K,KK,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J)
      AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
DELTAPSIA(Z,I,J,KK,K)=L=DELTA(Z,I,J,KK,K)+PSIA(Z,I,J,KK)-1;

*-------------------------------------------------------------------------
*EQ(R11)
AREA_REST3_B(S,K,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J) AND ALLOW(S,Z,I,J)=1
            AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
PAR_N_B(K,Z,I,J)=L=
      ASHELLMAX*(USHELL_B(K,Z,I,J)-SUM(KK$(ORD(KK) LE NHE0(S,Z,I,J)),
            DELTA(Z,I,J,KK,K)*USHELL0_B(K,Z,I,J)));
*-------------------------------------------------------------------------
*EQ(R12)
AREA_REST4_B(S,K,Z,I,J)$(OPT=1 AND ORD(K) LE KMAX(Z,I,J) AND ALLOW(S,Z,I,J)=1
            AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
   SUM(KK$(ORD(KK) LE NHE0(S,Z,I,J)),DELTA(Z,I,J,KK,K))=L=1;
*-------------------------------------------------------------------------
*EQ(R13)
AREA_REST5_B(S,K,Z,I,J)$(OPT=1 AND ORD(K) LE NHE0(S,Z,I,J) AND ALLOW(S,Z,I,J)=1
            AND FREEH(I) AND FREEC(J) AND BIF(Z,I,J)=1)..
   SUM(KK$(ORD(KK) LE KMAX(Z,I,J)),DELTA(Z,I,J,K,KK))=L=1;
*-------------------------------------------------------------------------
*EQ(R14)
AREA_REST6_B(S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I)
            AND FREEC(J) AND BIF(Z,I,J)=1)..
SUM((K,KK)$(ORD(K) LE KMAX(Z,I,J) AND ORD(KK) LE NHE0(S,Z,I,J)),
      DELTA(Z,I,J,KK,K)) =E= NHE0(S,Z,I,J);
*-------------------------------------------------------------------------
$OFFTEXT
*EQ(R15)
```

```
ADD_REST7(S,Z,I,J)$(OPT=1 AND ALLOW(S,Z,I,J)=1 AND FREEH(I) AND FREEC(J))..
                NHE(S,Z,I,J)-NHE0(S,Z,I,J)=L= NHE_ADD(Z,I,J);
*-------------------------------------------------------------------------
*EQ(R16)
ADD_REST8(S,Z,I,M,J,JJ)$(OPT=1 AND HOT(S,I,M)=1 AND ALLOW(S,Z,I,J)=1
     AND FREEH(I) AND FREEC(J) AND FREEC(JJ) AND NOTALLOW_H_ORD(Z,I,J,JJ))..
   SUM(L$(HOT(S,I,L) = 1 and ORD(L) LE ORD(M)),NHE_M0(S,Z,I,J,L))=L=
        SUM(L$(HOT(S,I,L) = 1 AND ORD(L) LE ORD(M)),NHE_M1(S,Z,I,JJ,L));
*-------------------------------------------------------------------------
*EQ(R17)
ADD_REST9(S,Z,J,N,I,II)$(OPT=1 AND COLD(S,J,N)=1 AND ALLOW(S,Z,I,J)=1
     AND FREEH(I) AND FREEH(II) AND FREEC(J) AND NOTALLOW_C_ORD(Z,J,I,II))..
   SUM(L$(COLD(S,J,L)=1 AND ORD(L) LE ORD(N)),NHE_N0(S,Z,I,J,L))=L=
      SUM(L$(COLD(S,J,L)=1 AND ORD(L) LE ORD(N)),NHE_N1(S,Z,II,J,L));

*-------------------------------------------------------------------------

* ADDED SUBROUNTINE TO CHECK FOR FEASIBILITY

EQUATIONS

 HBHS_aux(S,I,M)
 HBCS_aux(S,J,N)
 Aux1 ;

Positive variables
DHHP(S,I,M), DHCP(S,J,N)   ;

Variable
sumZ ;


*-------------------------------------------------------------
*EQ (3)
HBHS_aux(S,I,M)$(HOT(S,I,M)=1 AND NOT HU(I) AND FREEH(I) AND NIH(I)=0)..
 DHH(S,I,M)=E=SUM((Z,N,J)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND COLD(S,J,N)=1
        AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N))
      + DHHP(S,I,M);
*-------------------------------------------------------------------------
*EQ (4)
HBCS_aux(S,J,N)$(COLD(S,J,N)=1 AND NOT CU(J) AND FREEC(J) AND NIC(J)=0)..
 DHC(S,J,N)=E=SUM((Z,M,I)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND HOT(S,I,M)=1
        AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),Q(S,Z,I,M,J,N))
      + DHCP(S,J,N);
*-------------------------------------------------------------
* Auxiliary equation
```

```
Aux1..
    sumZ  =e= sum((S,I,M),DHHP(S,I,M)) + sum((S,J,N), DHCP(S,J,N)) ;


Model Checking /
HBHU
HBCU
HBHS_aux
HBCS_aux
TRANSFOR_M
TRANSFOR_N
HBHS_NI
HBCS_NI
NOISOH
NOISOC

* heat exchanger definition and counting
BINARY_M1
BINARY_M2
BINARY_M1_B
BINARY_M2_B
BINARY_N1
BINARY_N2
BINARY_N1_B
BINARY_N2_B
BINARY_M5
BINARY_M5b
BINARY_M3

BINARY_M8
BINARY_M9
BINARY_M6
BINARY_M3_B

BINARY_N5
BINARY_N5b
BINARY_N3

BINARY_N8
BINARY_N9
BINARY_N6
BINARY_N3_B

HE_COUNT_M0
HE_COUNT_M0_B
HE_COUNT_N0
```

HE_COUNT_N0_B
HE_COUNT_M1
HE_COUNT_M1_B
HE_COUNT_N1
HE_COUNT_N1_B
NEXCH
NEXCH_B

* heat transfer consistency

BIF_3
BIF_4
BIF_11
BIF_12
BIF_6
BIF_9
BIF_5
BIF_8
BIF_10
BIF_7
BIF_1
BIF_2

* temperature difference enforcing

FEAS_BEG_SP
FEAS_BEG_B_SP
FEAS_END_SP
FEAS_END_B_SP
FEAS_BEG3
FEAS_BEG
FEAS_BEG2
FEAS_END3
FEAS_END
FEAS_END2
FEAS_BEG4_B
FEAS_BEG2_B
FEAS_BEG1_B
FEAS_BEG3_B
FEAS_END3_B
FEAS_END_B
FEAS_END2_B

Aux1

/;

```
file res /Results.txt/ ;
put res  ;

parameters
        FlagH(I)
        FlagC(J)   ;


 OPTION LIMROW =5000;
 OPTION LIMCOL =5000;
 OPTION SOLPRINT = OFF;
 OPTION OPTCR=0    ;
 OPTION OPTCA=0    ;

SOLVE Checking USING MIP MINIMIZING sumZ ;

*display DHH, DHC ;
*display Q.l, DHHP.l, DHCP.l ;

If ((sumZ.l >= 0.001),

 FlagH(I)  = sum((S,M), DHHP.l(S,I,M))   ;
 FlagC(J)  = sum((S,N), DHCP.l(S,J,N))   ;


  loop(I,

    If  ((FlagH(I) >= 0.001),
     put ' improper interval division in stream ', I.tl  ;
    );
  );

  put /;

   loop(J,

    If  ((FlagC(J) >= 0.001),
     put ' improper interval division in stream ', J.tl ;
    );
  );

abort ' THE INTERVAL IS NOT DIVIDED PROPERLY, PLEASE TRY AGAIN '

);
```

MODEL MPERIOD /
HBHU
HBCU
HBHS
HBCS
TRANSFOR_M
TRANSFOR_N
HBHS_NI
HBCS_NI
NOISOH
NOISOC
BINARY_M1
BINARY_M2
BINARY_M1_B
BINARY_M2_B
BINARY_N1
BINARY_N2
BINARY_N1_B
BINARY_N2_B
BINARY_M5
BINARY_M5b
BINARY_M3
*BINARY_M4
BINARY_M8
BINARY_M9
BINARY_M6
*BINARY_M7
BINARY_M3_B
*BINARY_N4
BINARY_N5
BINARY_N5b
BINARY_N3
*BINARY_N4
BINARY_N8
BINARY_N9
BINARY_N6
*BINARY_N7
BINARY_N3_B
HE_COUNT_M0
HE_COUNT_M0_B
HE_COUNT_N0
HE_COUNT_N0_B
HE_COUNT_M1

HE_COUNT_M1_B
HE_COUNT_N1
HE_COUNT_N1_B
NEXCH
NEXCH_B

BIF_3
BIF_4
BIF_11
BIF_12
BIF_6
BIF_9
BIF_5
BIF_8
BIF_10
BIF_7
BIF_1
BIF_2

FEAS_M_01
FEAS_M_01_B
FEAS_M_02
FEAS_M_02_B
FEAS_M_03
FEAS_M_03_B
*FEAS_M_04
FEAS_M_2
FEAS_M_1
FEAS_M_3
FEAS_M_4
FEAS_M_3_B_2
FEAS_M_3_B_1
FEAS_M_4_B
FEAS_M_1_SP
FEAS_M_1_SP_B
FEAS_N_01
FEAS_N_01_B
FEAS_N_02
FEAS_N_02_B
FEAS_N_03
FEAS_N_03_B
*FEAS_N_04
FEAS_N_2
FEAS_N_1
FEAS_N_3
FEAS_N_4

FEAS_N_3_B_2
FEAS_N_3_B_1
FEAS_N_4_B
FEAS_N_1_SP
FEAS_N_1_SP_B
FEAS_BEG_SP
FEAS_BEG_B_SP
FEAS_END_SP
FEAS_END_B_SP
FEAS_BEG3
FEAS_BEG
FEAS_BEG2
FEAS_END3
FEAS_END
FEAS_END2
FEAS_BEG4_B
FEAS_BEG2_B
FEAS_BEG1_B
FEAS_BEG3_B
FEAS_END3_B
FEAS_END_B
FEAS_END2_B
PAREQ
*BIF_13_2
*BIF_13_2
*BIF_13_1
*BIF_13_1
*BIF_14
*BIF_15
*BIF_16
*BIF_17
*BIF_18
SHELL
SHELL_B

TOTALCOST
* EXTRA EQUATIONS NOT IN PAPER
KMAX1
KMAX2
UMAX1
UMAX2
TOTNEXCH_MAX
TOTNEXCH_MIN
**********ADD FOR RETROFIT**********
AREA_REST1
AREA_REST2

```
AREA_REST3
AREA_REST4
$ONTEXT
* BIF=1 DOES NOT WORK WELL
AREA_REST1_B
AREA_REST2_B
AREA_REST2_B1
AREA_REST2_B2
AREA_REST2_B3
AREA_REST3_B
AREA_REST4_B
AREA_REST5_B
AREA_REST6_B
$OFFTEXT
ADD_REST7
ADD_REST8
ADD_REST9 /;


* PMATCH.PRIOR(Z,I,J) = 0.5;
* HUMATCH.PRIOR(Z,S,J)=0.75;
* CUMATCH.PRIOR(Z,I,W)=0.75;

SOLVE MPERIOD USING MIP MINIMIZING TCOST ;

PARAMETER QMATCH(S,Z,I,J);
QMATCH(S,Z,I,J)=SUM((M,N)$(D(S,Z,M,N)=1 AND TL(S,N) LT TU(S,M) AND D(S,Z,M,N)=1
AND COLD(S,J,N) AND ALLOW_H(S,Z,I,M,J)=1 AND ALLOW_C(S,Z,J,N,I)=1),
                                    Q.L(S,Z,I,M,J,N));

PARAMETER FH_H(S,Z,I,J,M) Flowrate of hot stream per HEx;
FH_H(S,Z,I,J,M)$[HOT(S,I,M)]=QNEW_M.L(S,Z,I,J,M)/[(TU(S,M)-TL(S,M))*CPH(S,I,M)]

PARAMETER FC_C(S,Z,J,I,M) Flowrate of hot stream per HEx;
FC_C(S,Z,J,I,M)$[COLD(S,J,M)]=QNEW_N.L(S,Z,I,J,M)/[(TU(S,M)-TL(S,M))*CPC(S,J,M)]

PARAMETER UTILITY_COST ;
UTILITY_COST=
SUM(I$(HU(I) AND FREEH(I)),CHU(I)*FHU.L(I)*DTHU(I))
        + SUM(J$(CU(J) AND FREEC(J)),CCU(J)*FCU.L(J)*DTCU(J))
PARAMETER HOT_UTILITY_COST ;
HOT_UTILITY_COST=
SUM(I$(HU(I) AND FREEH(I)),CHU(I)*FHU.L(I)*DTHU(I))

PARAMETER COLD_UTILITY_COST ;
COLD_UTILITY_COST=
```

```
SUM(J$(CU(J) AND FREEC(J)),CCU(J)*FCU.L(J)*DTCU(J))

PARAMETER AREA_COST ;
AREA_COST=
SUM((Z,I,J),
      CAE*PAR.L(Z,I,J))
PARAMETER UNIT_COST ;
UNIT_COST=
SUM((Z,I,J),   CFE* SUM(S,NHE.L(S,Z,I,J)))
PARAMETER SHELL_COST ;
SHELL_COST=
SUM((Z,I,J), CFU*USHELL.L(Z,I,J))
PARAMETER SHELLS;
SHELLS=
SUM((Z,I,J), USHELL.L(Z,I,J))


DISPLAY DPAR_E.l;
DISPLAY PAR_N.l;
OPTION DHH:3:0:1; DISPLAY DHH;
OPTION DHC:3:0:1; DISPLAY DHC;
OPTION HHEAD:3:2:1; DISPLAY HHEAD;
OPTION CHEAD:3:2:1; DISPLAY CHEAD;
OPTION ALLOW:3:0:1; DISPLAY ALLOW;
OPTION ALLOW_H:3:0:1; DISPLAY ALLOW_H;
OPTION ALLOW_C:3:0:1; DISPLAY ALLOW_C;
OPTION ALLOW_2:2:0:1; DISPLAY ALLOW_2;
OPTION HOT:2:0:1; DISPLAY HOT;
OPTION COLD:2:0:1; DISPLAY COLD;

 OPTION Q:3:0:1; DISPLAY Q.L;
 OPTION QNEW_M:3:0:1; DISPLAY QNEW_M.L;
 OPTION QNEW_N:3:0:1; DISPLAY QNEW_N.L;
 OPTION QNEW2_M:3:0:1; DISPLAY QNEW2_M.L;
 OPTION QNEW2_N:3:0:1; DISPLAY QNEW2_N.L;
 OPTION Y_M:3:0:1; DISPLAY Y_M.L;
 OPTION Y_N:3:0:1; DISPLAY Y_N.L;
 OPTION NHE_M0:3:0:1; DISPLAY NHE_M0.L;
 OPTION NHE_M1:3:0:1; DISPLAY NHE_M1.L;
 OPTION NHE_N0:3:0:1; DISPLAY NHE_N0.L;
 OPTION NHE_N1:3:0:1; DISPLAY NHE_N1.L;
 OPTION Y_M_B:3:0:1; DISPLAY Y_M_B.L;
 OPTION Y_N_B:3:0:1; DISPLAY Y_N_B.L;
 OPTION NHE_M0_B:3:0:1; DISPLAY NHE_M0_B.L;
 OPTION NHE_M1_B:3:0:1; DISPLAY NHE_M1_B.L;
 OPTION NHE_N0_B:3:0:1; DISPLAY NHE_N0_B.L;
```

```
 OPTION NHE_N1_B:3:0:1; DISPLAY NHE_N1_B.L;
 OPTION ALFA_M:3:0:1; DISPLAY ALFA_M.L;
 OPTION ALFA_N:3:0:1; DISPLAY ALFA_N.L;
 OPTION NHE:3:0:1; DISPLAY NHE.L;
 OPTION D:3:0:1; DISPLAY D;
OPTION TU:3:0:1; DISPLAY TU;
OPTION TL:3:0:1; DISPLAY TL;
 OPTION LMTD:3:0:1; DISPLAY LMTD;
 OPTION QH:3:0:1; DISPLAY QH.L;
 OPTION QC:3:0:1; DISPLAY QC.L;
* OPTION X_B:3:0:1; DISPLAY X_B.L;
* OPTION Q2:3:0:1; DISPLAY Q2.L;
 OPTION B1:3:0:1; DISPLAY B1.L;
 OPTION FHU:3:0:1; DISPLAY FHU.L;
 OPTION FCU:3:0:1; DISPLAY FCU.L;
* OPTION NHE2:3:0:1; DISPLAY NHE2;
 OPTION NHE:3:0:1; DISPLAY NHE.L;
 OPTION USHELL:3:0:1; DISPLAY USHELL.L;
 OPTION USHELL_B:3:0:1; DISPLAY USHELL_B.L;

 OPTION PAR:3:0:1; DISPLAY PAR.L;
* OPTION PAR_B:3:0:1; DISPLAY PAR_B.L;
 OPTION QMATCH:3:0:1; DISPLAY QMATCH;
 OPTION FH_H:3:0:1; DISPLAY FH_H;
 OPTION FC_C:3:0:1; DISPLAY FC_C;
 OPTION UTILITY_COST:3:0:1; DISPLAY UTILITY_COST;
 OPTION HOT_UTILITY_COST:3:0:1; DISPLAY HOT_UTILITY_COST;
 OPTION COLD_UTILITY_COST:3:0:1; DISPLAY COLD_UTILITY_COST;
 OPTION AREA_COST:3:0:1; DISPLAY AREA_COST;
 OPTION UNIT_COST:3:0:1; DISPLAY UNIT_COST;
 OPTION SHELL_COST:3:0:1; DISPLAY SHELL_COST;
 OPTION SHELLS:3:0:1; DISPLAY SHELLS;OPTION FC_C:3:0:1; DISPLAY TCOST.L
```

Appendix D Sumary Report of HEN1

Table D1 Column T1 profile summary by using Light Arabia crude

Column T1 Profile Summary						
Tray	**Temperature C**	**Net Liq. Rate kg-mol / sec**	**Net Vap. Rate kg-mol / sec**	**Feed To Tray kg-mol / sec**	**Product From Tray kg-mol / sec**	**Heater Duty kW-hr / sec**
1	113.37375	4.562580	1.934848	4.424735	2.616466	14.84326
2	114.25989	4.581652	2.754317			
3	116.25237	4.634978	2.773389			
4	120.25083	4.737645	2.826715			
5	128.13825	0.460004	2.929382		4.424735	
6	146.08147	0.464557	3.076477			
7	152.20482	0.455916	3.081029			
8	155.35009	0.447063	3.072389			
9	157.42998	0.438670	3.063535			
10	159.08019	0.430301	3.055142			
11	160.58552	0.421196	3.046773			
12	162.13767	0.410002	3.037669			
13	163.9709	0.393823	3.026475			
14	166.54006	0.365454	3.010295			
15	171.00028	0.307092	2.981926			
16	180.59132	0.000322	2.923565		0.206092	
17	199.86324	0.723309	2.822887	0.549938		7.540088
18	217.55568	0.786229	2.995935			
19	227.98938	0.799716	3.058855			
20	236.99085	0.076362	3.072342		0.693208	
21	249.38128	0.906933	3.042196	0.529582		12.62074
22	271.20724	1.025125	3.343185			
23	281.14945	1.069583	3.461377			
24	287.02414	1.079787	3.505835			
25	291.57434	0.540336	3.516039		0.529582	
26	296.16879	0.526732	3.506170			
27	299.03888	0.513896	3.492566			
28	301.11185	0.501547	3.479730			
29	302.81668	0.488454	3.467381			
30	304.42718	0.472051	3.454288			
31	306.25265	0.443969	3.437885			
32	309.09824	0.336359	3.409803			
33	319.93806	0.498683	3.302193	0.9921		
34	312.25158	0.428253	2.472417			
35	308.97086	0.401957	2.401987			
36	308.06581	0.386197	2.375691			
37	310.07674	0.365204	2.359931			
38	320.85042	0.246603	2.338937	2.220337	0.246603	

Table D2 Stream data summary of HEN1 by using Light Arabia crude

Stream (Summary)	UOM	CRUDE FEED	KERO	MCR
Name		CRUDE FEED	KERO	MCR
Phase		Liquid	Liquid	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.992100039	0.20609221	0.14326922
Total Mass Rate	kg / sec	231.9400024	40.0000116	35.1699979
Temperature	C	29.9999939	180.591319	236.990854
Pressure	kg/cm2	6.131808642	2.05000006	2.05000006
Total Molecular Weight		233.7869099	194.087931	245.481867
Total Specific Enthalpy	kW-hr / kg	0.016773721	0.10598366	0.14311428
Total Cp	kcal/kg-K	0.442949727	0.59387347	0.63377459

Table D2 (Cotinued)

Stream (Summary)	UOM	NAPHTHA	PA1	PA2
Name		NAPHTHA	PA1	PA2
Phase		Vapor	Mixed	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	1.934848382	4.52027401	0.55098704
Total Mass Rate	kg / sec	66.92595209	636	135
Temperature	C	113.3737462	128.200006	236.899987
Pressure	kg/cm2	2.050000063	2.05000006	2.05000006
Total Molecular Weight		34.58976565	140.699434	245.014837
Total Specific Enthalpy	kW-hr / kg	0.397416084	0.07441648	0.14309606
Total Cp	kcal/kg-K	0.484108352	0	0

Table D2 (Cotinued)

Stream (Summary)	UOM	PA3	S1	S10
Name		PA3	S1	S10
Phase		Mixed	Liquid	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.530975848	0.99210003	0.99210003
Total Mass Rate	kg / sec	146	231.940002	231.940002
Temperature	C	290.8000122	122.236628	360.000024
Pressure	kg/cm2	2.050000063	18.3548918	18.3548918
Total Molecular Weight		274.9654258	233.786909	233.786909
Total Specific Enthalpy	kW-hr / kg	0.182391826	0.06900069	0.24927911
Total Cp	kcal/kg-K	0	0.53582585	0

Table D2 (Cotinued)

Stream (Summary)	UOM	S11	S12	S13
Name		S11	S12	S13
Phase		Liquid	Liquid	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.55098704	0.55098704	0.53097584
Total Mass Rate	kg / sec	135	135	146
Temperature	C	193.0041425	152.846508	214.992444
Pressure	kg/cm2	2.050000063	2.05000006	2.05000006
Total Molecular Weight		245.0148375	245.014837	274.965425
Total Specific Enthalpy	kW-hr / kg	0.111641332	0.08455902	0.12558645
Total Cp	kcal/kg-K	0.597316249	0.56219087	0.61269582

Table D2 (Cotinued)

Stream (Summary)	UOM	S14	S15	S17
Name		S14	S15	S17
Phase		Liquid	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.530975848	4.52027401	0.24660349
Total Mass Rate	kg / sec	146	636	117.564390
Temperature	C	171.8067918	90.3000122	320.850416
Pressure	kg/cm2	2.050000063	2.05000006	2.05000006
Total Molecular Weight		274.9654258	140.699434	476.734491
Total Specific Enthalpy	kW-hr / kg	0.095732952	0.05052944	0.19910854
Total Cp	kcal/kg-K	0.575768922	0.52393561	0.68181179

Table D2 (Cotinued)

Stream (Summary)	UOM	S18	S19	S2
Name		S18	S19	S2
Phase		Vapor	Water	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	2.220337431	0.68161801	0.99210003
Total Mass Rate	kg / sec	40	12.2795392	231.940002
Temperature	C	475.0000244	113.373746	31.3211933
Pressure	kg/cm2	4.092375905	2.05000006	18.3548918
Total Molecular Weight		18.01527977	18.0152797	233.786909
Total Specific Enthalpy	kW-hr / kg	0.952164939	0.13204362	0.01716728
Total Cp	kcal/kg-K	0.505492884	1.01151104	0.44515247

Table D2 (Cotinued)

Stream (Summary)	UOM	S20	S21	S22
Name		S20	S21	S22
Phase		Mixed	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.34936144	0.34936144	0.5309758
Total Mass Rate	kg / sec	75.1700096	75.1700096	146
Temperature	C	207.093283	237.764807	275.82602
Pressure	kg/cm2	2.05000006	2.05000006	2.0500006
Total Molecular Weight		215.164011	215.164011	274.96542
Total Specific Enthalpy	kW-hr / kg	0.12335606	0.14611189	0.1706758
Total Cp	kcal/kg-K	0	0	0.6662606

Table D2 (Cotinued)

Stream (Summary)	UOM	S3	S4	S5
Name		S3	S4	S5
Phase		Liquid	Liquid	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.992100039	0.99210003	4.52027401
Total Mass Rate	kg / sec	231.9400024	231.940002	636
Temperature	C	147.0033716	175.289291	98.4201401
Pressure	kg/cm2	18.35489183	18.3548918	2.05000006
Total Molecular Weight		233.7869099	233.786909	140.699434
Total Specific Enthalpy	kW-hr / kg	0.084763867	0.10355584	0.05551362
Total Cp	kcal/kg-K	0.558585755	0.58375848	0.53160756

Table D2 (Cotinued)

Stream (Summary)	UOM	S6	S7	S8	S9
Name		S6	S7	S8	S9
Phase		Liquid	N/A	Liquid	Liquid
Thermodynamic System		GS01	N/A	GS01	GS01
Total Molar Rate	kg-mol / sec	0.992100039	0	0.992100	0.9921
Total Mass Rate	kg / sec	231.9400024	N/A	231.9400	231.94
Temperature	C	166.9999939	N/A	193.7648	233.3245
Pressure	kg/cm2	18.35489183	N/A	18.35489	18.35489
Total Molecular Weight		233.7869099	N/A	233.7869	233.7869
Total Specific Enthalpy	kW-hr / kg	0.097963209	N/A	0.116271	0.144654
Total Cp	kcal/kg-K	0.576472135	N/A	0.599729	0.635377

Appendix E Sumary Report of HEN2

Table E1 Column T1 profile summary by using Rebco crude

Column T1 Profile Summary						
Tray	**Temperature °C**	**Net Liq. Rate kg-mol / sec**	**Net Vap. Rate kg-mol / sec**	**Feed To Tray kg-mol / sec**	**Product From Tray kg-mol / sec**	**Heater Duty kW-hr / sec**
1	113.0704	6.255764	1.625073	6.077115	2.564925	17.6721
2	114.0163	6.292027	2.743574			
3	114.2605	6.293655	2.779837			
4	115.8035	6.331916	2.781465			
5	123.0888	0.452008	2.819726		6.077115	
6	145.1564	0.46671	3.016933			
7	152.0708	0.459703	3.031635			
8	155.5241	0.451158	3.024628			
9	157.7859	0.442801	3.016084			
10	159.5768	0.434342	3.007726			
11	161.212	0.425028	2.999267			
12	162.9054	0.413334	2.989953			
13	164.9332	0.395608	2.978259			
14	167.8913	0.362295	2.960533			
15	173.3937	0.296981	2.92722			
16	184.8802	0.011957	2.861907		0.19964	
17	202.713	0.754605	2.776521	0.56133		7.86829
18	221.6603	0.831318	2.957839			
19	232.1671	0.858187	3.034553			
20	240.1043	0.13784	3.061422		0.707567	
21	249.571	1.02074	3.048642	0.55407		11.9937
22	268.8202	1.151183	3.377472			
23	277.0409	1.196323	3.507915			
24	281.8024	1.202729	3.553054			
25	285.7264	0.633077	3.55946		0.55407	
26	290.1025	0.615546	3.543879			
27	293.168	0.600464	3.526347			
28	295.4847	0.587226	3.511266			
29	297.3557	0.574351	3.498027			
30	299.0138	0.559408	3.485153			
31	300.7286	0.535072	3.470209			
32	303.1577	0.407796	3.445874			
33	315.0283	0.501369	3.318597	0.915382		
34	305.6954	0.412331	2.496789			
35	301.4271	0.377021	2.407751			
36	300.0296	0.35561	2.372441			
37	302.42	0.328651	2.35103			
38	317.0343	0.224917	2.324071	2.220337	0.224917	

Table E2 Stream data summary of HEN1 by using Rebco crude

Stream (Summary)	UOM	CRUDE FEED	KERO	MCR
Name		CRUDE FEED	KERO	MCR
Phase		Liquid	Liquid	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.915381727	0.1996396	0.1462369
Total Mass Rate	kg / sec	231.9400024	40	35.169998
Temperature	C	29.9999939	184.88015	240.10428
Pressure	kg/cm2	6.131808642	2.0500000	2.0500000
Total Molecular Weight		253.3806342	200.36097	240.50012
Total Specific Enthalpy	kW-hr / kg	0.017388703	0.1086721	0.1458323
Total Cp	kcal/kg-K	0.439954508	0.5973005	0.6376548

Table E2 (Cotinued)

Stream (Summary)	UOM	NAPHTHA	PA1	PA2
Name		NAPHTHA	PA1	PA2
Phase		Vapor	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	1.62507256	6.07503564	0.5613307
Total Mass Rate	kg / sec	56.10887519	858	135
Temperature	C	113.0703533	123.1	240.1
Pressure	kg/cm2	2.050000063	2.05000006	2.0500000
Total Molecular Weight		34.52699687	141.233739	240.49993
Total Specific Enthalpy	kW-hr / kg	0.395552877	0.07116122	0.1458291
Total Cp	kcal/kg-K	0.48507332	0	0.6376514

Table E2 (Cotinued)

Stream (Summary)	UOM	PA3	S1	S10
Name		PA3	S1	S10
Phase		Liquid	Liquid	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.554068689	0.91538172	0.91538172
Total Mass Rate	kg / sec	146	231.940002	231.940002
Temperature	C	285.6999756	122.090472	360.000024
Pressure	kg/cm2	2.050000063	18.3548918	18.3548918
Total Molecular Weight		263.5052347	253.380634	253.380634
Total Specific Enthalpy	kW-hr / kg	0.179258978	0.06919601	0.24794811
Total Cp	kcal/kg-K	0.675683797	0.53078808	0

Table E2 (Cotinued)

Stream (Summary)	UOM	S11	S12	S13
Name		S11	S12	S13
Phase		Liquid	Liquid	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.561330711	0.56133071	0.5540686
Total Mass Rate	kg / sec	135	135	146
Temperature	C	196.974142	156.960388	213.86027
Pressure	kg/cm2	2.050000063	2.05000006	2.0500000
Total Molecular Weight		240.4999358	240.499935	263.50523
Total Specific Enthalpy	kW-hr / kg	0.114732479	0.08752260	0.1254671
Total Cp	kcal/kg-K	0.602008791	0.56715362	0.6136190

Table E2 (Cotinued)

Stream (Summary)	UOM	S14	S15	S17
Name		S14	S15	S17
Phase		Liquid	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.554068689	6.07503564	0.22491742
Total Mass Rate	kg / sec	146	858	123.729421
Temperature	C	171.5693454	90.3000122	317.034289
Pressure	kg/cm2	2.050000063	2.05000006	2.05000006
Total Molecular Weight		263.5052347	141.233739	550.110428
Total Specific Enthalpy	kW-hr / kg	0.096169185	0.05056405	0.19528159
Total Cp	kcal/kg-K	0.577420563	0.52455655	0.67601545

Table E2 (Cotinued)

Stream (Summary)	UOM	S18	S19	S2
Name		S18	S19	S2
Phase		Vapor	Water	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	2.220337431	0.93985257	0.91538172
Total Mass Rate	kg / sec	40	16.9317070	231.940002
Temperature	C	475.0000244	113.070353	31.3462459
Pressure	kg/cm2	4.092375905	2.05000006	18.3548918
Total Molecular Weight		18.01527977	18.0152797	253.380634
Total Specific Enthalpy	kW-hr / kg	0.952164939	0.13168679	0.01777586
Total Cp	kcal/kg-K	0.505492884	1.01141603	0.44222167

Table E2 (Cotinued)

Stream (Summary)	UOM	S20	S21	S22
Name		S20	S21	S22
Phase		Mixed	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.345876595	0.34587659	0.55406868
Total Mass Rate	kg / sec	75.16999817	75.1699981	146
Temperature	C	210.937562	240.518471	271.163184
Pressure	kg/cm2	2.050000063	2.05000006	2.05000006
Total Molecular Weight		217.3318438	217.331843	263.505234
Total Specific Enthalpy	kW-hr / kg	0.126058397	0.14806407	0.16792907
Total Cp	kcal/kg-K	0	0	0.66460124

Table E2 (Cotinued)

Stream (Summary)	UOM	S3	S4	S5
Name		S3	S4	S5
Phase		Liquid	Liquid	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.915381727	0.91538172	6.07503564
Total Mass Rate	kg / sec	231.9400024	231.940002	858
Temperature	C	147.1062634	174.996005	101.170975
Pressure	kg/cm2	18.35489183	18.3548918	2.05000006
Total Molecular Weight		253.3806342	253.380634	141.233739
Total Specific Enthalpy	kW-hr / kg	0.085033444	0.10347571	0.057261
Total Cp	kcal/kg-K	0.556071001	0.58094338	0.53482065

Table E2 (Cotinued)

Stream (Summary)	UOM	S6	S7	S8	S9
Name		S6	S7	S8	S9
Phase		Liquid	N/A	Liquid	Liquid
Thermodynamic System		GS01	N/A	GS01	GS01
Total Molar Rate	kg-mol / sec	0.91538172	0	0.91538172	0.91538
Total Mass Rate	kg / sec	231.940002	N/A	231.940002	231.94
Temperature	C	166.999993	N/A	193.579016	231.080
Pressure	kg/cm2	18.3548918	N/A	18.3548918	18.3548
Total Molecular Weight		253.380634	N/A	253.380634	253.380
Total Specific Enthalpy	kW-hr / kg	0.09810600	N/A	0.11620575	0.14293
Total Cp	kcal/kg-K	0.57389945	N/A	0.59704489	0.62839

Appendix F Sumary Report of HEN3

Table F1 Column T1 profile summary by using Syrian crude

Column T1 Profile Summary						
Tray	**Temperature °C**	**Net Liq. Rate kg-mol / sec**	**Net Vap. Rate kg-mol / sec**	**Feed To Tray kg-mol / sec**	**Product From Tray kg-mol / sec**	**Heater Duty kW-hr / sec**
1	113.07823	27.117698	1.4111018	26.64367	5.738367	58.27574
2	114.61867	27.379483	6.2123972			
3	115.23111	27.470818	6.4741821			
4	115.59181	27.516595	6.5655166			
5	115.89617	0.7152597	6.6112939		26.64367	
6	130.59588	0.7086043	6.4536339			
7	136.36823	0.6941749	6.4469785			
8	139.42178	0.6808902	6.4325491			
9	141.4275	0.6686699	6.4192644			
10	143.00615	0.6560406	6.4070442			
11	144.48237	0.6414654	6.3944149			
12	146.08706	0.6227345	6.3798397			
13	148.08355	0.5949719	6.3611088			
14	150.99583	0.543695	6.3333462			
15	156.40048	0.4224424	6.2820692			
16	170.18155	0.0018267	6.1608166		0.193678	
17	203.60167	0.5774996	5.9338795	0.451744		8.148466
18	223.54908	0.6203259	6.057808			
19	235.17666	0.6215262	6.1006344			
20	245.01906	0.0024758	6.1018346		0.569432	
21	259.81962	0.65238	6.0522164	0.429100		14.75296
22	288.10568	0.7488765	6.2730198			
23	300.8139	0.787078	6.3695163			
24	307.90777	0.7954661	6.4077178			
25	312.98173	0.3566468	6.4161058		0.429100	
26	317.75704	0.3452595	6.4063873			
27	320.3266	0.3353948	6.3950001			
28	321.99589	0.3260089	6.3851353			
29	323.32129	0.3158257	6.3757495			
30	324.60393	0.3034715	6.3655663			
31	326.06953	0.2851808	6.3532121			
32	328.16099	0.209109	6.3349214			
33	336.92755	0.4222213	6.2588495	0.802746		
34	337.27503	0.3979162	5.6692157			
35	340.16596	0.3938834	5.6449106			
36	344.30355	0.3858247	5.6408777			
37	351.02827	0.3469461	5.6328191			
38	368.23291	0.1928323	5.5939405	5.439826	0.192832	

Table F2 Stream data summary of HEN1 by using Syrian crude

Stream (Summary)	UOM	CRUDE_FEED	KERO	MCR
Name		CRUDE_FEED	KERO	MCR
Phase		Liquid	Liquid	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.802746189	0.19367859	0.11768776
Total Mass Rate	kg / sec	231.9400024	39.9999996	35.1700394
Temperature	C	29.9999939	170.181549	245.019056
Pressure	kg/cm2	6.131808642	2.05000006	2.05000006
Total Molecular Weight		288.9331717	206.527723	298.841936
Total Specific Enthalpy	kW-hr / kg	0.017778207	0.09660675	0.14413541
Total Cp	kcal/kg-K	0.427576173	0.57440106	0.62664415

Table F2 (Cotinued)

Stream (Summary)	UOM	NAPHTHA	PA1	PA2
Name		NAPHTHA	PA1	PA2
Phase		Vapor	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	1.411101763	25.8277676	0.4494182
Total Mass Rate	kg / sec	47.90183528	3567	135
Temperature	C	113.0782325	115.999993	244.80001
Pressure	kg/cm2	2.050000063	2.05000006	2.0500000
Total Molecular Weight		33.94640737	138.107174	300.38835
Total Specific Enthalpy	kW-hr / kg	0.399768931	0.06733130	0.1439043
Total Cp	kcal/kg-K	0.483096097	0	0.6263398

Table F2 (Cotinued)

Stream (Summary)	UOM	PA3	S1	S10
Name		PA3	S1	S10
Phase		Liquid	Liquid	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.426267897	0.80274618	0.8027461
Total Mass Rate	kg / sec	146	231.940002	231.94000
Temperature	C	314.3999878	112.803708	360.00002
Pressure	kg/cm2	2.050000063	18.3548918	18.354891
Total Molecular Weight		342.5076135	288.933171	288.93317
Total Specific Enthalpy	kW-hr / kg	0.194716071	0.06264130	0.2414311
Total Cp	kcal/kg-K	0.676124204	0.50928804	0

Table F2 (Cotinued)

Stream (Summary)	UOM	S11	S12	S13
Name		S11	S12	S13
Phase		Liquid	Liquid	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.449418219	0.44941821	0.4262678
Total Mass Rate	kg / sec	135	135	146
Temperature	C	200.0689465	155.777721	221.21941
Pressure	kg/cm2	2.050000063	2.05000006	2.0500000
Total Molecular Weight		300.3883558	300.388355	342.50761
Total Specific Enthalpy	kW-hr / kg	0.112260307	0.08294137	0.1252469
Total Cp	kcal/kg-K	0.589837313	0.54793992	0.6044922

Table F2 (Cotinued)

Stream (Summary)	UOM	S14	S15	S17
Name		S14	S15	S17
Phase		Liquid	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.426267897	25.8277676	0.1928323
Total Mass Rate	kg / sec	146	3567	128.91110
Temperature	C	169.8125126	90.3000122	368.23290
Pressure	kg/cm2	2.050000063	2.05000006	2.0500000
Total Molecular Weight		342.5076135	138.107174	668.51401
Total Specific Enthalpy	kW-hr / kg	0.090513281	0.04985370	0.2310329
Total Cp	kcal/kg-K	0.556998373	0.51705248	0.6975308

Table F2 (Cotinued)

Stream (Summary)	UOM	S18	S19	S2
Name		S18	S19	S2
Phase		Vapor	Water	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	5.439826706	4.32726558	0.8027461
Total Mass Rate	kg / sec	98	77.9569001	231.94000
Temperature	C	475.0000244	113.078232	31.441730
Pressure	kg/cm2	4.092375905	2.05000006	18.354891
Total Molecular Weight		18.01527977	18.0152797	288.93317
Total Specific Enthalpy	kW-hr / kg	0.952164939	0.13169605	0.0181494
Total Cp	kcal/kg-K	0.505492884	1.01141850	0.4299384

Table F2 (Cotinued)

Stream (Summary)	UOM	S20	S21	S22
Name		S20	S21	S22
Phase		Mixed	Mixed	Liquid
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.311366361	0.31136636	0.4262678
Total Mass Rate	kg / sec	75.1700391	75.1700391	146
Temperature	C	205.148831	240.112700	297.72178
Pressure	kg/cm2	2.050000063	2.05000006	2.0500000
Total Molecular Weight		241.4199111	241.419911	342.50761
Total Specific Enthalpy	kW-hr / kg	0.118844112	0.14408688	0.1817195
Total Cp	kcal/kg-K	0	0	0.6639209

Table F2 (Cotinued)

Stream (Summary)	UOM	S3	S4	S5
Name		S3	S4	S5
Phase		Liquid	Liquid	Mixed
Thermodynamic System		GS01	GS01	GS01
Total Molar Rate	kg-mol / sec	0.802746189	0.80274618	25.827767
Total Mass Rate	kg / sec	231.9400024	231.940002	3567
Temperature	C	140.9007601	174.924069	114.04611
Pressure	kg/cm2	18.35489183	18.3548918	2.0500000
Total Molecular Weight		288.9331717	288.933171	138.10717
Total Specific Enthalpy	kW-hr / kg	0.079706302	0.10157019	0.0644382
Total Cp	kcal/kg-K	0.535038154	0.56771509	0.5390636

Table F2 (Cotinued)

Stream (Summary)	UOM	S6	S7	S8	S9
Name		S6	S7	S8	S9
Phase		Liquid	N/A	Liquid	Mixed
Thermodynamic System		GS01	N/A	GS01	GS01
Total Molar Rate	kg-mol / sec	0.80274618	0	0.80274618	0.80274
Total Mass Rate	kg / sec	231.940002	N/A	231.940002	231.94
Temperature	C	166.999993	N/A	194.648533	245.115
Pressure	kg/cm2	18.3548918	N/A	18.3548918	18.3548
Total Molecular Weight		288.933171	N/A	288.933171	288.933
Total Specific Enthalpy	kW-hr / kg	0.09637016	N/A	0.11478848	0.15033
Total Cp	kcal/kg-K	0.56078852	N/A	0.58465948	0

Appendix G Sensitivity Analysis on Number of Heat Exchanger of Grassroots GAMS Model

Table G1 Sensitivity analysis on number of heat exchanger by changing area cost at minimum ΔT min is 0°C

Minimum ΔT min (°C)	Shell cost ($)	Area cost ($)	No.of shell	Area (m^2)	Hot utility (Kw)	Cold utility (Kw)
0	5,291.90	100	50	14658.88	60365	2572.55
0	5,291.90	500	52	8650.74	76913.16	19120.84
0	5,291.90	1000	51	7317.95	87479.52	29687.20
0	5,291.90	1500	51	6511.87	99337.62	41545.30
0	5,291.90	2000	51	6142.67	106894	49101.68

Table G2 Sensitivity analysis on number of heat exchanger by changing area cost at minimum ΔT min is 33.5°C

Minimum ΔT min (°C)	Shell cost ($)	Area cost ($)	No.of shell	Area (m^2)	Hot utility (Kw)	Cold utility (Kw)
33.5	5,291.90	100	60	9581.45	74365.75	16573.43
33.5	5,291.90	500	51	8625.85	77422.91	19630.58
33.5	5,291.90	1000	58	7314.08	87479.52	29687.20
33.5	5,291.90	1500	49	6526.72	99139.47	41347.15
33.5	5,291.90	2000	51	6146.4	106894	49101.68

Table G3 Sensitivity analysis on number of heat exchanger by changing shell cost at minimum ΔT min is 0°C

Minimum ΔT min (°C)	Shell cost ($)	Area cost ($)	No.of shell	Area (m^2)	Hot utility (Kw)	Cold utility (Kw)
0	7000	100	50	14442.95	60507.90	2715.58
0	8000	100	47	14729.64	60512.12	2719.80
0	9000	100	52	14658.23	60383.28	2590.95
0	10000	100	50	14980.34	59944.74	2152.42
0	15000	100	50	14595.87	60507.90	2715.58

Table G4 Sensitivity analysis on number of heat exchanger by changing shell cost at minimum ΔT min is 33.5°C

Minimum ΔT min (°C)	Shell cost ($)	Area cost ($)	No.of Shell	Area (m^2)	Hot utility (Kw)	Cold utility (Kw)
33.5	7500	77.79	Resource limit exceeded, no integer solution found.			
33.5	9000	77.79	54	10316.457	72827.87	15035.55
33.5	11000	77.79	Resource limit exceeded, no integer solution found.			
33.5	13000	77.79	Resource limit exceeded, no integer solution found.			
33.5	15000	77.79	Resource limit exceeded, no integer solution found.			

Table G5 Sensitivity analysis on number of heat exchanger by changing number of intervals

Minimum ΔT min (°C)	Shell cost ($)	Area cost ($)	No.of Intervalsl	Area (m^2)	Hot utility (Kw)	Cold utility (Kw)
0	5,291.90	77.79	2	15,245	59,945	2,152
0	5,291.90	77.79	3	Resource limit exceeded, no integer solution found		
0	5,291.90	77.79	4	Resource limit exceeded, no integer solution found		
0	5,291.90	77.79	5	Resource limit exceeded, no integer solution found		
0	5,291.90	77.79	6	The interval is not divided properly		
0	5,291.90	77.79	10	The interval is not divided properly		

Table G6 Sensitivity analysis on number of heat exchanger by changing maximum number of heat exchanger

Minimum ΔT min (°C)	Shell cost ($)	Area cost ($)	No. of Exchanger	No. of Shell	Area (m^2)	Hot Utility (Kw)	Cold Utility (Kw)
0	5,291.9	77.79	30	Resource limit exceeded, no integer solution found			
0	5,291.9	77.79	40	Resource limit exceeded, no integer solution found			
0	5,291.9	77.79	45	Resource limit exceeded, no integer solution found			
0	5,291.9	77.79	50	49	15007	59944.74	2152.41
0	5,291.9	77.79	60	49	15124	59944.74	2152.41

Appendix H Calibration of grassroots GAMS model with base case condition (Qh = 68,316 kW and Qc = 10,523 kW)

Table H1 Result from grassroots model which the utility consumption close to refinery

	Matching between hot (I) and cold (J)	Hot fluid		Cold fluid				
		Temp. inlet (°C)	Temp. outlet (°C)	Temp. inlet (°C)	Temp. outlet (°C)	Overall heat transfer coef. W/m2/°C	Area (m2)	Duty (kW)
E1	I1-J24	105.72	105.3	50	50.379	0.32493	14.8	266.158
E2	I1-J1	128.5	105.72	30	61.122	0.464	429	142203
E3	I2-J2	174.52	158.66	61.71	68.91	0.484	72.5	3551.57
E4	I2-J3	213.5	174.52	86.597	103.37	0.399417	221.5	8725.98
E5	I3-J2	216.7	140.46	68.91	86.597	0.399417	223	8725.98
E6	I4-J20	163.04	163.02	124.6	124.61	0.416348	0.04	0.638
E7	I4-J4	223.1	163.04	103.37	123.56	0.532	70	2900.28
E8	I5-J5	214.4	165.10	103.37	117.37	0.484	140	5301.59
E9	I5-J1	216.9	214.4	61.12	61.71	0.473789	3.7	268.547
E10	I6-J6	194.68	175.10	119.62	128.44	0.506	158	4849.73
E11	I6-J20	217.3	194.68	124.6	142.78	0.408142	190	5600.87
E12	I7-J6	233	162.78	119.62	128.44	0.490542	164	5600.26
E13	I8-J8	220.4	192.95	148.44	165.24	0.439	441	9611.11
E14	I8-J4	220.4	220.4	123.56	123.57	0.481046	0.002	0.231
E15	I9-J7	237.52	205.48	138.62	146.33	0.251611	223	4400.35
E16	I9-J11	258.39	237.52	167.1	178.15	0.221169	172	2865.79
E17	I9-J21	281.6	258.39	206.3	220.70	0.263816	214	3187.34
E18	I10-J11	258.9	217.73	178.15	219.89	0.377032	731	10825.5
E19	I11-J5	213.42	212.71	117.37	118.09	0.380156	7.5	270.411
E20	I11-J9	241.19	213.42	165.24	183.24	0.221169	893	10455.1
E21	I11-J11	246.56	241.19	219.89	227.69	0.313	322	2021.79
E22	I11-J22	256.6	246.56	182	196.86	0.386467	157.3	3776.37
E23	I12-J12	253	215.97	167.1	201.30	0.476	183	4378.93
E24	I13-J22	261.19	222.3	196.86	204.84	0.502488	103	2028.18
E25	I13-J11	276.7	261.19	230.81	227.69	0.384994	54	808.78
E26	I14-J24	258.38	242.06	35.32	35.947	0.241201	80.51	440.2
E27	I14-J21	280.71	258.38	220.70	223.43	0.331953	38.8	602.553
E28	I14-J14	285.4	280.71	222.48	223.38	0.233	9	126.371
E29	I15-J21	266.08	259.54	235.33	223.43	0.450133	180	2633.48
E30	I15-J15	304.9	266.08	230.85	256.2	0.369	1017	15611.0
E31	I16-J14	287.91	282.98	223.38	225.07	0.2987	13	236.194
E32	I16-J16	299.33	287.91	260.48	261.80	0.416	41	546.838
E33	I16-J17	310.80	299.33	260.48	262.95	0.33826	37.6	549.229

Table H1 (Cotinued)

	Matching between hot (I) and cold (J)	Hot fluid		Cold fluid				
		Temp. inlet (°C)	Temp. outlet (°C)	Temp. inlet (°C)	Temp. outlet (°C)	Overall heat transfer coef. W/m2/°C	Area (m2)	Duty (kW)
E34	I16-J18	324	310.80	265.25	266.76	0.265532	46.5	631.777
E35	I17-J2	287.66	287.64	86.597	86.597	0.358752	0.01	0.857
E36	I17-J18	308.81	287.66	266.768	288.21	0.231563	87.5	601.079
E37	I17-J14	316.62	308.81	225.077	226.66	0.25639	10	221.745
E38	I17-J16	330	316.62	261.807	262.73	0.33826	18.5	380.191
E39	I18-J15	286.21	284.58	256.2	256.60	0.25516	34	250.783
E40	I18-J19	302.97	286.21	265.42	277.08	0.193488	571	2570.15
E41	I18-J18	350	302.97	288.213	285.55	0.195	1097	7212.37
E42	I19-J17	286.91	280.34	262.95	265.42	0.229434	124	549.229
E43	I19-J16	299.3	286.91	262.73	265.25	0.262737	137	1038.66
E44	I19-J18	311.02	299.3	285.55	287.91	0.193488	281.	982.214
E45	I19-J19	360	311.02	277.084	295.7	0.192	450	4102.04
E46	I20-J24	105.3	90.3	35.947	50	0.32493	551	9817.68
E47	I21-J20	216.4	206.88	142.789	151.76	0.332757	129	2761.67
E48	I21-J10	231.73	216.4	167.1	193.13	0.384902	261	4402.27
E49	I21-J7	236	231.73	146.334	148.44	0.38556	36	1201.06
E50	I22-J10	289.6	227.41	193.137	231.13	0.520453	272.5	6423.72
E51	I23-J13	271.92	254.65	201.31	222.48	0.445983	124	2837.20
E52	I23-J14	275.48	271.92	226.665	230.85	0.295146	44	584.31
E53	I23-J15	290	275.48	256.607	260.48	0.385023	260	2384.01
E54	I24-J23	499.82	480	290	360	1	414	67711
E55	I24-J12	499.82	499.82	201.305	201.31	0.64498	0.003	0.633
E56	I24-J18	500	499.82	287.91	289.36	0.32636	9	604.729

Table H2 Comparison when the utility consumption of grassroots model is close to the base case refinery

	Hot Utility (kW)	Cold Utility (kW)	Total Area (m^2)	No. of Heat Exchanger
Base Refinery	67,536	9,818	10,564	23
Grassroot GAMS Model	68,316	10,523	11,561	56

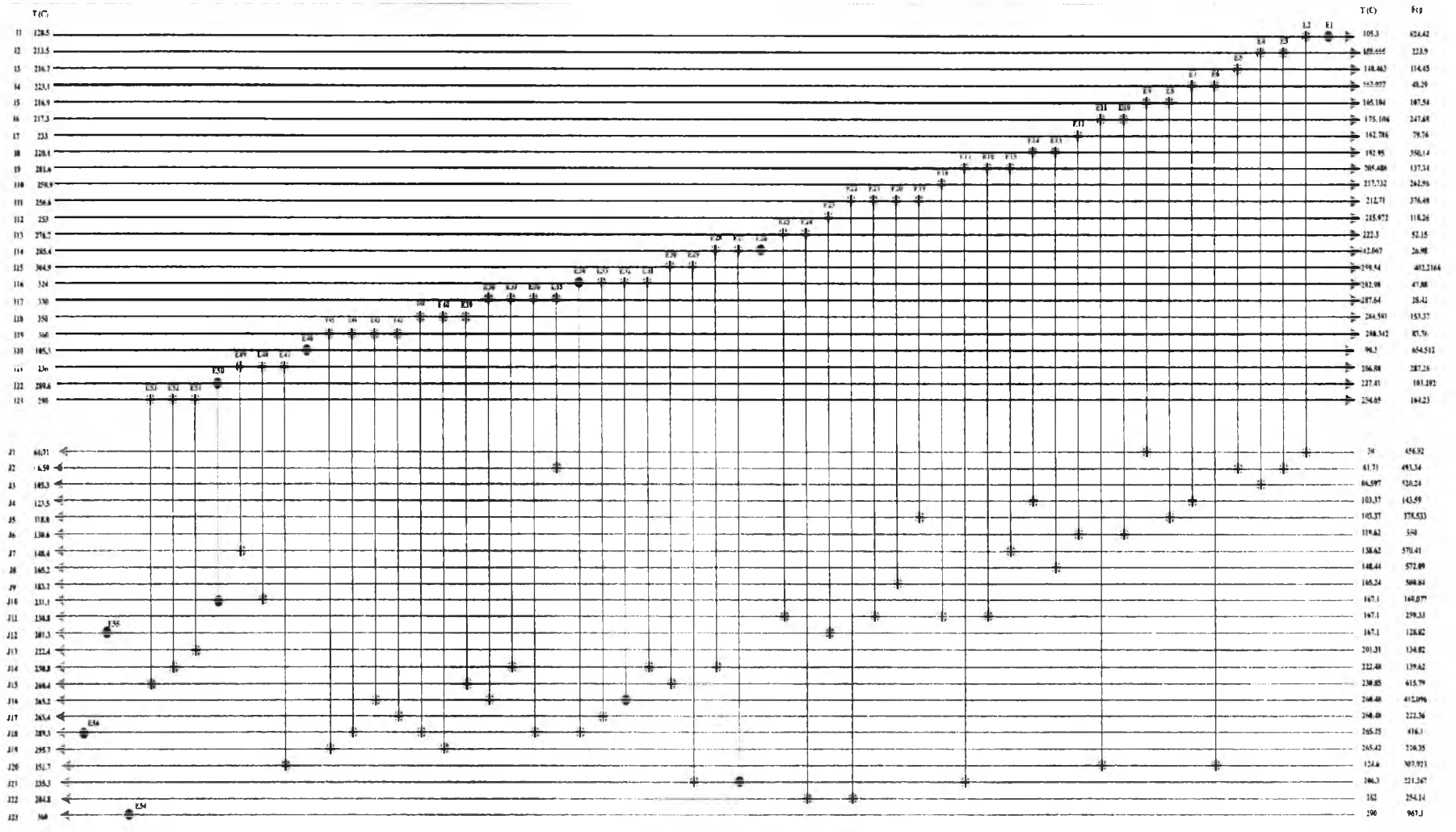

Figure H1 The grid diagram of grassroots model at hot and cold Utility consumption close to base case refinery

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