Elements for the design of new generation of heat exchangers for transcritical CO_2 heat pumps

J. M. Yin, C. W. Bullard and P. S. Hrnjak

ACRC CR-37 May 2001

For additional information:

Air Conditioning and Refrigeration Center
University of Illinois
Mechanical & Industrial Engineering Dept.
1206 West Green Street
Urbana, IL 61801

(217) 333-3115

The Air Conditioning and Refrigeration Center was founded in 1988 with a grant from the estate of Richard W. Kritzer, the founder of Peerless of America Inc. A State of Illinois Technology Challenge Grant helped build the laboratory facilities. The ACRC receives continuing support from the Richard W. Kritzer Endowment and the National Science Foundation. The following organizations have also become sponsors of the Center.

Amana Refrigeration, Inc.
Arçelik A. S.
Brazeway, Inc.
Carrier Corporation
Copeland Corporation
Dacor
Daikin Industries, Ltd.
DaimlerChrysler Corporation
Delphi Harrison Thermal Systems
Frigidaire Company
General Electric Company
General Motors Corporation
Hill PHOENIX
Honeywell, Inc.
Hussmann Corporation
Hydro Aluminum Adrian, Inc.
Indiana Tube Corporation
Invensys Climate Controls
Kelon Electrical Holdings Co., Ltd.
Lennox International, Inc.
LG Electronics, Inc.
Modine Manufacturing Co.
Parker Hannifin Corporation
Peerless of America, Inc.
Samsung Electronics Co., Ltd.
Tecumseh Products Company
The Trane Company
Thermo King Corporation
Valeo, Inc.
Visteon Automotive Systems
Wolverine Tube, Inc.
York International, Inc.

For additional information:

Air Conditioning & Refrigeration Center
Mechanical & Industrial Engineering Dept.
University of Illinois
1206 West Green Street
Urbana, IL 61801

217 333 3115

Elements for the design of new generation of heat exchangers for transcritical CO2 heat pumps

Jianmin Yin, Clark Bullard and Pega Hrnjak

Abstract

This document summarizes the evolution of the design of a 10 kW split system residential heat pump, to operate with R744 on the transcritical cycle. It is the first such prototype to be designed, and will be used for experimental purposes. The final design was influenced several factors, and tradeoffs were quantified by using our system simulation model, which was developed and validated using extensive experimental data from both residential and mobile ac systems. Several constraints prevented optimization of this particular design, including tube and fin dimensions and overall heat exchanger package dimensions. The numbers of serpentine passes were optimized by considering the total pressure drop and manufacturing processes.

Introduction

This document summarizes the evolution of the design of a 10 kW split system residential heat pump, to operate with R744 on the transcritical cycle. It is the first such prototype to be built; the first split system prototype was designed for a/c operation, but limited data were obtained in heating mode (Richter et al., 2000). That experience led to the present design.

One distinctive feature of this prototype is its reliance on serpentined microchannel tubes to reduce the number of headers and header tube diameter; this could reduce the charge dramatically and possibly improve refrigerant side distribution due to the short length of the headers. Because the refrigerant side pressure drop is higher in high quality region, the new heat exchanger design doubles the refrigerant-side cross-sectional area in the high quality region. Fins are attached separately in each air-side slab, to improve water drainage.

Key features of the design were proposed and provided to the project sponsor in late August and early September 2000. It was refined through a series of iterations and nearly finalized in late October 2000. Final refinements to optimize performance and to accommodate material and manufacturing constraints were completed by January 2001.

The final design was influenced several factors, and tradeoffs were quantified by using our system simulation model, which was developed and validated using extensive experimental data from both residential and mobile ac systems. Several constraints prevented optimization of this particular design, including tube and fin dimensions and overall heat exchanger package dimensions. The numbers of serpentine passes were optimized by considering the total pressure drop and manufacturing processes.

Indoor heat exchanger

Indoor coil will use 4 modules as shown in Figure 1. Two modules will make up each half of the “A” coils. There is only one refrigerant inlet per each module (4 for the complete indoor heat exchangers). For a given module, it has 3 air-side slabs and 2 refrigerant side slabs.

The following drawing shows two modules together, which is one-half of the A-coil. Each module has one inlet and one exit. Four modules together make one indoor heat exchanger. Options 7, 7a and 7b are identical except that 7b uses 1mm ports for indoor hx.

This new design will use very short header tube (possibly very small diameter). All the intermediate header, which is used to connect each slab together, will have NPT at both end, this will give us the possibility to block the 3rd air-side slab, so the test could be run with only two slabs to check the effectiveness of the 3rd slab.

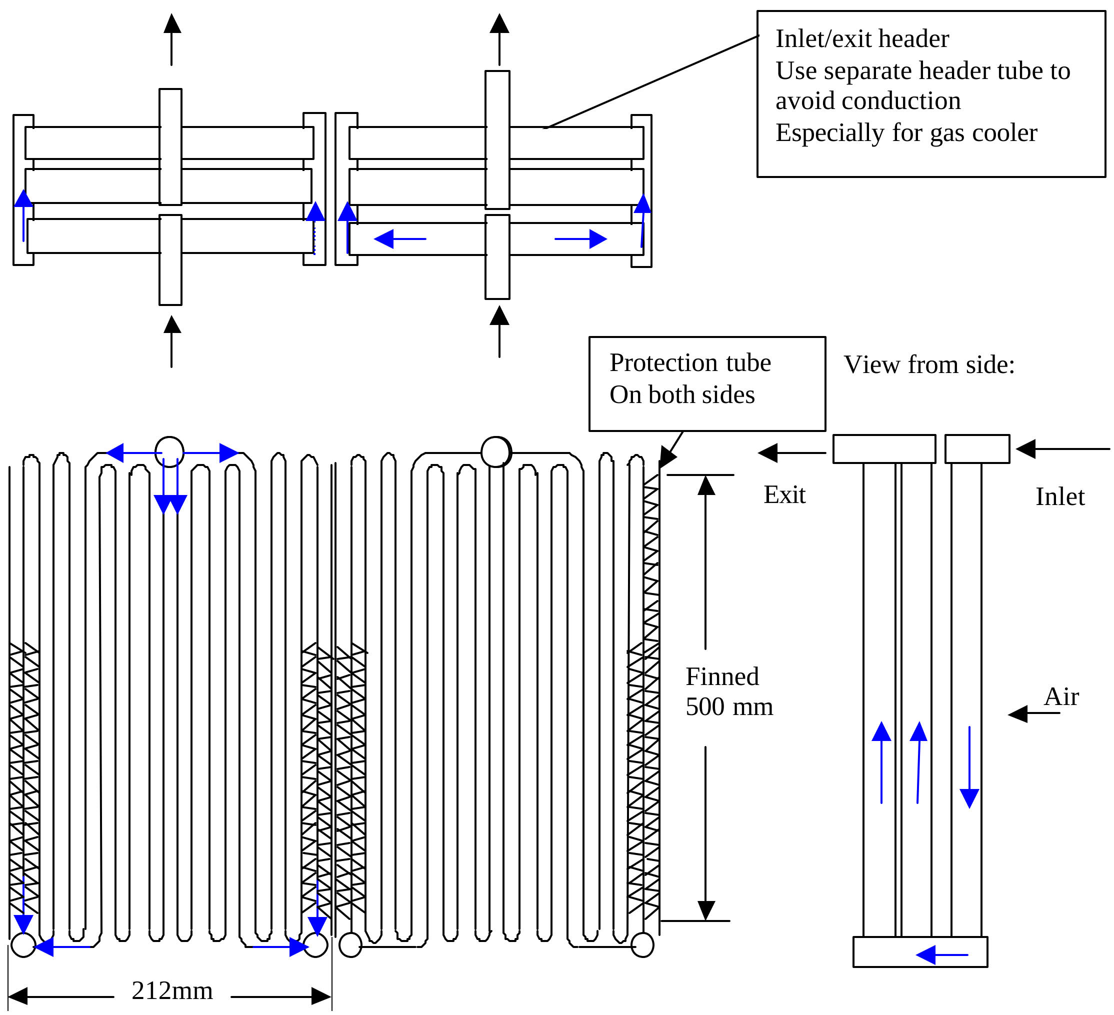

Figure 1. Indoor coil module

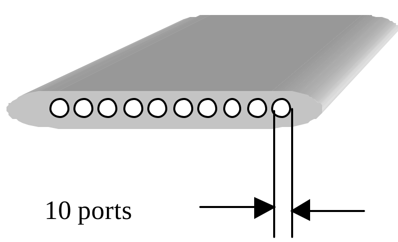

Figure 2. Microchannel tube

Figure 3 is a drawing of a single module (add protection tube on both side), which illustrates how each slab is connected.

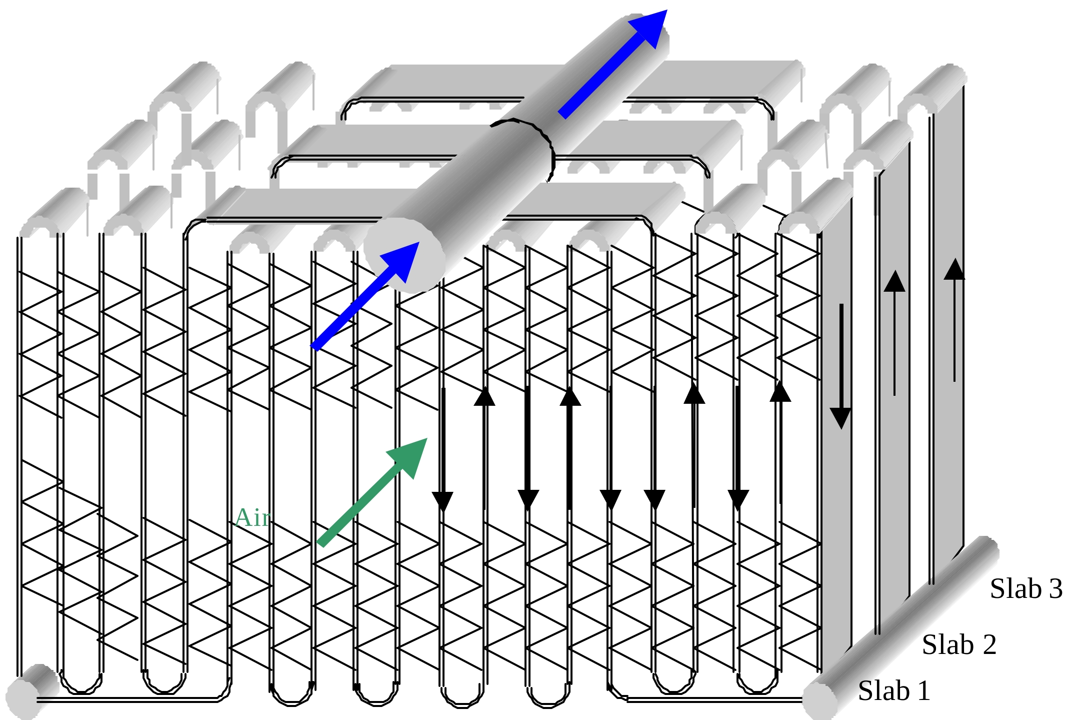

Figure 3. Multiple serpentine/multiple slab heat exchanger

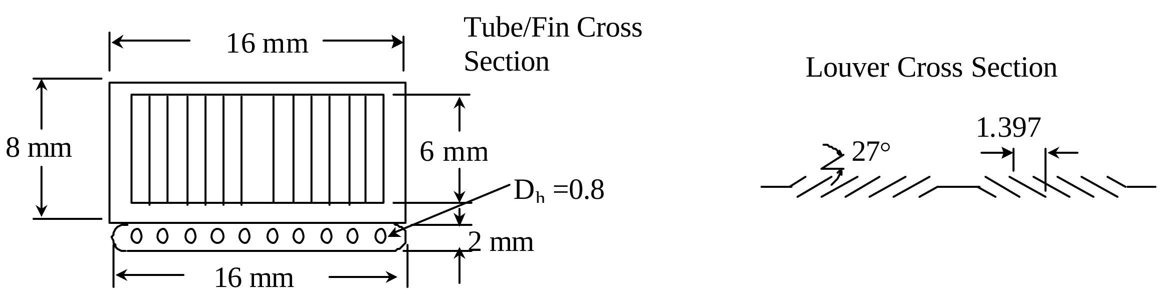

Figure 4. Fin dimension used in the heat exchanger design

Figure 4 shows the available fin dimension, and Figure 5 shows the header tube. Because each header tube need to have at least two microchannel tubes attached, so the dimension and structure need to be determined by considering the manufacturing process and burst pressure requirements.

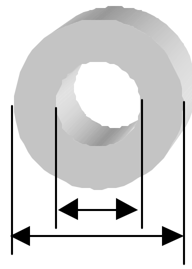

Figure 5. Header tube

Outdoor heat exchanger

Outdoor coil is very similar to indoor coil except for the number of serpentine and dimension.
Use 6 identical modules
One refrigerant inlet/exit per module (6 for outdoor HX)
Use 16x2mm tube, 10 ports @ 0.79mm in diameter tube
Fin height is: 8mm
Use 7 serpentines

The following drawings show one module. Two modules make one side of a three sided coil. Outdoor heat exchanger has six modules. Each module has one inlet and one exit.

This is the TWO slab version of one outdoor module (Option 7a):

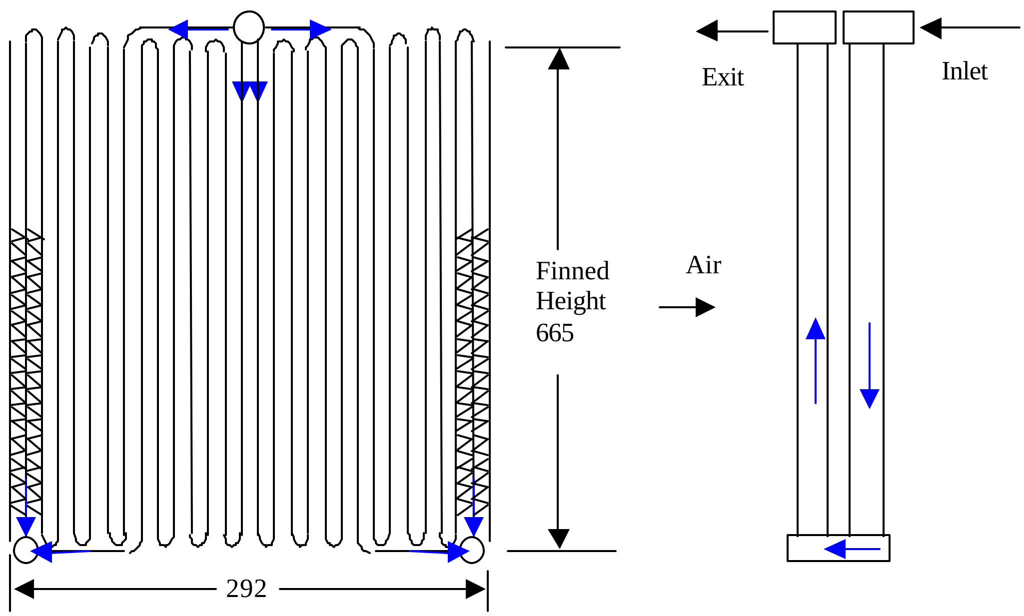

Figure 6. Outdoor coil (two slab version)

Figure 7 shows the THREE slab version of one outdoor module (Option 7 and 7b), same circuiting as indoor coil. Option 7b uses 1 mm ports for indoor heat exchanger, since pressure never exceeds 90 bar.

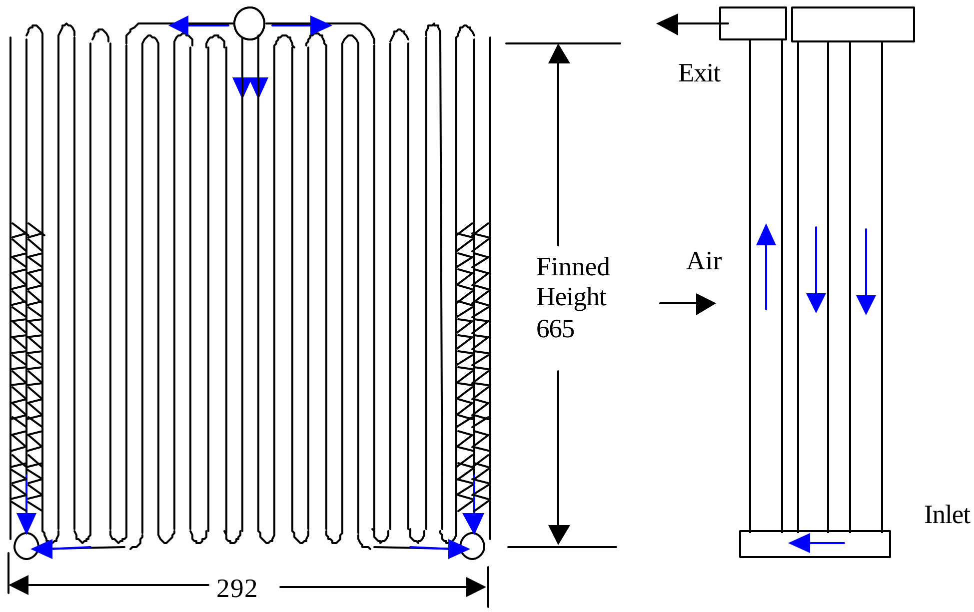

Figure 7. Outdoor heat exchanger module (three slab version)

Special requirement about the intermediate headers

For both indoor and outdoor coil, the intermediate header need to have NPT on both sides.

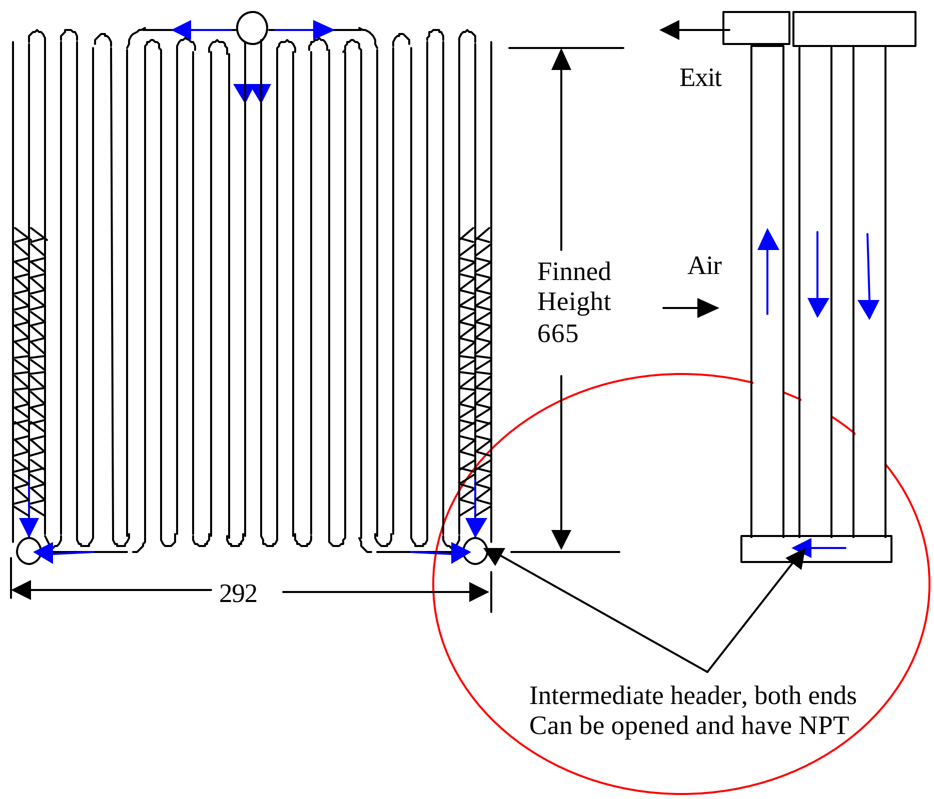

Figure 8. Intermediate headers

For option 8:

Indoor coil module width: 231mm
Indoor coil module finned height: 455mm
Outdoor coil module width and height are the same as Option 7

References

Richter, M. R., S. M. Song, J. M. Yin, M. H. Kim, C. W. Bullard and P. S. Hrnjak, 2000, “Transcritical CO_2 Heat Pump for Residential Applications,” *Proceedings of the IIF-IIR Commission B1, B2, E1, and E2*, Purdue University, W. Lafayette, IN, 9-16, July.

Table 1. Comparison of options 7 and 8

Indoor coil			**Option 7**	**Option 7a**	**Option 7b**	**Option 8**
Items	R410A heat pump	RAC1	1 inlet per module	1 inlet per module	1 inlet per module	1 inlet per module
Tube major (mm)	8 (copper)	16.5	16	16	16	16
Modules	2	1	4	4	4	4
Slabs/module	1	3	2 ref; 3 air	2 ref; 3 air	2 ref; 3 air	2 ref; 3 air
Serpentines/slab		1	5	5	5	5
Inlets/module	3	1	1	1	1	1
Headers			12x60mm	12x60mm	12x60mm	12x60mm
Free flow area (m^2)	0.231	0.284	0.313	0.313	0.313	0.317
Face area (m^2)	0.42	0.36	0.42	0.42	0.42	0.42
Core volume (m^3)	0.024	0.018	0.02	0.02	0.02	0.02
Core depth (mm)	56.5	49.5	48	48	48	48
Air side area (m^2)	27.48	22.5	22.9	22.9	22.9	25.5
Ref. Side area (m^2)	1.31	2.73	3.06	3.06	3.88	3.56
Fin density (fpi)	15	17	15	15	15	17
Louver angle (o)		23	27	27	27	23
Louver pitch (mm)		1	1.4	1.4	1.4	1
Fin height (mm)		8.9	8	8	8	8.9
Fin thickness (mm)		0.1	0.1	0.1	0.1	0.1
Port diameter (mm)		0.79	0.79	0.79	1	1
Port number		11	10	10	10	10
Tube major (mm)		16.5	16	16	16	16
Mass flow rate (g/s)	65	70.3	66.1	65.6	66.6	66.9
Ref-side pressure drop (kPa)	285^+	25	187	183	62	58
dP heat pump	9 (mr=31g/s)					
System performance						
COP	4.22	3.26	3.86	3.73	3.89	3.91
Total capacity at AC* (kW)	10.3	10.26	10.12	10.1	10.2	10.31
Latent capacity (kW)	1.95	2.45	1.86	1.85	1.92	1.86
Latent to total ratio	0.19	0.24	0.18	0.18	0.19	0.18
Discharge Pressure (MPa)	2.77	9.3	9.07	9.29	9.1	9.13
Suction Pressure (MPa)	1.05	4.59	4.79	4.79	4.81	4.82
Evaporation temp at exit (^oC)			13.1	13.1	13.3	13.4

+ Not comparable; measurement includes reverse flow through distributor; no instrument access downstream

Outdoor coil			**Option 7**	**Option 7a**	**Option 7b**	**Option 8**
Items	R410A HP	RAC1	6 modules	6 modules	6 modules	6 modules
Modules	1 U-shape	3	3	3	3	3
Slabs/module	2	1	2 ref; 3 air	2 ref; 2 air	2 ref; 3 air	2 ref; 3 air
Serpentines/slab		7 passes	7	7	7	7
Inlets/module	3	1	1	1	1	1
Headers			18@60mm	18@60mm	18@60mm	18@60mm
Free flow area (m^2)	0.638	1.223	0.876	0.876	0.876	0.876
Face area (m^2)	1.165	1.6	1.165	1.165	1.165	1.165
Core volume (m^3)	0.044	0.026	0.0559	0.0373	0.0559	0.0559
Core depth (mm)	38	16.5	48	32	48	48
Air side area (m^2)	66.9	50.4	63.9	42.6	63.9	63.9
Ref. Side area (m^2)	3.38	4.1	8.61	5.74	8.61	8.61
Fin density (fpi)	20	23	15	20	15	15
Louver angle (o)		23	27	27	27	27
Louver pitch (mm)		1	1.4	1.4	1.4	1.4
Fin height (mm)		8.9	8	8.0	8	8
Fin thickness (mm)		0.1	0.1	0.1	0.1	0.1
Port diameter (mm)		0.79	0.79	0.79	0.79	0.79
Port number		11	10	10	10	10
Tube major (mm)	19	16.5	16	16	16	16
Ref-side pressure drop (kPa)	76^{+} mr=65g/s, AC*	104 (mr=70.3g/s)	92	169	93	92
	9(mr=31g/s,HP**)					

+ Not comparable; measurement includes reverse flow through distribution tubes that are used during heat pump operation