

Energetic Analysis of Low Global Warming Potential Refrigerants as Substitutes for R410A and R134a in Ground-Source Heat Pumps

Laura Fedele ^{1,*}, Sergio Bobbo ¹, Davide Menegazzo ^{1,2}, Michele De Carli ², Laura Carnieletto ², Fabio Poletto ³, Andrea Tarabotti ³, Dimitris Mendrinou ⁴, Giulia Mezzasalma ⁵ and Adriana Bernardi ⁶

¹ Istituto per le Tecnologie della Costruzione, Consiglio Nazionale delle Ricerche, I-35127 Padua, Italy

² Dipartimento di Ingegneria Industriale, Università degli Studi di Padova, I-35131 Padua, Italy

³ Hi-Ref Spa, I-35020 Tribano, Italy; andrea.tarabotti.engineering@hiref.it

⁴ Geothermal Energy Department, Centre for Renewable Energy Sources and Saving, 19009 Pikermi, Greece; dmendrin@cres.gr

⁵ RED srl, Via le dell'Industria 58B, I-35127 Padua, Italy; giulia.mezzasalma@red-srl.com

⁶ Istituto di Scienze dell'Atmosfera e del Clima, Consiglio Nazionale delle Ricerche, I-35127 Padua, Italy; adriana.bernardi@isac.cnr.it

* Correspondence: laura.fedele@itc.cnr.it

Supporting information file

Figures

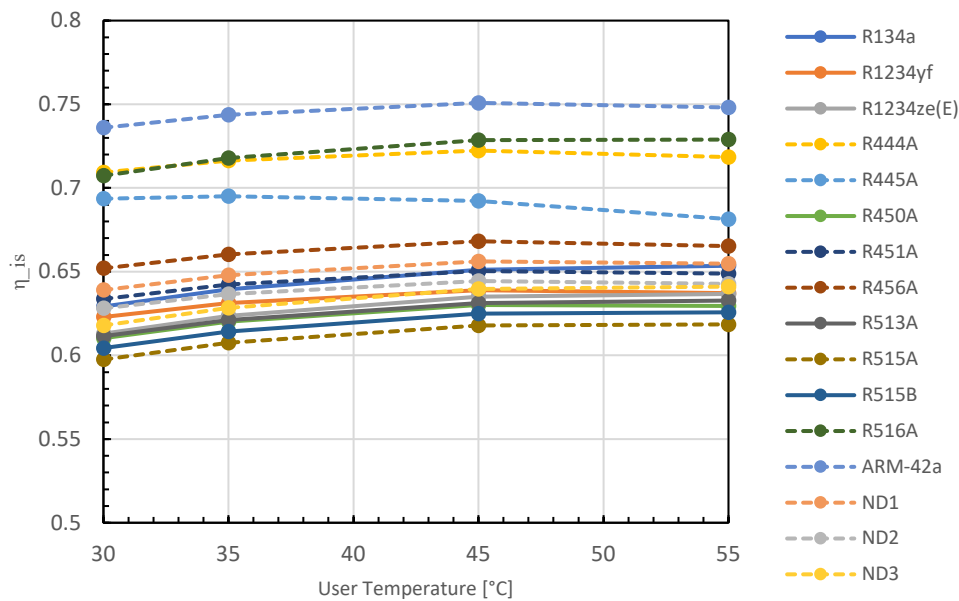


Figure S1. Compressor isentropic efficiency for R134a and its alternatives with the base cycle in Scenario C [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

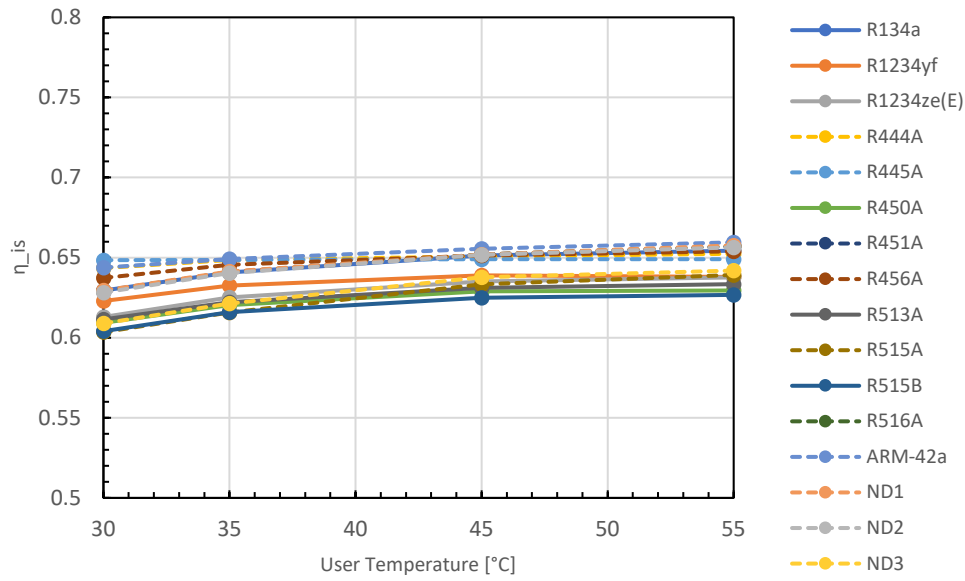


Figure S2. Compressor isentropic efficiency for R134a and its alternatives with the base cycle in Scenario D [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

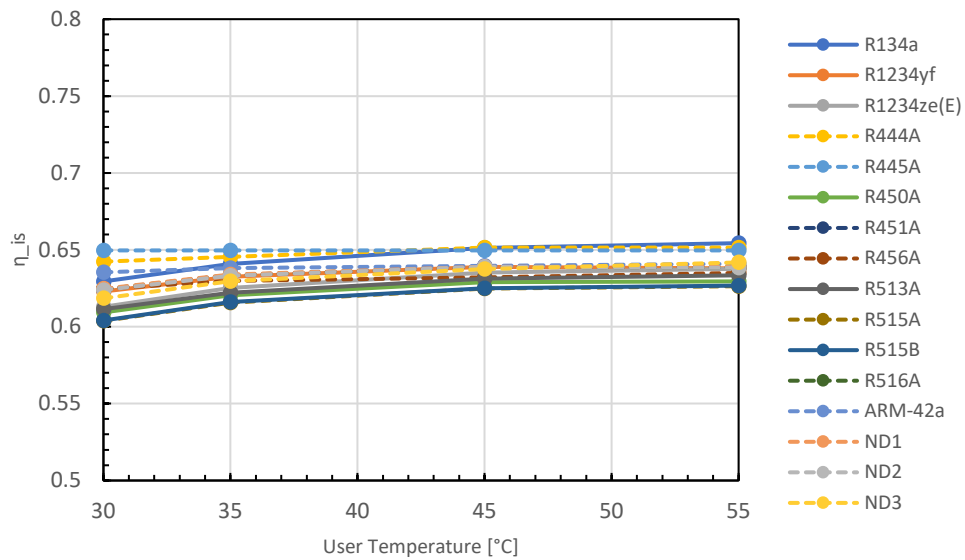


Figure S3. Compressor isentropic efficiency for R134a and its alternatives with the base cycle in Scenario E [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

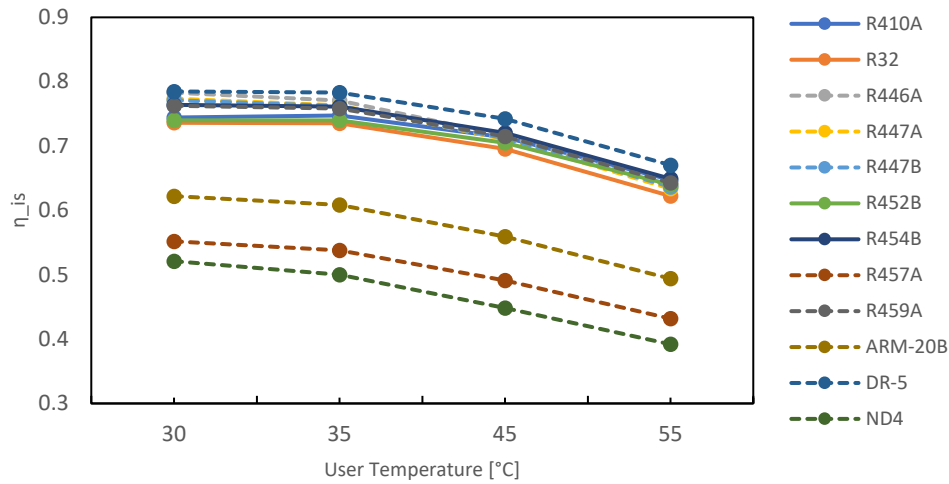


Figure S4. Compressor isentropic efficiency for R410A and its alternatives with the base cycle in Scenario C [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

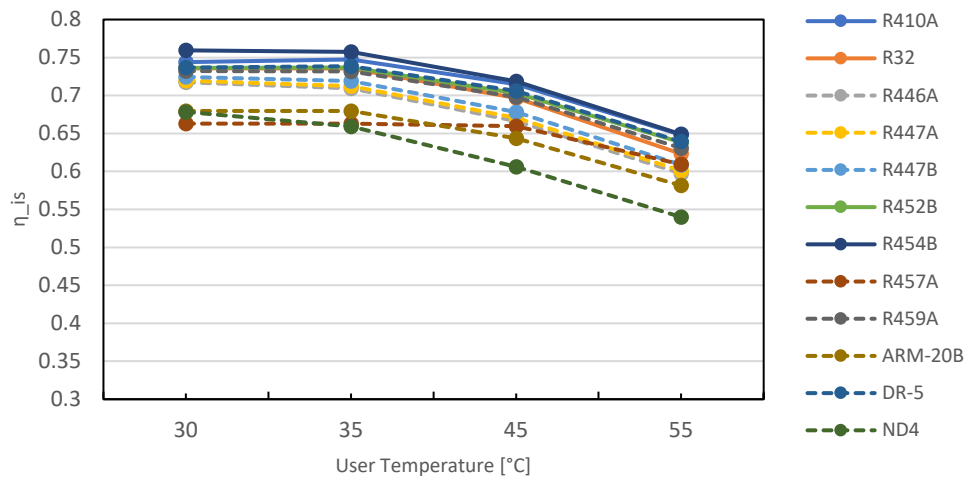


Figure S5. Compressor isentropic efficiency for R410A and its alternatives with the base cycle in Scenario D [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

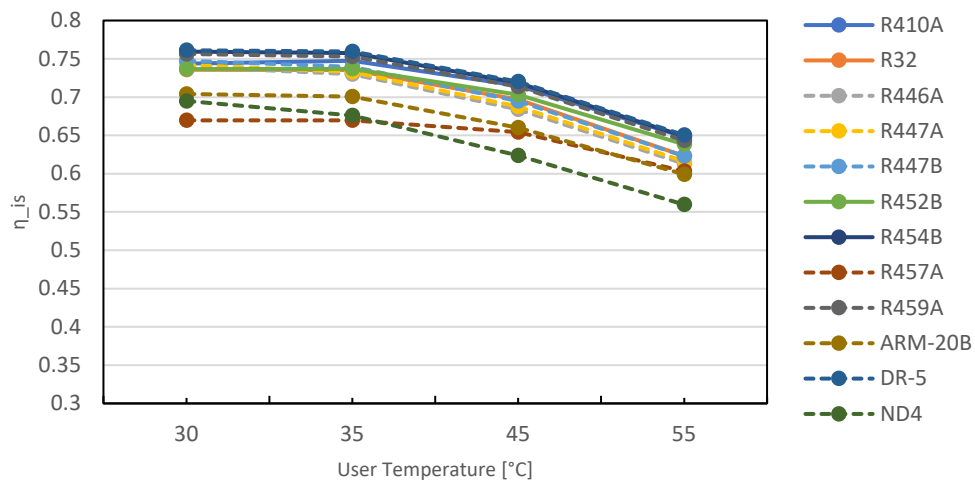


Figure S6. Compressor isentropic efficiency for R410A and its alternatives with the base cycle in Scenario E [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

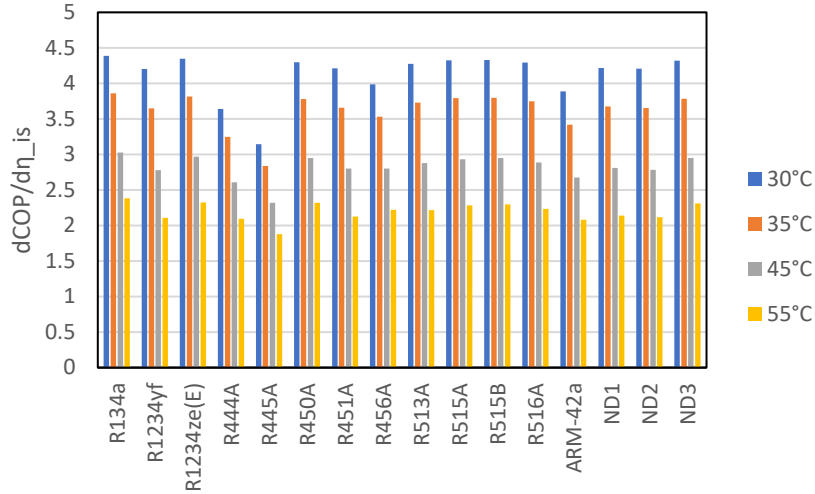


Figure S7. Sensitivity coefficient for R134a substitutes with base cycle. Source temperature:0/-3°C.

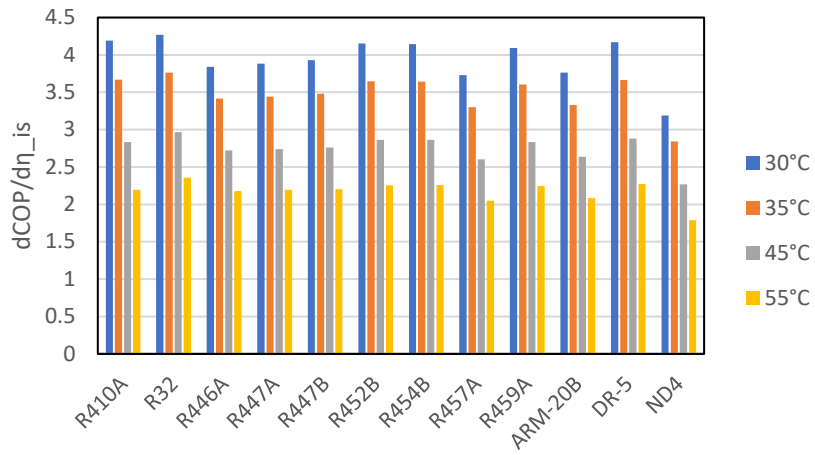


Figure S8. Sensitivity coefficient for R410A substitutes with base cycle. Source temperature:0/-3°C.

Further details on Eq.23

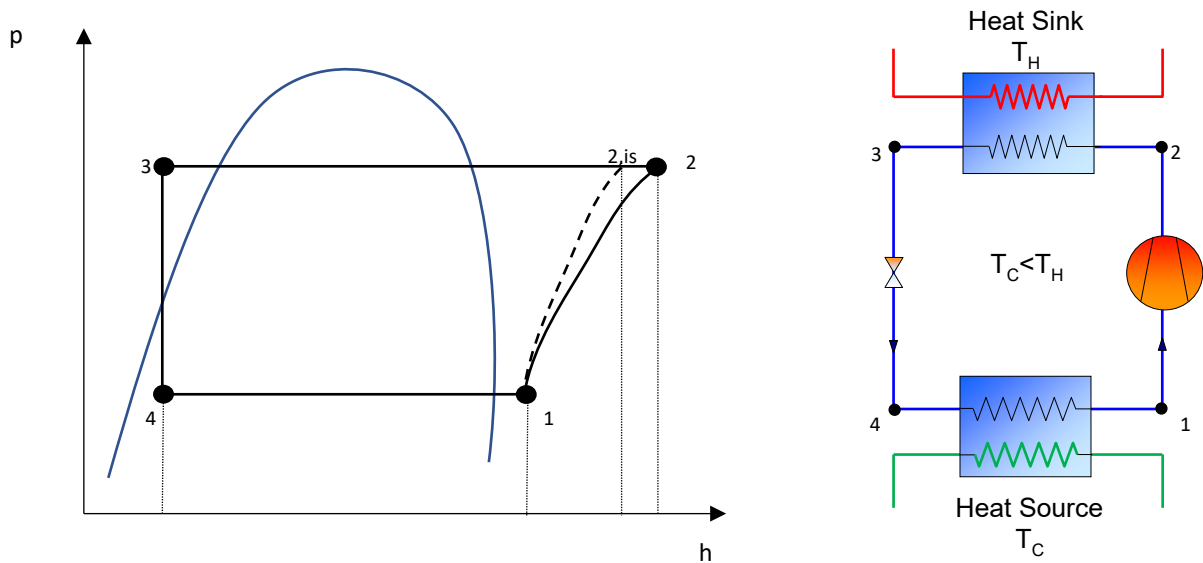


Figure S9. (left) example of p-h diagram referred to (right) a thermodynamic scheme of base cycle.

The following Eq. SI1-SI4 are meant to explain Eq. 23 shown in the main paper. The subscripts in Eq. SI1-SI4 are referred to Fig. SI9. The reader is pleased to refer to the main paper for the nomenclature.

$$COP = \frac{q_{cond}}{W_{compr}} = \frac{h_2 - h_3}{h_2 - h_1} = \frac{h_2 - h_3 + (h_1 - h_1)}{h_2 - h_1} = \frac{h_1 - h_3}{h_2 - h_1} + 1 \quad (SI1)$$

$$W_{compr} = h_2 - h_1 = \frac{h_2 - h_1}{\eta_{is}} \quad (SI2)$$

$$COP = \frac{h_1 - h_3}{h_{2,is} - h_1} \cdot \eta_{is} + 1 \quad (SI3)$$

$$\frac{dCOP}{d\eta_{is}} = \frac{h_1 - h_3}{h_{2,is} - h_1} = \frac{h_{ev,out} - h_{cond,out}}{h_{compr,out,is} - h_{ev,out}} \quad (SI4)$$

Tables

Table S1. Relative COP results for R134a alternatives with the base cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

	Scenario				
Fluid	A	B	C	D	E
R1234yf	-3.081	-2.865	-3.614	-3.612	-3.612
R1234ze(E)	-0.493	-0.215	-2.587	-2.536	-2.536
R444A	-14.566	-13.545	-6.760	-12.781	-13.028
R450A	-1.484	-1.380	-3.755	-3.865	-3.865
R451A	-2.960	-2.753	-2.246	-2.451	-3.390
R456A	-7.757	-7.213	-5.139	-6.707	-8.324
R513A	-1.995	-1.855	-3.681	-3.687	-3.687
R515A	-0.615	-0.601	-4.888	-3.636	-4.126
R515B	-0.536	-0.755	-4.006	-3.997	-3.997
R516A	-1.701	-1.582	7.374	-1.309	-2.267
ARM-42a	-9.796	-9.110	1.841	-7.792	-9.010
ND1	-2.845	-2.645	-1.469	-2.293	-3.247
ND2	-3.048	-2.835	-2.980	-2.797	-3.759
ND3	-1.018	-0.947	-2.749	-3.440	-2.704

Table S2. Relative VHE results for R134a alternatives with the base cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

	Scenario				
Fluid	A	B	C	D	E
R1234yf	-3.008	-2.792	-2.446	-2.448	-2.448
R1234ze(E)	-26.416	-26.342	-25.732	-25.708	-25.708
R444A	-6.881	-5.768	-8.044	-5.661	-5.553
R450A	-14.124	-14.033	-13.271	-13.238	-13.238
R451A	-0.746	-0.534	-0.631	-0.560	-0.226
R456A	-3.964	-3.399	-3.952	-3.373	-2.745
R513A	3.517	3.665	4.399	4.400	4.400

R515A	-27.522	-27.512	-26.383	-26.724	-26.593
R515B	-27.234	-27.265	-26.292	-26.295	-26.295
R516A	1.167	1.290	-1.619	1.241	1.579
ARM-42a	11.616	12.466	8.377	12.189	12.818
ND1	0.185	0.391	0.111	0.344	0.685
ND2	-1.855	-1.639	-1.504	-1.688	-1.401
ND3	-23.460	-23.405	-22.901	-22.710	-22.914

Table S3. Relative COP results for R134a alternatives with the regenerative cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

Scenario					
Fluid	A	B	C	D	E
R1234yf	-1.107	-0.997	-1.906	-1.871	-1.871
R1234ze(E)	0.310	-1.063	-2.118	-2.962	-2.962
R444A	-11.746	-10.178	-1.135	-9.008	-9.401
R450A	-1.844	-0.846	-2.618	-3.147	-3.147
R451A	-4.522	-3.370	-2.373	-3.096	-3.980
R456A	-3.967	-2.847	0.187	-2.136	-3.984
R513A	-3.625	-2.547	-4.005	-4.454	-4.454
R515A	-2.028	-0.994	-4.422	-3.883	-3.997
R515B	-1.937	-0.935	-3.495	-3.888	-3.888
R516A	-3.108	-2.018	7.796	-1.964	-2.665
ARM-42a	-6.129	-4.885	7.369	-3.948	-5.120
ND1	-4.161	-3.011	-1.384	-2.718	-3.593
ND2	-4.608	-3.470	-3.114	-3.265	-4.110
ND3	-2.129	-1.168	-1.684	-3.641	-2.096

Table S4. Relative VHE results for R134a alternatives with the regenerative cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

Scenario					
Fluid	A	B	C	D	E
R1234yf	-1.204	-1.094	-0.802	-2.448	-0.744
R1234ze(E)	-25.853	-27.004	-25.624	-25.708	-26.419
R444A	-0.009	1.768	-0.430	-5.661	1.925
R450A	-13.867	-12.992	-11.820	-13.238	-12.186
R451A	-2.551	-1.375	-0.879	-0.560	-0.931
R456A	3.178	4.381	4.214	-3.373	5.021
R513A	1.670	2.807	4.151	4.400	3.693
R515A	-28.432	-27.676	-26.308	-26.724	-26.805
R515B	-28.148	-27.413	-26.192	-26.295	-26.529
R516A	-0.418	0.701	-1.388	1.241	1.129
ARM-42a	19.029	20.607	17.203	12.189	21.054
ND1	-1.284	-0.100	0.192	0.344	0.335
ND2	-3.657	-2.507	-1.782	-1.688	-2.032

ND3	-23.687	-22.938	-22.129	-22.710	-22.484
------------	---------	---------	---------	---------	---------

Table S5. Relative COP results for R410A alternatives with the base cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

Scenario					
Fluid	A	B	C	D	E
R32	1.539	1.426	-0.188	-0.116	-0.116
R446A	-6.718	-6.224	-5.226	-10.699	-8.991
R447A	-6.073	-5.626	-5.192	-9.861	-8.057
R447B	-5.097	-4.722	-4.256	-8.280	-6.402
R452B	-0.788	-0.938	-1.902	-2.122	-2.122
R454B	-0.964	-0.893	0.126	-0.185	-0.185
R457A	-8.395	-7.777	-28.264	-14.225	-13.600
R459A	-1.964	-1.775	-1.277	-3.794	-1.738
ARM-20B	-8.100	-7.504	-21.407	-13.975	-12.974
DR-5	-0.481	-0.445	2.858	-1.511	0.600
ND4	-19.632	-18.028	-38.855	-26.220	-25.251

Table S6. Relative VHE results for R410A alternatives with the base cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

Scenario					
Fluid	A	B	C	D	E
R32	9.258	9.136	9.699	9.674	9.674
R446A	-16.782	-16.341	-16.719	-14.904	-15.549
R447A	-15.271	-14.868	-15.005	-13.574	-14.176
R447B	-12.452	-12.106	-12.310	-11.021	-11.641
R452B	-4.266	-4.230	-3.859	-3.721	-3.721
R454B	-5.337	-5.269	-5.583	-5.492	-5.492
R457A	-46.602	-46.242	-40.549	-44.869	-45.021
R459A	-7.771	-7.593	-7.821	-7.051	-7.684
ARM-20B	-34.123	-33.695	-29.472	-32.005	-32.302
DR-5	-3.261	-3.226	-4.195	-2.835	-3.478
ND4	-35.458	-34.254	-24.012	-31.437	-31.780

Table S7. Relative COP results for R410A alternatives with the regenerative cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

Scenario					
Fluid	A	B	C	D	E
R32	0.832	-0.222	-2.582	-2.029	-2.029
R446A	-1.783	-1.666	2.228	-4.084	-1.929
R447A	-1.030	-0.967	2.090	-3.116	-0.928
R447B	0.118	0.101	3.066	-1.446	0.783
R452B	1.029	0.948	0.494	0.226	0.226

R454B	1.176	1.085	3.000	2.642	2.642
R457A	-3.571	-3.329	-23.030	-11.394	-10.726
R459A	1.412	1.295	2.897	0.417	2.703
ARM-20B	-3.195	-3.146	-15.547	-8.271	-6.009
DR-5	1.179	1.088	5.198	0.519	2.755
ND4	-16.118	-14.993	-34.695	-21.091	-19.602

Table S8. Relative VHE results for R410A alternatives with the regenerative cycle [User temperature: 30°C/35°C (inlet/outlet), Source temperature: -3°C/0°C].

Scenario					
Fluid	A	B	C	D	E
R32	8.081	6.951	6.437	9.674	6.972
R446A	-10.757	-10.651	-11.669	-14.904	-10.613
R447A	-9.140	-9.082	-9.887	-13.574	-9.114
R447B	-6.136	-6.152	-6.922	-11.021	-6.338
R452B	-2.213	-2.290	-2.153	-3.721	-2.080
R454B	-2.934	-3.021	-3.515	-5.492	-3.425
R457A	-42.267	-42.122	-37.360	-44.869	-40.683
R459A	-3.738	-3.850	-4.404	-7.051	-4.212
ARM-20B	-29.105	-28.805	-25.660	-32.005	-28.228
DR-5	-1.430	-1.519	-2.581	-2.835	-1.958
ND4	-30.414	-29.481	-21.295	-31.437	-28.250