Abschlussbericht

des Projektes

Mitarbeit der deutschen Solarindustrie bei der Überarbeitung der europäischen Normen für thermische Solaranlagen (Eurosol)

gefördert von der

Deutsche Bundesstiftung Umwelt

unter AZ 21589

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Bundesverband Solarwirtschaft e.V. (BSW)
(ehemals Bundesverband Solarindustrie e.V. (BSi))
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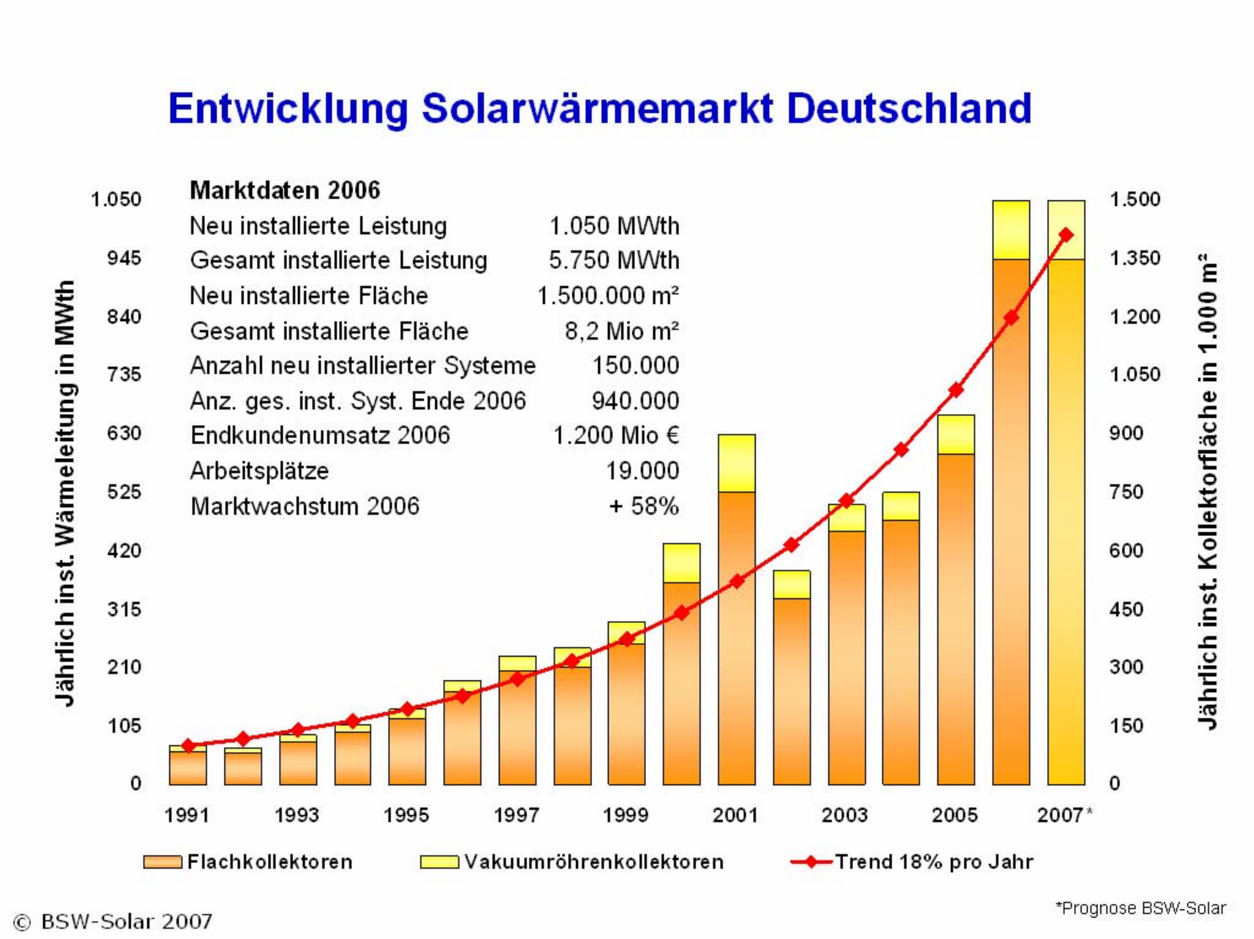
10243 Berlin

in Kooperation mit

Universität Stuttgart, Institut für Thermodynamik
und Wärmetechnik (ITW),
Steinbeis-Transferzentrum, Solar- und Wärmetechnik Stuttgart (SWT)
sowie den Solarthermieunternehmen
ELCO Klöckner Heiztechnik, Consolar, KBB Kollektorbau, PARADIGMA Energie und Umwelttechnik, Pro Solar Energietechnik, RESOL Elektronische Regelungen, Solar Diamant Systemtechnik, SOLVIS, Speichertechnik Forstner, Sunset Energietechnik, Vaillant und Wagner & Co. Solartechnik

Einleitung

Die Markteinführung von Solarwärmeanlagen schreitet in Deutschland deutlich voran. Nach einer kontinuierlichen Wachstumsperiode von Beginn der 90er Jahre bis zum Jahr 2001 hatte die Branche im Jahr 2002 eine starke Korrektur zu verkraften. Seit 2003 wächst der Markt wieder deutlich an und erreichte im Jahr 2006 eine abgesetzte Kollektorfläche von 1,5 Millionen Quadratmeter, was einer Wärmeleistung von 1.050 MWth entspricht.



Entwicklung Solarwärmemarkt Deutschland

Marktdaten 2006	
Neu installierte Leistung	1.050 MWth
Gesamt installierte Leistung	5.750 MWth
Neu installierte Fläche	1.500.000 m²
Gesamt installierte Fläche	8,2 Mio m²
Anzahl neu installierter Systeme	150.000
Anz. ges. inst. Syst. Ende 2006	940.000
Endkundenumsatz 2006	1.200 Mio €
Arbeitsplätze	19.000
Marktwachstum 2006	+ 58%

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*Prognose BSW-Solar

Abb 1: Marktentwicklung Solarwärme in Deutschland und Marktdaten 2006

Auch wenn Deutschland mit ca. 50% Anteil immer noch der größte Einzelmarkt Europas ist, hat sich in vielen anderen Ländern Europas der Markt in den letzten Jahren sehr positiv entwickelt. Der Markt in Österreich weist nach wie vor pro Einwohner den größten Absatz in Europa auf und konnte seit 2004 weiter steigende Absatzzahlen vermelden. Länder wie Frankreich, Spanien, Italien und Großbritannien, deren Solarwärmemärkte über eine sehr lange Zeit auf sehr niedrigem Niveau verharrten, haben in den letzten Jahren ihre Rahmenbedingungen so verbessert, dass sich derzeit starke Wachstumszahlen ergeben.

Der Beschluss des europäischen Rates vom 9. März 2007, ein verbindliches Ziel von 20% Erneuerbare Energien für das Jahr 2020 zu setzen, erfordert u.a. einen starken Ausbau der Nutzung der Solarwärme für Warmwasserbereitung, Raumheizung, Prozesswärme und Kühlung.

Der europäische Solarthermie-Industrieverband ESTIF hat für das Jahr 2020 das Ziel gesteckt, im europäischen Schnitt einen Quadratmeter Kollektorfläche pro Einwohner installiert zu haben. Dies bedeutet, dass sich die gesamt installierte Solarwärmeleistung von 13.300 MWth Ende 2006 auf 330.000 MWth erhöhen muss. Der jährliche Absatz an Solarkollektoren wird sich dann von ca. 3 Mio m² auf 100 Mio m² steigern.

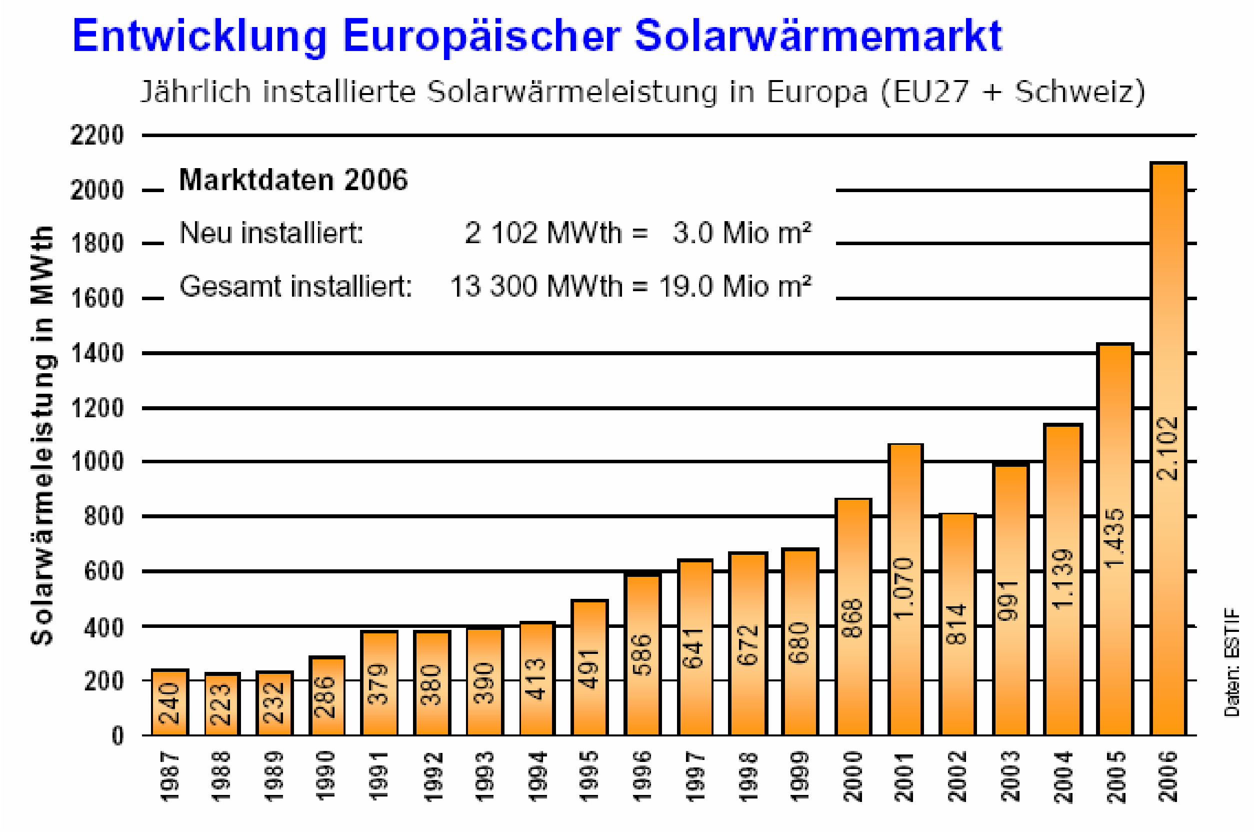

Abb 2: Entwicklung der jährlich installierten Solarwärmeleistung in Europa

Diese Ziele sind nur erreichbar, wenn mit dem Ausbau der Märkte und der Produktion die Technik weiter entwickelt, die Anlagen effizienter und günstiger werden, die solaren Deckungsanteile in den jeweiligen Anwendungen ansteigen und gleichzeitig eine hohe Qualität der Solarwärmesysteme und –installationen gewährleistet wird.

Technische Weiterentwicklung und Qualitätssicherung setzen ausgereifte und an die Praxis angepasste Normen für Leistungs- und Sicherheitstests von Solarkollektoren und –systemen voraus. Deshalb stellen die Arbeiten, die im Rahmen dieses Projektes geleistet wurden, einen wesentlichen Baustein zur weiteren Entwicklung des Solarmarktes dar.

Die Zusammenarbeit der Forschungs- und Testinstitute ITW und SWT mit dem Solarbranchenverband BSW-Solar (ehemals BSi), sowie einer großen Zahl renommierter Hersteller gewährleistete eine praxisorientierte Ausrichtung der Arbeit und marktorientierte Ergebnisse. Zu den Projekttreffen waren jeweils auch die Experten anderer Forschungs- und Testinstitute eingeladen, was einen breiten Austausch der Fachwelt gewährleistete.

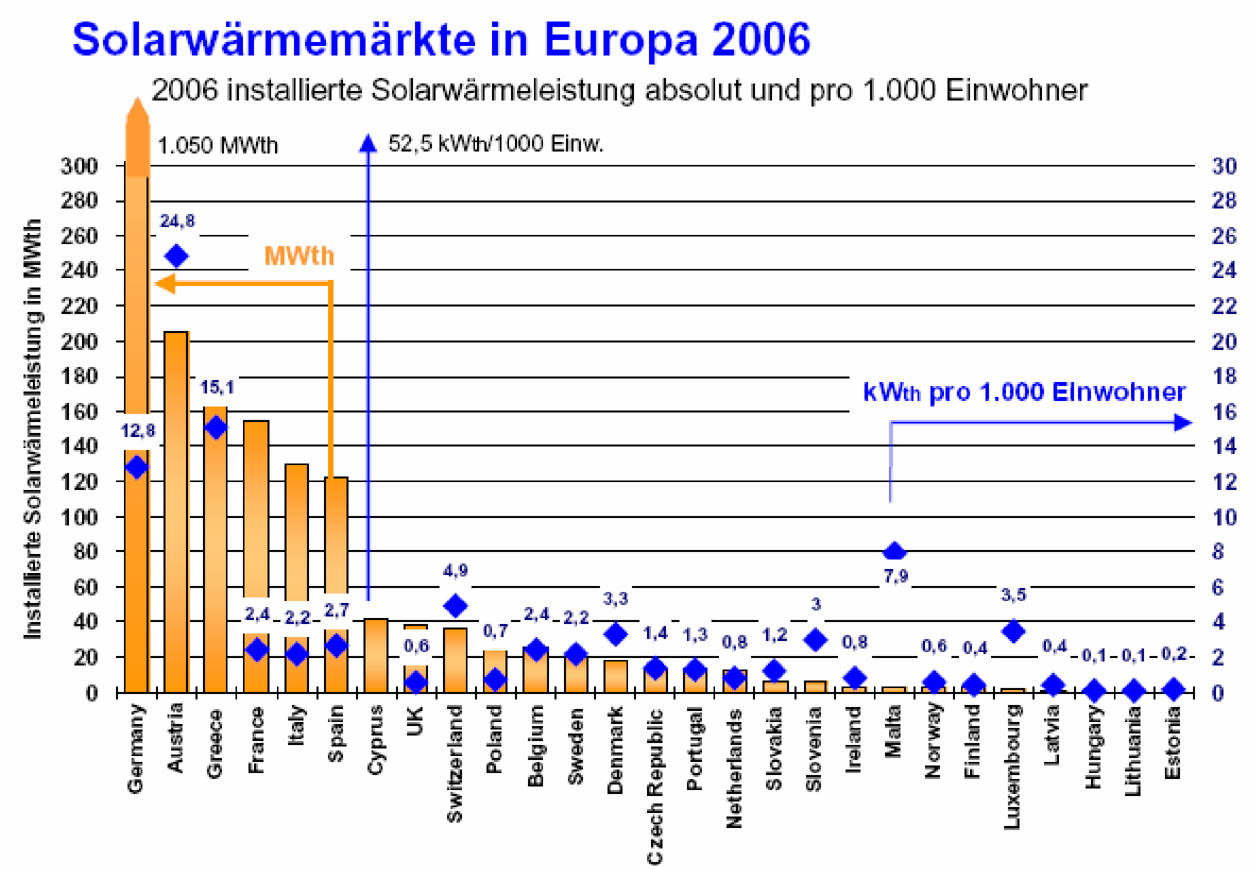

Abb. 3: Installierte Solarwärmeleistung in den Ländern Europas im Jahr 2006, absolut (orange Balken, linke y-Achse) und pro 1.000 Einwohner (blaue Rauten, rechte y-Achse)

Die bereits existierende Normung für Solarwärmekollektoren konnte in den letzten Jahren wesentlich zur Sicherung eines einheitlichen hohen Qualitätsstandards in Europa beitragen. Mittlerweile ist das „Solar Keymark“ für Kollektoren, das auf der europäischen Norm EN 12975 basiert, weit verbreitet und wird in fast allen Ländern Europas als Qualitätslabel akzeptiert. Durch die europäische Harmonisierung der Qualitätsanforderungen an Kollektoren wurde der internationale Vertrieb und damit auch der Know-how-Austausch wesentlich vereinfacht.

Durch das Projekt EuroSol konnten jetzt wichtige Beiträge zur Überarbeitung der vorhandenen Normen für Solarkollektoren und fabrikfertige Systeme (EN 12975 und EN 12976) geliefert und Neukonzeption und Ausweitung der Norm für kundengefertigte Solarwärmeanlagen (Vornorm ENV 12977) durch wissenschaftliche Grundlagenarbeit maßgeblich vorangetrieben und unterstützt werden.

Konkret wurden im Projekt u.a. folgende Arbeiten durchgeführt:

- Teilnahme an Sitzungen einschlägiger nationaler, europäischer und ggf. internationaler Normungsgremien
- Wissenschaftliche Untersuchung offener Fragestellungen
- Redaktionelle Arbeiten an den Normen
- Erweiterung des Prüfverfahrens für Sonnenkollektoren in der Normreihe EN 12975 durch einen Test zur Bestimmung des biaxialen Einfallswinkelkorrekturverhaltens
- Durchführung von Untersuchungen zur Bestimmung der effektiven Wärmekapazität von Sonnenkollektoren

- Entwicklung einer Methodik, um in der Normreihe ENV 12977 zur Ermittlung der thermischen Leistungsfähigkeit der Gesamtanlage den Prüfaufwand für verschiedene Baugrößen eines Speichers zu reduzieren
- Abstimmung der Normentwürfe mit den Solarunternehmen und Branchenexperten
- Öffentlichkeitsarbeit zur Verbreitung der überarbeiteten Normen

Das Projekt EuroSol konnte im Herbst 2006 erfolgreich abgeschlossen werden. Die überarbeiteten Normungsentwürfe befinden sich in der internationalen Abstimmung, wobei die im Projekt erarbeiteten Grundlagen und Vorschläge weitgehend aufgenommen und berücksichtigt wurden.

Die Arbeit an den Normen konnte Dank der Förderung des Projektes EuroSol durch die Deutsche Bundesstiftung Umwelt mit der notwendigen Gründlichkeit erfolgen und durch die enge Kooperation der Forschungs- und Testinstitute mit den Herstellern von Solarwärmekollektoren und –systemen markt- und praxisorientiert realisiert werden. EuroSol trägt damit aktiv zur Qualitätssicherung von Solarkollektoren und –systemen und zur Beschleunigung der Verbreitung von Solarwärmeanlagen bei.

Wir danken der DBU für die Förderung des Projektes, dem ITW der Universität Stuttgart und dem SWT Stuttgart für die professionelle Durchführung sowie den Solarfirmen und allen Experten, die sich an den Arbeiten und Diskussionen beteiligt haben für die aktive Mitarbeit und Unterstützung.

Berlin, Juli 2007

Gerhard Stryi-Hipp
Geschäftsführer Bundesverband Solarwirtschaft (BSW-Solar)

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Forschungs- und Testzentrum für Solaranlagen
Professor Dr. Dr.-Ing. habil. H. Müller-Steinhagen

in Kooperation mit

Abschlussbericht

(Technischer Teil)

zum Vorhaben

Mitarbeit der deutschen Solarindustrie bei der Überarbeitung der europäischen Normen für thermische Solaranlagen

Akronym „EuroSol“

Harald Drück
Stephan Fischer
Stephan Bachmann

Durchgeführt im Auftrag des Bundesverbands Solarwirtschaft (BSW)
und gefördert durch die Deutsche Bundesstiftung Umwelt (DBU)

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Stuttgart, 19. Juli 2007

Kurzfassung

Durch das Projekt „EuroSol“ erfolgte im Zeitraum von September 2003 bis September 2006 die maßgebliche Mitarbeit der deutschen Solarindustrie bei der Überarbeitung und Erweiterung der europäischen Normen für thermische Solaranlagen und ihre Bauteile.

Im Hinblick auf Sonnenkollektoren (Normreihe EN 12975) wurde die Eignung von unterschiedlichen Parameteridentifikationswerkzeugen untersucht und das für die Ermittlung der thermischen Leistungsfähigkeit der Kollektoren dienende Prüfverfahren um die Bestimmung des biaxialen Einfallswinkelkorrekturverhaltens erweitert. Zusätzlich wurden Untersuchungen zur Bestimmung der effektiven Wärmekapazität von Sonnenkollektoren durchgeführt.

In der Normreihe EN 12976 werden sogenannte fabrikfertige Solaranlagen zur Trinkwassererwärmung behandelt. Da zusätzlich zur Energieeinsparung auch der von einer Solaranlage bereitgestellte Warmwasserkomfort eine entscheidende Größe ist, ist in der EN 12975-2 ein Verfahren zur „Ermittlung des Lasthaltevermögens“ enthalten, das jedoch gewissen Nachteile aufweist. Der Schwerpunkt der die Normreihe EN 12976 betreffenden Arbeiten lag daher bei der Untersuchung von Verfahren zur Ermittlung der Leistungsfähigkeit von Speichern bei der Trinkwassererwärmung

In der Normreihe ENV 12977 werden kundenspezifische Solaranlagen behandelt. Gegenwärtig ist zur Ermittlung der thermischen Leistungsfähigkeit der Gesamtanlage eine Prüfung von allen Baugrößen eines Speichers vorgeschrieben. Zur Reduktion des Prüfaufwands wurde eine Methodik entwickelt, die es auf der Basis von Messungen an einem Speicher ermöglicht, die wichtigsten wärmetechnischen Kenngrößen auf Speicher gleicher Bauart, jedoch unterschiedlichen Volumens, zu extrapolieren. Diese Methodik wurde in den neuen Entwurf der Norm EN 12977-3 aufgenommen.

Da solare Kombianlagen in den zu Beginn des Projektes verfügbaren europäischen Solarnormen nicht explizit berücksichtigt waren, wurde die Normreihe ENV 12977 entsprechend erweitert. Hierzu wurde diese grundlegend überarbeitet, unstrukturiert und durch zwei neue Teile ergänzt. Die heutige Normreihe EN bzw. CEN/TS 12977 verfügt damit über insgesamt 5 Teile.

Durch die Publikation von zahlreichen Fachartikeln und die Präsentation ausgewählter Projektergebnisse bei mehreren nationalen und internationalen Tagungen und Kongressen wurde über die Ergebnisse der projektspezifischen Arbeiten informiert. Zusätzlich wurde über die Inhalte und den aktuellen Status der Normen sowie über die Aktivitäten der einschlägigen nationalen, europäischen und internationalen Normungsgremien anlässlich mehrerer Informationsveranstaltungen berichtet.

Die innerhalb dieses Projektes durchgeführten Arbeiten sowie die dabei erzielten Ergebnisse und gewonnen Erkenntnisse werden in diesem Bericht detailliert beschrieben.

Inhaltsverzeichnis

Nomenklatur

Lateinische Buchstaben

a_1	Wärmedurchgangskoeffizient	$[W/(m^2K)]$
a_2	temperaturabhängiger Wärmedurchgangskoeffizient	$[W/(m^2K^2)]$
A	Fläche, Aperturfläche	$[m^2]$
b_0	Faktor zur Bestimmung des Einfallswinkelkorrekturvermögens der direkten Bestrahlungsstärke	[-]
b_{h1}	Exponent zur Beschreibung der Massenstromabhängigkeit des Wärmeübertragungsvermögens eines eingetauchten Wärmeübertragers	[-]
b_{h3}	Exponent zur Beschreibung der Temperaturabhängigkeit des Wärmeübertragungsvermögens eines eingetauchten Wärmeübertragers	[-]
$b_{h1,aux}$	Exponent zur Beschreibung der Massenstromabhängigkeit des Wärmeübertragungsvermögens des Nachheizkreis-Wärmeübertragers	[-]
$b_{h3,aux}$	Exponent zur Beschreibung der Temperaturabhängigkeit des Wärmeübertragungsvermögens des Nachheizkreis-Wärmeübertragers	[-]
$b_{h1,HW}$	Exponent zur Beschreibung der Massenstromabhängigkeit des Wärmeübertragungsvermögens des Trinkwasser-Wärmeübertragers	[-]
$b_{h3,HW}$	Exponent zur Beschreibung der Temperaturabhängigkeit des Wärmeübertragungsvermögens des Trinkwasser-Wärmeübertragers	[-]
$b_{h1,sol}$	Exponent zur Beschreibung der Massenstromabhängigkeit des Wärmeübertragungsvermögens des Solarkreis-Wärmeübertragers	[-]
$b_{h3,sol}$	Exponent zur Beschreibung der Temperaturabhängigkeit des Wärmeübertragungsvermögens des Solarkreis-Wärmeübertragers	[-]
$b_{h1,sol,aux}$	Gemeinsamer Exponent zur Beschreibung der Massenstromabhängigkeit des Wärmeübertragungsvermögens des Solarkreis- und Nachheizkreis-Wärmeübertragers	[-]

c	spezifische Wärmekapazität	[J/(kg K)]
c_{abs}	Wärmekapazität des Absorbers (flächenbezogen)	[J/(m^{2}K)]
c_{eff}	effektive Wärmekapazität (flächenbezogen)	[J/(m^{2}K)]
c_{fl}	Wärmekapazität des Fluids (flächenbezogen)	[J/(m^{2}K)]
c_p	spezifische Wärmekapazität (bei konstantem Druck)	[J/(kg K)]
D	Diffusstrahlungsanteil	[-]
F’	Kollektorwirkungsgradfaktor	[-]
f_{sav}	anteilige Energieeinsparung	[-], [%]
G	Hemisphärische Bestrahlungsstärke	[W/m^2]
G_{dir}	Direkte Bestrahlungsstärke	[W/m^2]
G_d	Diffuse Bestrahlungsstärke	[W/m^2]
H_s	Speicherhöhe	[m]
IAM	Einfallswinkelkorrekturvermögen der direkten Bestrahlungsstärke	[-]
IAMdfu	Einfallswinkelkorrekturvermögen der diffusen Bestrahlungsstärke	[-]
IAMreg	Einfallswinkelkorrekturvermögen (ermittelt durch Regression)	[-]
K	Einfallswinkelkorrekturvermögen	[-]
K_b	Einfallswinkelkorrekturvermögen der direkten Bestrahlungsstärke	[-]
K_d, K_{dfu}	Einfallswinkelkorrekturvermögen der diffusen Bestrahlungsstärke	[-]
K_θ	Einfallswinkelkorrekturvermögen der hemisphärischen Bestrahlungsstärke	[-]
kA	Wärmeübertragungsvermögen	[W/K]
K_{aux}	Konstante zur Beschreibung des Wärmeübertragungsvermögens des Nachheizkreis-Wärmeübertragers	[W/K]
K_{HW}	Konstante zur Beschreibung des Wärmeübertragungsvermögens des Trinkwasser-Wärmeübertragers	[W/K]
K_{sol}	Konstante zur Beschreibung des Wärmeübertragungsvermögens des Solarkreis-Wärmeübertragers	[W/K]

K_{WT}	Konstante zur Beschreibung des Wärmeübertragungsvermögens eines Wärmeübertragers	[W/K]
kint	interner Wärmedurchgangskoeffizient	[W/(m^2K)]
$\dot{m}$	Massenstrom	[kg/s]
n	Schichtungskennzahl für die direkte Entladung	[-]
Obj.	Zielfunktion	[W]
p	Druck	[N/m^2]
P_{col}	Kollektorleistung	[W]
$P_{col,gem}$	gemessene Kollektorleistung	[W]
$P_{col,ber.}$	berechnete Kollektorleistung	[W]
Q	Wärme, Wärmemenge	[J], [kWh]
Q_{col}	Kollektorertrag	[kWh]
$Q_{HW,meas}$’	Wärmemenge, die bei der Trinkwasser-Zapfung entnommen wird	[J]
$\dot{Q}$	Wärmestrom	[kW]
$\dot{Q}_{NH}$	Nenn-Heizleistung	[kW]
$\dot{q}_{abs,fl}$	flächenbezogener Wärmestrom zwischen Absorber und Fluid	[W/m^2]
$\dot{q}_{nutz}$	flächenbezogener Nutzwärmestrom	[W/m^2]
$\dot{q}_{verl}$	flächenbezogener Verlustwärmestrom	[W/m^2]
sol_{co}	Konstante zur Beschreibung des sekundären thermosiphonischen Massenstroms	[-]
t	Zeit	[s]
T	thermodynamische Temperatur	[K]
T_{cin}	Kollektoreintrittstemperatur	[°C]
T_{cout}	Kollektoraustrittstemperatur	[°C]
T_m	mittlere (Kollektor)Temperatur	[°C]
T_{umg}	Umgebungstemperatur	[°C]
U_1	Wärmedurchgangskoeffizient	[W/(m^2K)]

U_2	temperaturabhängiger Wärmedurchgangskoeffizient	$[W/(m^2K^2)]$
UA_{hx}	Wärmeübertragungsvermögen	[W/K]
UA_{sa}	Wärmeverlustrate	[W/K]
V	Volumen	[l]
V_{hx}	Volumen eines Wärmeübertragers	[l]
$V_{hx,aux}$	Volumen Nachheizkreis-Wärmeübertrager	[l]
$V_{hx,HW}$	Volumen Trinkwasser-Wärmeübertrager	[l]
$V_{hx,sol}$	Volumen Solarkreis-Wärmeübertrager	[l]
V_{nutz}	nutzbares Warmwasservolumen	[l]
V_s	Volumen des Wasserraums des Speichers	[l]
$\dot{V}$	Volumenstrom	$[m^3/s]$
$\dot{V}_{NH}$	Volumenstrom im Nachheizkreis	$[m^3/s]$
z_x	Relative Höhe eines Anschlusses oder eines Temperaturfühlers bezogen auf die Speicherhöhe H_s	[-]
$Z_{aux,HW,out}$	relative Höhe Austritt Trinkwassernachheizkreis	[-]
$Z_{aux,in}$	relative Höhe Eintritt Nachheizkreis	[-]
$Z_{aux,out}$	relative Höhe Austritt Nachheizkreis	[-]
$Z_{aux,out/SH,in}$	rel- Höhe Austritt Nachheizkreis / Eintritt Raumheizkreis	[-]
z_{KW}	relative Höhe Eintritt Kaltwasser	[-]
$Z_{SH,in}$	relative Höhe Eintritt Raumheizkreis	[-]
$z_{sol,aux,in}$	relative Höhe Eintritt Solarkreis bzw. Nachheizkreis	[-]
$z_{sol,in}$	relative Höhe Eintritt Solarkreis	[-]
$z_{sol,out}$	relative Höhe Austritt Solarkreis	[-]
z_{Taux}	relative Höhe Temperaturfühler Nachheizung	[-]
$z_{Taux,SH,off}$	relative Höhe des Temperaturfühlers zum Ausschalten der Nachheizung für den Raumheizkreis	[-]
$z_{Taux,SH,on}$	relative Höhe des Temperaturfühlers zum Einschalten der Nachheizung für den Raumheizkreis	[-]
z_{Tsol}	relative Höhe Temperaturfühler Regelung Solarkreis	[-]

z_{WW}	relative Höhe Austritt Warmwasser	[-]

Griechische Buchstaben

Δ	Differenz	[-]
$\Delta\vartheta_{NH}$	Temperaturspreizung der Nachheizung ($\Delta\vartheta_{NH} = \vartheta_{ein} - \vartheta_{aus}$)	[K]
γ	Kollektoranstellwinkel	[°]
η	Wirkungsgrad	[-]
η_0	Konversionsfaktor hemisphärischen Bestrahlungsstärke	[-]
ϑ	Celsius-Temperatur	[°C]
ϑ_{abs}	Absorbertemperatur	[°C]
ϑ_{amb}	Umgebungstemperatur	[°C]
ϑ_{fl}	Fluidtemperatur	[°C]
$\vartheta_{fl,m}$	mittlere Fluidtemperatur	[°C]
$\vartheta_{fl,aus}$	Fluidaustrittstemperatur	[°C]
$\vartheta_{fl,ein}$	Fluideintrittstemperatur	[°C]
ϑ_m	mittlere lokale Temperatur	[°C]
ϑ_{NH}	Nachheiztemperatur	[°C]
$\vartheta_{TW,soll}$	Abschalttemperatur für Nachheizung Trinkwasser	[°C]
ϑ_{WT}	Wärmeübertragertemperatur	[°C]
$\vartheta_{WT,aus}$	Wärmeübertrager-Austrittstemperatur	[°C]
$\vartheta_{WT,ein}$	Wärmeübertrager-Eintrittstemperatur	[°C]
θ	Einfallswinkel	[°]
θ_l	Longitudinaler Einfallswinkel	[°]
θ_t	Transversaler Einfallswinkel	[°]
θ_z	Zentiwinkel	[°]
λ_{eff}	effektive (vertikale) Wärmeleitfähigkeit	[W/(mK)]
ρ	Dichte	[kg/m³]
$\tau\alpha$	Transmissions-Absorptions-Produkt	[-]

Indizes

abs	Absorber
amb	Umgebung
aus	Austritt
aux	Nachheizung
fl	Fluid
fl,aus	Fluid, Austritt
fl,ein	Fluid, Eintritt
fl,m	Fluid, mittel
ber	berechnet
col	Kollektor (Collector)
d	diffus
dir	direkt
ein	Eintritt
eff	Effektiv
gem	gemessen
hx	Wärmeübertrager (heat exchanger)
HW	Warmwasser (hot water)
KW	Kaltwasser
l	longitudinal
m	Anzahl der Zeitschritte einer Sequenz
max	maximal
n	Norden
nutz	nutzbar
NH	Nachheizung
o	Osten
s	Süden/Speicher
sav	Einsparung (savings)
SH	Raumheizung (space heating)
sol	solar

t	transversal
T	Temperaturfühler
Tsol	Temperatur(fühler) Solarkreis
Taux	Temperatur(fühler) Nachheizkreis
TW	Trinkwasser
umg	Umgebung
verl	Verlust bzw. an die Umgebung abgegeben
WT	Wärmeübertrager
WW	Warwasser
x	Platzhalter (z. B. für ‘C‘ oder ‘D‘)??

Abkürzungen

ACDC	Annual Calculation – Direct Comparison
Alt	Höhenwinkel (Altitude)
BDH	Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik
BSW	Bundesverband Solarwirtschaft
bzgl.	bezüglich
bzw.	beziehungsweise
cos	Cosinus
CEN	Comité Européen de Normalisation / Europäisches Komitee für Normung
CTSS	Component Testing – System Simulation
CPC	Compound Parabolic Concentrator
DBU	Deutsche Bundesstiftung Umwelt
DF	Dynamic Fitting
DFS	Deutscher Fachverband Solarenergie
DIN	Deutsches Institut für Normung; Deutsche Industrienorm
DIN V	DIN Vornorm
EN	Europäische Norm
ENV	Europäische Vornorm
EU	Europäische Union
evtl.	eventuell

ggf.	gegebenenfalls
Gl	Gleichung
i.a.	im Allgemeinen
IA	Einfallswinkel
IAL	longitudinaler Einfallswinkel
IAT	transversaler Einfallswinkel
IEA SH&C	Intenational Energy Agency, Solar Heating and Cooling Program
incl.	inklusive
ISO	International Standardisation Organisation
ITW	Institut für Thermodynamik und Wärmetechnik
KW	Kaltwasser
max.	maximal
min.	Minuten
MLR	Multi-lineare Regression
norm.	normiert
prEN	vorläufige (preliminary) Europäische Norm
sin	Sinus
stat.	statisch
tan	Tangens
TC	Technical Committee / Technisches Komitee
TS	Technical Specification
u. a.	unter anderem
vgl.	vergleiche
WG	Working Group / Arbeitsgruppe
WT	Wärmeübertrager
WW	Warmwasser
z. B.	zum Beispiel

1 Einleitung

Im Jahr 1994 wurde auf Anregung des europäischen Herstellerverbands ESIF und unterstützt durch das Altener-Programm der EU das europäische Normungskomitee CEN TC 312 eingesetzt. Von diesem wurden in den Jahren 1994 bis 2000 europäische Normen für Sonnenkollektoren, Warmwasserspeicher und vollständige Solaranlagen erarbeitet. In den Normen sind sowohl Mindestanforderungen an die Produkte definiert, als auch Testmethoden zur Überprüfung dieser Anforderungen sowie zur Ermittlung der thermischen Leistungsfähigkeit beschrieben.
Die Zielgruppe sind somit die Hersteller von solarthermischen Produkten und die einschlägigen Prüfinstitute.

Das Normungskomitee CEN TC 312 ist in drei Arbeitsgruppen unterteilt, in denen von Experten aus der Industrie sowie von Forschungs- und Prüfinstituten Normen für Kollektoren, ‚vorgefertigte Anlagen‘ und ‚kundenspezifisch gefertigte Anlagen‘ erstellt wurden.
Die im Folgenden aufgeführten drei Normen umfassen insgesamt sieben Teile und berücksichtigen den Großteil der auf dem europäischen Markt gängigen Typen von Solaranlagen bzw. Kollektoren und Speichern.

EN 12975-1: Kollektoren - Teil 1- Allgemeine Anforderungen

EN 12975-2: Kollektoren - Teil 2- Prüfverfahren

EN 12976-1: Vorgefertigte Anlagen - Teil 1 - Allgemeine Anforderungen

EN 12976-2: Vorgefertigte Anlagen - Teil 2 - Prüfverfahren

ENV 12977-1: Kundenspezifisch gefertigte Anlagen - Teil 1 Allgemeine Anforderungen

ENV 12977-2: Kundenspezifisch gefertigte Anlagen - Teil 2 - Prüfverfahren

ENV 12977-3: Kundenspezifisch gefertigte Anlagen - Teil 3 - Leistungsprüfung von Warmwasserspeichern von Solaranlagen

1.1 Aktueller Stand und Perspektiven der CEN-Normen

Die europäischen Normen für thermische Solaranlagen und ihre Bauteile sind in den meisten Ländern Europas im Jahr 2001 in Kraft gesetzt worden und haben die bisher dort angewandten nationalen Normen ersetzt. Es ist somit nun erstmals möglich die Produkte nach europaweit einheitlichen Verfahren zu prüfen. Für die Kunden hat das insbesondere den Vorteil, dass die ermittelten Ergebnisse untereinander vergleichbar sind. Für die Hersteller und Vertreiber solarthermischer Produkte ergibt sich durch die europaweit einheitliche Prüfung eine deutliche Reduktion der Prüfkosten.

Weiterhin ist bereits heute zu beobachten, dass die EN-Normen die Hersteller auf breiter Ebene zu einer Verbesserung ihrer Produkte anregen und ein hohes Qualitätsniveau bei solarthermischen Komponenten und Anlagen sicherstellen. Die Sicherung der Produktqualität, einschließlich der Anlagensicherheit und der Leistung, wird die Entwicklung eines anspruchsvollen europäischen Solartechnikmarktes fördern.
Unterstützt wird diese Entwicklung auch durch die europaweit einheitliche Zertifizierung von Solaranlagen und Kollektoren. Hierzu wurde im Zeitraum von 2001 bis 2003 im Rahmen eines von der EU geförderten Altener-Vorhabens ein Zertifizierungsprogramm für das „Solar Keymark“ erarbeitet. Das Keymark ist ein europaweit anerkanntes und einheitliches Qualitätslabel. Die Basis für die Zertifizierung der Produkte mit dem Solar Keymark sind ebenfalls die EN-Normen für thermische Solaranlagen und ihre Bauteile. Das Solar Keymark hat sich in den vergangenen Jahren erfolgreich am Markt etabliert. Gegenwärtig (Sommer 2007) sind bereits etwa 40 bis 50 % der in Europa verkauften Sonnenkollektoren nach den Regeln des Solar Keymarks zertifiziert.

Im Herbst 2001 wurde vom Normungskomitee CEN TC 312 die Revision der Normen für thermische Solaranlagen beschlossen. Diese ist notwendig um die Normen an die aktuellen Entwicklungen im Bereich der Produkte und Prüfverfahren anzupassen, sowie darin enthaltene Unklarheiten und Fehler zu beseitigen. Weiterhin ist vom CEN TC 312 beschlossen worden, Normen für solare Kombianlagen (Solaranlagen zur kombinierten Trinkwassererwärmung und Heizungsunterstützung) zu fordern. Von holländischer Seite wird hierzu bis Ende 2002 ein formaler Vorschlag für einen neuen Arbeitspunkt vorbereitet (Resolution 2, CEN/TC 312 – Athens, 2001-22-1/2).

Um die Interessen der deutschen Solarindustrie sowie die umfangreichen nationalen Erfahrungen bei der Prüfung solarthermischer Produkte in die Überarbeitung und Erweiterung der europäischen Normen einfließen zu lassen, ist eine intensive Mitarbeit Deutschlands angebracht. Diese Mitarbeit erfolgte im Rahmen eines von der Deutschen Bundesstiftung Umwelt geförderten Vorhabens mit dem Titel „Mitarbeit der deutschen Solarindustrie bei der Überarbeitung der europäischen Normen für thermische Solaranlagen“, Akronym „EuroSol“.

1.2 Arbeitsziele und Arbeitsinhalte

Ziel des Projektes war die Mitarbeit bei der Überarbeitung und Erweiterung der europäischen Normen für thermische Solaranlagen und ihrer Bauteile. Das Vorhaben war so angelegt, dass zusätzlich zu einer Teilnahme an den Sitzungen der europäischen Normungsgremien auch offene Fragestellungen wissenschaftlich untersucht und redaktionelle Arbeiten an den Normen durchgeführt werden konnten.

Im Einzelnen wurden hierbei folgende zentrale Arbeitspunkte behandelt:

- Mitarbeit bei Überarbeitung der Normen für Kollektoren (Normreihe EN 12975)
- Begleitung der Überarbeitung der Normen für fabrikfertige Solaranlagen (Normreihe EN 12976)
- Mitgestaltung der Normen für „kundenspezifisch gefertigte Solaranlagen“ (Normreihe ENV 12977)
- Normreihe für Kombianlagen
- Öffentlichkeitsarbeit

Die Inhalte der einzelnen Arbeitspunkte sowie die bei der Bearbeitung erzielten Ergebnisse und gewonnen Erkenntnisse sind in diesem Bericht beschrieben. Hierbei ist jedem der oben aufgeführten Arbeitspunkte ein separates Kapitel gewidmet.

2. Mitarbeit bei Überarbeitung der Normen für Kollektoren (Normreihe EN 12975)

Die europäischen Normen für Sonnenkollektoren werden in der europäischen Normungsgruppe CEN TC312/WG 1 bearbeitet und sind bereits relativ weit entwickelt, da sie im wesentlichen auf den bekannten Kollektor-Normen ISO 9806, Teil 1, Teil 2 und Teil 3 für die Bestimmung der thermischen Leistung und die Prüfung der Gebrauchstauglichkeit (und somit auch auf der ursprünglichen deutschen Norm DIN 4757) beruhen. Diskussionsbedarf besteht bei der Überarbeitung insbesondere bei den Anforderungen und Prüfverfahren bzgl. Schnee- und Windlast sowie der Hagelschlagfestigkeit von Vakuumröhren.

Für die Ermittlung der thermischen Leistungsfähigkeit ist nach der EN 12975-2 als Erweiterung des klassischen (stationären) Testverfahrens nach ISO 9806-1 bzw. DIN V 4757-4 erstmals auch ein Verfahren unter quasi-dynamischen Bedingungen festgeschrieben. Der entscheidende Vorteil dieses Verfahrens ist ein deutlich reduzierter Zeitbedarf für die Durchführung der Prüfungen der zu geringeren Prüfkosten führt. In Zusammenhang mit dem quasi-dynamischen Testverfahren ist noch zu klären, welche Anforderungen an die zur Kennwertbestimmung einsetzbaren Algorithmen (Parameteridentifikationswerkzeuge) gestellt werden müssen.

Die Berechnung der Nutzwärmeleistung die von Kollektoren mit einem biaxialen Einfallswinkelkorrekturverhalten abgegeben wird, ist gegenwärtig nicht vollständig normativ erfasst. Da dieses Problem nahezu alle Vakuumröhrenkollektoren betrifft, war es notwendig, das in der Norm angegebene Prüfverfahren gemeinsam mit dem ebenfalls genormten Rechenmodell entsprechend zu erweitern.

Die Bestimmung der Wärmekapazität des Kollektors ist nach EN 12975-2 mit diversen Verfahren möglich. Es hat sich gezeigt, dass mit den einzelnen Verfahren Ergebnisse ermittelt werden, die teilweise um den Faktor 3 differieren. Da die Wärmekapazität einen deutlichen Einfluss auf den Kollektorertrag hat, musste die Ursache für diese Diskrepanz näher untersucht werden.

2.1 Eignung Parameteridentifikationswerkzeuge

Die Bestimmung von Kennwerten eines Modell (Parameteridentifikation) durch Anpassung der Kennwerte an gemessene Daten ist eine etablierte Methode. Der grundsätzliche Ansatz ist i. a. für alle Modelle der Gleiche /Press1992/. Es wird eine Zielfunktion definiert mit der die Übereinstimmung der gemessenen Daten mit dem aus dem Modell unter der Verwendung der Modellkennwerte berechneten Ergebnis verglichen wird. Die Zielfunktion wird normalerweise so gewählt, dass kleine Werte der Zielfunktion eine gute Übereinstimmung repräsentieren. Die Kennwerte des Modells werden dann so geändert, dass die Zielfunktion minimiert wird um den passenden Kennwertsatz zu finden. Der Prozess der Anpassung ist also eine Minimierung der Zielfunktion im mehrdimensionalen Raum der mit unterschiedlichen Verfahren durchgeführt werden kann.

2.1.1 Multi-lineare Regression (MLR)

Die multi-lineare Regression ist eine schnelle, nicht iterative Matrixoperation. Linear bedeutet, dass das Model als Summe von Werten geschrieben wird die jeweils mit einem Kennwert p_m multipliziert werden (vgl. Gl. 1).

$$y(x_1, x_2, x_3) = p_1 \cdot f(x_1) + p_2 \cdot g(x_2, x_3) + p_3 \cdot h(x_1, x_2, x_3) \qquad (1)$$

Die Funktionen $f(x_1)$, $g(x_2,x_3)$ und $h(x_1,x_2,x_3)$ können durchaus nicht linear sein.

Angenommen es werden N Datenpunkte $(x_{1,i}, x_{2,i}, x_{3,i}, y_i)$, $i=1,\ldots, N$ an ein Modell mit M freien Kennwerten, p_j $j=1,\ldots,M$, angepasst. Dabei spiegelt das Modell den funktionalen Zusammenhang zwischen den gemessenen unabhängigen und den abhängigen Variablen wider (vgl. Gl. 2), wobei die Abhängigkeit der Kennwerte auf der rechten Seite der Gleichung dargestellt sind.

$$y(x_1, x_2, x_3) = y(x_1, x_2, x_3; p_1 \ldots p_M) \qquad (2)$$

Die Funktion kann nach der Methode der kleinsten Fehlerquadrate (vgl. Gl. 3) minimiert werden.

$$\sum_i^N [y_i - y(x_1, x_2, x_3; p_1 \ldots p_M)]^2 \qquad (3)$$

Die notwendigen Matrizenoperation können mit jedem Tabellenkalkulationsprogramm schnell und einfach durchgeführt werden.

2.1.2 Iterative Kennwertbestimmung

Iterative Methoden der Kennwertbestimmung verwenden den gleichen Ansatz wie zuvor beschrieben, nämlich die Definition einer Zielfunktion und die Bestimmung der Kennwerte durch die Minimierung der Zielfunktion mit Hilfe der Methode der kleinsten Fehlerquadrate. Bei Vorhandensein von nicht linearen Abhängigkeiten muss die Minimierung jedoch iterativ erfolgen. Der Vorteil der iterativen Methoden ist ihre hohe Flexibilität in Bezug auf die Eingangsdaten und die verwendeten Modelle.

Innerhalb dieses Projekts wurde das DF Programm /Spirkl1994/ zur Kennwertbestimmung benutzt. Das DF Programm nutzt den Levenberg Marquart Algorithmus zur Bestimmung der Kennwerte, ein weit verbreiteter Algorithmus der u. a. in /Press1992/ beschrieben wird.

Die Vergleichbarkeit der mit dem DF Programm erzielten Ergebnisse und der durch die multi-lineare Regression bestimmten wurde von /Fischer2003/ nachgewiesen.

Aufgrund der intensiven Bearbeitung der Punkte Einfallswinkelkorrektur und effektive Wärmekapazität sowie der mittlerweile geringen Relevanz der Fragestellung wurde von der Arbeitsgruppe 12975 beschlossen den Arbeitspunkt Parameteridentifikationswerkzeuge nicht zu bearbeiten.

2.2 Biaxialer Einfallswinkelkorrekturfaktor

Neben dem biaxialen Einfallswinkelkorrekturvermögen wurden auch Untersuchungen zum isotropen und multiaxialen Einfallswinkelkorrekturvermögen innerhalb des Projekts durchgeführt. Im Folgenden werden die Unterschiede zwischen den Einfallswinkelvermögen sowie die Ergebnisse der im Rahmen des Projekts durchgeführten Untersuchungen zum Thema Einfallswinkelkorrekturvermögen dargestellt.

Kollektoren können gemäß ihres Einfallwinkelkorrekturvermögens in Bezug auf die direkte Bestrahlungsstärke in drei Gruppen unterteilt werden:

Bei Kollektoren mit isotropen Einfallswinkelkorrekturvermögen ist die Kollektorleistung unabhängig von der Richtung des Einfallwinkels. Streng genommen ist dies nur bei einem kreisrunden Kollektor mit isotroper Kollektorabdeckung und Absorberbeschichtung möglich. Im Allgemeinen wird jedoch davon ausgegangen, dass dies für alle Flachkollektoren zutrifft /Duffie1991/, /GORDON2001/.

Für Kollektoren deren Einfallswinkelkorrekturvermögen von der Einfallsrichtung abhängig ist kennt die Literatur /Duffie1991/, /GORDON2001/ den sogenannten „biaxialen Einfallswinkelkorrekturfaktor“. Kollektoren dieser Art sind z. B. Vakuumröhrenkollektoren, CPC Kollektoren oder 1-achsig nachgeführte Kollektoren. Es können aber auch Flachkollektoren mit besonderer Geometrie bzw. Bauteilen sein.

Besteht nicht nur eine 2-dimensonale sondern eine 3-dimensionale Abhängigkeit von der Einfallsrichtung der direkten Bestrahlungsstärke wird von einem multiaxialen Einfallswinkelkorrekturvermögen gesprochen /Fischer2005/. Kollektoren dieser Art sind z. B. Vakuumröhrenkollektoren mit flachem Absorbern die nicht parallel zur Kollektorebene ausgerichtet sind und sogenannte MaReCo’s /Adsten2002/ wie sie in den letzten Jahren in Schweden entwickelt wurden. Ein Beispiel für einen „multiaxialen Kollektoren“ ist in Bild 2.1 dargestellt. Das Ausrichten der Röhren hat folgende Auswirkungen auf das thermische Verhalten des Vakuumröhrenkollektors:

(a) Die Verringerung des Konversionsfaktors bei senkrechter Einstrahlung aufgrund der verminderten projizierten Absorberfläche und des schrägen Einfallwinkels auf den Absorber

(b) Eine Verbesserung der Effizienz bei schrägem Strahlungseinfall von rechts (am Beispiel von Bild 2.1) solang keine Verschattung auftritt

(c) Eine Verschlechterung der Effizienz bei schrägem Strahlungseinfall von links (am Beispiel von Bild 2.1)

Die Auswirkungen (b) und (c) haben weiterhin zur Folge, dass das bisher symmetrische Verhalten in Bezug auf die Einstrahlung quer zur Röhre in zwei Bereiche unterteilt werden muss. Dieser Tatsache wurde bislang bei der Simulation von Vakuumröhrenkollektoren mit verdrehten Röhren meist keine Rechnung getragen. Um beides zu ermöglichen wurde der TRNSYS TYPE 132 um den Modus des multiaxialen Einfallswinkelkorrekturfaktors erweitert /Fischer2005/.

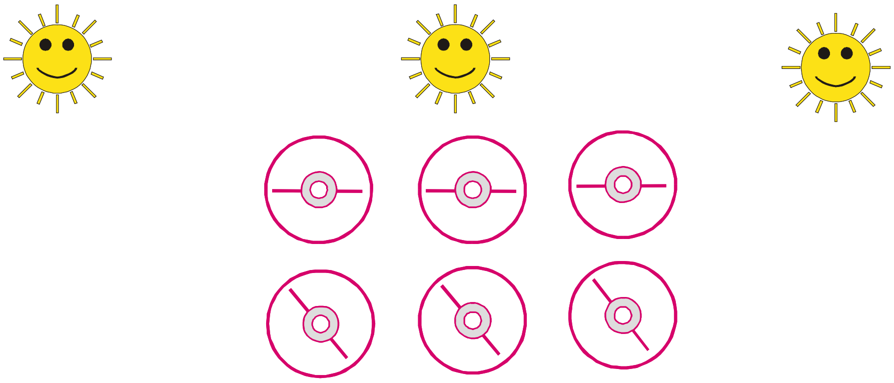


Bild 2.1: Schematischer Querschnitt dreier Röhren mit flachem Absorber in „Normalstellung“ (Abb. oben) und verdrehter Stellung (Abb. unten)

2.2.1 Isotropes Einfallswinkelkorrekturvermögen

2.2.1.1 Ansatz nach Souka/Safwat (b_0-Ansatz)

Der in der EN 12975 verwendete **Ansatz nach Souka/Safwat** (b_0-Ansatz) geht davon aus, dass sich das Einfallswinkelkorrekturvermögen durch die Verwendung des Ausdrucks (1/cos(θ)-1) linearisieren lässt. Damit ergibt sich die Gradengleichung des Einfallwinkelkorrekturvermögens mit der Steigung b_0 zu

$$K_b(\theta) = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) \tag{1}$$

Bild 2.2 zeigt den Verlauf des Einfallswinkelkorrekturvermögens nach Souka/Safwat für zwei Kollektoren. Die meisten isotropen Kollektoren weisen ein Einfallswinkelkorrekturvermögen zwischen den beiden dargestellten Kurven auf.

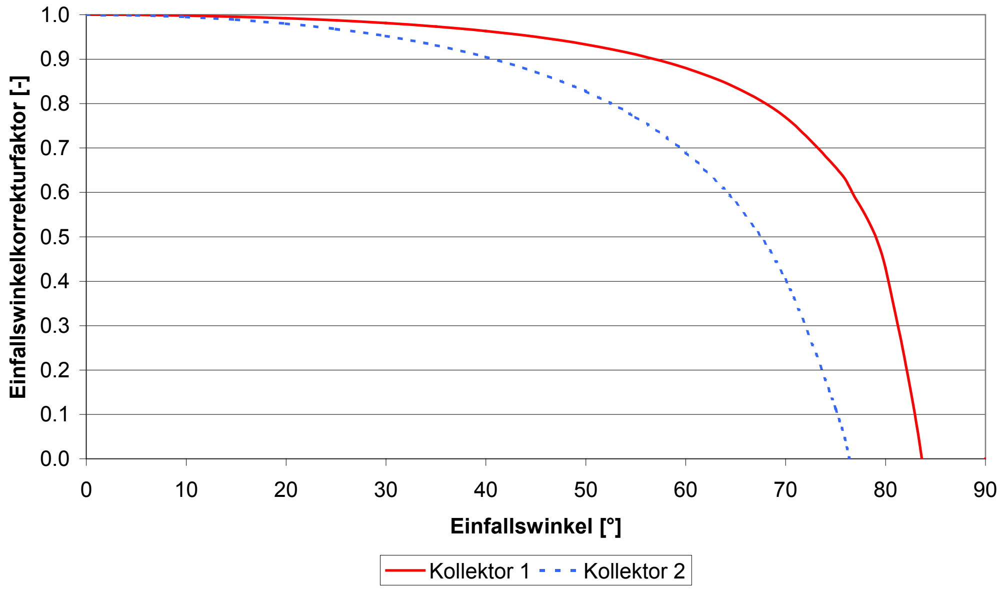


Bild 2.2: Verlauf des Einfallwinkelkorrekturvermögens für Kollektor 1 ($b_0 = 0.12$) und Kollektor 2 ($b_0 = 0.31$) nach Souka/Safwat.

2.2.1.2 Vergleich theoretischer und messtechnisch bestimmter Werte Einfallswinkelkorrekturvermögen von Flachkollektoren

Für die theoretische Bestimmung des Einfallwinkelkorrekturvermögens wurden gemäß Gl. 2 die winkelabhängigen Einflüsse der transparenten Abdeckung, der selektiven Schicht und des Kollektorgehäuses berücksichtigt.

$$K_b(\theta) = K_{b,abdeckung}(\theta) \cdot K_{b,schicht}(\theta) \cdot K_{b,gehäuse}(\theta) \qquad (2)$$

Die winkelabhängige Verläufe des Transmissionsvermögen der transparenten Abdeckung und des Absorptionsvermögen der selektiven Schicht können messtechnisch bestimmt oder der Literatur entnommen werden. Für den Einfluss der Kollektorgeometrie wurde innerhalb des Projekts ein vereinfachtes Model entwickelt. Das Einfallswinkelkorrekturvermögen $K_{b,gehäuse}(\theta)$ kann danach mit Gleichung (3) für Kollektorgeometrien nach Bild 2.3 abgeschätzt werden.

$$K_{b,gehäuse}(\theta) = \frac{(x_1 - x_3) - MAX(h_1 \tan\theta - x_2, 0) - h_2 \tan\theta}{(x_1 - x_3)} \qquad (3)$$

mit: x_1: Absorberbreite
x_2: Abstand Rand – Absorber
x_3: Stegbreiter
h_1: Höhe des Kollektorrahmens
h_3: Höhe des Stegs
θ: Einfallswinkel

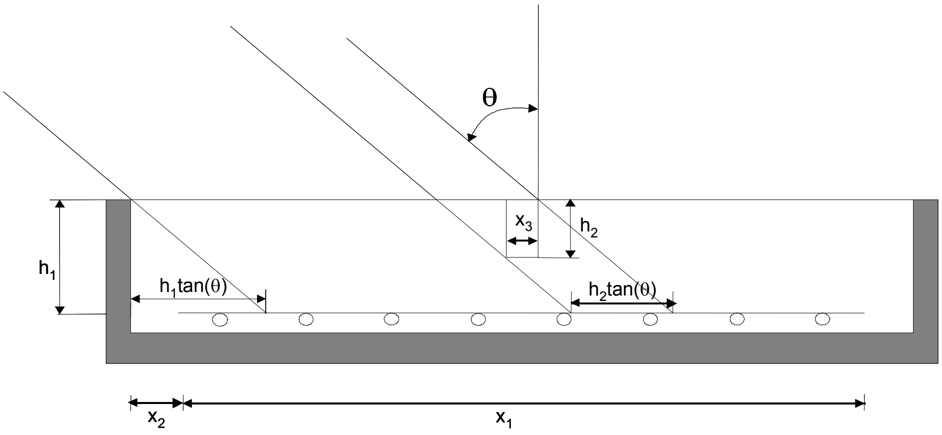


Bild 2.3: Darstellung der geometrischen Verhältnisse am Flachkollektor

Mit gemessenen und theoretischen Einfallswinkelkorrekturverhalten von unterschiedlichen transparenten Abdeckungen und Absorberschichten lässt sich so das theoretische Einfallswinkelkorrekturvermögen beliebiger Kombinationen von Kollektorgeometrie, transparenter Abdeckung und Absorberschicht, ohne Berücksichtigung etwaiger Randreflexionen, mit Gleichung (3) abschätzen.

Für zwei Kollektoren wurden die theoretischen Werte des Einfallwinkelkorrekturvermögens mit den aus der Messung bestimmten Verläufen (b_0-Ansatz) verglichen. Kollektor 1 (vgl.

Bild 2.4) ist ein Kollektor mit zwei Glasscheiben die durch einen senkrechten Steg voneinander getrennt sind.

Die entsprechenden Gehäusegeometrien sind Bild 2.4 und 2.5 zu entnehmen. Neben den theoretischen Werten des Einfallwinkelkorrekturvermögens in Quer- und Längsrichtung ist auch der aus der Messung bestimmte Verlauf des Einfallwinkelkorrekturvermögens dargestellt. Für Kollektor 2 stimmen die theoretisch ermittelten Werte gut mit dem b_0-Ansatz überein. Für Kollektor 1 hingegen kann der durch die Glasscheibe verursachte untypische Verlauf nicht so gut durch den b_0-Ansatz nachgebildet werden. Der Nulldurchgang des b_0-Ansatz bei einem Einfallswinkel $\theta < 80°$ tritt unter den theoretischen Betrachtungen für beide untersuchten Kollektoren nicht auf.

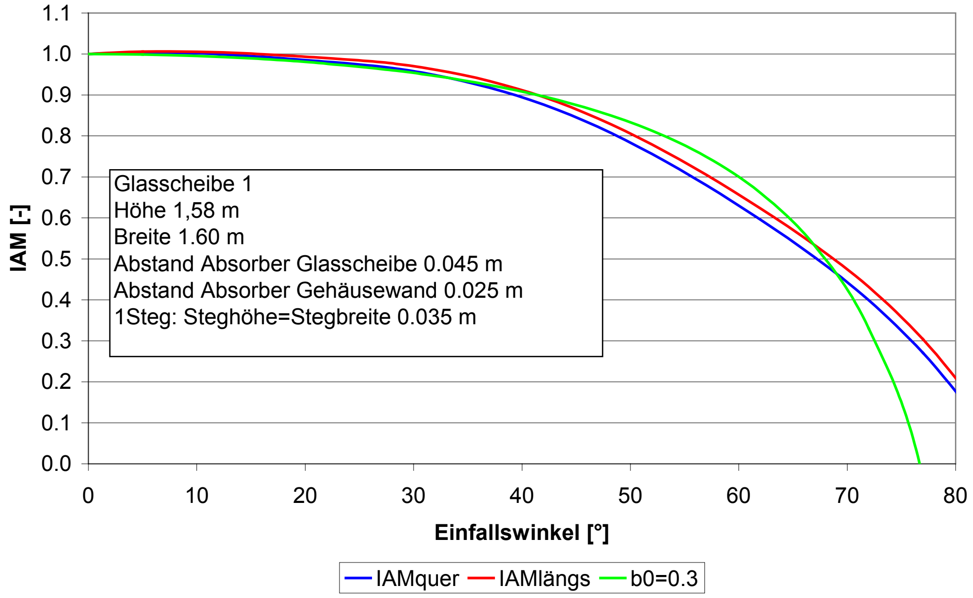


Bild 2.4: Theoretischer und messtechnisch ermittelter IAM Verlauf Kollektor 1

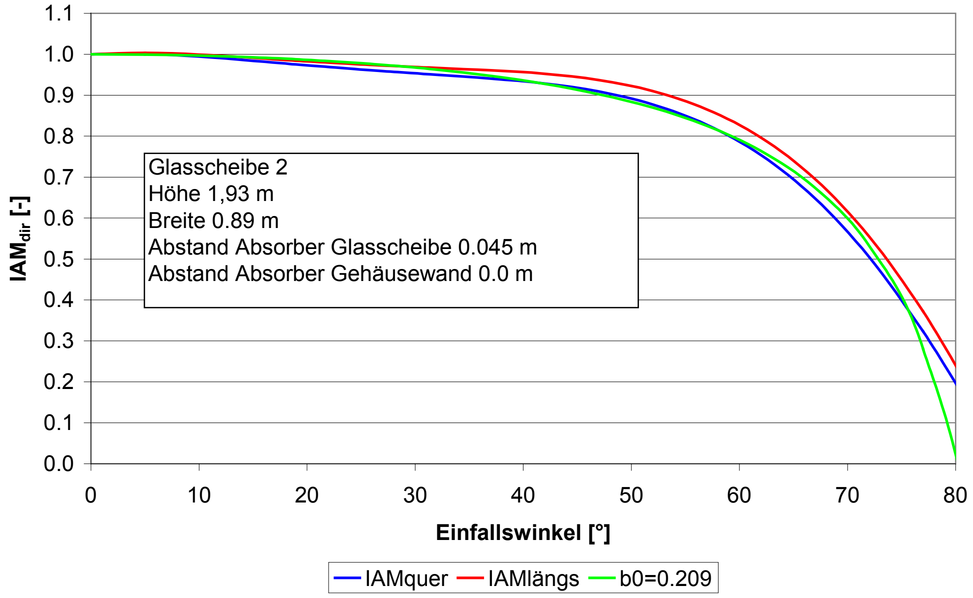


Bild 2.5: Theoretischer und messtechnisch ermittelter IAM Verlauf Kollektor 2

2.2.1.3 Vergleich der unter stationären und dynamischen Bedingungen ermittelten Einfallswinkelkorrekturvermögen

An zwei Kollektoren wurde das Einfallswinkelkorrekturvermögen der direkten Bestrahlungsstärke sowohl unter stationären als auch unter dynamischen Bedingungen bestimmt. Kollektor 1 verfügt über ein „gutes“ Einfallswinkelkorrekturvermögen, Kollektor 2 über ein „schlechtes“ Einfallswinkelkorrekturvermögen.

In Bild 2.6 und 2.7 sind jeweils folgende Verläufe des Einfallswinkelkorrekturvermögens dargestellt:

1. Die schwarzen Symbole kennzeichnen die unter stationären Bedingungen gemessenen Einfallwinkelkorrekturvermögen an den entsprechenden Einfallswinkeln (Stützstellen) der direkten Bestrahlungsstärke. Hierbei wurde nicht zwischen direkter G_{dir} und diffuser Bestrahlungsstärke G_d unterschieden. D. h. als Referenzstrahlung wurde die hemisphärische Bestrahlungsstärke G verwendet. Der Diffusstrahlungsanteil $D = G_d/G$ war gemäß EN 12975 stets kleiner 30%.
2. Die roten Linien repräsentieren die Regression gemäß des b_0-Ansatz über die unter stationären Bedingungen ermittelten Einfallswinkelkorrekturvermögen (schwarze Symbole).
3. Die blauen Linien zeigen das unter dynamischen Bedingungen ermittelte Einfallswinkelkorrekturvermögen für die <u>direkte</u> Bestrahlungsstärke G_{dir}
4. Die grünen Linien zeigen die unter dynamischen Bedingungen ermittelter Einfallswinkelkorrekturvermögen für die <u>hemisphärische</u> Bestrahlungsstärke (Berechnung mit $D = G_d/G = 0.15$ und $\theta = 15°$, siehe Gl. 4)

$$K_\theta(\theta,D) = \frac{\eta_0(\theta,D)}{\eta_0(\theta=0,D)} = \frac{\eta_0 K_b(\theta)(1-D)+\eta_0 K_d D}{\eta_0(1-D)+\eta_0 K_d D} \qquad (4)$$

Auf der zweiten y-Achse von Bild 2.6 und 2,7 sind für jeden einzelnen durch die schwarzen Symbole gekennzeichneten Wert des Einfallswinkelkorrekturvermögens ein nach Gl. 1 ermittelter b_0-Wert als rotes Symbole dargestellt. Hierbei ist eine deutliche Abhängigkeit des bestimmten b_0-Werts von der verwendeten Stützstelle zu beobachten.

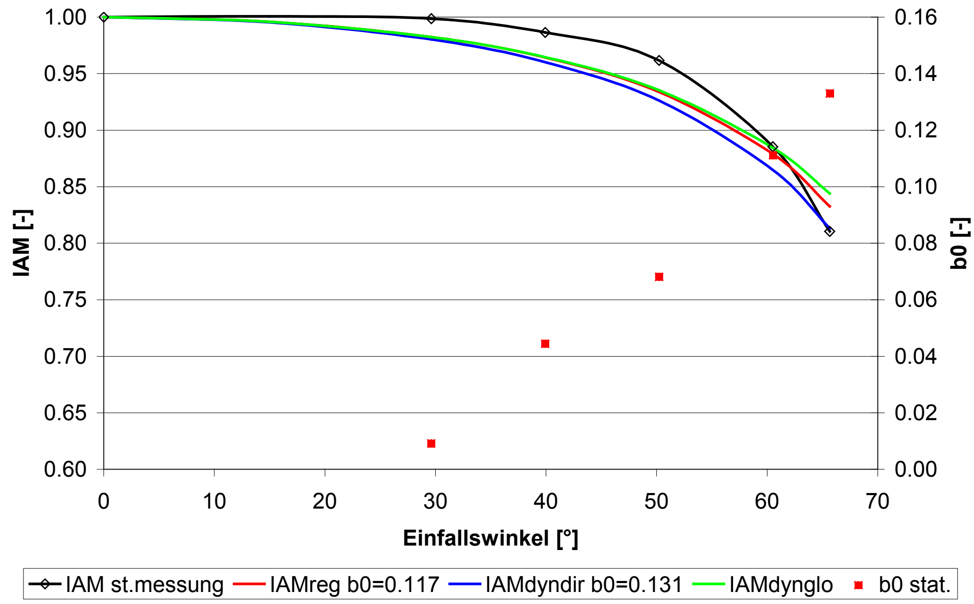


Bild 2.6: Vergleich für Kollektor 1

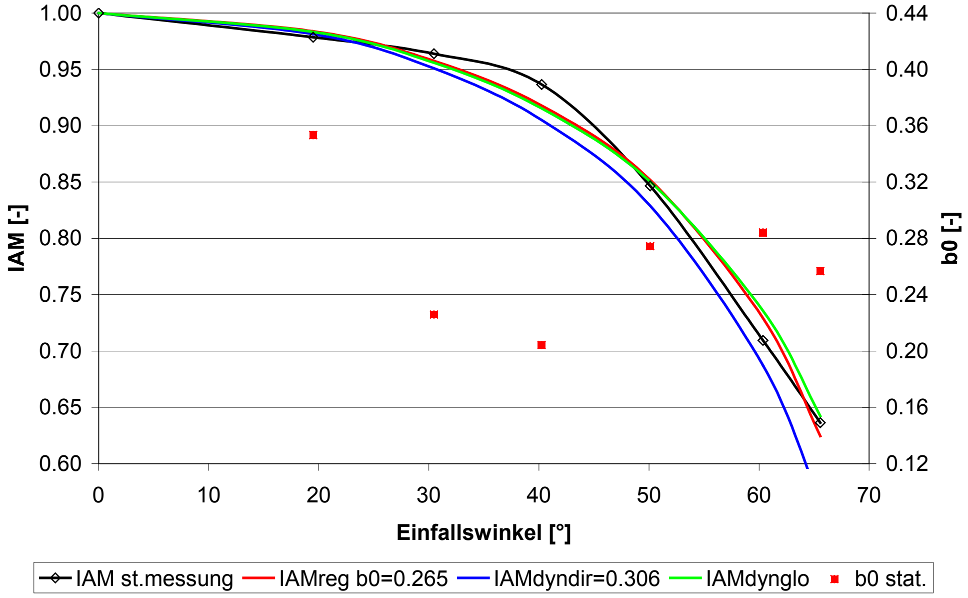


Bild 2.7: Vergleich für Kollektor 1

2.2.1.4 Einführung eines Interpolationsansatzes zur Beschreibung des Einfallswinkelkorrekturvermögens

Um die Abhängigkeit des Einfallwinkelkorrekturvermögens von der verwendeten Stützstelle zu umgehen wird der Interpolationsansatz eingeführt. Dieser pragmatische Ansatz verzichtet auf die Abbildung des Einfallswinkelkorrekturvermögens in Form von einer mathematischen Gleichung. Vielmehr werden n Winkel (Stützstellen) festgelegt ($\theta_1 ... \theta_n$) für die das

Einfallswinkelkorrekturvermögen bestimmt wird ($K_b(\theta_1)...K_b(\theta_n)$). Zwischen den Stützstellen wird linear interpoliert.

$$K_b(\theta_j) = K_b(\theta_i) + (\theta_j - \theta_i)\left(\frac{K_b(\theta_i) - K_b(\theta_{i+1})}{\theta_i - \theta_{i+1}}\right) \tag{5}$$

Es wurde untersucht ob sich das Einfallswinkelkorrekturvermögen von Flachkollektoren mit Hilfe von Stützwerten und linearer Interpolation zwischen den Stützstellen genauer abbilden lässt als durch den normativen b_0-Ansatz. Es wurden für drei Kollektoren folgende Ansätze untersucht:

1. $K_b(0°) = 1$, $K_b(30°) = \text{fit}$, $K_b(50°) = \text{fit}$, $K_b(90°) = 0$
2. $K_b(0°) = 1$, $K_b(40°) = \text{fit}$, $K_b(60°) = \text{fit}$, $K_b(90°) = 0$
3. $K_b(0°) = 1$, $K_b(20°) = 1$, $K_b(40°) = \text{fit}$, $K_b(60°) = \text{fit}$, $K_b(90°) = 0$

Variante 1 führt bei Kollektoren mit „schlechtem“ Einfallswinkelkorrekturvermögen zu einer geringfügigen Verbesserung gegenüber dem b_0-Ansatz. Bei Kollektoren mit „gutem“ Einfallswinkelkorrekturvermögen schneidet der Ansatz jedoch wesentlich schlechter ab, da die Unterschätzung des Einfallwinkelkorrekturvermögens bei Einfallswinkel größer als 50° durch einen zu hohen Wert bei 50° (>1) kompensiert wird. Nachteilig ist weiterhin, dass aufgrund der geringen Abweichung des IAM(30°) von 1 dieser nicht genau bestimmt werden kann.

Variante 2 führt bei 2 der untersuchten Kollektoren zu einer Verbesserung der Abbildung des IAM beim dritten Kollektor jedoch nicht. Bei Kollektoren deren Konversionsfaktor bei Winkeln > 0° (EN 12975 lässt bis zu 20° zu) gemessen wurde, tritt hier eine gegenüber des b_0-Ansatzes deutlich größere Erhöhung des Konversionsfaktor (bei 0°) auf. Um diesem Effekt entgegenzuwirken wurde für Variante 3 der IAM(20°) gleich 1 gesetzt.

Variante 3 führt bei zwei der untersuchten Kollektoren zu einer weiteren Verbesserung. Beim 3. Kollektor steigt im Vergleich zu Variante 2 ebenfalls die Genauigkeit, sie erreicht hier jedoch nicht die Genauigkeit des b_0-Ansatzes.

Die Bilder 2.8 bis 2.10 zeigen die Verläufe der unterschiedlichen Ansätze zur Beschreibung des Einfallwinkelkorrekturvermögens für die 3 untersuchten Kollektoren.

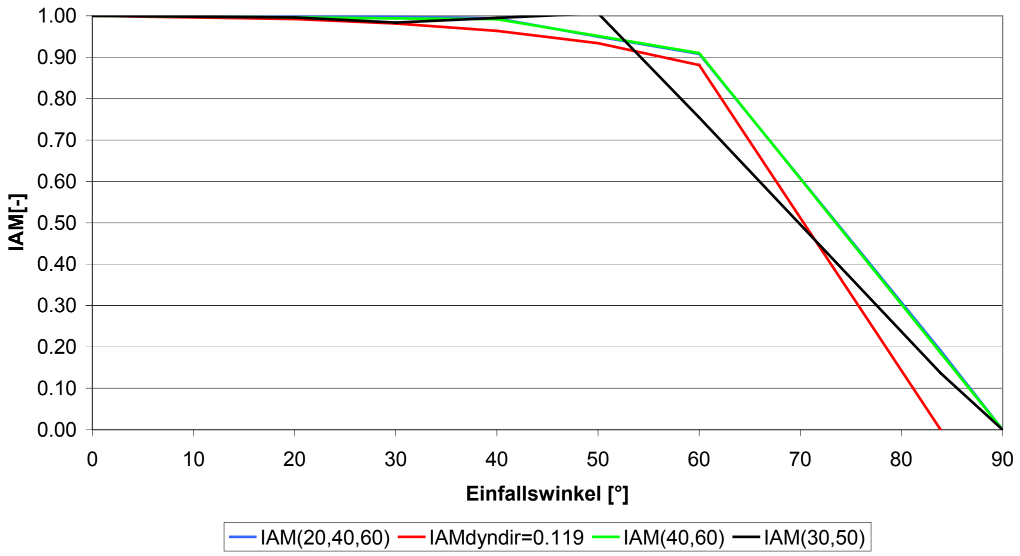


Bild 2.8: Verläufe des Einfallwinkelkorrekturvermögens der untersuchten Varianten (Kollektor 1)

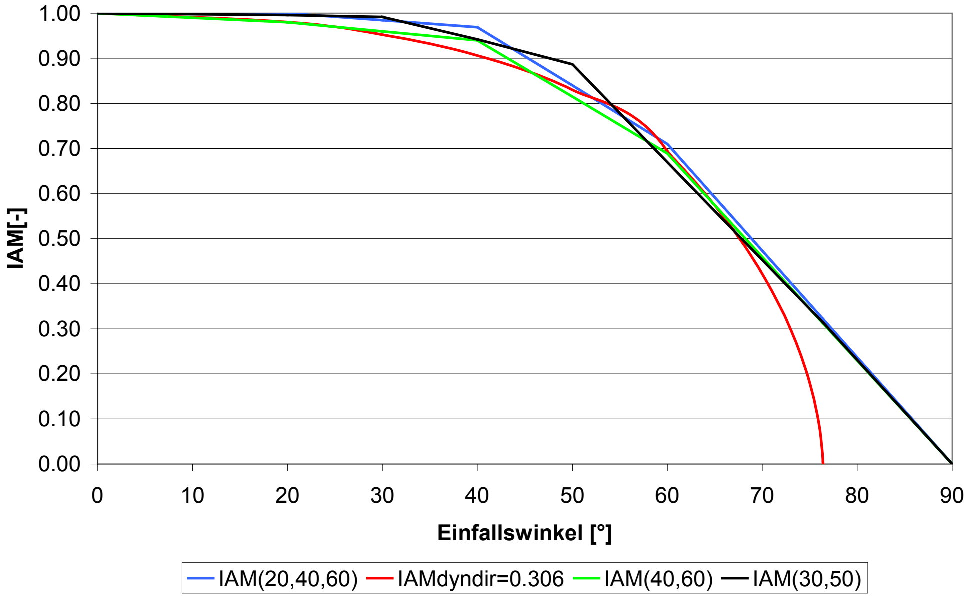


Bild 2.9: Verläufe des Einfallwinkelkorrekturvermögens der untersuchten Varianten (Kollektor 2)

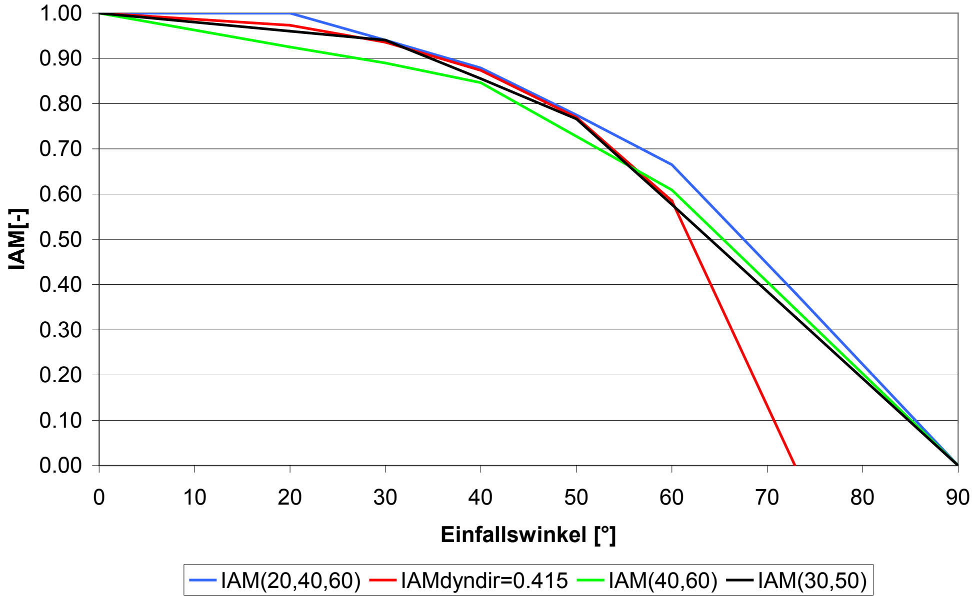


Bild 2.10: Verläufe des Einfallwinkelkorrekturvermögens der untersuchten Varianten (Kollektor 2)

2.2.1.5 Empfehlungen zum Einfallswinkelkorrekturvermögen bei Flachkollektoren

Aus den durchgeführten Untersuchungen werden folgende Empfehlungen für die Zukunft abgeleitet:

1. Um den Einfluss der gewählten Stützstelle auf das Einfallswinkelkorrekturvermögen auszuschalten und eine größere Übereinstimmung zwischen stationärem und quasi-dynamischen Verfahren zu erreichen wird die Modellierung des $K_b(\theta)$ mit folgenden Stützstellen vorgeschlagen: $K_b(0°) = 1$, $K_b(20°) = 1$, $K_b(40°)$ = Messung, $K(60°)$ = Messung und $K_b(90°) = 0$. Zwischen den Stützstellen wird linear interpoliert. Die Stützstellen 40° und 60° sind innerhalb der Grenzen von +- 2° einzuhalten.
2. Um einen Einfluss der Montage des Kollektors (hochkant oder quer) auszuschließen, sollten alle Kollektoren grundsätzlich hochkant (d.h. die beiden langen Seiten des Kollektors zeigen nach Osten und Westen) vermessen werden. Wenn die Kollektoren ausdrücklich für die Quermontage bestimmt sind kann hiervon abgesehen werden.
3. Um Flachkollektoren mit „schlechtem“ Einfallswinkelkorrekturvermögen in der Simulation nicht zu benachteiligen sollte in Zukunft der Ansatz $K_{dfu} = K_b(57°)$ vollständig entfallen und durch den Ansatz $K_{dfu} = 0.9$ ersetzt werden. Bei Messungen unter quasi-dynamischen Bedingungen muss der dabei ermittelte Wert in der Simulation verwendet werden.

2.2.2 Biaxiales Einfallswinkelkorrekturvermögen

Bei Kollektoren mit biaxialem Einfallswinkelkorrekturvermögen besteht ein Unterschied in der Kollektorleistung, je nachdem ob die direkte Strahlung längs der Symmetrieachse oder quer zu dieser einfällt. Die Symmetrieachse wird dabei als longitudinale Achse, jene senkrecht dazu als transversale Achse bezeichnet (vgl. Bild 2.11).

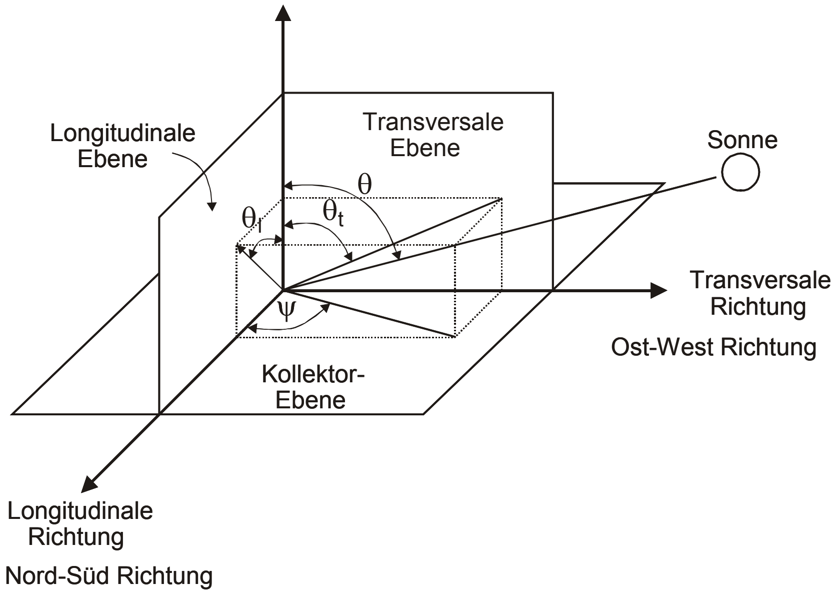


Bild 2.11: Koordinatensystem für biaxiale Kollektoren nach /Theunissen1985/.

Zur Behandlung der biaxialen Kollektoren wird der Einfallswinkel der direkten Bestrahlungsstärke θ in zwei Komponenten zerlegt. Der longitudinale Einfallswinkel θ_l ist die Projektion der Verbindungslinie zwischen Sonne und Kollektor in die longitudinale Ebene, θ_t die Projektion in die transversale Ebene. Die Winkel können nach /Theunissen1985/ durch die Gleichungen 6 und 7 angegeben werden, der Zusammenhang zwischen θ, θ_l und θ_t ist durch Gl. 8 gegeben.

$$\theta_l = \left|\tan^{-1}\left(\tan\theta_z \cos(\gamma_k - \gamma_s)\right) - \beta\right| \tag{6}$$

$$\theta_t = \left|\tan^{-1}\left(\frac{\sin\theta_z \sin(\gamma_k - \gamma_s)}{\cos\theta}\right)\right| \tag{7}$$

$$\tan^2\theta = \tan^2\theta_l + \tan^2\theta_t \tag{8}$$

In Bild 2.12 sind die Einfallswinkel zusammen mit dem Höhenwinkel der Sonne für einen Kollektor (Neigungswinkel 49.8°, Südausrichtung) am Standort Würzburg am 22. Juni dargestellt.

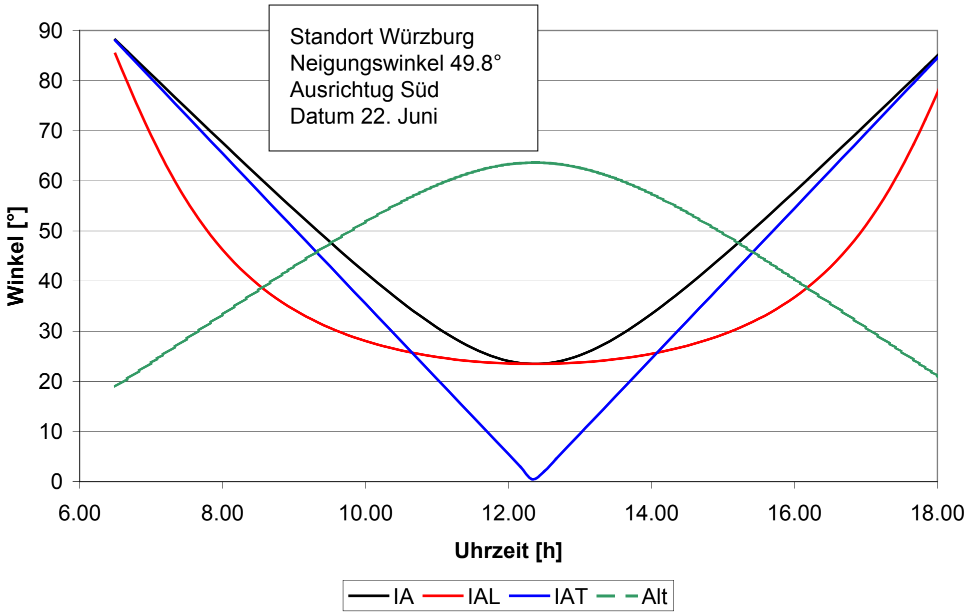


Bild 2.12: Verlauf der Einfallswinkel und des Höhenwinkels der Sonne für den Standort Würzburg am 22. Juni.

Das Einfallswinkelvermögen der biaxialen Kollektoren kann nach /McIntire1982/ mit Gl. 9 angenähert werden.

$$K_b(\theta_l,\theta_t)=K_b(\theta_l,0)\cdot K_b(0,\theta_t) \tag{9}$$

Dieser Ansatz stellt den derzeitigen Stand der Beschreibung biaxialem Einfallswinkelkorrekturvermögens dar. In Bild 2.13 ist das Einfallswinkelkorrekturvermögen in longitudinaler und transversaler Richtung über dem Einfallswinkel für einen typischen Vakuumröhrenkollektor mit planem Absorber aufgetragen.

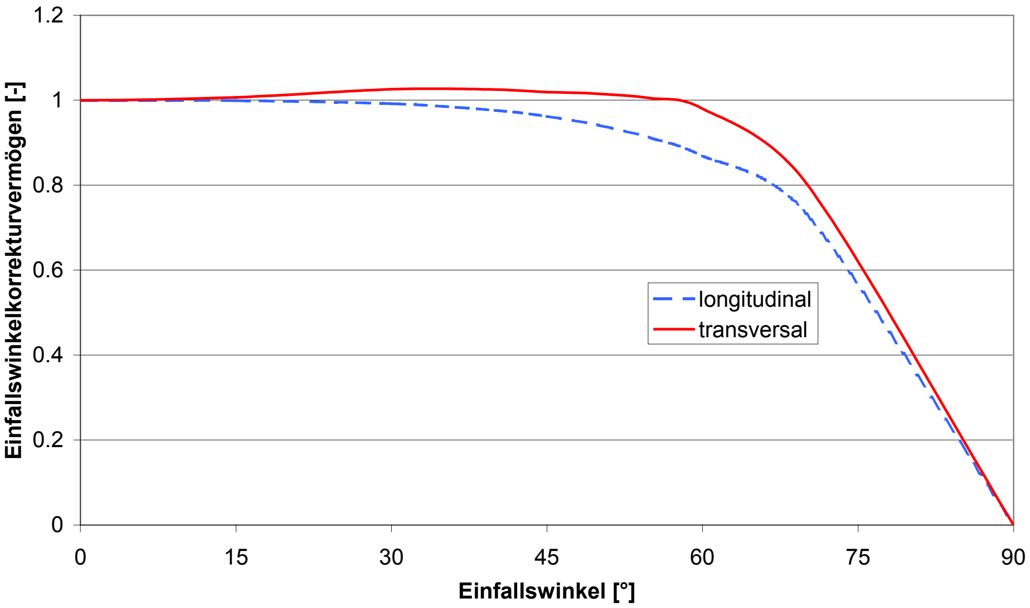


Bild 2.13: Typisches Einfallswinkelkorrekturvermögen eines Vakuumröhrenkollektors mit planem Absorber

Das Einfallskorrekturvermögen in longitudinaler Richtung von Vakuumröhrenkollektoren weist meist ein ähnlichen Verlauf wie das der isotropen Kollektoren auf. In transversaler Richtung sind jedoch erheblich Unterschiede (vgl. Bild 2.14) möglich.

Bei Vakuumröhrenkollektoren mit planem Absorber ist i. a. eine leichte Überhöhung des transversalen Einfallswinkelkorrekturvermögens im Bereich von 30 < θ_t < 60° zu beobachten. Grund hierfür ist die Tatsache, dass an den Glasröhren reflektierte Sonnenstrahlung auf die benachbarten Röhren trifft.

Bei Vakuumröhrenkollektoren mit halbrunden oder zylindrischen Absorbern treten starke Überhöhungen im Bereich θ_t >30° auf. Neben den auch hier vorhandenen Reflexionen auf benachbarte Röhren ist vor allem die durch die zylindrische Geometrie gegebene „Nachführung“ des Absorbers zusammen mit dem Bezug auf senkrechte Einstrahlung für die Überhöhung verantwortlich.

Bei der Verwendung von zylindrischen Absorbern zusammen mit Reflektoren treten i. a. ebenfalls erhebliche Überhöhungen des transversalen Einfallswinkelkorrekturvermögens auf. Je nach Geometrie des Reflektors können auch Werte deutlich unter 1 beobachtet werden.

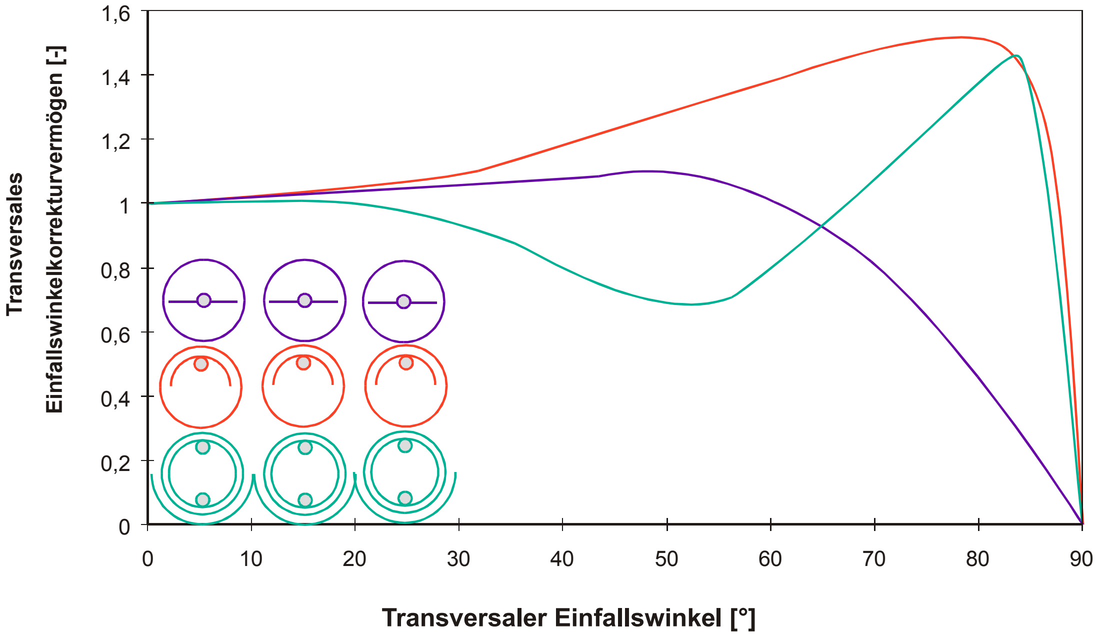


Bild 2.14: Transversales Einfallswinkelkorrekturvermögen unterschiedlicher Vakuumröhrengeometrien.

2.2.3 Multiaxiales Einfallswinkelkorrekturvermögen

Für die Beschreibung von Kollektoren mit multiaxialem Einfallswinkelkorrekturvermögen müssen die zwei Symmetrieachsen nochmals in zwei Abschnitte unterteilt werden (vgl. Bild 2.15). Die longitudinale Achse in einen Nord- und in einen Südabschnitt und die transversale Achse in einen Ost- und Westabschnitt.

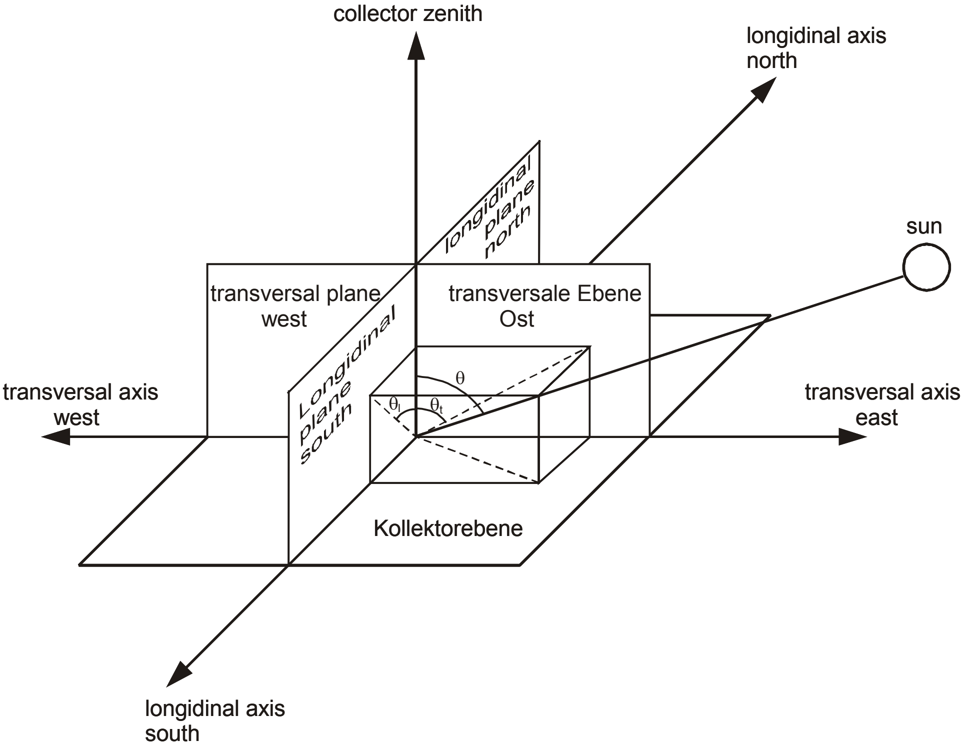


Bild 2.15: Koordinatensystem für multiaxiale Kollektoren.

Für Einfallswinkel kleiner 90° wird die Verbindungslinie Sonne – Kollektor immer von zwei der vier Ebenen eingeschlossen. Analog zum biaxialem Fall ist der longitudinale Einfallswinkel θ_l die Projektion der Verbindungslinie zwischen Sonne und Kollektor in die longitudinale Ebene, θ_t die Projektion in die transversale Ebene. Da beim multiaxialen Einfallswinkelkorrekturvermögen eine Unterscheidung zwischen Nord- und Südfläche und/oder eine Unterscheidung zwischen Ost- und Westebene notwendig ist, werden die Indizes n, o, s, und w für Norden, Osten, Süden und Westen eingeführt (vgl. Gl. 10).

$$K_b = f\left(\theta_{\ln}, \theta_{to}, \theta_{ls}, \theta_{tw}\right) \tag{10}$$

Um zwischen θ_{ln} und θ_{ls} bzw. θ_{to} und θ_{tw} unterscheiden zu können, werden die Winkel entsprechend Gleichungen 6 und 7 nicht mehr als Absolutwerte berechnet, womit sich negative Werte für θ_{ln} und θ_{to} ergeben. Bei einer Südausrichtung des Kollektors wechselt somit der transversale Einfallswinkelkorrektur jeweils zum Sonnenhöchststand sein Vorzeichen von „-„ zu „+“. Ob und wann sich ein Vorzeichenwechsel beim longitudinalen

Einfallswinkel im Verlauf des Jahres ergibt hängt vom Breitengrad und der Kollektorneigung ab.

Die Vermessung eines multiaxialen Kollektors wurde erstmals von /Fischer2005/ beschrieben. Zur Untersuchung des multiaxialen Einfallswinkelkorrekturfaktors wurde die thermische Leistungsfähigkeit eines Vakuumröhrenkollektors mit flachem Absorber bestimmt. Bild 2.16 beschreibt das Einfallswinkelkorrekturvermögen in longitudinaler und transversaler Richtung.

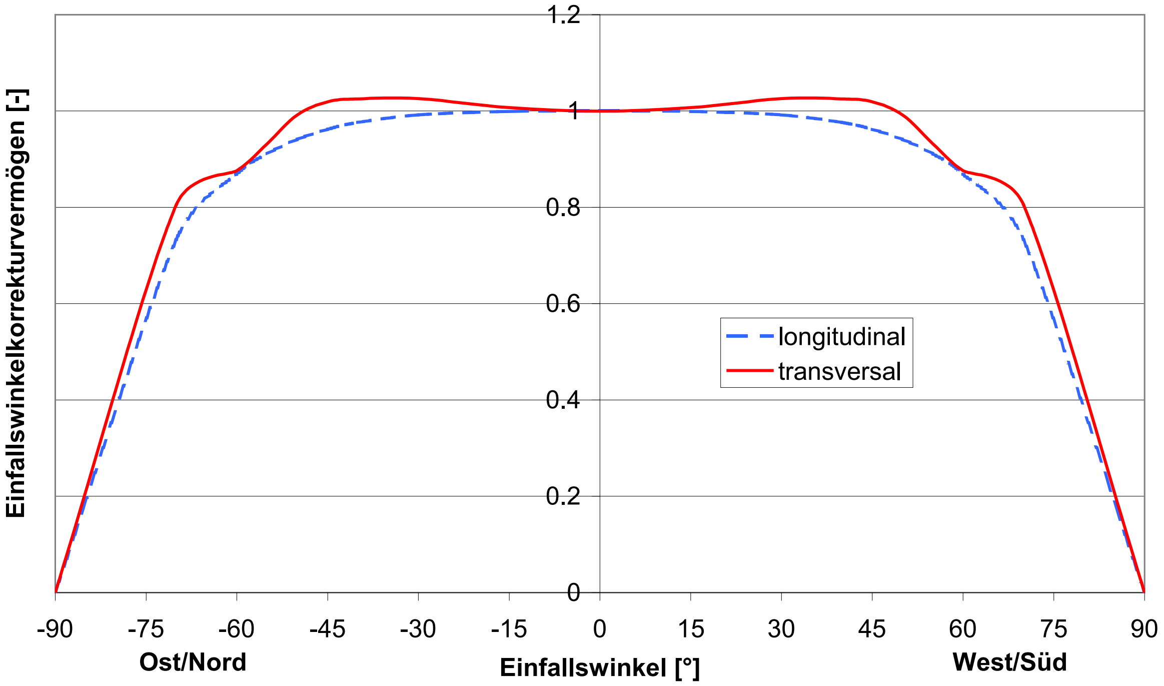


Bild 2.16: Longitudinales und transversales Einfallswinkelkorrekturvermögen eines Vakuumröhrenkollektors mit flachem Absorber

Anschließend wurden die Röhren um 30° nach Osten verdreht und der Konversionsfaktor η_0 und die Einfallswinkelkorrekturfaktoren neu bestimmt. In Tabelle 2.1 sind die ermittelten Kennwerte der zwei Kollektorkonfigurationen zusammengefasst. Dabei wurde davon ausgegangen, dass sich die Wärmedurchgangskoeffizienten a_1 und a_2 sowie die effektive Wärmekapazität c_{eff} des Kollektors durch die Ausrichtung nicht ändern. Bild 2.17 zeigt das transversale Einfallswinkelkorrekturvermögen der beiden Kollektorvarianten.

	η_0 [-]	$K_{\theta d}$ [-]	a_1 [W/(m²K)]	a_2 [W(m²K²)]	c_{eff} [J/(m²K)]
Ausgangszustand	0.782	0.977	1.259	0.008	19300
gedrehte Röhren	0.675	0.972	1.259	0.008	19300

Tabelle 2.1: Kollektorkennwerte

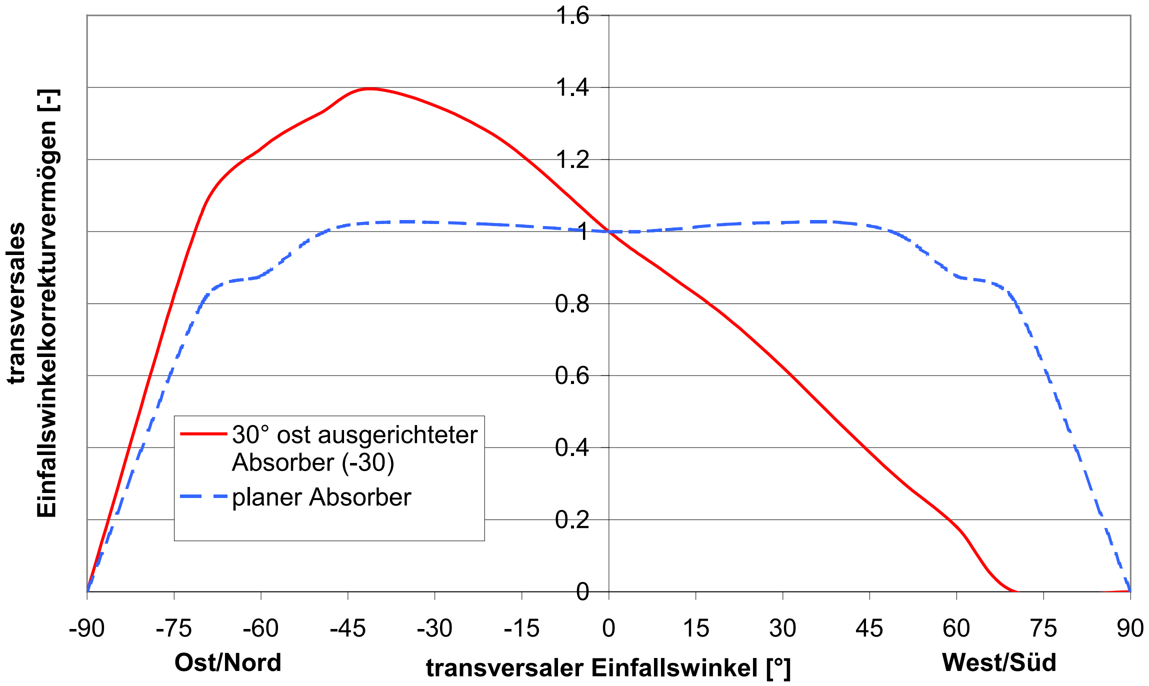


Bild 2.17: Verlauf der transversalen Einfallswinkelkorrekturfaktoren der zwei Kollektorvarianten

Um die Auswirkung auf den Kollektorjahresertrag zu bestimmen wurde dieser für beide Kollektorvarianten in einer Referenzanlage bei zwei unterschiedlichen Kollektorausrichtungen simuliert.

1. Der Kollektor liegt auf einem Flachdach, die Röhren sind in Ost – West Richtung ausgerichtet („Flachdach“).
2. Der Kollektor befindet sich auf einem 60° nach Westen zeigendem Dach mit einer Dachneigung von 50° („Westdach“).

In Tabelle 2.2 sind die berechneten Kollektorerträge dargestellt. Die untersuchte Ausrichtung der Röhren resultiert trotz einer erheblichen Reduktion des Konversionsfaktors in einer Ertragssteigerung von 6% für den Fall „Flachdach“ und 4% für das „Westdach“.

	Grundkonfiguration	mit ausgerichteten Röhren
Flachdach	564 kWh/(m²a)	597 kWh/(m²a)
Westdach	593 kWh/(m²a)	614 kWh/(m²a)

Tabelle 2.2: Simulationsergebnisse

2.3. Effektive Wärmekapazität

Während der Projektbearbeitung kam die zu diesem Thema gebildete Arbeitsgruppe zu der Erkenntnis, dass die Einführung eines 2-Knotenmodells am besten geeignet wäre die Probleme im Bezug auf die effektive Wärmekapazität zu lösen.

2.3.1 Einführung

Alle heute verwendeten nationalen und internationalen Normen benutzen ein sogenanntes 1-Knotenmodell zur Beschreibung der thermischen Leistungsfähigkeit von Sonnenkollektoren. Hierbei werden alle thermischen Massen des Kollektors und die Wärmeübergangsmechanismen zwischen den einzelnen Massen in einer flächenbezogenen effektiven Wärmekapazität c_{eff} zusammengefasst. Bezugstemperatur ist dabei die mittlere Fluidtemperatur.

Diese Vereinfachung kann bei Kollektoren, die im Betrieb einen hohen Temperaturunterschied zwischen Absorber und Wärmeträgerfluid aufweisen, zu einer Fehlinterpretation der effektiven Wärmekapazität führen.

Das im Folgenden vorgestellte 2-Knoten-Modell berücksichtigt die Temperaturdifferenz zwischen Absorber- und Fluidtemperatur durch zwei Kapazitäten c_{abs} und c_{fl}, sowie einem Wärmeübertragungsvermögen (kA) zwischen den beiden Kapazitäten.

2.3.2 Kollektormodelle

2.3.2.1 1-Knotenmodell

Das bisher in nationalen und internationalen Normen, z. B. EN 12975 und ISO 9806 etablierte Kollektormodell ist ein 1-Knoten-Modell (siehe Bild 2.18).

In diesem Fall sind alle Wärmekapazitäten der Kollektorkomponenten in einer gemeinsamen Kapazität c_{eff} zusammengefasst, die sich auf die Fluidtemperatur bezieht. Das 1-Knoten-Modell wird durch folgende Differentialgleichung beschrieben:

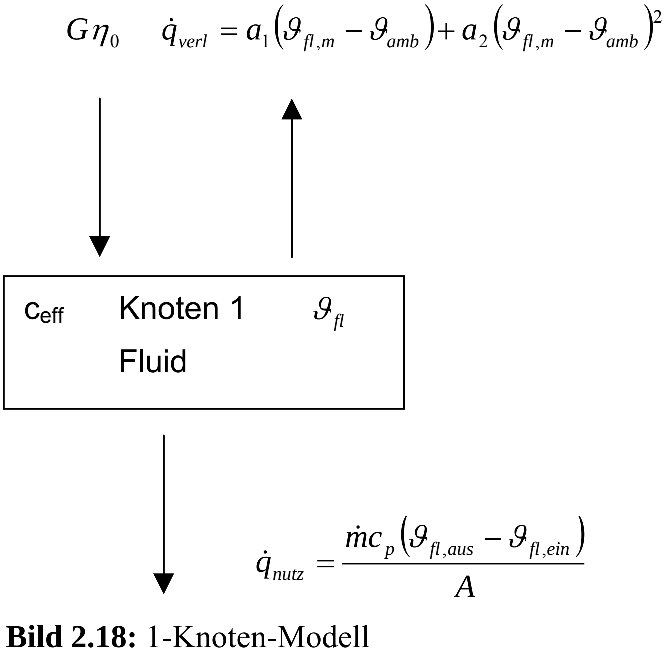


Bild 2.18: 1-Knoten-Modell

$$c_{eff}\frac{d\vartheta_{fl,m}}{dt} = G\eta_0 - a_1(\vartheta_{fl,m} - \vartheta_{amb}) - a_2(\vartheta_{fl,m} - \vartheta_{amb})^2 - \frac{\dot{m}c_p(\vartheta_{fl,aus} - \vartheta_{fl,in})}{A} \qquad (11)$$

Die Reduzierung der internen Wärmeübergangsmechanismen auf einen Kapazitätsknoten erlaubt bei Kollektoren mit geringer Temperaturdifferenz zwischen Absorber- und Fluidtemperatur, wie sie bei Flachkollektoren vorherrscht, eine gute Abbildung der thermischen Leistungsfähigkeit. Auch stimmen bei diesen Kollektoren die unter dynamischen Bedingungen bestimmten effektiven Wärmekapazitäten gut mit den berechneten überein.

Bei größeren Temperaturdifferenzen zwischen Absorber- und Fluidtemperatur führt die messtechnische Bestimmung der effektiven Wärmekapazität zu Werten, die die Summe der Kapazitäten der einzelnen Kollektorbauteile um ein Vielfaches übersteigen können. Als Beispiel eines derartigen Kollektors ist u.a. der sogenannte „Sydney-Kollektor“ nach dem Thermoskannen-Prinzip zu nennen. Hier können im Betrieb Temperaturdifferenzen zwischen Absorber (beschichtetes Glasrohr) und Fluid von 30 K und mehr auftreten. Um diese Tatsache zu berücksichtigen und die im Kollektor vorherrschenden Wärmeübergangsmechanismen besser abzubilden zu können, wurde ein 2-Knoten Modell eingeführt und für die Auswertung von Kollektortestdaten herangezogen.

2.3.2.2 2-Knotenmodell

Das 2-Knoten-Modell ist in Bild 2.19 dargestellt. Hier wird die Wärmekapazität des Kollektors unterteilt in die Wärmekapazität des Absorbers c_{abs} und des Fluids c_{fl}. Der Absorberknoten wird in Abhängigkeit vom entsprechenden Wert des Transmissions-Absorptions-Produkts (τα) durch die einfallende Solarstrahlung G erwärmt. Die Wärmeverluste des Absorbers $\dot{q}_{verl}$ beziehen sich auf die Temperaturdifferenz zwischen Absorber und Umgebung.

Der Wärmeübergang vom Absorber $\dot{q}_{abs,fl}$ zum Fluid wird durch das Wärmeübertragungsvermögen (kA) und die Temperaturdifferenz zwischen Absorber und Fluid bestimmt.

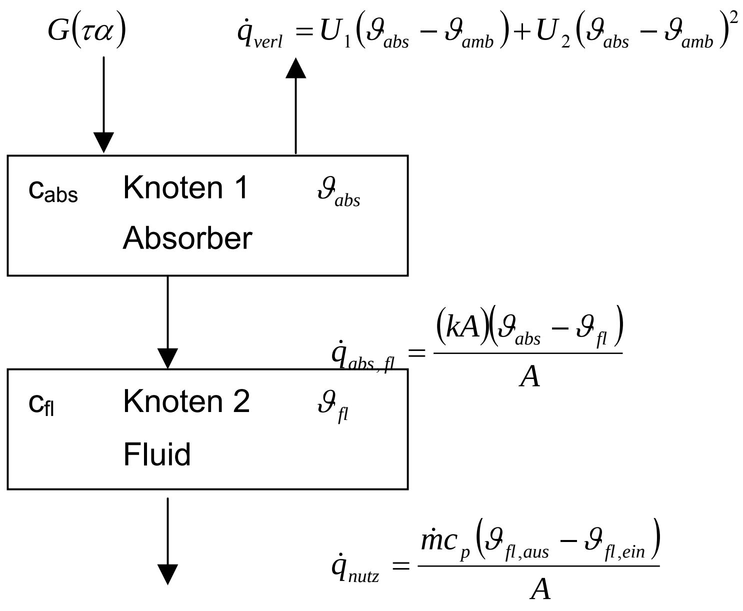


Bild 2.19: 2-Knoten-Modell

Das 2-Knoten-Modell wird durch die beiden gekoppelten Differentialgleichungen (12) und (13) beschrieben.

$$c_{fl}\frac{d\vartheta_{fl,m}}{dt} = (kA)(\vartheta_{abs}-\vartheta_{fl,m}) - \frac{\dot{m}c_p(\vartheta_{fl,aus}-\vartheta_{fl,ein})}{A} \tag{12}$$

$$(kA)(\vartheta_{abs}-\vartheta_{fl,m}) = G(\tau\alpha) - U_1(\vartheta_{abs}-\vartheta_{amb}) - U_2(\vartheta_{abs}-\vartheta_{amb})^2 - c_{abs}\frac{d\vartheta_{abs}}{dt} \tag{13}$$

Für die folgenden Untersuchungen wurde dieses 2-Knoten-Modell in den TRNSYS Type 132 implementiert.

2.3.3 Anwendung des 2-Knotenmodells bei der Kollektorprüfung

Das vorgestellte 2-Knoten-Modell wurde exemplarisch bei der Auswertung der Messungen an einem „Sydney-Kollektor“ parallel zum genormten 1-Knoten-Modell angewandt. Der untersuchte Kollektor besitzt eine Aperturfläche A von 1.33 m² und ist mit 16 Vakuumröhren ausgestattet. In Tabelle 2.3 sind die bei Verwendung des 1-Knoten-Modells ermittelten Kollektorparameter zusammengefasst.

η_0 [-]	IAMdfu[-]	a_1 [W/(m²K)]	a_2 [W/(m²K²)]	c_{eff} [J/(m²K)]
0.651	1.19	1.361	0.0096	44030

Tabelle 2.3: Kollektorkennwerte bei Verwendung des 1-Knoten-Modells

Berechnet man nach den Vorgaben der EN 12975 die effektive Wärmekapazität des Kollektors ergibt sich diese zu knapp 22000 J/(m²K). Vergleicht man diesen Wert mit dem messtechnisch bestimmten Wert der effektiven Kapazität aus Tabelle 2.3, so unterscheiden sich beide Kapazitäten um den Faktor 2. Verantwortlich für diese Diskrepanz ist die deutliche Temperaturerhöhung des Absorbers gegenüber der Fluidtemperatur im Betrieb und die fehlende Modellierung des Wärmeübergangs zwischen Absorber und Fluid beim 1-Knoten-Modell.

Zum Vergleich wurden die selben Messdaten mit Hilfe des 2-Knoten-Modells ausgewertet. Die entsprechenden Kennwerte sind in Tabelle 2.4 zusammengefasst. Hierbei ist zu beachten, dass bei der Kennwertbestimmung die beiden Kapazitäten c_{abs} und c_{fl} als Konstanten vorgegeben wurden. Die Kapazität des Absorbers wurde hierbei aus den Materialwerten der Glasabsorber zuzüglich der Aluminiumleitbleche berechnet, die Fluidkapazität aus dem Fluidinhalt und der Masse der durchströmten Kupferrohre.

$(\tau\alpha)$ [-]	IAMdfu [-]	U_1 [W/(m²K)]	U_2 [W/(m²K²)]	c_{abs} [J/(m²K)]	c_{fl} [J/(m²K)]	(kA) [W/K]
0.673	1.18	1.337	0.0101	10465	9515	99.0

Tabelle 2.4: Kollektorkennwerte bei Verwendung des 2-Knoten-Modells

Mit Hilfe des Verfahrens nach /Rockendorf1993/ lassen sich aus den Kennwerten des 2-Knoten-Modells die Kollektorkennwerte des 1-Knoten-Modells und der Kollektorwirkungsgradfaktor F’ abschätzen. Tabelle 2.5 zeigt die für den Kollektor ermittelten Werte.

η_0 [-]	a_1 [W/(m²K)]	a_2 [W/(m²K²)]	F´ [-]
0.661	1.314	0.0097	0.982

Tabelle 2.5: Abschätzung der Kollektorkennwerte des 1-Knoten-Modells aus den Kennwerten des 2-Knoten-Modells

2.3.4 Anwendung des 2-Knotenmodells bei der Simulation

Bislang wird nicht nur bei der Leistungsprüfung sondern auch bei der Simulation von Sonnenkollektoren das 1-Knoten-Modell verwendet. Eine Vergleichsgröße bei der Bewertung von Sonnenkollektoren ist der jährliche flächenbezogene Kollektorertrag, der durch eine Simulation des jeweiligen Kollektors bzw. seiner Kennwerte in Kombination mit einer Referenzanlage ermittelt wird. In Tabelle 2.6 sind die Ergebnisse für die Simulation der Referenzanlage unter Verwendung der beiden Modelle gegenübergestellt.

Modell	1-Knoten	2-Knoten
Kollektorertrag Q_{col} [kWh/(m²a)]	600	595

Tabelle 2.6: Vergleich Kollektorertrag in der Referenzanlage

Die Abweichung beim Kollektorertrag liegt unter 1%. Entgegen der anfänglichen Vermutung lässt sich für den hier untersuchten Kollektor das thermische Verhalten dieses Kollektors trotz der scheinbar falschen effektiven Wärmekapazität mit dem 1-Knoten-Modell ausreichend genau beschreiben.

2.3.5 Anwendung des 2-Knotenmodells auf einen Sydney Kollektor unter Verwendung von Messwerten mit negativer Leistung

Ein Sydney Kollektor mit einer Aperturfläche von 1,33 m², ohne Reflektor und mit 21 Röhren wurde im Außentest unter quasi-dynamischen Bedingungen vermessen (vgl. Tabelle 2.7).

η_0 [-]	IAMdfu[-]	a_1 [W/(m²K)]	a_2 [W/(m²K²)]	c_{eff} [J/(m²K)]	Obj.[W]
0.701	1.18	1.414	0.016	63080	19.9

Tabelle 2.7: Kennwerte Sydney Kollektor (1-Knoten)

Außerdem wurde im Sonnensimulator eine Wärmeverlustmessung bei Kollektoreintrittstemperaturen von 40°C, 60°C, 80°C und 100°C durchgeführt. Diese Daten der

Wärmeverlustmessung wurden zusammen mit der eta0-Sequenz aus dem Außentest mit dem 2-Knotenmodell ausgewertet (vgl. Tabelle 2.8)

$(\tau\alpha)$ [-]	IAMdfu [-]	U_1 [W/(m²K)]	U_2 [W/(m²K²)]	c_{abs} [J/(m²K)]	c_{fl} [J/(m²K)]	kA [W/K]	Obj. [W]
0.752	1.19	1.543	0.013	5220	17058	37.1	7.8

Tabelle 2.8: Kennwerte Sydney Kollektor (2-Knoten)

Unter Verwendung der Umrechnung nach /Rockendorf1993/ ergeben sich folgende Werte für das 1-Knotenmodell

η_0 [-]	a_1 [W/(m²K)]	a_2 [W/(m²K²)]	F´ [-]	kint [W/(m²K)]
0.706	1.463	0.012	0.948	28.0

Tabelle 2.9: Parameter 1-Knotenmodel berechnet aus Parameter 2-Knotenmodel

Das 2-Knotenmodell ist in der Lage die negative Kollektorleistung während der Wärmeverlustmessung sehr gut nachzubilden. Auffällig ist außerdem, dass die Summe der effektiven Wärmekapazitäten des Absorbers und des Fluids (C_{abs} + C_{fl}) sehr gut mit der berechneten effektiven Wärmekapazität übereinstimmen. Die Umrechnung nach Rockendorf führt zu einem Parametersatz der mit dem des Einknotenmodells übereinstimmt.

2.3.6 Anwendung des 2-Knotenmodells auf einen Flachkollektor unter Verwendung von Messwerten mit negativer Leistung

Das 2-Knotenmodell wurde auf einen Flachkollektor angewandt. Hierbei handelt es sich um einen Standardflachkollektor mit 9 geschweißten Finnen und einer Aperturfläche von 2.25 m². Die Kennwerte des Kollektors (1-Knotenmodell) sind in Tabelle 2.10 zusammengefasst.

η_0 [-]	IAMdfu[-]	a_1 [W/(m²K)]	a_2 [W/(m²K²)]	b_0[-]	c_{eff} [J/(m²K)]	Obj.[W]
0.733	0.944	3.905	0.016	0.229	9836	16.8

Tabelle 2.10: Kennwerte Flachkollektor (1-Knoten)

Für die Auswertung mit dem 2-Knotenmodell wurden auch Daten mit Temperatursprüngen und negativer Leistung verwendet (vgl. Bild 2.20 und 2.21).

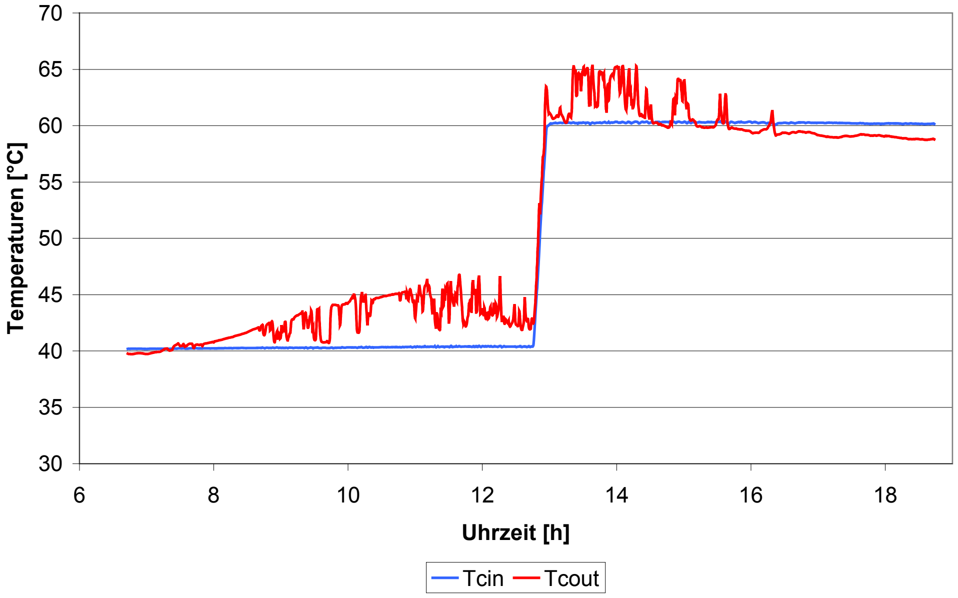


Bild 2.20: Eingangsdaten mit Temperatursprung

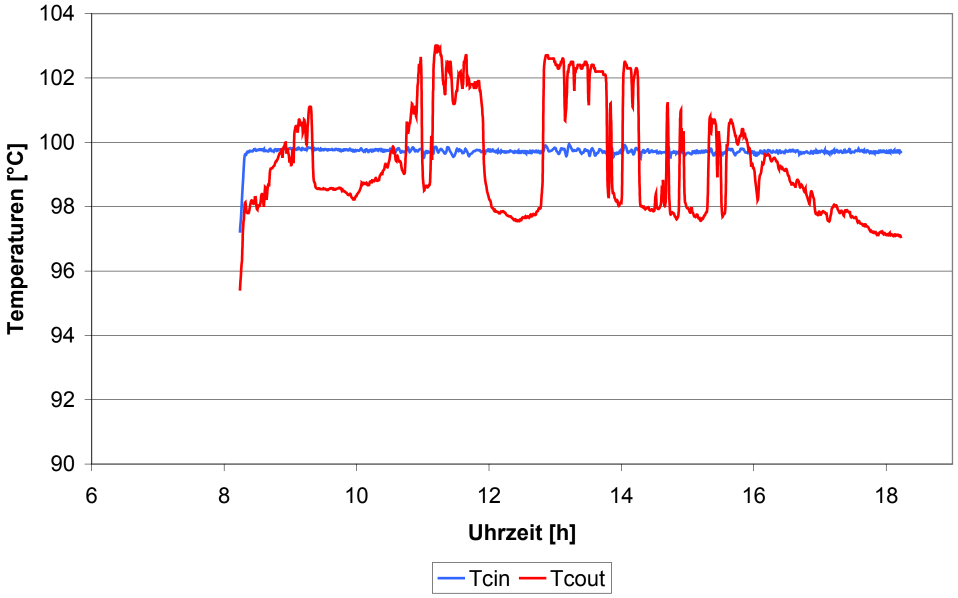


Bild 2.21: Eingangsdaten mit negativer Leistung

Bei Flachkollektoren ist der Temperaturunterschied zwischen Fluid und Absorber nicht so ausgeprägt wie bei den Sydney Kollektoren. Dies hat eine hohe Korrelation zwischen dem Absorption-Transmissions-Produkt und dem Wärmeübertragungsvermögen zur Folge. Dies kann zu Kennwertsätzen führen, welche, obwohl in den Einzelwerten sehr unterschiedlich, die Kollektorleistung mit der gleichen Genauigkeit abbilden können. Tabelle 2.11 zeigt zwei Kennwertsätze die unter Verwendung des 2-Knotenmodells die verwendeten Testsequenzen gleich gut abbilden (vgl. Bild 2.22 und Bild 2.23).

#	(τα) [-]	IAMdfu [-]	U_1 [W/(m²K)]	U_2 [W/(m²K²)]	b_0 [-]	c_{abs} [J/(m²K)]	c_{fl} [J/(m²K)]	kA [W/K]	Obj. [W]
1	0.811	0.940	4.333	0.014	0.255	1129	2546	131.9	16.2
2	0.900	0.942	5.007	0.013	0.256	822	1800	63.7	16.2

Tabelle 2.11: Kennwerte Flachkollektor (2-Knoten)

In Tabelle 2.12 sind die nach /Rockendor1993/ berechneten Kennwerte des 1-Knotenmodells für die zwei Parametersätze des 2-Knotenmodells zusammengefasst. Auf der Grundlage des Parametersatzes des 1-Kontenmodells (vgl. Tabelle 2.10) und den Parametersätzen nach Tabelle 2.12 wurden Simulationen im Referenzsystem durchgeführt. Für die Simulation wurden die Parameter aus Tabelle 2.12 durch die b_0-Werte und die Summe aus C_{abs} und C_{eff} aus Tabelle 2.11 ergänzt. Tabelle 2.13 zeigt die Kollektorerträge für das 1-Knotenmodell (0) und die beiden anderen Parametersätze.

#	η_0 [-]	a_1 [W/(m²K)]	a_2 [W/(m²K²)]	F´ [-]	kint [W/(m²K)]
1	0.753	4.036	0.012	0.931	58.7
2	0.757	4.256	0.009	0.850	28.3

Tabelle 2.12: Parameter 1-Knotenmodel berechnet aus Parameter 2-Knotenmodel

#	0	1	2
Ertrag [kWh/(m²a)]	444	460	456

Tabelle 2.13: Kollektorerträge

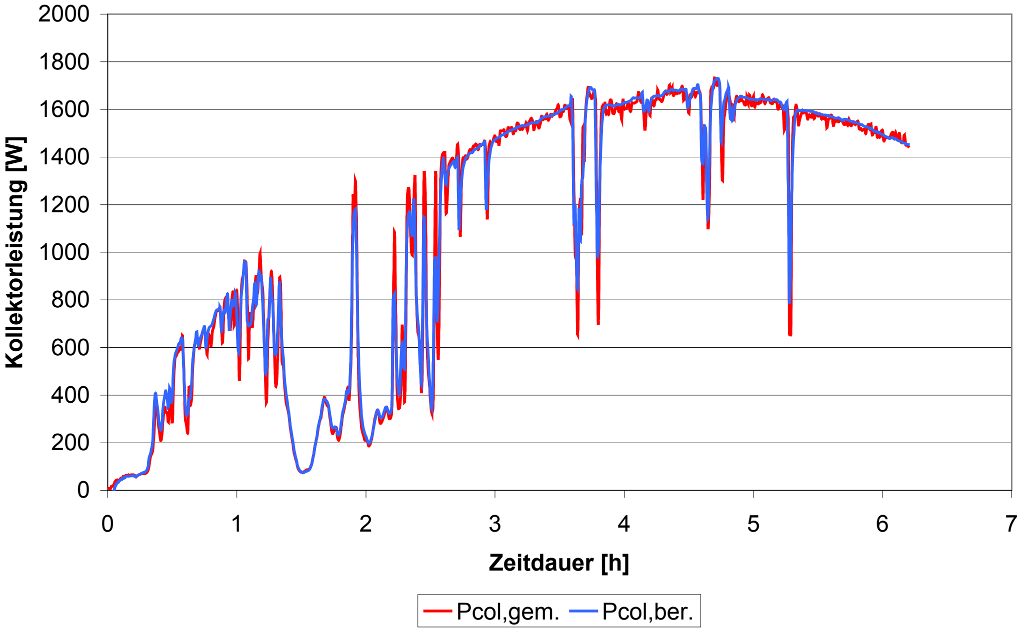


Bild 2.22: Vergleich gemessene/berechnete Kollektorleistung

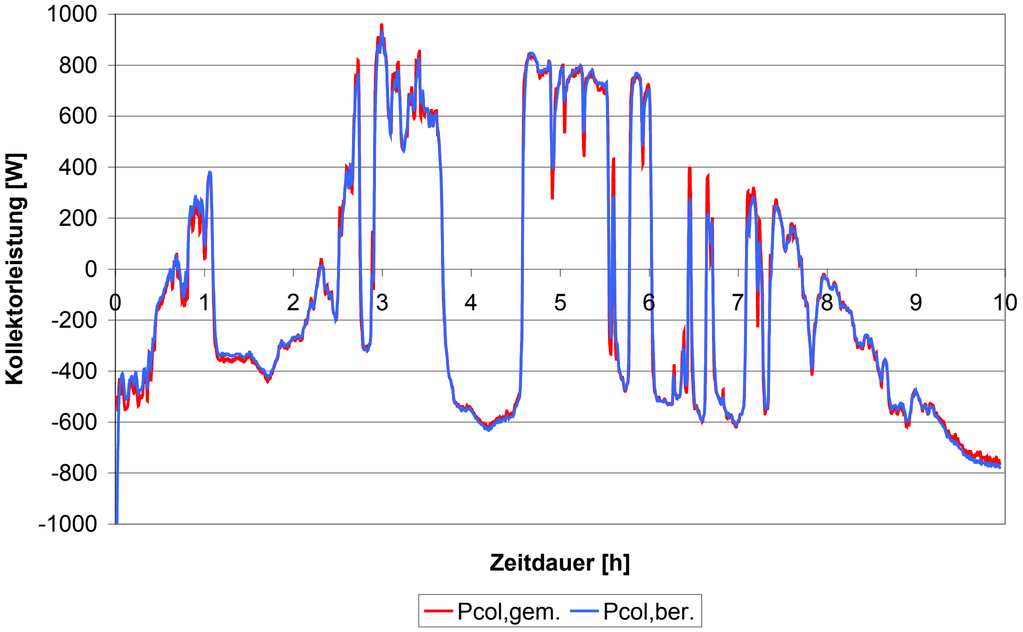


Bild 2.23: Vergleich gemessene/berechnete Kollektorleistung

2.3.7 Ausblick und Empfehlungen zur Behandlung effektiver Wärmekapazität

Ein 2-Knoten-Modell wurde für die Auswertung von Kollektortestdaten und zur Simulation von Sonnenkollektoren eingeführt. Vorteile des 2-Knoten-Modells gegenüber dem 1-Knoten-Modell sind die genauere Abbildung der physikalischen Vorgänge und die Möglichkeit den Kollektorwirkungsgradfaktor F’ abschätzen zu können. Weiterhin weichen die in Verbindung mit dem 2-Knoten-Modell ermittelten Wärmekapazitäten deutlich weniger von den theoretisch rechnerisch ermittelten Werten ab.

Zumindest bei Flachkollektoren ist es bislang noch nicht gelungen eindeutige Parametersätze zu bestimmen mit denen auch eine Abschätzung des Kollektorwirkungsgradfaktors F’ möglich ist. Hier sind weiterführende Untersuchungen notwendig, um Prüfbedingungen zu definieren, mit denen eine genauere Bestimmung der Kennwerte möglich ist. Vor dem Hintergrund einer Zeit- und Kostenersparnis bei der Prüfung von Sonnenkollektoren ist die Einführung des 2-Knotenmodells aber jetzt schon ein Gewinn. Als Nachteil ist die Erhöhung der Parameteranzahl anzusehen.

Das 2-Knotenmodell wird von einer innerhalb dieses Projekts zu dem Thema gebildeten Arbeitsgruppe positiv bewertet. Langfristig wäre es wünschenswert dieses in der EN 12975 zu verankern. Vor dem Hintergrund stark reduzierter Prüfzeiten (nur noch 2 Prüfsequenzen anstatt bisher 4-6) ist mittelfristig folgende Übergangslösung anzustreben:

1. eta0-Messung unter Bestrahlung (mit $T_m \cong T_{umg}$)
2. Wärmeverlust Messung ohne Bestrahlung (mit $T_m > T_{umg}$)
3. Auswertung unter Verwendung des 2-Knotenmodells
4. Umrechnung nach /Rockendorf1993/ auf Kennwerte des 1-Knotenmodells
5. Simulation unter Verwendung der nach 4. erzielten Kennwerte, effektive Wärmekapazität als Summe der Einzelkapazitäten aus 3.

3 Begleitung der Überarbeitung der Normen für fabrikfertige Solaranlagen (Normreihe EN 12976)

Die Normreihe EN 12976 wird durch die Arbeitsgruppe (Working Group) CEN TC312/WG 2 bearbeitet. Ein wichtiger Aspekt bei der Überarbeitung ist es, sicherzustellen, dass die bereits festgeschriebenen, relativ hohen Anforderungen an die Anlagentechnik, die notwendigen Prüfungen und die Dokumentation erhalten bleiben.

Da zusätzlich zur Energieeinsparung auch der von einer Solaranlage bereitgestellte Warmwasserkomfort eine entscheidende Größe ist, ist in der EN 12975-2 ein Verfahren zur „Ermittlung des Lasthaltevermögens“ enthalten. Bezüglich der Anwendung dieses Verfahrens liegen noch sehr wenige Erfahrungen vor. Zusätzlich weist dieses Verfahren den Nachteil auf, dass es ausschließlich bei der Prüfung von Solaranlagen nach EN 12975-2 zur Anwendung kommt. Für die Hersteller resultieren hieraus zusätzliche Prüfkosten, da die Leistungsfähigkeit der von ihnen angebotenen Analgen bzw. Speicher bei der Trinkwassererwärmung meist auch nach anderen Verfahren bestimmt werden muss. Diesen Nachteil weist auch der bereits Ende der neunziger Jahre im Rahmen eines vom DFS (Deutscher Fachverband Solarenergie) initiierten und von der DBU geförderten Projektes (Kombianlagenprojekt) entwickelte „DFS-Warmwasserleistungstest“(siehe Anhang A) auf.

Der Schwerpunkt der im Rahmen dieses Arbeitspunktes durchgeführten Arbeiten lag daher bei der Untersuchung von Verfahren zur Ermittlung der Leistungsfähigkeit von Speichern bei der Trinkwassererwärmung.

3.1 Einführung

Um die Leistungsfähigkeit von Trinkwasserspeichern bei der Trinkwassererwärmung bestimmen zu können, wurde von der Arbeitsgruppe TC57/WG8 am 16.12.2004 ein Entwurf vorgelegt, der seit Januar 2005 als englischsprachiges Dokument TC57/WG8 N0051 verfügbar ist. Zwischenzeitlich ist dieses Dokument in leicht modifizierter Version als prEN 15332 verfügbar. Generell ist das in diesem Dokument beschriebene Verfahren für die Anwendung auf monovalente Trinkwasserspeicher vorgesehen, wie sie in konventionellen Heizungsanlagen zur Trinkwassererwärmung eingesetzt werden. Um zu überprüfen, ob das Verfahren auch für Speicher die in Verbindung mit Solaranlagen eingesetzt werden geeignet ist, wurden entsprechende Untersuchungen durchgeführt. Hierzu wurde das Verfahren simulationstechnisch auf mono- und bivalente Trinkwasserspeicher sowie auf 2 unterschiedliche Kombispeicher angewendet. Die entsprechende Vorgehensweise sowie die dabei ermittelten Ergebnisse und daraus abgeleiteten Erkenntnisse sind in diesem Bericht beschrieben.

Die hier angewendete Untersuchung auf der Basis von Simulationsrechnungen mit sehr detaillierten Rechenmodellen hat gegenüber einer experimentellen bzw. messtechnischen Untersuchung zwei entscheidende Vorteile. Zum Einen können belastbarere Ergebnisse erzielt werden, da das Auftreten von Messfehlern ausgeschlossen werden kann und zum Anderen ist der Aufwand im Vergleich zu experimentellen Prüfungen deutlich geringer.

3.2 Beschreibung des Verfahrens nach TC57/WG8

Das Verfahren nach TC57/WG8 ermöglicht eine Klassifizierung von Speichern auf der Basis der Wärmeverlustrate des Speichers sowie dessen „nutzbarer Speicherkapazität“. Für die Ermittlung der „nutzbaren Speicherkapazität“ ist es zunächst erforderlich die Wärmeübertragungsleistung des Nachheizkreiswärmeübertragers zu ermitteln.

3.2.1 Ermittlung der Wärmeübertragerleistung des Nachheizkreis-wärmeübertragers

Die Ermittlung der Wärmeübertragerleistung des Nachheizkreiswärmeübertragers erfolgt im stationären Zustand bei gleichzeitiger Trinkwasserzapfung. Der Trinkwasser- und der Heizwassermassenstrom werden dabei so eingestellt, dass

- die Temperaturdifferenz zwischen Heizungsvorlauftemperatur und Kaltwassertemperatur 70 K beträgt
- und die Temperaturdifferenz zwischen Heizungsvor- und Rücklauftemperatur 20 K beträgt
- und die Temperaturdifferenz zwischen Kalt- und Warmwassertemperatur 50 K beträgt

Der hier ermittelte Heizwassermassenstrom wird zur Bestimmung der „nutzbaren Speicherkapazität“ verwendet.

3.2.2 Ermittlung der „nutzbaren Speicherkapazität“

Die Ermittlung der „nutzbaren Speicherkapazität“ erfolgt nach folgendem Testablauf:

a) Nachheizung des Speichers bis zur Abschalttemperatur
b) Zapfung bis zum Einschalten der Nachheizung
c) Nachheizung des Speichers bis zur Abschalttemperatur
d) Zapfung bis zum Einschalten der Nachheizung
e) Nachheizung des Speichers bis zur Abschalttemperatur
f) Zapfung mit Nachheizung, bis Warmwassertemperatur= Kaltwassertemperatur + 35 K unterschreitet

Der Zapfvolumenstrom muss so gewählt werden, dass in Phase f die Warmwassertemperatur nach 10 min. unterschritten wird. Kann der Speicher nicht mit dem max. möglichen Massenstrom (nicht näher definiert) nach 10 min. entladen werden, so wird die Messung trotzdem nach 10 min. abgebrochen.

Die „nutzbare Speicherkapazität“ entspricht dem in Phase f gezapften Wasservolumen, umgerechnet auf Warmwassertemperatur

Randbedingungen für die Nachheizung:

- es wird mindestens die unter 2.1 ermittelte Nachheizleistung aufgeprägt
- Heizungsvorlauftemperatur = Kaltwassertemperatur + 70 K
- Heizungsmassenstrom aus 3.2.1
- Schalthysterese = 5 K am entsprechenden Fühler. Die Abschalttemperatur wird so gewählt, dass die Warmwassertemperatur mindestens 60°C beträgt, aber nicht höher als 65°C ist

3.3 Anwendung des Verfahrens auf unterschiedliche Speichertypen

3.3.1 Monovalenter Trinkwasserspeicher (Nennvolumen 190 l)

Bei diesem Speicher handelt es sich um einen emaillierten Stahlstandspeicher mit einem eingetauchten Glattrohrwärmeübertrager, der sich fast über die gesamte Höhe des Speichers erstreckt und von oben nach unten durchströmt wird.

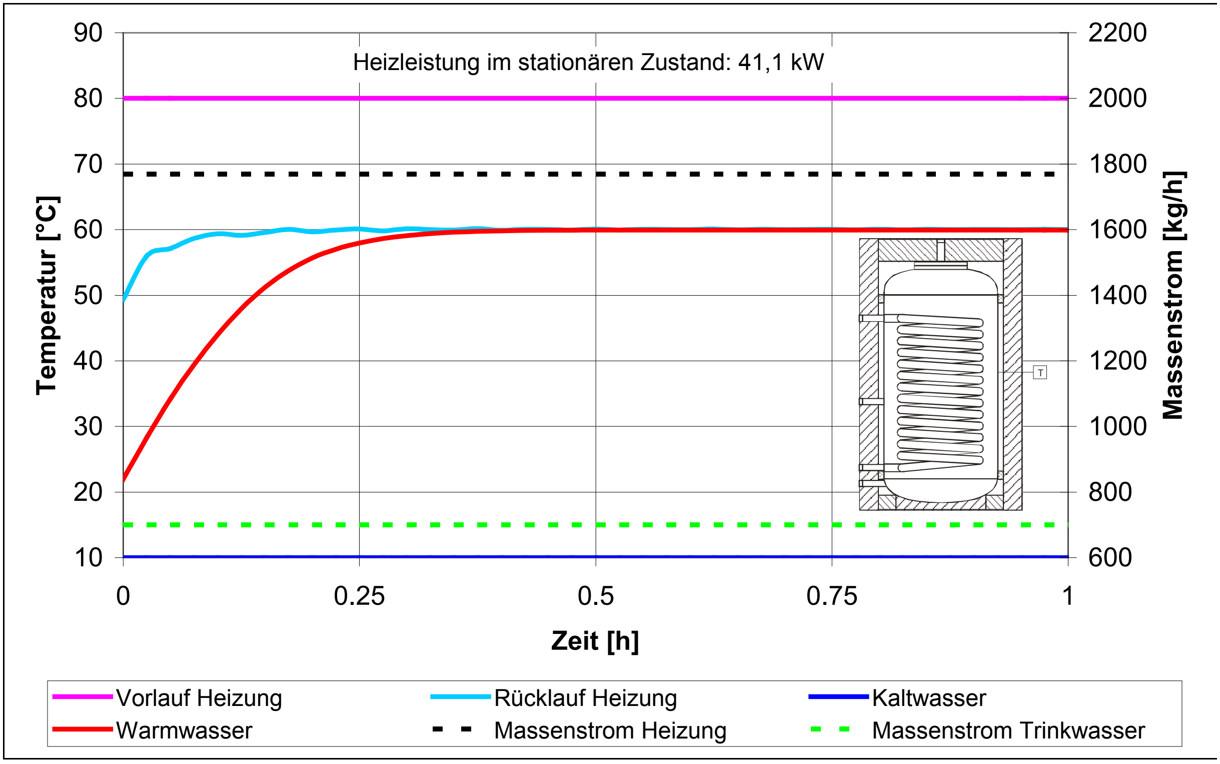


Bild 3.1: Ermittlung der Wärmeübertragerleistung bzw. des Heizungsmassenstroms

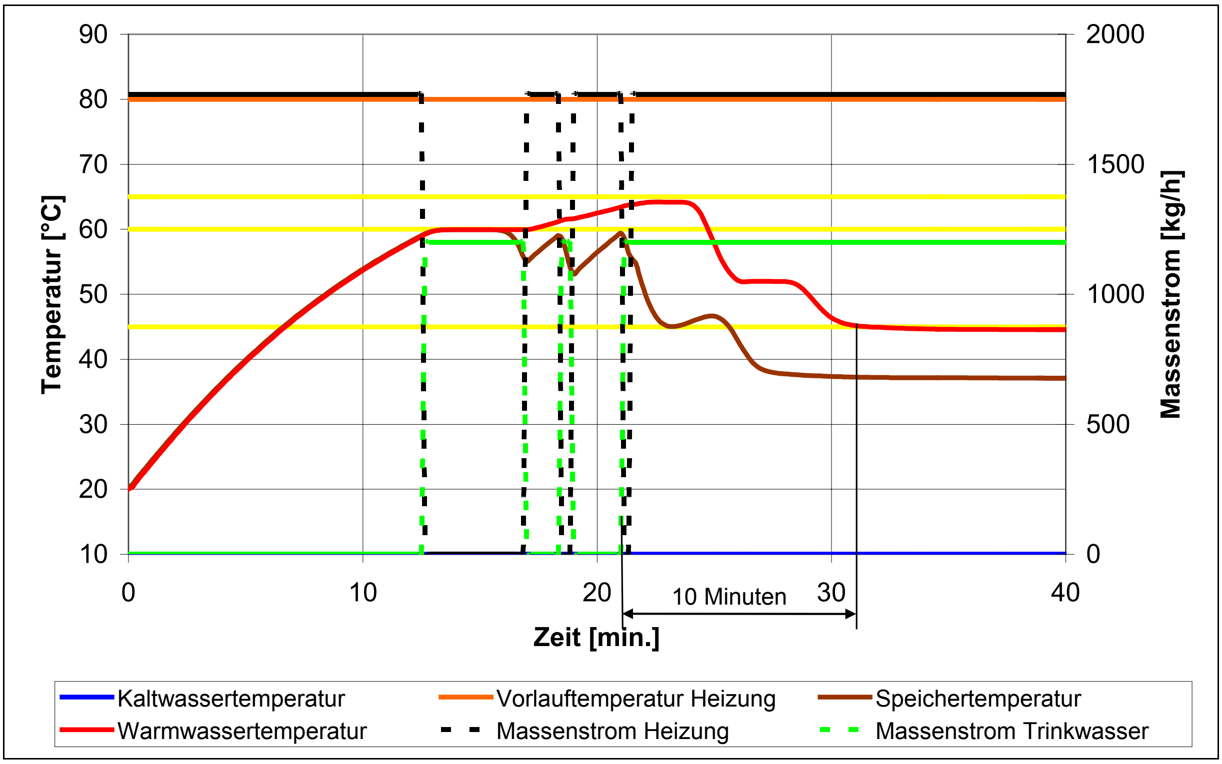


Bild 3.2: Bestimmung der „nutzbaren Speicherkapazität“

Für die ermittelte Nachheizleistung von 41,1 kW ergibt sich für diesen monovalenten Trinkwasserspeicher eine „nutzbare Speicherkapazität“ von 277 Litern.

3.3.2 Bivalenter Trinkwasserspeicher (Nennvolumen 300 l)

Bei diesem Speicher handelt es sich um einen emaillierten Stahlstandspeicher, mit einem eingetauchten Glattrohrwärmeübertrager im oberen (Bereitschafts-) Teil des Speichers, der von oben nach unten durchströmt wird.

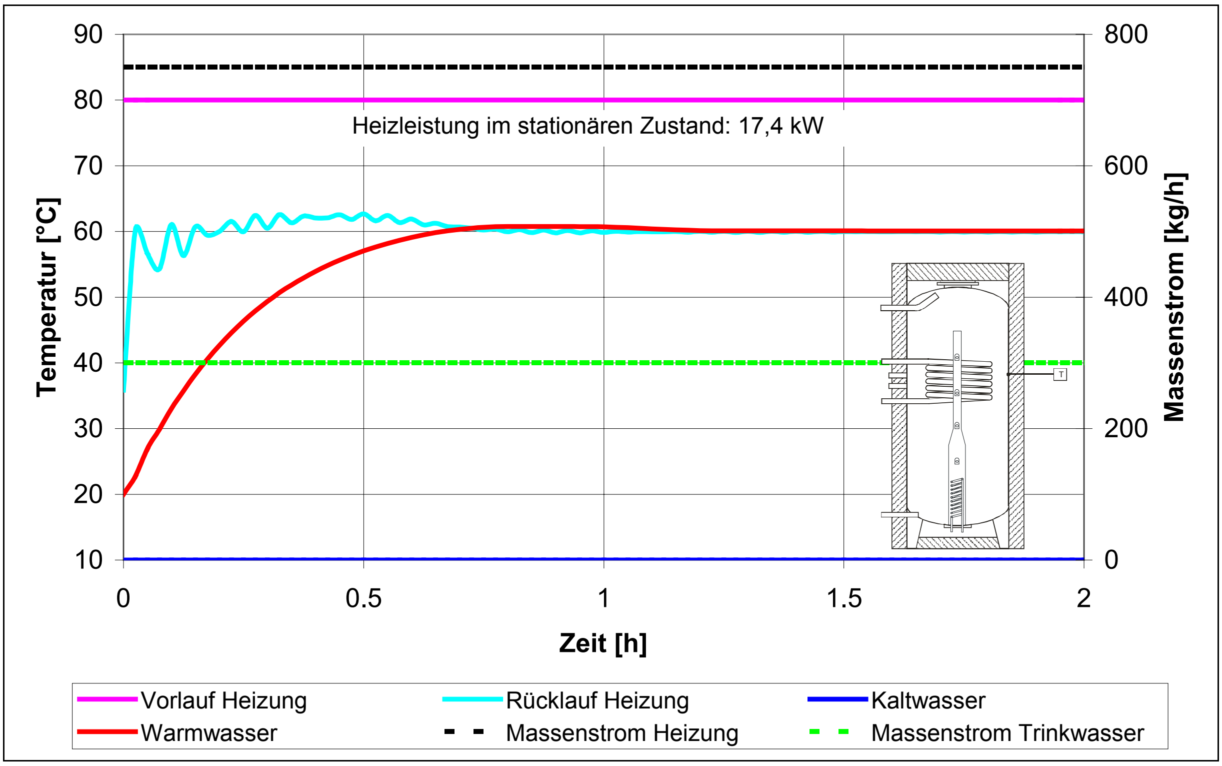


Bild 3.3: Ermittlung der Wärmeübertragerleistung bzw. des Heizungsmassenstroms

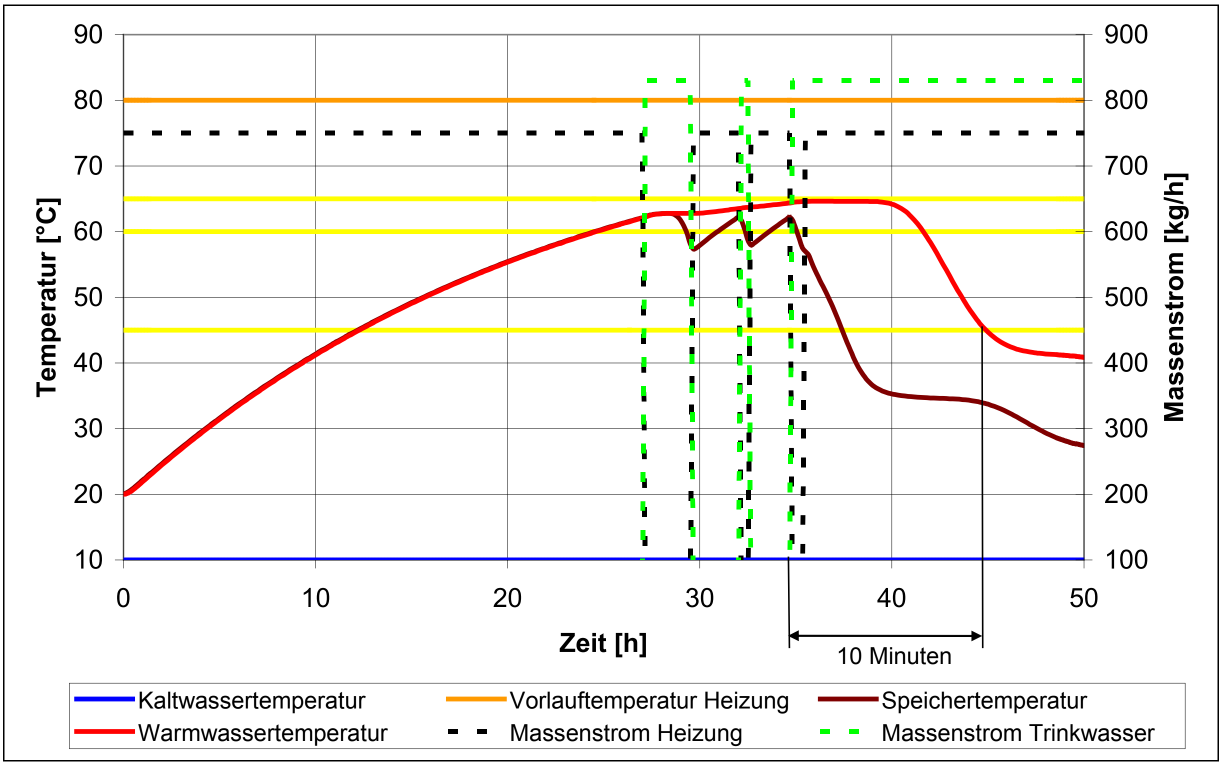


Bild 3.4: Bestimmung der „nutzbaren Speicherkapazität“

Für die ermittelte Nachheizleistung von 17,4 kW ergibt sich für diesen bivalenten Trinkwasserspeicher eine „nutzbare Speicherkapazität“ von 202 Litern.

3.3.3 Tank-im-Tank-Speicher (Nennvolumen 700 l)

Bei diesem Kombispeicher handelt es sich um einen Tank-im-Tank-Speicher. Der Trinkwassertank erstreckt sich bis zum Boden des Speichers und wird über das ihn umgebende Heizungswasser nachgeheizt

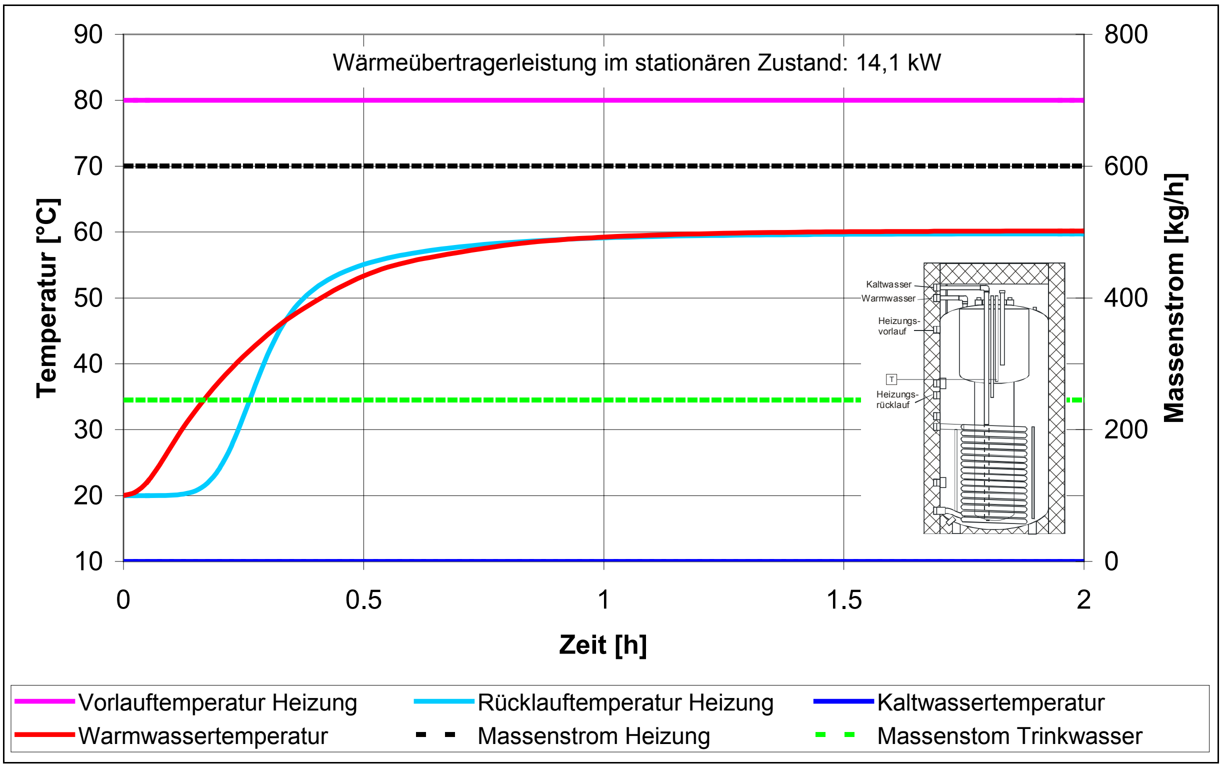


Bild 3.5: Ermittlung der Wärmeübertragerleistung bzw. des Heizungsmassenstroms

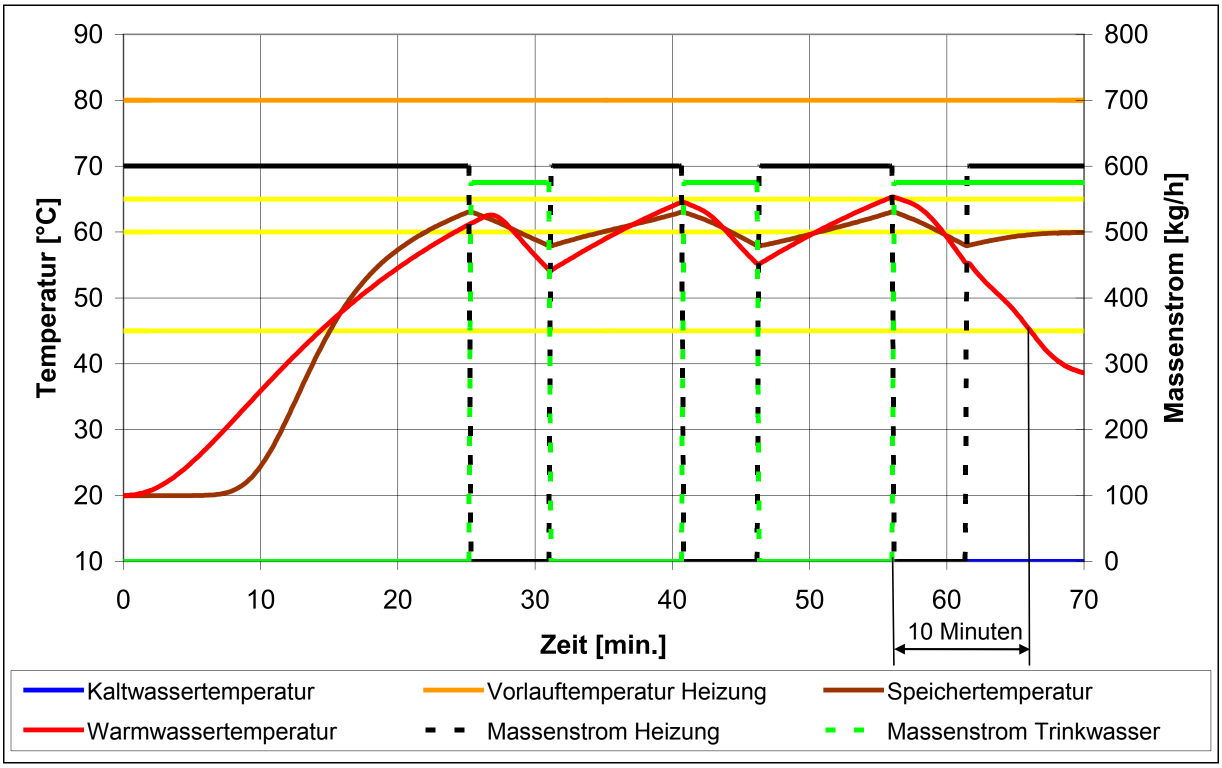


Bild 3.6: Bestimmung der „nutzbaren Speicherkapazität“

Für die ermittelte Nachheizleistung von 14,1 kW ergibt sich für diesen Tank-im-Tank-Speicher eine „nutzbare Speicherkapazität“ von 129 Litern.

3.3.4 Kombispeicher mit eingetauchtem Trinkwasserwärmeübertrager (Nennvolumen 750 l)

Bei diesem Kombispeicher wird das Trinkwasser im Durchlauf in einem Edelstahlwellrohr, das sich über die gesamte Höhe des Speichers erstreckt, erwärmt. Der obere (Bereitschafts-) Teil des Speichers wird direkt nachgeheizt.

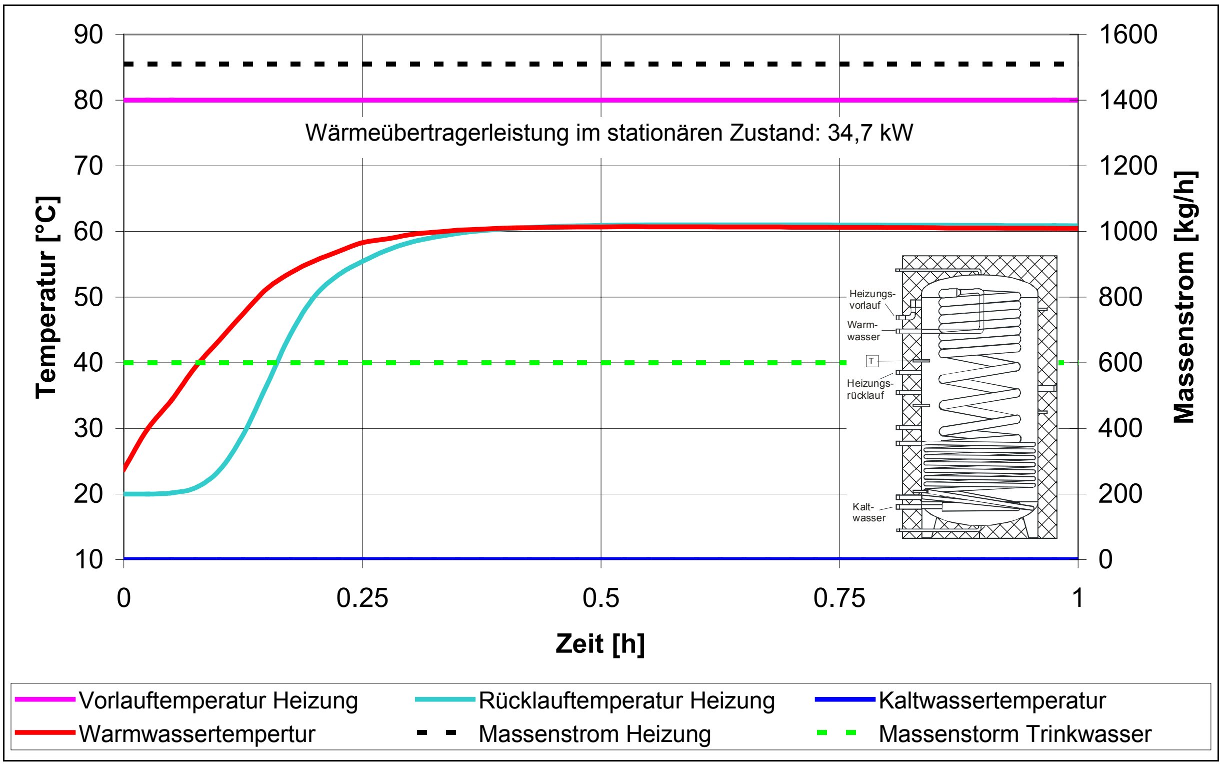


Bild 3.7: Ermittlung der Wärmeübertragerleistung bzw. des Heizungsmassenstroms

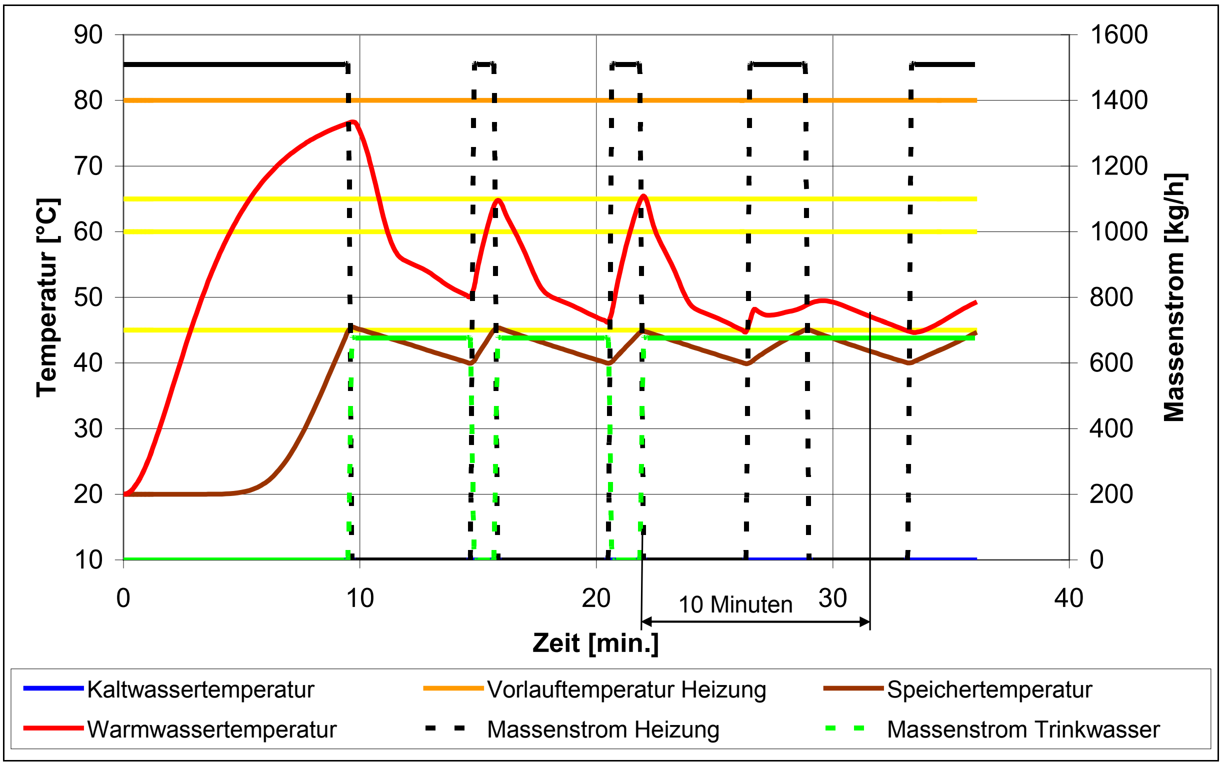


Bild 3.8: Bestimmung der „nutzbaren Speicherkapazität“

Bei diesem Kombispeicher mit Edelstahlwellrohr als Trinkwasserwärmeübertrager konnte für eine Heizleistung von 34,7 kW kein Zapfmassenstrom gefunden werden, bei dem nach 10 min. Zapfzeit eine Warmwassertemperatur von 45 °C unterschritten wurde. Bei dem in Bild 3.8 dargestellten Fall für einen Zapfmassenstrom von ca. 700 kg/h wurde diese Temperatur bereits nach 4 min. leicht unterschritten, nach ca. 12 min. erfolgte das zweite Mal eine Unterschreitung. Bei einer minimalen Reduktion des Zapfmassenstroms ergibt sich eine Unterschreitung der Warmwassertemperatur von 45 °C noch zu einem viel späteren Zeitpunkt.

3.3.5 Beurteilung des Verfahrens

Die Bestimmung der „nutzbaren Speicherkapazität“ gemäß dem vorliegenden Entwurf von TC57/WG8 kann prinzipiell auch auf Solarspeicher angewendet werden. Außer beim Kombispeicher mit eingetauchtem Trinkwasserwärmeübertrager (Edelstahlwellrohr) liefert das Verfahren plausible Werte auf Basis von Simulationsrechnungen. Eventuell ist die mit 34,7 kW relativ hohe Nachheizleistung bei diesem Kombispeicher ursächlich dafür, dass kein Massenstrom gefunden werden konnte, bei dem das Abbruchkriterium nach 10 min. erreicht ist.

Grundsätzlich stellt sich allerdings die Frage, ob die Bestimmung der Leistung des Wärmeübertragers für die Nachheizung und damit der Nachheizparameter zur Bestimmung der „nutzbaren Speicherkapazität“ für Solarspeicher sinnvoll ist.

Zum Einen gibt es bei Kombispeichern häufig keinen Wärmeübertrager für die Nachheizung, da diese direkt nachgeheizt werden. Zum Anderen wird die thermische Leistungsfähigkeit von Solaranlagen u. a. durch die beiden Kennwerte anteilige Energieeinsparung und einer Größe zur Charakterisierung der Leistungsfähigkeit bei der Trinkwassererwärmung, wie z. B. die „nutzbare Warmwassermenge“ angegeben.

Dies ist jedoch nur sinnvoll, wenn beide Größen mit den gleichen Parametern für die Nachheizung (max. Leistung, max. Vorlauftemperatur, Volumenstrom, Ein- und Ausschalttemperatur) ermittelt werden. Da diese Parameter vom Hersteller zumindest in Bereichen vorgegeben werden, kann eine Bestimmung des Heizmassenstroms nach Kap. 3.2.1 entfallen.

3.4 Einfluss der Nachheizleistung auf die „nutzbare Speicherkapazität“ und die anteilige Energieeinsparung

Um den Einfluss der Nachheizleistung auf die „nutzbare Speicherkapazität“ und die anteilige Energieeinsparung zu ermitteln, wurde diese für die vorgestellten Speicher bei konstantem Volumenstrom und unveränderten Abschalttemperaturen variiert und die „nutzbare Speicherkapazität“ wie vorgestellt bestimmt. Zusätzlich wurden die Speicher simulationstechnisch in Anlagen integriert und die anteilige Energieeinsparung f_{sav} mit der jeweiligen Nachheizleistung bestimmt. Als maximale Leistung wurde die nach dem

Verfahren der TC57/WG8 bestimmte Wärmeübertragungsleistung gewählt. Beim Kombispeicher mit eingetauchtem Trinkwasserwärmeübertrager wurde eine kleinere max. Leistung gewählt, da mit der ermittelten Wärmeübertragerleistung die Prüfung zur Bestimmung der „nutzbaren Speicherkapazität“ zu keinem Ergebnis führte (siehe Kap. 3.3.4). Tabelle 3.1(A+B) zeigt die Ergebnisse im Überblick.

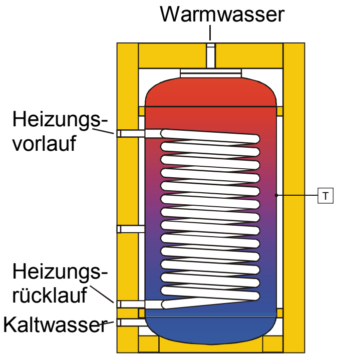
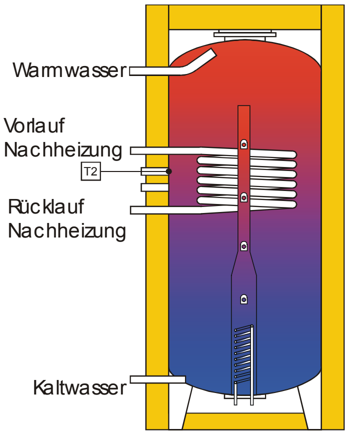
	 Monovalenter TW-Speicher		 Bivalenter TW-Speicher	
Nachheizung [kW]	15,0	41,1	10	17,4
f_{sav} [%]	52,2	54,9	55,5	55,1
„nutzbare Speicher-kapazität“ [l]	202	250	186	202

Tabelle 3.1A: Einfluss der Nachheizleistung auf die „nutzbare Speicherkapazität“ und die anteilige Energieeinsparung f_{sav} (monovalenter und bivalenter TW-Speicher)

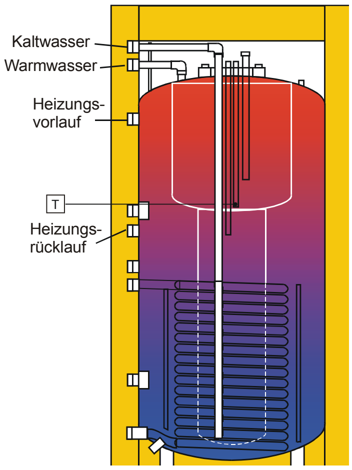
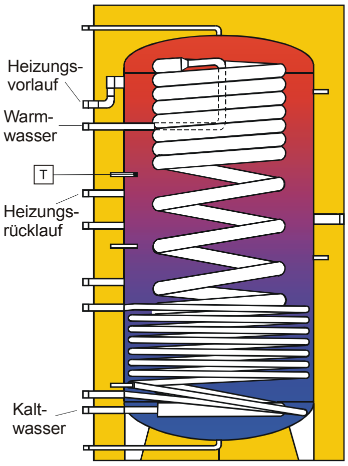
	 Tank-im-Tank Speicher		 Kombispeicher	
Nachheizung [kW]	7,0	14,1	10,0	20
f_{sav} [%]	23,8	23,7	21,2	20,9
„nutzbare Speicher-kapazität“ [l]	150	131	126	131

Tabelle 3.1B: Einfluss der Nachheizleistung auf die „nutzbare Speicherkapazität“ und die anteilige Energieeinsparung f_{sav} (Tank-im-Tank und Kombi-Speicher)

3.4.1 Beurteilung

Tabelle 3.1 zeigt für den bivalenten Trinkwasserspeicher und den Kombispeicher mit eingetauchtem Trinkwasser-Wärmeübertrager eine relativ geringe Abhängigkeit der „nutzbaren Speicherkapazität“ von der Nachheizleistung. Am größten ist sie beim monovalenten Trinkwasserspeicher, da dessen Wärmeübertrager über die größte Wärmeübertragerleistung verfügt. Allerdings differieren hier auch die Heizleistungen am stärksten. Beim Tank-im-Tank-Speicher steigt die „nutzbare Speicherkapazität“ sogar mit abnehmender Nachheizleistung. Dies ist dadurch begründet, dass mit abnehmender Heizleistung die Aufheizzeit steigt und damit der Trinkwassertank besser durchgewärmt wird.

Außer beim monovalenten Trinkwasserspeicher hängt die anteilige Energieeinsparung f_{sav} fast nicht von der Leistung der Nachheizung ab. Beim monovalenten Trinkwasserspeicher wird je nach Nachheizleistung mehr oder weniger der ganze Speicher nachgeheizt. Deshalb hat die Leistung der Nachheizung bei diesem System den größten Einfluss.

3.5 Schlussfolgerungen

Wie bereits in den Abschnitten 3.3.5 und 3.4.1 diskutiert, ist das von TC57/WG8 vorgeschlagene Verfahren grundsätzlich für die Bestimmung der „nutzbaren Speicherkapazität“ geeignet.

Für bestimmte Speicherbauarten ergeben sich jedoch bei der Anwendung des Verfahrens relativ hohe Heizleistungen. Diese liegen teilweise deutlich über den beim Einsatz der entsprechenden Speicher in einem Ein- oder Zweifamilienhaus zur Verfügung stehenden Heizleistungen. Die Durchführung von Simulationsrechnungen zur Berechnung der anteiligen Energieeinsparung unter Verwendung dieser hohen, zuvor nach TC57/WG8 ermittelten Heizleistungen, erscheint daher fragwürdig.
Es stellt sich die Frage, ob nicht für den Anwendungsfall „Ein- und Zweifamilienhaus“ ein Standardheizkessel mit einer Leistung von z. B. 15 kW definiert werden sollte. Dies hätte den Vorteil, dass es sich bei der zur Verfügung stehenden Heizleistung um einen realistischen Wert handelte, ohne dass sich hierdurch für die nach TC57/WG8 ermittelte „nutzbare Speicherkapazität“ sowie die anteilige Energieeinsparung grundsätzlich andere Ergebnisse ergeben würden (vgl. Kapitel 3.3 und 3.4).

4 Mitgestaltung der Normen für „kundenspezifisch gefertigte Solaranlagen“ (Normreihe ENV 12977)

Auf das Marktsegment der kundenspezifisch gefertigten Solaranlagen entfällt der größte Teil der in Deutschland produzierten und installierten Anlagen, so dass diese Normreihe für die deutsche Industrie von erheblicher Relevanz ist. In den gegenwärtig verfügbaren Vornormen, werden primär Solaranlagen zur Trinkwassererwärmung behandelt. Im Zuge der Überarbeitung dieser Normreihe durch die Arbeitsgruppe (Working Group) CEN TC312/WG 3 ist beabsichtigt, den Teil ENV 12977-3 zu einer endgültigen Normen weiterzuentwickeln. Hierzu wurde im Rahmen dieses Projekts ein entsprechender Normentwurf erstellt. Dieser ist, ebenso wie sämtliche anderen Teile der Normreihe ENV bzw. CEN/TS die innerhalb dieses Projektes überarbeitet und erarbeitet wurden, diesem Bericht als Anhang B beigefügt.

Für die Leistungsprüfung von kundenspezifisch gefertigten Analgen kommt das sogenannte CTSS[1]-Verfahren zur Anwendung. Das komponentenorientierte CTSS-Verfahren bietet gegenüber dem in der Normreihe EN 12976 festgeschriebenen Gesamtanlagentestverfahren den Vorteil, dass mehrere, auf der Kombination einiger gleicher Komponenten (Kollektoren, Speicher, Regelungen) basierende Anlagen deutlich kostengünstiger geprüft werden können. Eine weitere, deutliche Reduktion der Prüfkosten lässt sich erreichen, wenn nicht mehr, wie in der ENV 12977-3 gefordert, jeder einzelne Speichertyp geprüft werden muss. Im Rahmen dieses Arbeitspunktes wurde daher untersucht, inwieweit alle Speicher einer Baureihe durch die Prüfung einzelner Produktderivate (z. B. des kleinsten und größten Speichers der Baureihe) ausreichend charakterisiert werden können. Hierzu wurden mehrere Baureihen unterschiedlicher Speicherbauarten vollständig vermessen und auf Basis dieser Ergebnisse Regeln für eine Extrapolation bzw. Interpolation der Speicherkennwerte hergeleitet. Die hierzu durchgeführten Untersuchungen werden im Folgenden ausführlich beschrieben.

4.1 Einführung

Um das thermische Verhalten von Warmwasserspeichern beschreiben zu können, wurde am ITW, Universität Stuttgart für das Simulationsprogramm TRNSYS ein mathematisches Rechenmodell (TRNSYS-Type 140) entwickelt. Für die numerische Abbildung eines Speichers werden dessen Kennwerte (Volumen, Wärmeverlustrate, Wärmeübertragungsvermögen der eingetauchten Wärmeübertrager,…) als Parameter in dieses Modell eingegeben. In der ENV 12977-3 wird bislang gefordert, dass zur Ermittlung dieser Parameter auch alle Speicher einer Baureihe, die sich nur durch das Volumen und die Größe der eingetauchten Wärmeübertrager unterscheiden, geprüft werden müssen. Um die Prüfkosten zu reduzieren wird im Rahmen des Projekts EuroSol untersucht, inwieweit alle Speicher einer Baureihe durch die Prüfung eines Einzelnen ausreichend charakterisiert werden können.

---

[1] CTSS: Component Testing – System Simulation (komponentenorientiertes Testverfahren)

Hierzu wurden von verschiedenen Herstellern jeweils 2 bis 3 Speicher einer Baureihe geprüft und deren Kennwerte über ein Parameteridentifikationsverfahren ermittelt. Anschließend wurde untersucht, inwieweit Algorithmen zur Berechnung von Kennwerten eines Speichers aus den für den kleineren oder größeren Speichern der gleichen Baureihe ermittelten Prüfergebnissen abgeleitet werden können.

4.2 Untersuchte Speicher

Es wurden 4 Baureihen von Trinkwasserspeichern und zwei Baureihen von Kombispeichern geprüft. Bild 4.1 zeigt das Schema der Speicher der **Baureihe B**: Es handelt sich um 3 Trinkwasserspeicher mit einem Nennvolumen von 300 l, 400 l und 500 l mit eingetauchten Wärmeübertragern für die Nachheizung und den Solarkreis. Der Solarkreiswärmeübertrager ist mit einer Schichtbeladeeinrichtung kombiniert. Alle Speicher sind mit einer Weichschaumdämmung einheitlicher Stärke versehen.

Bild 4.2 zeigt das Schema der Speicher der **Baureihe V**: Es handelt sich um 3 Trinkwasserspeicher mit einem Nennvolumen von 300 l, 400 l und 500 l mit eingetauchten Wärmeübertragern für die Nachheizung und den Solarkreis. Die Speicher sind mit unterschiedlichen Dämmkonzepten (Weichschaum/ Hartschaum) versehen. Aus diesem Grund wurde bei diesen Speichern auf eine Skalierung des Wertes für die Wärmeverlustrate verzichtet.

Bild 4.3 zeigt das Schema der Speicher der **Baureihe W**: Es handelt sich wieder um 3 Trinkwasserspeicher mit einem Nennvolumen von 300 l, 400 l und 500 l mit eingetauchten Wärmeübertragern für die Nachheizung und den Solarkreis. Alle Speicher sind mit einer Weichschaumdämmung einheitlicher Stärke versehen.

Bild 4.4 zeigt das Schema der Speicher der **Baureihe F**: Es handelt sich um 3 Kombispeicher mit einem Nennvolumen von 560 l, 800 l und 1440 l mit eingetauchten Wärmeübertragern für die Trinkwassererwärmung und den Solarkreis. Alle Speicher sind mit einer Hartschaumdämmung versehen, deren Stärke nicht einheitlich ist. Die Speicher verfügen außerdem über eine unterschiedliche Anzahl von Anschlüssen. Sie haben als einzige Speicher Edelstahlwellrohre als Wärmeübertrager. Alle anderen Speicher verfügen über Glattrohrwärmeübertrager.

Bild 4.5 zeigt das Schema der Speicher der **Baureihe P**: Es handelt sich wieder um 3 Trinkwasserspeicher mit einem Nennvolumen von 290 l, 390 l und 490 l mit eingetauchten Wärmeübertragern für die Nachheizung und den Solarkreis. Alle Speicher sind mit einer Wärmedämmung aus Polystirol und Melaminharz versehen.

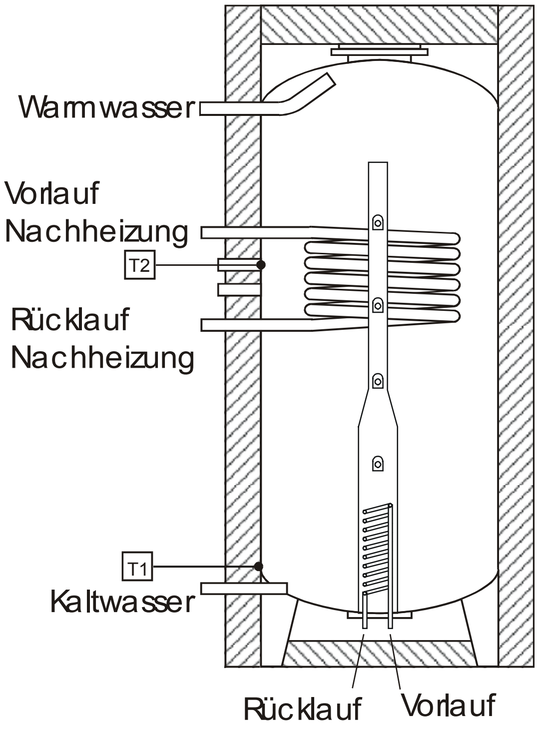


Bild 4.1: Speicher der Baureihe B

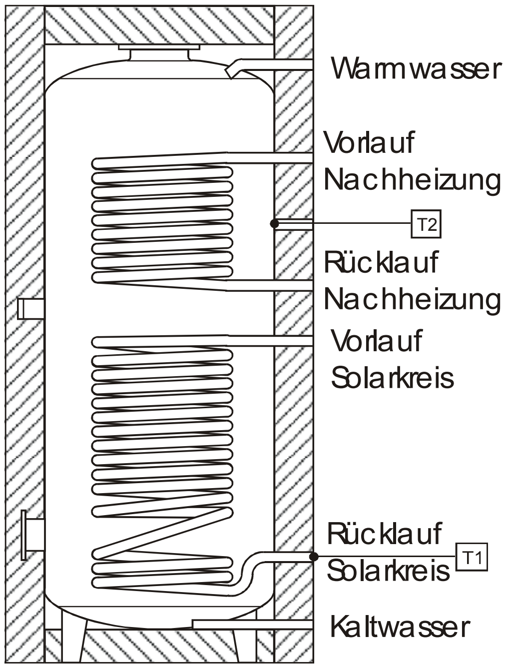


Bild 4.2: Speicher der Baureihe V

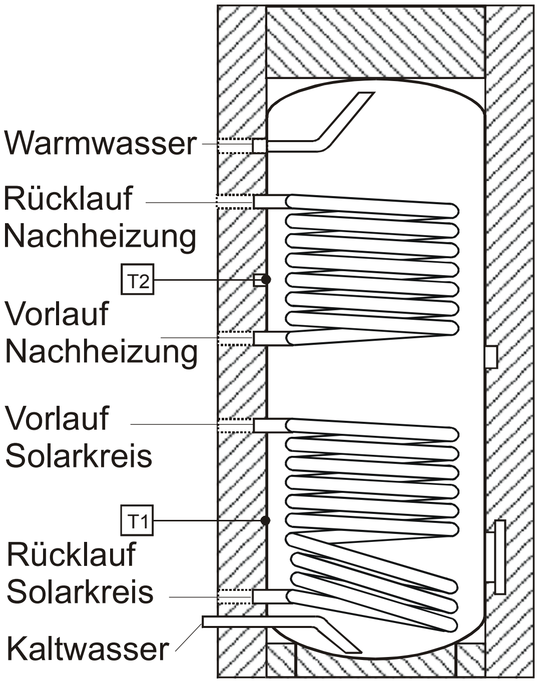


Bild 4.3: Speicher der Baureihe W

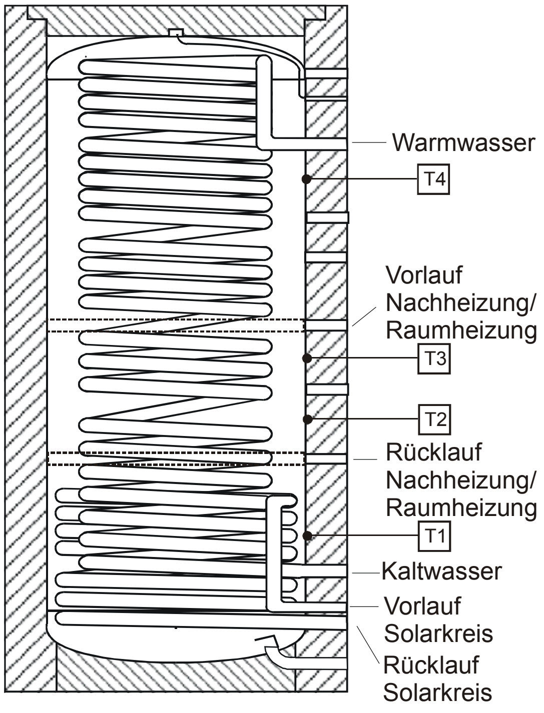


Bild 4.4: Speicher der Baureihe F

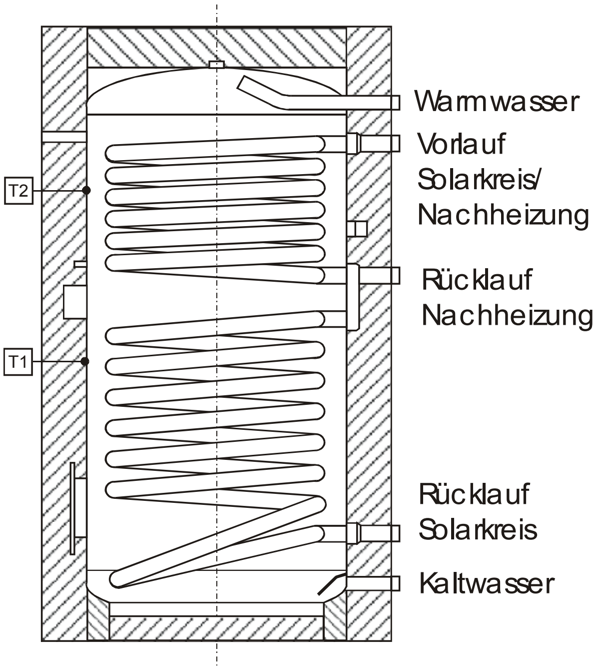


Bild 4.5: Speicher der Baureihe P

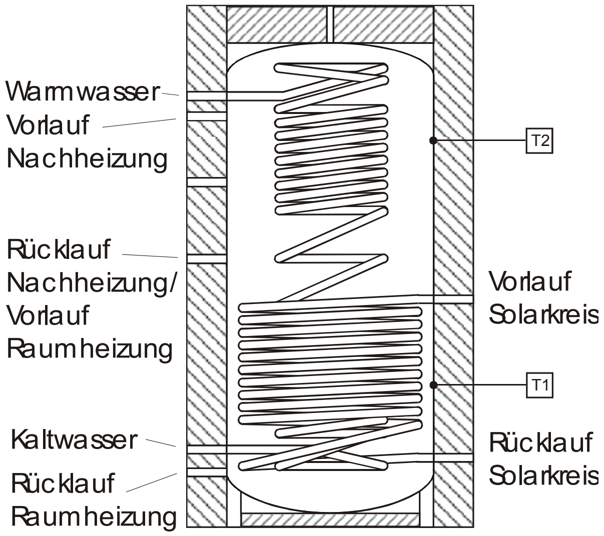


Bild 4.6: Speicher der Baureihe S1

Bild 4.6 zeigt das Schema der Speicher der **Baureihe S1**: Es handelt sich um 2 Kombispeicher mit einem Nennvolumen von 750 l und 1000 l mit eingetauchten Wärmeübertragern für die Trinkwassererwärmung und den Solarkreis. Alle Speicher sind mit einer Weichschaumdämmung einheitlicher Stärke versehen.

4.3 Speicherkennwerte

Tabelle 4.1 gibt einen Überblick über die wichtigsten Speicherkennwerte, die im TRNSYS-Type 140 verwendet werden:

Kennwert:	Bezeichnung:
H_s [m]	Speicherhöhe
V_s [l]	Volumen des Wasserraums des Speichers
V_{hx} [l]	Volumen eines eingetauchten Wärmeübertragers
λ_{eff} [W/(m·K)]	Effektive vertikale Wärmeleitfähigkeit des Speichers
UA_{sa} [W/K]	Wärmeverlustrate des Speichers
K_{WT} [W/K]	Konstante zur Beschreibung des Wärmeübertragungsvermögens eines eingetauchten Wärmeübertragers

b_{h1} [-]	Massenstromabhängigkeit des Wärmeübertragungsvermögens eines eingetauchten Wärmeübertragers
b_{h3} [-]	Temperaturabhängigkeit des Wärmeübertragungsvermögens eines eingetauchten Wärmeübertragers
n [-]	Schichtungskennzahl für die direkte Entladung
z_x [-]	Relative Höhe eines Anschlusses oder eines Temperaturfühlers, bezogen auf die Speicherhöhe H_s

Tabelle 4.1: Speicherkennwerte

4.4 Mögliche Vorgehensweise bei der Berechnung der Speicherkennwerte

4.4.1 Die Wärmeverlustrate

Die Wärmeverlustrate des Speichers hat großen Einfluss auf die thermische Leistungsfähigkeit der Solaranlage. Wird sie nicht messtechnisch bestimmt, so könnte Sie über die Gleichung (1) berechnet werden:

$$UA_{sa} = a \cdot \sqrt{V} \tag{1}$$

mit UA_{sa} = Wärmeverlustrate des Speichers [W/K]
V = gesamtes Speichervolumen [Liter]
a = konstanter Faktor (bauartabhängig) [-]

Vorgehensweise: Ist die Wärmeverlustrate des größten Speichers einer Baureihe bekannt, so wird der Faktor a für dessen Volumen angepasst, so dass Gl. 1 erfüllt ist. Für kleinere Speicher dieser Baureihe kann dann über Gl. 1 deren Wärmeverlustrate bestimmt werden. Die Bilder 4.7 bis 4.12 zeigen das Ergebnis für die Baureihen B, W, F, P, V und S1. Die Wärmeverlustrate ist hier bezogen auf den Wert für den größten Speicher.
Bild 4.8 zeigt, dass dieses Verfahren für die Speicher der Baureihe W eine sehr gute Übereinstimmung zwischen Messung und Rechnung ergibt. Bild 4.7 zeigt für den kleinen und mittelgroßen Speicher der Baureihe B eine Abweichung um ca. 5% bis 8% zu den gemessenen Werten. Bei den Speichern der Baureihe F (Bild 4.9) zeigt der Speicher mittlerer Größe eine große Abweichung zwischen gemessenem und berechnetem Wert. Hier ist allerdings zu bedenken, dass wie bereits in Kapitel 4.2 erwähnt, diese Speicher nicht im strengen Sinn baugleich sind, da sie sich in der Dämmstärke und der Anzahl der Anschlüsse unterscheiden. Bild 4.10 zeigt für die Baureihe P eine Abweichung von 3% bis 5%. Bild 4.11 zeigt für die Baureihe V eine gute Übereinstimmung für den mittelgroßen Speicher (< 1%). Der kleinste Speicher dieser Baureihe war mit einem anderen Dämmkonzept versehen und wurde deshalb hier nicht mit einbezogen. Bild 4.12 zeigt für die Baureihe S1, die nur aus 2 Speichern besteht eine Abweichung von nur 2% für den kleinen Speicher.

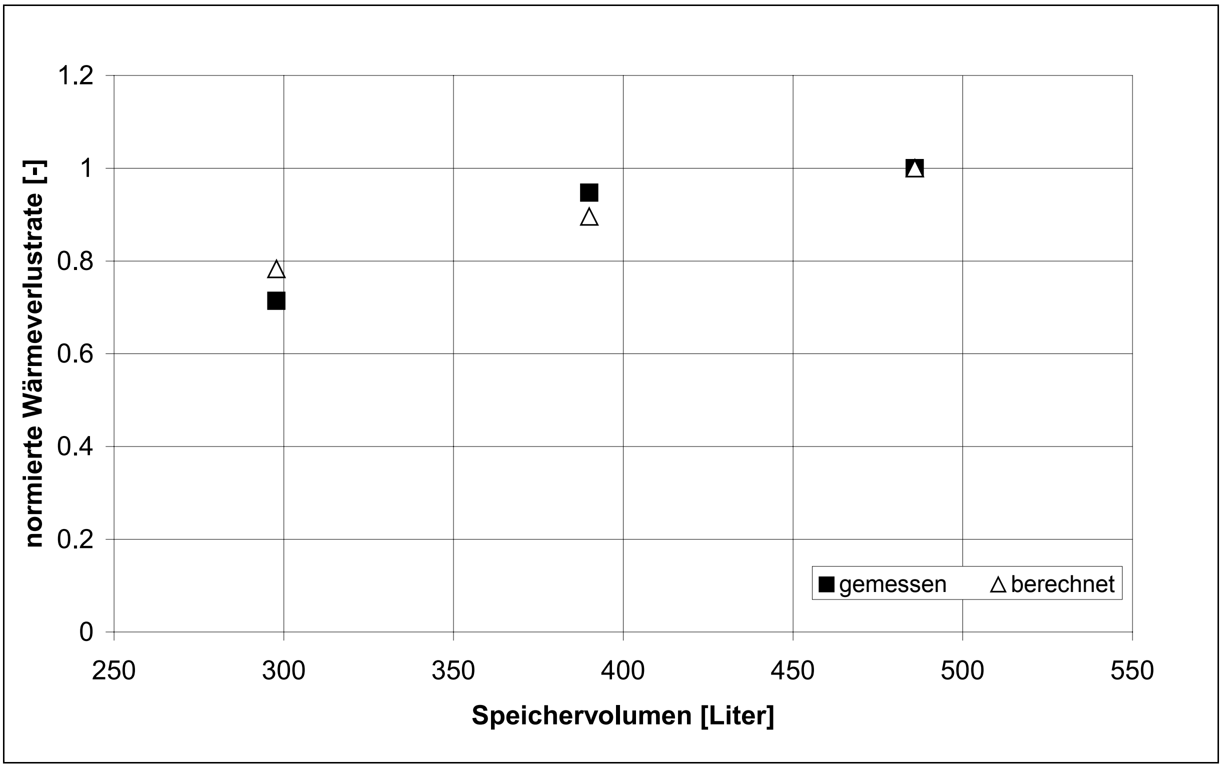


Bild 4.7: gemessene und berechnete Wärmeverlustraten (normiert) der Speicher der Baureihe B

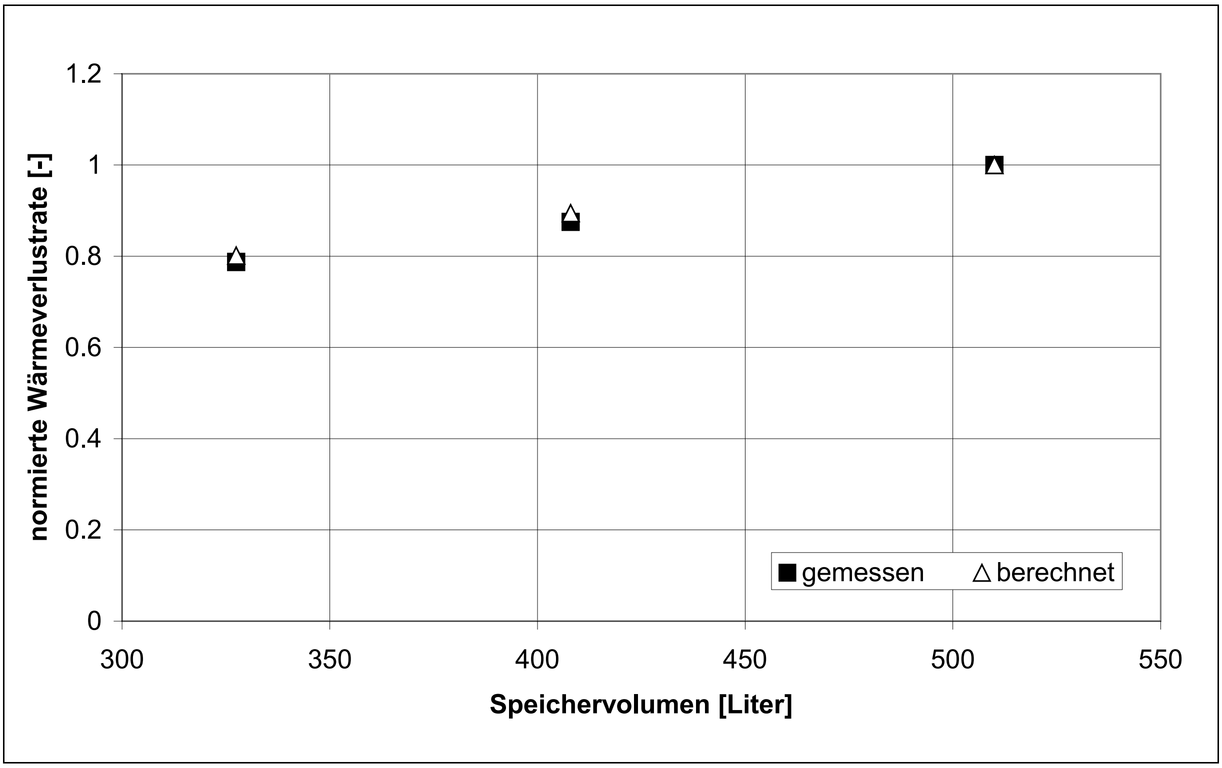


Bild 4.8: gemessene und berechnete Wärmeverlustraten (normiert) der Speicher der Baureihe W

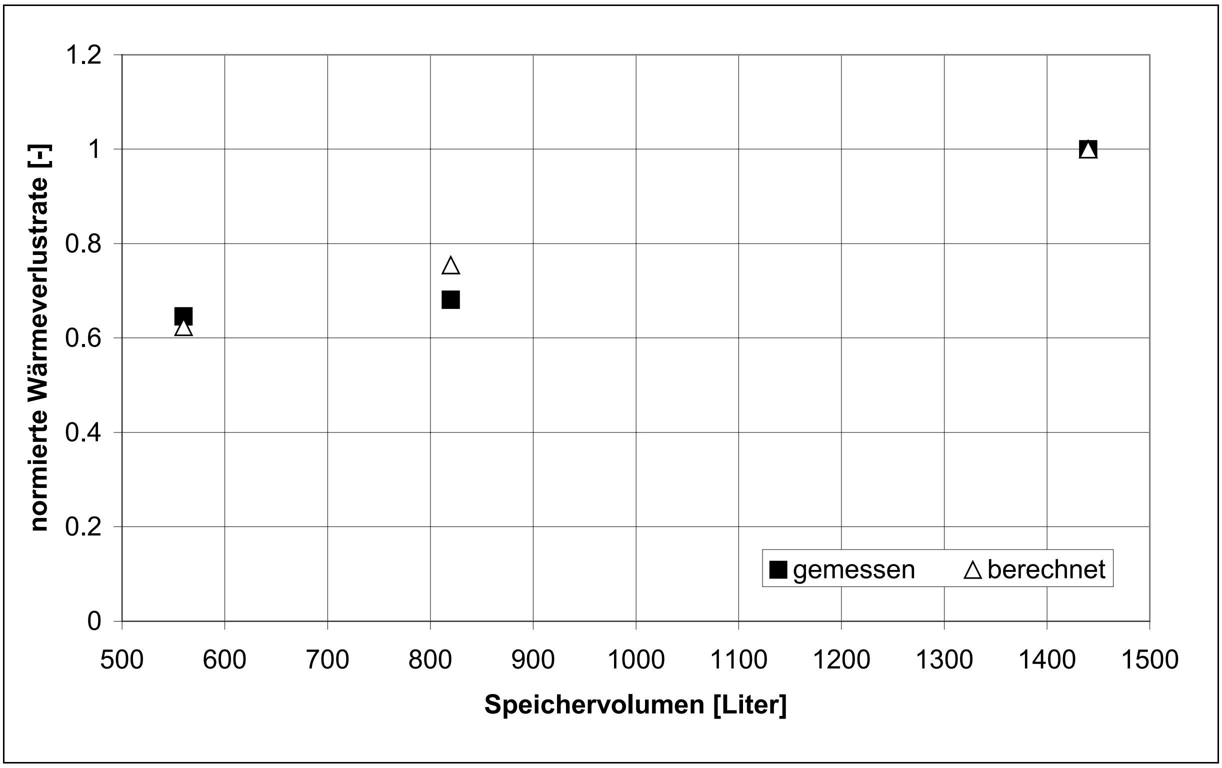


Bild 4.9: gemessene und berechnete Wärmeverlustraten (normiert) der Speicher der Baureihe F

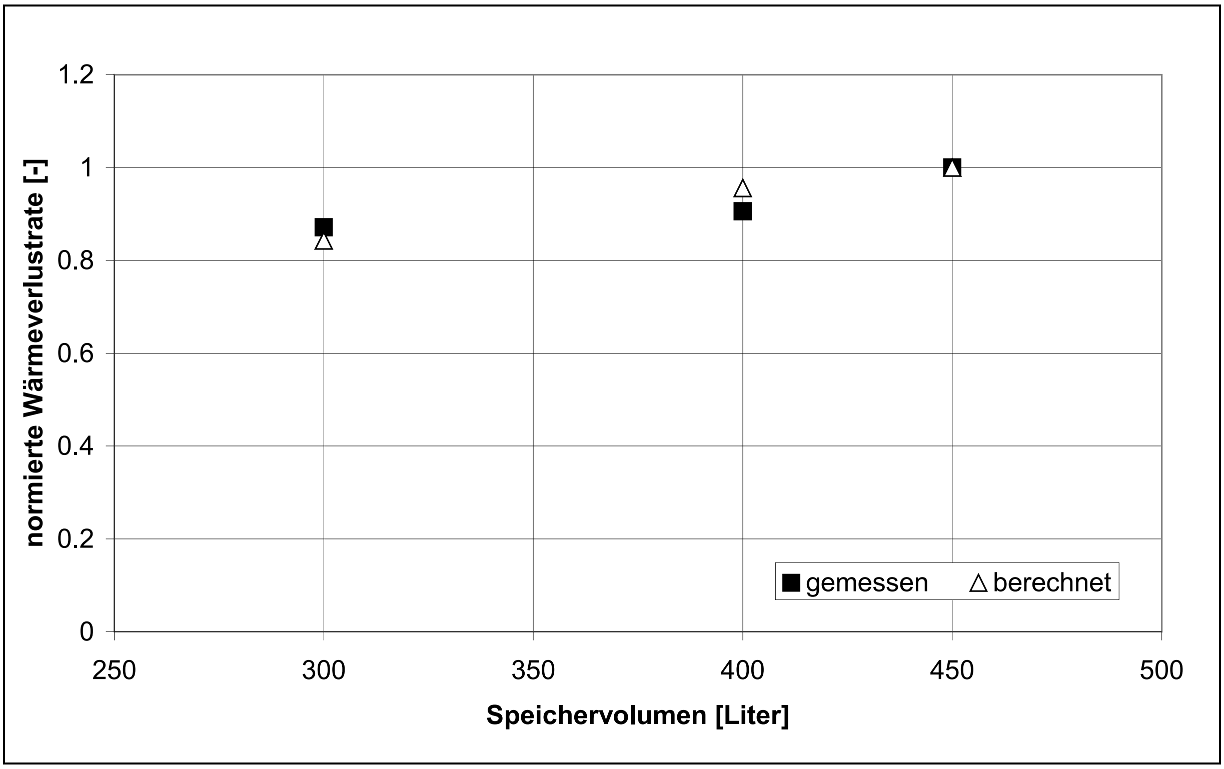


Bild 4.10: gemessene und berechnete Wärmeverlustraten (normiert) der Speicher der Baureihe P

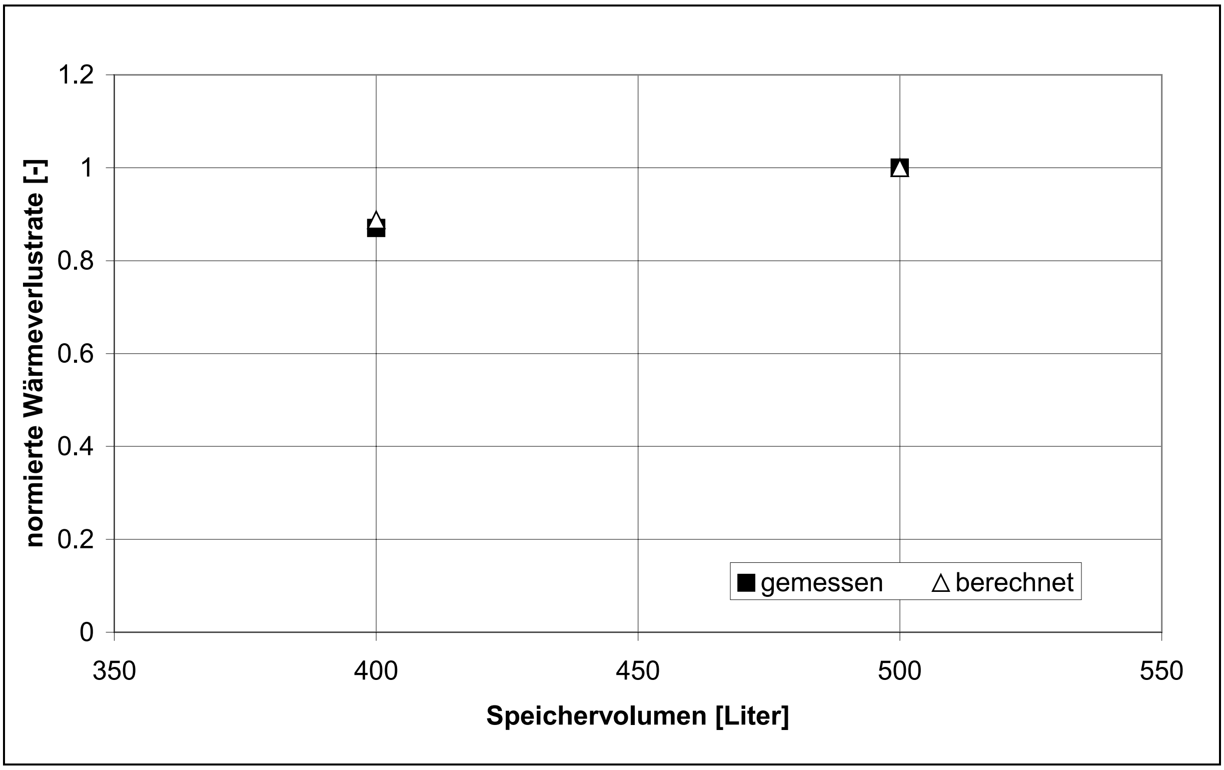


Bild 4.11: gemessene und berechnete Wärmeverlustraten (normiert) der Speicher der Baureihe V

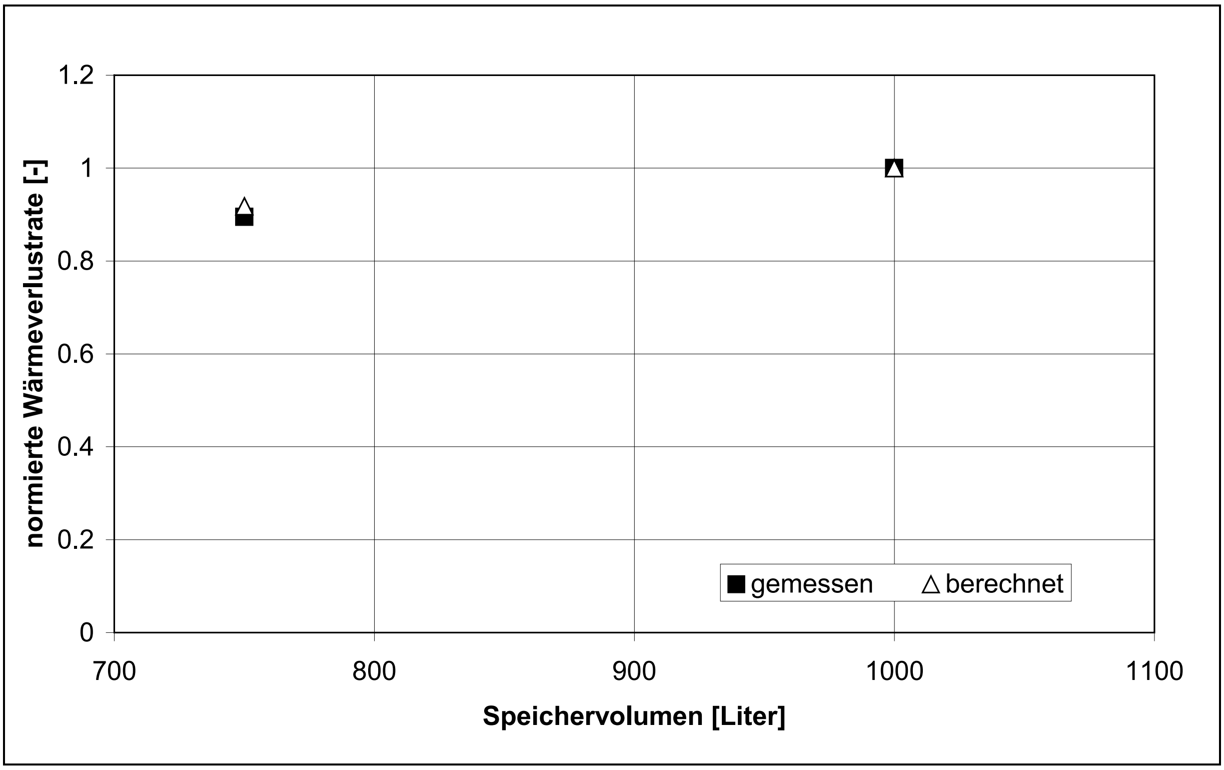


Bild 4.12: gemessene und berechnete Wärmeverlustraten (normiert) der Speicher der Baureihe S1

4.4.3 Wärmeübertrager

Um das thermische Verhalten des Wärmeübertragers im Speichermodell wiedergeben zu können, müssen die Parameter K_{WT}, b_{h1} und b_{h3} für die Gleichung 2 ermittelt werden.

$$\begin{aligned} &UA_{hx} = K_{WT} \cdot \dot{m}^{bh1} \cdot \vartheta_m^{bh3} \\ &mit\; UA_{hx} = W\ddot{a}rme\ddot{u}bertragungsverm\ddot{o}gen\,[W/K] \\ &\quad \dot{m} = Massenstrom\,[kg/s] \\ &\quad \vartheta_m = mittlere\; lokale\; Temperatur\,[°C] \end{aligned} \tag{2}$$

Bild 4.13 zeigt für verschiedene Wärmeübertrager K_{WT} die Abhängigkeit von der Fläche des Wärmeübertragers. Die Bilder 4.14 und 4.15 zeigen diese Abhängigkeit für die Parameter b_{h1} und b_{h3}. Man erkennt für die meisten Parameter eine lineare Abhängigkeit von der Fläche des Wärmeübertragers. Da die Steigungen dieser linearen Funktionen unterschiedlich sind, benötigt man aber 2 Stützstellen, d. h. es müssen 2 Speicher der Baureihe (z.B. der kleinste und der größte) geprüft werden.

Die Nachheizkreiswärmeübertrager zeigen hier die größten Abweichungen zu einer linearen Abhängigkeit. Da das Wärmeübertragungsvermögen des Nachheizkreiswärmeübertragers erfahrungsgemäß einen nur sehr geringen Einfluss auf die anteilige Energieeinsparung hat, wird dennoch davon ausgegangen, dass dieses Verfahren auch auf diese Wärmeübertrager anwendbar ist (siehe Simulationen Kap. 4.5)

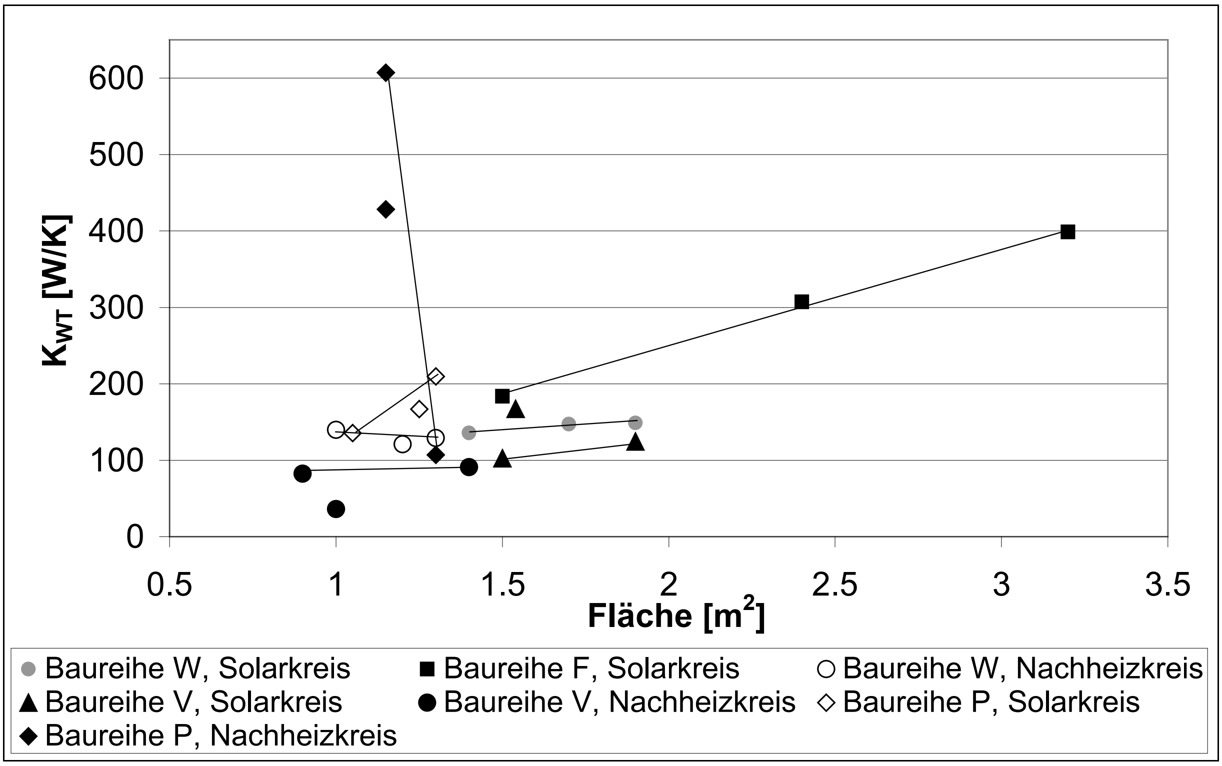


Bild 4.13: Abhängigkeit des Parameters K von der Wärmeübertragerfläche der Wärmeübertrager für die Baureihen F, W, P und V

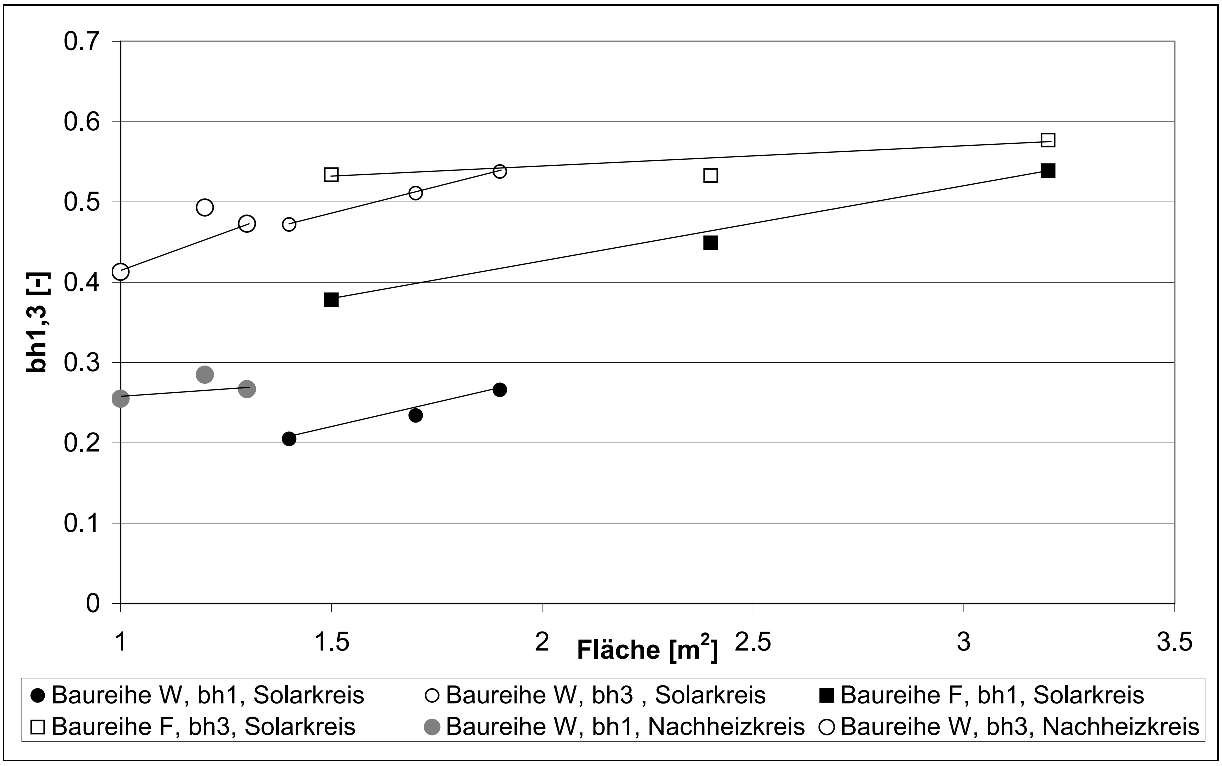


Bild 4.14: Abhängigkeit der Parameter b_{h1} und b_{h3} von der Wärmeübertragerfläche für die Baureihen W und F

Die Solarkreiswärmeübertrager der Baureihe B sind mit einer Schichtbeladeeinrichtung versehen. Hier konnte keine Gesetzmäßigkeit für die gezeigte Abhängigkeit der Parameter erkannt werden (siehe Kapitel 4.5). Die Wärmeübertrager für die Nachheizung der Baureihe B sowie die Wärmeübertrager zur Trinkwassererwärmung der Baureihe F sind jeweils identisch. Die Baureihe S1 besteht nur aus 2 Speichern, so dass sie für diese Untersuchung nicht herangezogen werden konnte.

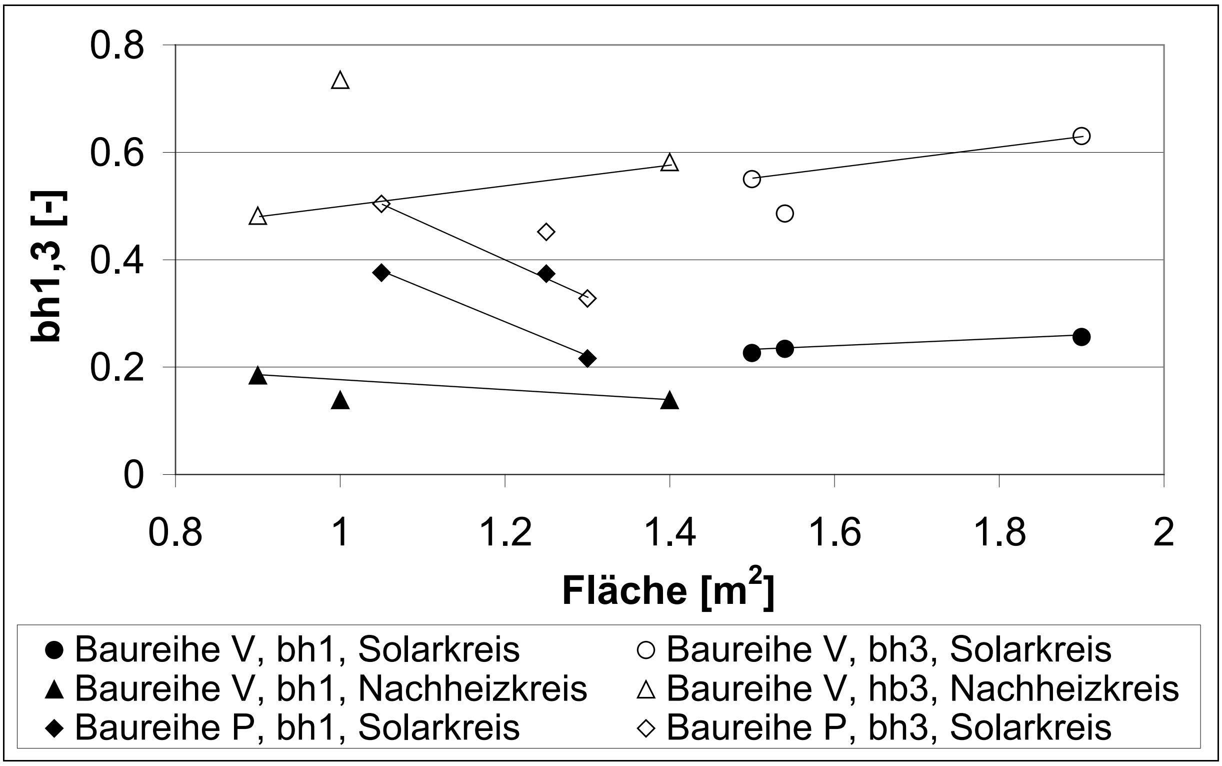


Bild 4.15: Abhängigkeit der Parameter b_{h1} und b_{h3} von der Wärmeübertragerfläche für die Baureihen P und V

4.4.3 Volumina

Die Volumina des Speichers und der Wärmeübertrager müssen den Herstellerangaben entnommen werden. Die Speicherhöhe H_s kann aus dem Speichervolumen und dem Durchmesser des Speichers (Herstellerangabe) für eine zylinderförmige Geometrie berechnet werden.

4.4.4 Relative Höhe von Anschlüssen und Temperaturfühlern

Diese Parameter können auf Basis der Konstruktionszeichnung des Speichers und der ermittelten Speicherhöhe H_s berechnet werden.

4.4.5 Effektive vertikale Wärmeleitfähigkeit λ_{eff}

Die effektive vertikale Wärmeleitfähigkeit des Speichers ist ein Maß für den von oben nach unten stattfindenden Wärmetransport der auf die Wärmeleitung in den Speicherwänden, im Wasser und in den evtl. vorhandenen Einbauten (z. B. Wärmeübertrager) sowie auf Konvektionsströmungen zurückzuführen ist.
Tabelle 4.2 zeigt einen Überblick über die ermittelten Werte für die effektive vertikale Wärmeleitfähigkeit λ_{eff} der geprüften Speicher.

Baureihe:	B	V	W	F	P	S1
λ_{eff} [W/(m·K)]	1,76	1,21	1,81	1,22	2,02	0,92
	2,01	1,71	1,87	1,00	1,86	0,68
	2,03	1,38	1,9	1,06	1,81	

Tabelle 4.2: Effektive vertikale Wärmeleitfähigkeit

Tabelle 4.2 zeigt, dass sich die Werte einer Baureihe nur geringfügig unterscheiden. Da sich die Unterschiede nur unwesentlich auf das thermische Verhalten des Speichers auswirken, kann man einen Wert für alle Speicher einer Baureihe verwenden.

4.4.6 Schichtungskennzahl n

Die Schichtungskennzahl n stellt ein Maß für den Erhalt der Temperaturschichtung während der direkten Entladung dar. Die Schichtungskennzahl entspricht der für die 'Nachsimulation' der Entnahmeprofile, mit einem auf dem Finite-Differenzen-Verfahren basierenden Speichermodell, erforderlichen homogenen Diskretisierungsdichte. (Anzahl horizontaler Schichten, mit der das Modell rechnet).

Tabelle 4.3 zeigt einen Überblick über die ermittelten Werte für die Schichtungskennzahl n der geprüften Trinkwasserspeicher. Für Kombispeicher kann die Schichtungskennzahl nicht ermittelt werden, da diese nicht wie Trinkwasserspeicher vollständig direkt entladen werden. Sie wird deshalb bei Speichern der hier untersuchten Größe mit 100 festgelegt.

Baureihe:	B	V	W	P
n [-]	111	84	108	112
	135	128	167	175
	167	151	174	190

Tabelle 4.3: Schichtungskennzahlen

Wie Simulationsrechnungen von Solaranlagen zeigen, wirken sich Unterschiede im Bereich großer Schichtungskennzahlen nur noch sehr gering auf den solaren Deckungsanteil bzw. die anteilige Energieeinsparung aus. Vergrößert man die Schichtungskennzahl z. B. von 30 auf 100, so erhöht sich dabei die anteilige Energieeinsparung für eine Standardanlage zur Trinkwassererwärmung um ca. 1 %. Hieraus folgt, dass große Schichtungskennzahlen, wie sie hier ermittelt wurden nicht umgerechnet werden müssen.

4.5 Ergebnisse

Um die Eignung der in Kapitel 4.4 dargestellten Methoden zu überprüfen, wurden für die Speicher der einzelnen Baureihen vergleichende Simulationsrechnungen zur Ermittlung der anteiligen Energieeinsparung durchgeführt. Hierbei wurde davon ausgegangen, dass der größte Speicher vollständig und beim kleinsten Speicher nur die Wärmeübertrager geprüft wurden. (Da die Baureihe S1 nur aus zwei Speichern besteht, konnten die Parameter für die Wärmeübertrager nicht berechnet werden. Hier wurden die aus der Prüfung gewonnenen Parameter verwendet.)

Basierend auf diesen Prüfergebnissen wurden unter Anwendung der in Kapitel 4.4 dargestellten Methoden die Kennwerte für den mittelgroßen Speicher berechnet. Die Tabellen 4.4 bis 4.9 zeigen für die jeweilige Baureihe die Kennwerte, die aus der Prüfung gewonnen wurden (Spalten „gemessen“) sowie die durch Extrapolation bzw. Interpolation berechneten Kennwerte (Spalte „berechnet/Hersteller“). Zusätzlich sind jeweils für die beiden Parametersätze die ermittelten Werte für die anteilige Energieeinsparung f_{sav} sowie die berechnete „nutzbare Warmwassermenge“ dargestellt. Bei den Trinkwasserspeichern wurde die „nutzbare Warmwassermenge“ aus dem Bereitschaftsvolumen berechnet. Bei den Kombispeichern ist dies nicht möglich, da das Trinkwasser im Durchlauf erwärmt wird. Hier wurde die „nutzbare Warmwassermenge“ durch Simulation bestimmt

	300l	400l		500l
Parameter	gemessen	gemessen	berechnet/ Hersteller	gemessen
V_s [l]	322	405	391	503
H_s [m]	1,43	1,51	1,44	1,60
λ_{eff} [W/(m·K)]	1,81	1,87	1,90	1,90
UA_{sa} norm. [-]	0,79	0,88	0,90	1,0
$V_{hx,sol}$ [l]	8,3	10,2	10,0	12,8
K_{sol} [W/K]	135,8	147,2	143,7	148,9
$b_{h1,sol}$ [-]	0,205	0,234	0,242	0,266
$b_{h3,sol}$ [-]	0,472	0,511	0,512	0,538
n [-]	108	167	174	174

$V_{hx,aux}$ [l]	6,0	6,9	7,0	9,0
K_{aux} [W/K]	139,7	120,8	132,7	129,2
$b_{h1,aux}$ [-]	0,255	0,285	0,263	0,267
$b_{h3,aux}$ [-]	0,413	0,493	0,453	0,473
$z_{sol,in}$ [-]	0,43	0,42	0,43	0,51
$z_{sol,out}$ [-]	0,0	0,0	0,0	0,0
$Z_{aux,in}$ [-]	0,59	0,61	0,64	0,58
$Z_{aux,out}$ [-]	0,85	0,85	0,88	0,86
z_{KW} [-]	0,0	0,0	0,0	0,0
z_{WW} [-]	1,0	1,0	1,0	1,0
z_{Tsol} [-]	0,09	0,10	0,12	0,09
z_{Taux} [-]	0,70	0,72	0,76	0,71
f_{sav} [%]	63,0	73,7	73,5	77,5
„nutzbare WW-Menge“ [l]	141	169	149	226

Tabelle 4.4: Vergleich Speicherparameter und Simulationsergebnisse Baureihe W

Tabelle 4.4 zeigt eine sehr gute Übereinstimmung der Werte für die anteilige Energieeinsparung für die beiden Datensätze für den 400l-Speicher. Dies bestätigt den geringen Einfluss des Wärmeübertragungsvermögens des Nachheizkreiswärmeübertragers auf die Energieeinsparung. Bei der Nutzbaren Warmwassermenge (für beide Fälle berechnet) ergibt sich allerdings für die berechneten Parameter ein um 12 % niedrigerer Wert.

	300l	400l		500l
Parameter	gemessen	gemessen	berechnet/ Hersteller	gemessen
V_s [l]	298	398	381	496
H_s [m]	1,21	1,23	1,18	1,53
λ_{eff} [W/m·K]	1,76	2,01	2,03	2,03
UA_{sa} norm. [-]	0,71	0,95	0,89	1,0
$V_{hx,sol}$ [l]	0,9	1,4	1,4	1,4
K_{sol} [W/K]	1180	364,7	364,7	768,3
$b_{h1,sol}$ [-]	0,535	0,534	0,534	0,600
$b_{h3,sol}$ [-]	0,24	0,619	0,619	0,442
sol_{co} [-][2]	2,6	2,4	2,4	5,5
n [-]	111	135	167	167
$V_{hx,aux}$ [l]	7,5	7,5	7,5	7,5
K_{aux} [W/K]	420,6	43,0	223,9	27,2
$b_{h1,aux}$ [-]	0,387	0,092	0,248	0,108
$b_{h3,aux}$ [-]	0,221	0,664	0,483	0,745
$z_{sol,in}$ [-]	0,94	0,96	0,96	0,94
$z_{sol,out}$ [-]	0,0	0,0	0,0	0,0
$Z_{aux,in}$ [-]	0,77	0,79	0,81	0,75
$Z_{aux,out}$ [-]	0,57	0,55	0,55	0,56
z_{KW} [-]	0,0	0,0	0,0	0,0

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[2] Parameter für Schichtbeladeeinrichtung

z_{WW} [-]	1,0	1,0	1,0	1,0
z_{Tsol} [-]	0,06	0,08	0,10	0,06
z_{Taux} [-]	0,71	0,69	0,74	0,61
f_{sav} [%]	*63,6*	*69,8*	*70,0*	*72,4*
„nutzbare WW-Menge“ [l]	117	164	158	200,0

Tabelle 4.5: Vergleich Speicherparameter und Simulationsergebnisse Baureihe B

Bei den Speichern der Baureihe B ist der Wärmeübertrager des Solarkreises mit einer Schichtbeladeeinrichtung kombiniert. Zur Charakterisierung des thermischen Verhaltens dieser thermosiphonisch arbeitenden Schichtbeladeeinrichtung wird ein zusätzlicher Parameter (sol_{co}) ermittelt, der ein Maß für die Sekundärströmung um den Wärmeübertrager darstellt. Wie aus Tabelle 4.5 ersichtlich ist, zeigen die Parameter für die Solarkreis-Wärmeübertrager (K_{sol}, $b_{h1,sol}$, $b_{h3,sol}$, sol_{co}) der Baureihe B keine systematische Abhängigkeit. Eine Berechnung dieser Parameter für den Speicher mittlerer Größe ist daher nicht möglich, so dass hier für sämtliche Baugrößen die gemessenen Werte verwendet wurden.

Eine weitere Schwierigkeit tritt bei den Speichern der Baureihe B im Hinblick auf das Wärmeübertragungsvermögen der Nachheizkreiswärmeübertrager auf. Obwohl diese identisch und flächengleich ausgeführt sind, ergeben sich bei der Prüfung unterschiedliche Parameter für das Wärmeübertragungsvermögen. Dies liegt vor allem daran, dass sich in unterschiedlich großen Speichern unterschiedliche Konvektionsströmungen ausbilden.
Da die Flächen aller Nachheizkreiswärmeübertrager identisch sind, wurden hier die Parameter für den 400l-Speicher durch Ermittlung des arithmetischen Mittels der Parameter des kleinsten und größten Speichers bestimmt.

	300l	400l		500l
Parameter	gemessen	gemessen	berechnet/ Hersteller	gemessen
V_s [l]	296	402,5	400	508
H_s [m]	1,47	1,26	1,26	1,59
λ_{eff} [W/m·K]	1,21	1,71	1,38	1,38

UA_{sa} norm. [-]	0,83	0,87	0,89	1
$V_{hx,sol}$ [l]	10	10,5	10,5	12,5
K_{sol} [W/K]	102,7	167,3	104,9	124,6
$b_{h1,sol}$ [-]	0,226	0,234	0,229	0,256
$b_{h3,sol}$ [-]	0,550	0,486	0,558	0,630
n [-]	84	128	151	151
$V_{hx,aux}$ [l]	6	7,5	7,5	9
K_{aux} [W/K]	82,3	36,1	84,0	91
$b_{h1,aux}$ [-]	0,185	0,139	0,176	0,139
$b_{h3,aux}$ [-]	0,482	0,735	0,502	0,582
$z_{sol,in}$ [-]	0,48	0,53	0,53	0,49
$z_{sol,out}$ [-]	0,04	0,07	0	0,08
$Z_{aux,in}$ [-]	0,81	0,85	0,84	0,82
$Z_{aux,out}$ [-]	0,56	0,64	0,62	0,58
z_{KW} [-]	0	0	0	0
z_{WW} [-]	1	1	1	1
z_{Tsol} [-]	-	0,15	0,16	0,14
z_{Taux} [-]	0,62	0,81	0,83	0,80
f_{sav} [%]	*64,8*	*72,4*	*72,3*	*73,7*
„nutzbare WW-Menge“ [l]	154	155	162	238

Tabelle 4.6: Vergleich Speicherparameter und Simulationsergebnisse Baureihe V

Tabelle 4.6 zeigt ebenfalls eine sehr gute Übereinstimmung der Werte für die anteilige Energieeinsparung wie auch für die Nutzbare Warmwassermenge für die beiden Datensätze für den 400l-Speicher.

	560l	800l		1440l
Parameter	gemessen	gemessen	berechnet/ Hersteller	gemessen
V_s [l]	521,9	759,7	764,3	1388
H_s [m]	1,7	1,73	1,74	1,85
λ_{eff} [W/m·K]	1,22	1,0	1,06	1,06
UA_{sa} norm. [-]	0,65	0,68	0,76	1
$V_{hx,sol}$ [l]	5,2	9,7	9,7	13
K_{sol} [W/K]	183,8	307,2	297,7	398,9
$b_{h1,sol}$ [-]	0,378	0,449	0,463	0,539
$b_{h3,sol}$ [-]	0,534	0,533	0,557	0,577
$V_{hx,HW}$ [l]	46	46	46	46
K_{HW} [W/K]	618,1	41,1	332,0	45,8
$b_{h1,HW}$ [-]	0,531	0,407	0,430	0,329
$b_{h3,HW}$ [-]	0,779	1,450	1,071	1,363
$z_{sol,in}$ [-]	0,28	0,20	0,21	0,25
$z_{sol,out}$ [-]	0,00	0,00	0,04	0,00
$Z_{aux,in}$ [-]	0,40	0,48	0,50	0,67
$Z_{aux,out/SH,in}$ [-]	0,20	0,23	0,26	0,32
z_{KW} [-]	0,00	0,08	0,11	0,07
$Z_{aux,HW,out}$ [-]	0,72	0,68	0,67	-
z_{WW} [-]	1	1	0,98	1
z_{Tsol} [-]	0,16	0,16	0,17	0,16

$z_{Taux,HW}$ [-]	0,86	0,72	0,75	0,85
$z_{Taux,SH,on}$ [-]	0,27	0,43	0,43	0,60
$z_{Taux,SH,off}$ [-]	-	0,30	0,31	0,40
f_{sav} [%]	16,4	21,9	21,2	24,8
„nutzbare WW-Menge“ [l]	250	351	277	486

Tabelle 4.7: Vergleich Speicherparameter und Simulationsergebnisse Baureihe F

Die Trinkwasserwärmeübertrager der Baureihe F sind alle identisch. Die Parameter für diesen Wärmeübertrager wurden deshalb durch Bildung des arithmetischen Mittels der Werte des großen und des kleinen Speichers ermittelt. Verwendet man die Parameter des größeren Speichers, ergibt sich f_{sav} zu 20,8 %. Die Bildung des arithmetischen Mittels ist hier also besser als die Verwendung der Parameter des geprüften Speichers. Bei der normierten Wärmeverlustrate (UA_{sa}) ergeben sich hier große Unterschiede (68% bzw. 76%).Dies hängt damit zusammen, dass die Speicher nicht im strengen Sinn baugleich sind: Sie unterscheiden sich in der Anzahl der Anschlüsse und in der Dämmstärke. Der Vergleich der Werte für die anteilige Energieeinsparung, ermittelt mit den aus der Messung gewonnenen und den berechneten Parametern, zeigt bei diesen Kombispeichern demzufolge auch eine größere Differenz als bei den Trinkwasserspeichern. Bei der Nutzbaren Warmwassermenge ergeben sich ebenfalls große Unterschiede.

	300l	400l		500l
Parameter	gemessen	gemessen	berechnet/ Hersteller	gemessen
V_s [l]	300,6	398,4	410	448,9
H_s [m]	1,14	1,48	1,51	1,67
λ_{eff} [W/m·K]	2,02	1,86	1,81	1,81
UA_{sa} norm. [-]	0,87	0,91	0,96	1
$V_{hx,sol}$ [l]	8	8	8,35	10
K_{sol} [W/K]	135,5	167,0	194,9	209,7

$b_{h1,sol,aux}$ [-]	0,376	0,374	0,248	0,216
$b_{h3,sol}$ [-]	0,504	0,452	0,363	0,328
n [-]	112	175	190	190
$V_{hx,aux}$ [l]	6,5	7	7,65	7
K_{aux} [W/K]	428,3	607,2	428,3	106,9
$b_{h3,aux}$ [-]	0,223	0,166	0,223	0,526
$z_{sol,aux,in}$ [-]	0,93	0,83	0,82	0,85
$z_{sol,out}$ [-]	0	0	0	0
$Z_{aux,out}$ [-]	0,6	0,62	0,61	0,62
z_{KW} [-]	0	0	0	0
z_{WW} [-]	1	1	1	1
z_{Tsol} [-]	0,47	0,38	0,38	0,34
z_{Taux} [-]	0,73	0,71	0,71	0,75
f_{sav} [%]	*58,7*	*60,0*	*59,7*	*60,8*
„nutzbare WW-Menge“ [l]	120	151	160	171

Tabelle 4.8: Vergleich Speicherparameter und Simulationsergebnisse Baureihe P

Tabelle 4.8 zeigt wiederum eine sehr gute Übereinstimmung der Werte für die anteilige Energieeinsparung für die Trinkwasserspeicher der Baureihe P. Auch die Werte für die Nutzbare Warmwassermenge stimmen gut überein.

	750l		1000l
Parameter	gemessen	berechnet/ Hersteller	gemessen
V_s [l]	690,4	707	846,1
H_s [m]	1,71	1,70	1,82
λ_{eff} [W/m·K]	0,92	0,68	0,68
UA_{sa} norm. [-]	0,89	0,92	1
$V_{hx,sol}$ [l]	12	13	15
K_{sol} [W/K]	220,9	220,9	216,5
$b_{h1,sol}$ [-]	0,359	0,359	0,341
$b_{h3,sol}$ [-]	0,584	0,584	0,591
$V_{hx,HW}$ [l]	28	30	28
K_{HW} [W/K]	231,8	231,8	96,2
$b_{h1,HW}$ [-]	0,445	0,445	0,459
$b_{h3,HW}$ [-]	0,851	0,851	1,100
$z_{sol,in}$ [-]	0,44	0,44	0,41
$z_{sol,out}$ [-]	0	0	0
$Z_{aux,in}$ [-]	0,85	0,85	0,88
$Z_{aux,out/SH,out}$ [-]	0,46	0,52	0,44
$Z_{SH,in}$ [-]	0	0	0
z_{KW} [-]	0	0	0
z_{WW} [-]	0,95	1,0	0,96
$z_{Tsol,SH}$ [-]	0,26	0,26	0,23

$z_{Taux,HW}$ [-]	0,72	0,75	0,75
f_{sav} [%]	22,6	23,1	22,4
„nutzbare WW-Menge“ [l]	174	147	208

Tabelle 4.9: Vergleich Speicherparameter und Simulationsergebnisse Baureihe S1

Die Baureihe S1 besteht nur aus 2 Speichern. Hier konnten deshalb die Parameter für die Wärmeübertrager nicht berechnet werden. Es wurden die Parameter aus der Prüfung verwendet. Die Werte für die normierte Wärmeverlustrate (UA_{sa}) differieren hier nur um 3%. Die Werte für die anteilige Energieeinsparung unterscheiden sich um 0,5%. Die Nutzbare Warmwassermenge ist mit dem berechneten Parametersatz, bedingt durch den höheren Austritt für die Nachheizung ($z_{aux,out}$) und die höhere Position des Fühlers ($z_{Taux,HW}$), kleiner.

4.6 Bestimmung der Parameter für die Wärmeübertrager durch Regression

Die Bestimmung der Parameter K_{WT}, b_{h1} und b_{h3} für die Wärmeübertrager kann alternativ auch über die Betrachtung des „Kennfeldes“ des Wärmeübertragers geschehen. Das Kennfeld des Wärmeübertragers beschreibt das Wärmeübertragungsvermögen in Abhängigkeit von den Betriebsgrößen „Temperaturniveau“ und „Massenstrom durch den Wärmeübertrager“ Die Vorgehensweise für die hier durchgeführte Bestimmung der Parameter K_{WT}, b_{h1} und b_{h3} ist Folgende:

1. Berechnung einiger Werte für das Wärmeübertragungsvermögen des größten und des kleinsten Wärmeübertragers für unterschiedliche Massenströme und Temperaturen.
2. Berechnung der entsprechenden Werte für den Wärmeübertrager mittlerer Größe durch lineare Interpolation der Werte des großen und kleinen Wärmeübertragers entsprechend der Flächen der Wärmeübertrager.
3. Bestimmung der Parameter des Wärmeübertragers mittlerer Größe durch Regression dieser Werte mit Gleichung 2

Tabelle 4.10 zeigt die Parameter und die damit ermittelten Werte für die anteilige Energieeinsparung für beide Verfahren. Das in Kapitel 4.4.2 vorgestellte Verfahren wird dabei mit A und das in diesem Kapitel vorgestellte Verfahren mit B bezeichnet.

Baureihe	Kreis	Verfahren	K_{WT} [W/K]	b_{h1} [-]	b_{h3} [-]	f_{sav} **A** [%]	f_{sav} **B** [%]
W	Solar	A	143,7	0,242	0,512	73,5	73,5
		B	143,5	0,243	0,514		
	Nachheizung	A	132,7	0,263	0,453		
		B	132,0	0,263	0,455		
V	Solar	A	104,9	0,229	0,558	72,3	72,3
		B	104,6	0,230	0,561		
	Nachheizung	A	84,0	0,176	0,502		
		B	82,3	0,171	0,512		
P	Solar	A	194,9	0,248	0,363	59,7	59,9
		B	194,2	0,242	0,357		
F	Solar	A	297,7	0,463	0,557	21,2	20,9
		B	294,6	0,481	0,562		
	Trinkwasser	A	332,0	0,430	1,071		
		B	290,8	0,470	0,948		

Tabelle 4.10: Vergleich Verfahren zur Bestimmung der Wärmeübertrager-Parameter

Tabelle 4.10 zeigt, dass die mit den beiden Verfahren bestimmten Parameter insbesondere für die Trinkwasserspeicher sehr gut übereinstimmen. Für die anteilige Energieeinsparung ist es irrelevant, welches Verfahren zur Bestimmung der Parameter der Wärmeübertrager angewandt wird.

4.7 Schlussfolgerungen

Unter der Voraussetzung, dass die Wärmedämmung der Speicher einer Baureihe identisch ausgeführt ist, ist eine Bestimmung der Wärmeverlustrate aller Speicher einer Baureihe auf der Basis der Messungen an einem Speicher möglich.

Die Betrachtung der Parameter für die eingetauchten Wärmeübertrager ohne Schichtbeladeeinrichtung hat gezeigt, dass es nicht möglich ist, aus der Prüfung eines einzelnen Speichers auf die Parameter der anderen Speicher zu schließen. Hierzu ist die Prüfung von zwei Speichern nötig. Dadurch können dann die Parameter eines Wärmeübertragers anderer Größe über eine lineare Abhängigkeit bzw. über eine Regression berechnet werden.

Werden die Wärmeübertrager mit Schichtbeladeeinrichtungen kombiniert, so zeigen die Ergebnisse für die Baureihe B, dass keine systematische Abhängigkeit zwischen den Parametern unterschiedlich großer Speicher erkennbar ist. In diesem Fall müssen alle Wärmeübertrager geprüft werden.

Werden identische Wärmeübertrager in unterschiedlich großen Speichern eingesetzt, so ergeben sich aus der Prüfung unterschiedliche Parameter für diese. Neben der Berechnung des arithmetischen Mittels der Parameter aus dem größten und kleinsten Speicher, hat die Verwendung der Parameter des geprüften Speichers im Fall der Baureihe F eine noch größere Abweichung für die anteilige Energieeinsparung ergeben.

Die Bestimmung der Parameter von nicht geprüften Wärmeübertragern kann vereinfachend durch eine Interpolation der einzelnen Parameter erfolgen. Eine Ermittlung der individuellen Parameter durch eine auf dem gesamten Kennfeld des nicht geprüften Wärmeübertragers basierende Regression ist nicht zwingend notwendig.

Der Einfluss der effektiven vertikalen Wärmeleitfähigkeit und der Schichtungskennzahl auf die anteilige Energieeinsparung ist für typische solare Trinkwassererwärmungsanlagen im Allgemeinen gering, so dass sich die Ermittlung dieser Größen hier eher unkritisch darstellt.

Zusammenfassend kann aufgrund der bisher durchgeführten Untersuchungen festgestellt werden, dass für **identische Speicher** einer Baureihe Folgendes gilt:

- Die Ermittlung der Wärmeverlustrate baugleicher Speicher ist auf der Basis von Messungen an einem Speicher möglich.
- Das Wärmeübertragungsvermögen eingetauchter Wärmeübertrager ohne Schichtbeladeeinrichtung kann auf der Basis von Messungen an zwei Speichern ermittelt werden.
- Für die effektive vertikale Wärmeleitfähigkeit und die Schichtungskennzahl können die Kennwerte des geprüften Speichers für andere baugleiche Speicher verwendet werden.

Die bislang durchgeführten Untersuchungen haben gezeigt, dass die Ermittlung der anteiligen Energieeinsparung mit den berechneten Speicherkennwerten für **alle Trinkwasserspeicherbaureihen** eine gute Übereinstimmung ergibt mit der anteiligen Energieeinsparung, die aus der durch Prüfung gewonnenen Speicherkennwerte ermittelten

wurde. Da bisher nur zwei **Kombispeicherbaureihen** untersucht wurden, von denen eine Baureihe nicht im strengen Sinn baugleich ist und die andere nur aus 2 Speichern besteht, kann für die Kombispeicher hier noch keine Aussage gemacht werden. Es deutet sich aber an, dass bei den Kombispeichern vermutlich mit einem etwas größeren Fehler bei der Ermittlung der anteiligen Energieeinsparung über einen berechneten Satz von Speicherkennwerten gerechnet werden muss.
Generell ist es für eine breitere Validierung und Akzeptanz des Verfahrens jedoch wünschenswert, noch weitere Speicher-Baureihen in die Untersuchung mit einzubeziehen.

Aufgrund der positiven Erfahrungen sowie der daraus resultierenden Einsparung von Prüfkosten wird empfohlen, das hier beschriebene Verfahren für Trinkwasserspeicher von Solaranlagen in die europäische Norm EN 12977-3 (Thermal solar systems and components – custom build systems - Test methods for solar water heaters and combisystems) als Anhang aufzunehmen. Ein entsprechender Textvorschlag ist diesem Dokument als Anhang A beigefügt.

5 Normreihe für Kombianlagen

Solare Kombianlagen gewinnen zunehmend an Marktrelevanz. Aus diesem Grunde wurde auch vom Normungskomitee CEN/TC 312 beschlossen in naher Zukunft eine Normreihe für Kombianlagen zu fordern.

5.1 Einführung

Für die Ermittlung der thermischen Leistungsfähigkeit von Kombianlagen stehen gegenwärtig prinzipiell zwei Verfahren zur Verfügung:

- Das **CTSS-Verfahren** (component testing - system simulation). Hierbei handelt es sich um eine Weiterentwicklung des komponentenorientierten Testverfahrens für Solaranlagen zur Trinkwassererwärmung. Beim CTSS-Verfahren werden die zentralen Komponenten wie Kollektor, Speicher und Regelung separat geprüft. Mit den dabei ermittelten Parametern wird in Verbindung mit entsprechend detaillierten Simulationsmodellen der jährliche Energieertrag für definierte Randbedingungen berechnet.
- Beim **ACDC-Verfahren** (annual calculation - direct comparison) wird die Kombianlage nahezu vollständig aufgebaut und während eines Zeitraums von ca. 3 Wochen entsprechend definierter Testsequenzen betrieben. Um von der Witterung unabhängig zu sein, wird der Energieeintrag durch den Kollektor mittels eines sogenannten 'Kollektorsimulators' nachgebildet. Bei diesem Kollektorsimulator handelt es sich prinzipiell um einen ansteuerbaren elektrischen Heizkreis. Während des ca. dreiwöchigen Prüfzykluses werden sämtliche Wärmemengen, die der Kombianlage zu- und von ihr abgeführt werden, messtechnisch erfasst. Auf der Basis dieser Wärmemengen wird mit einem einfachen Rechenverfahren der jährliche Energieertrag der geprüften Kombianlage für definierte Randbedingungen ermittelt.

In Deutschland wurde die Thematik *Kombianlagen* bereits im Rahmen eines vom DFS (Deutscher Fachverband Solarenergie) initiierten und von der DBU geförderten Projektes vom ITW gemeinsam mit ca. 20 Industrievertretern behandelt. Wichtige Ergebnisse dieses Projektes sind unter anderem das CTSS-Verfahren zur thermischen Leistungsprüfung von Kombianlagen inkl. einer Methode zur Funktionsüberprüfung von Regelungen sowie ein Verfahren zur Charakterisierung der Leistungsfähigkeit von Kombispeichern bei der Trinkwassererwärmung (DFS-Warmwasserleistungstest, siehe Anhang A). National werden die erarbeiteten Prüfverfahren insbesondere vom ITW bereits intensiv angewendet. Bei den bis Ende 2006 am ITW durchgeführten Prüfungen von ca. 60 Kombianlagen konnten umfangreiche und positive Erfahrungen mit den im Kombianlagenprojekt erarbeiteten Verfahren gewonnen werden.

Das ACDC-Verfahren wird insbesondere von Holland, Schweden und der Schweiz favorisiert.

Im Rahmen der Mitarbeit des ITW in der IEA SH&C Task 26 wird ein intensiver Vergleich der beiden Testverfahren durchgeführt. Ein endgültiges Ergebnis steht erst nach Abschluss der gegenwärtig noch andauernden Untersuchungen fest. Es zeichnet sich allerdings ab, dass sich das ACDC-Verfahren gut für einen grundsätzlichen Vergleich unterschiedlicher Anlagen eignet. Allerdings bereitet die Ermittlung des jährlichen Energieertrags der geprüften Kombianlage auf der Basis der beim Testzyklus gemessenen Wärmemengen erhebliche Schwierigkeiten. An der Lösung dieses Problems wird von Ländern, die das ACDC-Verfahren favorisieren, intensiv gearbeitet. Insbesondere für Deutschland ist die Ermittlung der jährlichen Energieeinsparung allerdings sehr wichtig, da diese Größe z. B. bei der Berücksichtigung der durch Kombianlagen erzielbaren Primärenergieeinsparung im Rahmen der Energieeinsparverordnung bestimmt werden muss.

Für die deutsche Solarindustrie ist es von entscheidendem Vorteil das CTSS-Verfahren in die europäische Normung einzubringen, da dieses Verfahren im Rahmen des Kombianlagenprojekts gemeinsam mit der Industrie erarbeitet wurden und so auch deren Interessen widerspiegelt.

Die europäische Normreihe ENV 12977 bezieht sich auf sogenannte kundenspezifisch gefertigte Anlagen. Hierunter sind Anlagen zu verstehen, die entweder individuell geplant oder aus einem Sortiment an Komponenten (wie z. B. Kollektor, Speicher und Regler) zusammengestellt werden. Da diese Klassifizierung auf die meisten der in Deutschland verkauften Solaranlagen zur Trinkwassererwärmung sowie auf solare Kombianlagen zutrifft, besitzt die Normreihe als Anlagennorm die größte Relevanz. Im Hinblick auf die Normung von Kombianlagen bietet es sich daher an, Kombianlagen mit in die Normreihe ENV 12977 mit aufzunehmen.

Um dieses Ziel zu erreichen wurde im Rahmen dieses Projekts die Überarbeitung der Normreihe ENV 12977 koordiniert (Übernahme des Vorsitzes von CEN/TC 312) und auch maßgeblich bei der Erstellung der einzelnen Normteile redaktionell mitgearbeitet.

5.2 Ursprüngliche Struktur der Normreihe ENV 12977

Beim Beginn des Projektes wies die Normreihe ENV 12977, die aus den folgenden drei Teilen bestehende Struktur auf:

ENV 12977-1,	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 1: Allgemeine Anforderungen; Deutsche Fassung ENV 12977-1:2001
ENV 12977-2	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 2: Prüfverfahren; Deutsche Fassung ENV 12977-2:2001

ENV 12977-3	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 3: Leistungsprüfung von Warmwasserspeichern für Solaranlagen; Deutsche Fassung ENV 12977-3:2001

Bei der Normreihe ENV 12977 handelt es sich um eine sogenannte Vornorm die eine Gültigkeit von 3 Jahren besitzt. Danach kann sie durch eine Norm ersetzt oder ihre Gültigkeit als Vornorm verlängert werden. Im Allgemeinen werden Regelwerke dann als Vornorm verabschiedet, wenn die beschriebene Anlagentechnologie noch relativ neu ist und sich noch dynamisch weiterentwickelt. Ebenso bietet es sich an, statt einer Norm eine Vornorm zu publizieren, wenn sich die darin beschriebenen Prüfverfahren noch im Erprobungsstadium befinden und im Hinblick auf ihre Anwendung erst noch weitere Erfahrungen gesammelt werden sollen.

Beide Kriterien trafen auf die Normreihe ENV 12977 zu, da das dort verwendete komponentenorientierte Prüfverfahren zur Ermittlung der thermischen Leistungsfähigkeit der Solaranlagen bei der Erarbeitung der Norm vor ca. 10 bis 15 Jahren noch relativ neu war. Heute ist das Verfahren jedoch etabliert und umfangreich validiert.

5.3 Neue Struktur der Normreihe EN bzw. CEN/TS 12977

Um solare Kombianlagen in der Normreihe EN bzw. CEN/TS 12977 zu integrieren wurde diese überarbeitet und entsprechend erweitert. Sie besteht jetzt aus den im folgenden aufgeführten 5 Teilen:

CEN/TS 12977-1,	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 1: Allgemeine Anforderungen für solare Trinkwassererwärmungsanlagen und Kombianlagen
CEN/TS 12977-2	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 2: Prüfverfahren für solare Trinkwassererwärmungsanlagen und Kombianlagen
EN 12977-3	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 3: Leistungsprüfung von Warmwasserspeichern für Solaranlagen
CEN/TS 12977-4	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 4: Leistungsprüfung von solaren Kombispeichern
CEN/TS 12977-5	Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 5: Prüfverfahren für Regeleinrichtungen

Aufgrund interner Umstrukturierungen bei der europäischen Normungsbehörde CEN werden Vornormen zukünftig nicht mehr als “ENV“ sondern als “CEN TS“ bezeichnet (TS: Technical Specification).

Mit Ausnahme von Teil 3 (Leistungsprüfung von Warmwasserspeichern für Solaranlagen), der eine „richtige“ EN-Norm werden soll, sollen alle anderen Teile der Normreihe den Status einer “CEN TS“ erhalten.

Die Er- bzw. Überarbeitung der Normentwürfe ist weitgehend abgeschlossen und bildete somit die Basis für das sogenannte CEN-Enquiry (CEN-Umfrage), das Ende 2006 bzw. Anfang 2007 stattgefunden hat. Unter Berücksichtigung der dabei von den einzelnen Ländern abgegebenen Kommentare werden die Normentwürfe gegenwärtig überarbeitet. Die daraus resultierenden Normvorschläge werden dann den CEN-Mitgliedsländern zur formalen Abstimmung vorgelegt bei der über die Annahme bzw. Ablehnung entschieden wird.

Bei der im Rahmen dieses Projekts durchgeführten Erweiterung der Normreihe EN bzw. CEN/TS 12977 auf Kombianlagen wurden Teil 1 (Allgemeine Anforderungen für solare Trinkwassererwärmungsanlagen und Kombianlagen) und Teil 2 (Prüfverfahren für solare Trinkwassererwärmungsanlagen und Kombianlagen) im Hinblick auf Kombianlagen erweitert. So wurden z. B. die für die Ertragsberechnung von Kombianlagen relevanten Randbedingungen für die Raumheizungslasten zusätzlich mit aufgenommen.

Der Teil 3 (Leistungsprüfung von Warmwasserspeichern für Solaranlagen) wurde grundlegend überarbeitet und beschränkt sich nun auf die Leistungsprüfung von Speichern für Solaranlagen zur Trinkwassererwärmung.

Teil 4 (Leistungsprüfung von solaren Kombispeichern) und Teil 5 (Prüfverfahren für Regeleinrichtungen) wurden komplett neu erarbeitet. Mit den im Teil 5 beschriebenen Prüfverfahren ist es erstmals möglich jede Form von elektronischen Reglern und deren Zubehör wie Sensoren und elektrisch angesteuerte Aktoren (Pumpen, Ventilen usw.), die in thermischen Solaranlagen eingesetzt werden, zu überprüfen.

Die Normentwürfe[3] der 5 Teile der Normreihe EN bzw. CEN/TS 12977 sind in der Fassung, wie sie den CEN Mitgliedsländern Ende 2006 zur Umfrage vorgelegt wurden, diesem Bericht als Anhang B beigefügt.

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[3] Entsprechend der CEN-Nomenklatur werden Entwürfe durch die Buchstaben „pr“ (preliminary bzw. vorläufig) vor der eigentlichen Normbezeichnung gekennzeichnet, z.B. prEN 12977-3.

6 Öffentlichkeitsarbeit

Im Hinblick auf die Akzeptanz der Normen ist es notwendig, dass diese den Zielgruppen (Solarindustrie, Planer, Installateure) vorgestellt und erläutert werden. Hierzu wurde eine Vielzahl von Fachartikeln publiziert.

Zusätzlich wurde über die Inhalte und den aktuellen Status der Normen sowie über die Aktivitäten der einschlägigen nationalen, europäischen und internationalen Normungsgremien anlässlich mehrerer Informationsveranstaltungen informiert. Ein wichtiges Forum bildeten in diesem Zusammenhang die im allgemeinen zweimal jährlich stattfindenden Treffen des gemeinsam vom BSW und BDH organisierten Arbeitskreises Normung und Technik.

Die wichtigsten, im Rahmen dieses Projekts entstandenen Veröffentlichungen sind im Folgenden aufgeführt:

S. Bachmann, H. Drück, W. Heidemann, H. Müller-Steinhagen
Methodik zur Umrechnung von Speicherkennwerten baugleicher Speicher auf andere Größen, Tagungsband zum 15. Symposium Thermische Solarenergie, Seiten 353-357, Otti, Regensburg, 2005 ISBN 3-934681-39-5

S. Fischer, H. Müller-Steinhagen
Vermessung und Simulation von Kollektoren mit multi-axialem Einfallswinkelkorrekturverhalten, Tagungsband zum 15. Symposium Thermische Solarenergie, Otti, Regensburg, 2005, ISBN 3-934681-39-5

S. Fischer, D. Krüger, E. Lüpfert, H. Müller-Steinhagen
Bestimmung der thermischen Leistungsfähigkeit eines Parabolrinnenkollektors, Tagungsband zum 15. Symposium Thermische Solarenergie, Otti, Regensburg, 2005, ISBN 3-934681-39-5

S. Bachmann, H. Drück, H. Müller-Steinhagen
Ermittlung der Leistungsfähigkeit von Speichern bei der Trinkwassererwärmung in Anlehnung an prEN 15332:2005, Tagungsband zum 16. Symposium Thermische Solarenergie, Seiten 359-364, Otti, Regensburg, 2006 ISBN 3-934681-45-X

S. Fischer, W. Heidemann, H. Müller-Steinhagen
Test and simulation of solar thermal collectors with multi axial incident angle behaviour, Proceedings of the International Solar Energy Society 2005 Solar World Congress, Orlando, USA

M. Peter, H. Drück
Qualitätssicherung und Erhöhung der Betriebssicherheit durch die Prüfung von Reglern für Solaranlagen, Tagungsband zum 16. Symposium Thermische Solarenergie, Seiten 353-358, Otti, Regensburg, 2006 ISBN 3-934681-45-X

S. Fischer, H. Müller-Steinhagen
Einführung eines 2-Knotenmodells zur besseren Beschreibung der thermischen Leistungsfähigkeit von Sonnenkollektoren, Tagungsband zum 16. Symposium Thermische Solarenergie, Seiten 342 - 347, Otti, Regensburg, 2006, ISBN 3-934681-45-X.

H. Drück, S. Bachmann, H. Müller-Steinhagen
Testing of solar hot water stores by means of up- and down-scaling algorithms, Conference Proceeding of EuroSun 2006, 27 - 30 June 2006, Glasgow, United Kingdom,
ISBN 0 904963 73 1

S. Fischer, H. Müller-Steinhagen
Leistungsprüfung von Sonnenkollektoren – Kürzere Prüfzeiten durch die Verwendung eines 2-Kontenmodells, Tagungsband zum 17. Symposium Thermische Solarenergie, Seiten 256 - 258, Otti, Regensburg, 2007, ISBN 978-3-934681-55-2.

M. Peter, H. Drück. H. Müller-Steinhagen
Testing of control equipment for thermal solar systems according prEN TS 12977-5, Proceedings of ISES 2007 Solar World Congress, Peking, China (to be published)

S. Fischer, H. Müller-Steinhagen
Collector efficiency testing – reduction of test duration by using a 2-node collector model, Proceedings of ISES 2007 Solar World Congress, Peking, China (to be published)

7 Literaturverzeichnis

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/Fischer2003/ Fischer S., Heidemann W., Müller-Steinhagen H. (2003): Collector Parameter Identification – Iterative Methods Versus Multiple Linear Regression, Proceedings ISES Solar World Congress 2003, Göteburg, Schweden

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Hinweis:
Die in diesem Bericht aufgeführten europäischen Normen können im Internet unter www.beuth.de bestellt werden.

Anhang

Anhang A: Ermittlung des nutzbaren Warmwasservolumens

Das **nutzbare Warmwasservolumen V_{nutz}** dient zur Charakterisierung der Leistungsfähigkeit von Kombispeichern bei der Trinkwassererwärmung. Es gibt an wieviel Wasser dem Speicher theoretisch mit einer Temperatur von 45 °C entnommen werden kann, wenn sein Nachheizteil unmittelbar vor der Zapfung solange aufgeheizt wurde, bis am Temperaturfühler für die Nachheizung eine vorgegebene Abschalttemperatur ($\vartheta_{TW,soll}$) erreicht wurde.

Das nutzbare Warmwasservolumen wird wie folgt ermittelt:

Durchführung der Prüfung:

- Konditionierung des Speichers auf eine einheitliche Temperatur von 30 °C.
- Aufheizen des Speichers wie im Abschnitt A.1 beschrieben (siehe unten).
- Trinkwasserzapfung wie in Abschnitt A.2 beschrieben (siehe unten).

Auswertung:

- Berechnung der Wärmemenge $Q_{HW,meas}$, die dem Speicher bei der Zapfung entnommen wurde, bis die Temperatur des aus dem Speicher austretenden Trinkwassers 45 °C dauerhaft[19)] unterschreitet.
- Berechnung des 'nutzbaren Warmwasservolumens' V_{nutz} als diejenige Warmwassermenge, die mit der Energie $Q_{HW,meas}$, von 10 °C auf 45 °C erwärmt werden könnte.

Anmerkung:

Ein großes „Nutzbares Warmwasservolumen“ kann durch einen großen Nachheizteil und/oder eine hohe Abschalttemperatur $\vartheta_{TW,soll}$ erreicht werden. Da beide Größen einen Einfluss auf die thermische Leistungsfähigkeit der Kombianlage haben (höhere Wärmeverluste des Speichers, geringere solare Erträge), ist die Jahressimulation zur Bestimmung der anteiligen Energieeinsparung mit dem selben Nachheizvolumen (selbe Anschlüsse und Fühlerpositionen) und der selben Abschalttemperatur $\vartheta_{TW,soll}$, wie sie zur messtechnischen Bestimmung des „nutzbaren Warmwasservolumens“ verwendet wurde, durchzuführen.

[19)] Unter einer dauerhaften Unterschreitung ist hier ein Betriebszustand zu verstehen, bei dem die Austrittstemperatur während eines Zeitraums von 2 min kontinuierlich unter 45 °C beträgt. Sinkt die Austrittstemperatur nur kurzzeitig, d. h. weniger als 2 min, unter den Wert von 45 °C und steigt danach wieder auf Werte größer als 45 °C an, so wird diese Unterschreitung nicht als dauerhaft betrachtet.

A.1: Randbedingungen für Aufheizung:

- Vor Beginn der Aufheizung wird der Speicher auf eine einheitliche Temperatur von 30 °C konditioniert.
- Die Nenn-Heizleistung $\dot{Q}_{NH}$ beträgt 15 kW ± 10 % und wird aus dem Volumenstrom $\dot{V}_{NH}$ im Nachheizkreis sowie der Eintrittstemperatur ϑ_{ein} und Austrittstemperatur ϑ_{aus} nach folgender Gleichung berechnet:

$$\dot{Q}_{NH} = \dot{V}_{NH} \cdot \rho \cdot c_p \cdot (\vartheta_{ein} - \vartheta_{aus}) = \quad \dot{Q}_{NH} = \dot{V}_{NH} \cdot \rho \cdot c_p \cdot \Delta\vartheta_{NH} \qquad (A.1)$$

- Aufheizen des Nachheizteils mit der vom Hersteller angegebenen Temperaturdifferenz $\Delta\vartheta_{NH} = \vartheta_{ein} - \vartheta_{aus}$.
- Der Volumenstrom wird berechnet aus der Nenn-Heizleistung von 15 kW und $\Delta\vartheta_{NH}$
- Liegt keine Herstellerangabe für eine maximale Eintrittstemperatur ϑ_{ein} des Beladekreislaufs in den Speicher vor, so wird diese auf ca. 80 °C begrenzt. In diesem Fall ist die dem Speicher zugeführte Heizleistung geringer als die Nenn-Heizleistung. Der Volumenstrom wird an diese neuen Bedingungen jedoch **nicht angepasst**.
- Liegt keine Herstellerangabe für die Temperaturdifferenz $\Delta\vartheta_{NH}$ vor, so wird ein Volumenstrom von 350 l/h verwendet und die Heizleistung auf 15 kW geregelt (Begrenzung der Eintrittstemperatur auf 80 °C)
- Die Nachheizung wird beendet, wenn am Fühler für die Regelung der Trinkwasser-Nachheizung die Temperatur $\vartheta_{TW,soll}$ erreicht ist.
- Für $\vartheta_{TW,soll}$ wird der vom Hersteller vorgegebene Wert verwendet. Liegt keine Herstellerangabe vor, so ist $\vartheta_{TW,soll}$ = 60 °C an zunehmen.
- Wird während der Trinkwasserzapfungen am Fühler für die Regelung der Trinkwasser-Nachheizung die Temperatur $\vartheta_{TW,soll}$ unterschritten, so wird die Nachheizung **nicht** aktiviert.

A.2: Randbedingungen für Trinkwasserzapfungen:

- Kaltwassereintrittstemperatur: 15°C ± 2 K
- Trinkwasser - Entnahme (Zapfprofil):
  - 5 min mit 300 l/h
  - 3 min mit 900 l/h
  - anschließend 600 l/h, bis zum Ende der Trinkwasserentnahme
  Zulässige Abweichungen: Zapfdauer: ± 5 %, Volumen und Volumenströme: ± 15 %
- Beginn der Trinkwasserentnahme unmittelbar nach Beendigung der Aufheizung
- Ende der Trinkwasserentnahme, wenn eine Trinkwassertemperatur von 30 °C dauerhaft unterschritten wird (Definition von *dauerhaft*: siehe Fußnote auf der vorangegangenen Seite).

Anhang

Anhang B: Entwürfe Normreihe EN bzw. CEN/TS 12977

Dieser Anhang enthält folgende Normentwürfe der Normreihe EN bzw. CEN/TS 12977 in der Fassung, wie sie den CEN Mitgliedsländern Ende 2006 zur Umfrage vorgelegt wurde.

prCEN/TS 12977-1:
Thermal Solar Systems and Components –Custom built systems - General requirements for solar water heaters and combisystems

prCEN/TS 12977-2:
Thermal Solar Systems and Components –Custom built systems - Test methods for solar water heaters and combisystems

prEN 12977-3:
Thermal Solar Systems and Components –Custom built systems - Performance test methods for solar water heater stores

prCEN/TS 12977-4:
Thermal Solar Systems and Components –Custom built systems - Performance test methods for solar combistores

prCEN/TS 12977-5:
Thermal Solar Systems and Components –Custom built systems - Performance test methods for control equipment

CEN/TC 312/WG 3 N 0119
CEN/TC 312

Date: 2005-12

prCEN/TS 12977-1:2005

CEN/TC 312

Secretariat: ELOT

Thermal solar systems and components — Custom built systems — Part 1: General requirements for solar water heaters and combisystems

Thermische Solaranlagen und ihre Bauteile — Kundenspezifisch gefertigte Anlagen — Teil 1: Allgemeine Anforderungen ...

Installations solaires thermiques et leurs composants — Installations assemblées à façon — Partie 1 : Exigences générales ...

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Contents

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Foreword

This document (prCEN/TS 12977-1:2005) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This document is currently submitted to the CEN Enquiry.

Introduction

a) Drinking water quality

In respect of potential adverse effects on the quality of drinking water intended for human consumption, caused by the product covered by this document it should be noted that

- this document provides no information as to whether the product may be used without restriction in any of the Member States of the EU or EFTA;
- while awaiting the adoption of verifiable European criteria, existing national regulations concerning the use and/or the characteristics of this product remain in force.

b) Factory Made and Custom Built solar heating systems

EN 12976-1, EN 12976-2 and prEN TS 12977-1 to -5, distinguish two categories of solar heating systems:

- **Factory Made** solar heating systems and
- **Custom Built** solar heating systems.

The classification of a system as Factory Made or Custom Built is a choice of the final supplier, in accordance to the following definitions:

1) **Factory Made solar heating systems** are batch products with one trade name, sold as complete and ready to install kits, with fixed configurations. Systems of this category are considered as a single product and assessed as a whole.

   If a Factory Made Solar Heating System is modified by changing its configuration or by changing one or more of its components, the modified system is considered as a new system for which a new test report is necessary. Requirements and test methods for Factory Made solar heating systems are given in EN 12976-1 and EN 12976-2.

2) **Custom Built solar heating systems** are either uniquely built, or assembled by choosing from an assortment of components. Systems of this category are regarded as a set of components. The components are separately tested and test results are integrated to an assessment of the whole system. Requirements for Custom Built solar heating systems are given in prEN TS 12977-1, test methods are specified in prEN TS 12977-2 to -5. Custom Built solar heating systems are subdivided into two categories:

- **Large Custom Built systems** are uniquely designed for a specific situation. In general they are designed by HVAC engineers, manufacturers or other experts.
- **Small Custom Built systems** offered by a company are described in a so-called assortment file, in which all components and possible system configurations, marketed by the company, are specified. Each possible combination of a system configuration with components from the assortment is considered as **one** Custom Built system.

Table 1 shows the division for different system types.

Table 1 — Division for factory made and custom built solar heating systems

Factory Made solar heating systems (EN 12976-1, -2)	**Custom Built solar heating systems (prEN TS 12977-1, -2, -4, -5 and prEN 12977-3)**
Integral collector-storage systems for domestic hot water preparation	Forced-circulation systems for hot water preparation and/or space heating/cooling, assembled using components and configurations described in a documentation file (mostly small systems)
Thermosiphon systems for domestic hot water preparation	
Forced-circulation systems as batch product with fixed configuration for domestic hot water preparation	Uniquely designed and assembled systems for hot water preparation and/or space heating/cooling (mostly large systems)

NOTE 1 Forced circulation systems can be classified either as Factory Made or as Custom Built, depending on the market approach chosen by the final supplier.

NOTE 2 Both Factory Made and Custom Built systems for domestic hot water preparation are performance tested under the same set of basic reference conditions as specified in EN 12976-2, Annex B and in prEN TS 12977-2, Annex A. In practice, the installation conditions may differ from these reference conditions.

NOTE 3 Solar heating systems for both heating and cooling can so far not be performance tested, – if cooling option is not considered then the solar heating can be performance tested as a space heating system.

1 Scope

This document (prEN TS 12977-1) specifies requirements on durability, reliability and safety of small and large custom built solar heating and cooling systems with liquid heat transfer medium in the collector loop for residential buildings and similar applications.

This document contains also requirements on the design process of large custom built systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 253, *Preinsulated bonded pipe systems for underground hot water networks — Pipe assembly of steel service pipes, polyurethane thermal insulation and outer casing of polyethylene*

EN 307, *Heat exchangers — Guidelines to prepare installation, operating and maintenance instructions required to maintain the performance of each type of heat exchanger*

EN 806-1, *Specifications for installations inside buildings conveying water for human consumption — Part 1: General*

EN 809, *Pumps and pump units for liquids — General safety requirements*

EN 1151, *Pump — Rotodynamic pumps — Circulation pumps having an electrical effect not exceeding 200 W for heating installations and domestic hot water installations — Requirements, testing, marking*

EN 1717, *Protection against pollution of potable water in drinking water installations and general requirements of devices to prevent pollution by backflow*

EN 1991-1-3, *Eurocode 1 — Actions on structures — Part 1-3: General actions — Snow loads*

EN 1991-1-4, *Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions*

EN 1993-1-1, *Eurocode 3 — Design of steel structures — Part 1-1: General rules and rules for buildings*

EN 1999-1-1, *Eurocode 9: Design of aluminium alloy structures — Part 1-1: General rules and rules for buildings*

EN 12828, *Heating systems in buildings — Design for water-based heating systems*

EN 12975-1, *Thermal solar systems and components — Solar collectors — Part 1: General Requirements*

EN 12975-2, *Thermal solar systems and components — Solar collectors — Part 2: Test methods*

EN 12976-1, *Thermal solar systems and components — Factory made systems — Part 1: General requirements*

prEN TS 12977-2, *Thermal solar systems and components — Custom built systems — Part 2: Test methods for solar water heaters and combisystems*

prEN 12977-3, *Thermal solar systems and components — Custom built systems — Part 3: Performance test methods for solar water heater stores*

prEN TS 12977-4, *Thermal solar systems and components — Custom built systems — Part 4: Performance test methods for solar combistores*

prEN TS 12977-5, *Thermal solar systems and components — Custom built systems — Part 5: Performance test methods for controllers*

EN 60335-1, *Household and similar electrical appliances — Safety — Part 1: General requirements*

EN 60335-2-21, *Safety of household and similar electrical appliances — Part 2: Particular requirements for storage water heaters (IEC 60335-2-21:1997 + corrigendum 1998, modified)*

IEC 61024-1, *Protection of structures against lightning — Part 1: General principles*

EN ISO 9488, *Solar energy — Vocabulary*

ISO 9459-1, *Solar heating — Domestic water heating systems — Part 1: Performance rating procedure using indoor test methods*

ISO/TR 10217, *Solar energy — Water heating systems — Guide to material selection with regard to internal corrosion*

prEN 15316-4-3, *Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-3: Space heating generation systems, thermal solar systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12975-1, EN 12976-1 and EN ISO 9488 and the following apply.

3.1
assortment

complete list of components (collectors, stores, controllers, pumps etc.) which a company offers for its solar heating systems

NOTE For the purpose of this document the assortment is restricted to components used for small custom built solar heating systems marketed by a company.

3.2
assortment file

technical documentation file for small custom built systems of a company which includes:

- the complete assortment for small custom built systems;
- the complete description of all system configurations;
- the complete description of all marketed combinations of system configurations and components including the component dimensions and number of units;
- further technical information

3.3
blow-off line

connecting line between the outlet of the safety valve and the environment (preferable an open vessel at atmospheric pressure)

3.4
collector array

group of collectors that are closely connected in series, in parallel or in combination of both modes, with one hydraulic input and one hydraulic output

3.5
control equipment

controllers, sensors, pumps, actuators etc. used for controlling a solar heating systems including optional auxiliary heaters and other parts of the heating generating and distribution system

NOTE Requirements and test methods for control equipment are given in prEN TS 12977-5.

3.6
solar combisystem

solar heating system providing both hot water and space heating

3.7
expansion line

- for systems with closed expansion vessels, the connecting line between the collectors and the pressure expansion vessel,
- for systems with open expansion vessels, the connecting line between the collector array and the open expansion vessel

3.8
large custom built system
solar heating system for the purpose of hot water preparation and/or space heating/cooling. It is designed for a specific situation by combining various components to a unique system

NOTE In general the collector area is greater than 30 m^2 and the store volume is greater than 3 m^3.

3.9
safety line

- for systems with closed expansion vessels, the connecting line between the collector array and the safety valve,
- for systems with open expansion vessels, the connecting line between the collector array and the open expansion vessel

3.10
small custom built system
modular solar heating system of the remote storage type for the purpose of hot water preparation and/or space heating and/or cooling. The system has a well identified configuration (see 3.8). It is assembled from components chosen from the market and described in an assortment file prepared by a company

NOTE 1 In general the assortment file includes the possible system configurations, the assortment of components and their possible combinations and dimensions. The ‘company’ may be the manufacturer of all or of parts of the components in the assortment; this company may also be only a consulting engineer who just produces the technical documentation and purchases the components from suppliers.

NOTE 2 In general the collector area is greater than 1 m^2 and less than 30 m^2 and the store volume is less than 3 m^3.

NOTE 3 The system can be tested by experimentally testing the components and predicting the system performance for different combinations of components by computer simulation.

3.11
system configuration
characteristics of a solar heating system including its hydraulic scheme (hydraulic connections between the collector array, the store(s) and other components) and its control concept. Systems differing by any other parameter, by the type or dimensions of the used components or the controller settings are considered to have the same configuration

4 Symbols and abbreviations

$(UA)_{\mathrm{S,a,sb}}$	stand-by heat loss rate of the store, in W/K;
V_{S}	store volume, in l.

5 System classification

5.1 Small custom built systems

Small custom built systems are classified as described in ISO 9459-1, clause 5. According to the purpose of these systems the additional classification in Table 2 applies.

Table 2 — Classes of small custom built systems according to their purpose

Class	Purpose
A	domestic hot water preparation only
B	space heating only
C	domestic hot water preparation and space heating
D	others (e.g. including cooling)

5.2 Large custom built systems

Large custom built systems are classified in accordance with Table 3.

Table 3 — Classification of large systems

Class	Purpose
A	A system in which the store(s) and the collector array(s) are located in one building for which the heat/cool is provided. No seasonal store and no heat/cool distribution network outside the building are included.
B	A system which consists of a central heating/cooling plant and one or more collector array(s). The heat/cool is transported via a heat/cool distribution network to the heating plant and/or to other buildings. No seasonal store is included.
C	A large custom built system which mainly consists of one or more large collector array(s) and in which the heat/cool is transferred to a seasonal store or directly into a heat/cool distribution network.
D	Others

6 Requirements

Subsequent requirements refer to the test methods given in prEN TS 12977-2 and prEN TS 12977-4.

NOTE Regarding large systems, the wording „no requirements on … however it is recommended that …" does not imply the need for a test method in prEN TS 12977-2.

6.1 General

6.1.1 Suitability for drinking water

See EN 806-1.

6.1.2 Water contamination

The system has to be designed to avoid water contamination from backflow from all circuits to drinking main supplies.

6.1.3 Freeze resistance

See EN 12976-1:….., 4.1.3.

6.1.4 High-temperature protection

6.1.4.1 Scald protection

Systems in which the temperature of the domestic hot water delivered to the user can exceed 60 °C, shall be fitted with an automatic cold water mixing device or any other device to limit the temperature to at maximum 60 °C shall be installed.

6.1.4.2 High-temperature protection for materials

The design of the system shall ensure that the highest permissible temperatures to which the system components may be exposed are not exceeded taking into account also pressure conditions if relevant

Maximum temperature in the collector is the collector stagnation temperature according to the EN 12975-2 test report (EN 12975-2, Annex D)

NOTE 1 Care should be taken in cases where under stagnation conditions steam or hot water can enter the collector pipes, pipework, distribution network or heat exchanger (see [1]).

NOTE 2 Maximum temperature in the rest of the collector loop depends on safety valve pressure setting and the actual fluid

NOTE 3 Guidelines for determination of highest temperature – depending on safety valve and fluid should be provided

6.1.5 Reverse flow prevention

The installation of the system as described in the hydraulic scheme shall ensure that no unintentional reverse flow occurs in any hydraulic loop of the system.

6.1.6 Pressure resistance

The storage tank and heat exchangers shall withstand 1,5 times the manufacturer's stated maximum individual working pressures.

The drinking water circuit shall withstand the maximum pressure required by national/European drinking water regulations for open or closed drinking water installations.

The system shall have been designed in such a way that the maximal allowed pressure of any materials in the system is never exceeded, taking into account temperature conditions if relevant.

Every closed circuit in the system shall contain a safety valve. This safety valve shall withstand the highest temperature that can be reached at its location. It shall conform to EN 1489. If thermostatic valves are used, these shall conform to EN 1490.

NOTE 1 In addition collector arrays of large custom built systems should be designed in a way, that they can also withstand short and high pressure peaks.

NOTE 2 If, due to stagnation, considerable heat transfer medium quantities in the collector array evaporate, pressure peaks may occur due to high flow velocities of steam or liquid. These pressure peaks may significantly exceed the release pressure of the safety valve.

6.1.7 Electrical safety

See EN 60335-1 and EN 60335-2-21.

6.2 Materials

It shall be stated in the documentation for the installers that materials placed outdoor shall be resistant to UV radiation and other weather conditions over a prescribed life time.

All materials used in the collector loop should comply with ISO/TR 10217 in order to avoid any internal corrosion.

6.3 Components and pipework

6.3.1 Collector and collector array

The collector shall meet the requirements given in EN 12975-1.

For parts and joints of the collector array see 6.3.8.

NOTE 1 Care should be taken in order to ensure long term durability and tightness of the collector joints.

If the collector array includes several parallel connected rows of collectors, the maximum disparity of the mass flow rate per unit collector area of each row should not exceed 20 % of the nominal flow rate per unit collector area of the whole array, if not explicitly stated by the manufacturer.

NOTE 2 In general, balanced flow can be reached by means of hydraulic adjustment of collectors and tubes. If this is not possible, the flow can be controlled by suitable fittings.

6.3.2 Supporting frame

Manufacturer shall state the maximum possible loads for their metallic supporting frame, in accordance with EN 1993-1-1 and EN 1999-1-1.

For non metallic supporting frames the maximum acceptable load shall be stated.

This shall be mentioned in the documents for the installer

Allowance of installing the system is depending on national requirements. Guidelines can be found in ENV 1991-3 and ENV 1991-1-4.

6.3.3 Collector and other loops

Collector and other loops shall be able to withstand expansion/contraction due to thermal mechanical influences.

6.3.4 Circulation pumps

See EN 809, EN 1151 and prEN TS 12977-5

6.3.5 Expansion vessels

For certain system design e.g. drain-back systems, a separate expansion vessel is not necessary, when the integrated expansion facility is adequately designed to fulfil its task, in terms of volume, temperature and pressure resistance.

6.3.5.1 Open expansion vessels

Each open system shall be provided with an expansion vessel, the volume of which shall be dimensioned such that it is capable of absorbing at least the entire expansion of the heat transfer medium between the lowest and the highest possible operating temperature. Each expansion vessel shall be provided with a connection to atmosphere, which cannot be shut off, and with a spill line.

6.3.5.2 Closed expansion vessels

- Small systems

  The expansion device of the collector loop shall be dimensioned such, that even after an interruption of the power supply to the circulation pump in the collector loop just when solar irradiance is maximum, operation can be resumed automatically after power is available again.

  When the heat transfer medium can evaporate under stagnation conditions this rule implies a special dimensioning of the expansion volume: In addition to the dimensioning as it is usual for closed space heating systems (expansion of the whole heat transfer medium), the expansion vessel shall be able to compensate for the volume of the heat transfer medium in the whole collector array including all connection pipes between the collectors plus 10 %.

  Alternatively, when the system does not automatically resume operation after stagnation conditions, a warning shall be added to the operating instructions.

  The manufacturer’s instructions shall be followed.

- Large systems

  No requirements for large systems, however it is recommended that expansion devices for such systems be designed to take into account all potential thermal expansion.

6.3.6 Heat exchangers

See EN 307.

If the system is intended to be used in areas with high water hardness and at temperatures above 60 °C, heat exchangers in contact with drinking water shall be designed such that scaling is prevented or there shall be a means for cleaning.

NOTE 1 High temperature difference between the metal surface of the heat exchanger and the surrounding drinking water mainly causes scaling. This can be avoided by increasing the heat exchanger area.

Any heat exchanger(s) between the collector loop and the hot water supply system should not reduce the collector efficiency due to an increase of the collector’s operating temperature by more than the following criterion specifies:

When the solar gain of the collector has reached its highest possible value, the reduction of the collector efficiency induced by the heat exchanger should not exceed 10 % (absolute). If more than one heat exchanger is installed, this value should also not be exceeded by the sum of reductions induced by each of them. The criterion also applies if a load-side heat exchanger is part of the system.

NOTE 2 If only one heat exchanger is used between the collector loop and the store of a small custom built system, the heat transfer rate of the heat exchanger per unit collector area should not be less than 40 W/(K m^2).

6.3.7 Water store(s)

Stores of small custom built solar systems for domestic hot water should be tested as described in EN 12977-3.

Stores of small custom built solar combisystems should be tested as described in prEN TS 12977-4.

The stand-by heat loss rate, $(UA)_{\mathrm{S,a,sb}}$ of stores of small custom built systems should not exceed the value given by equation (1):

$$(UA)_{\mathrm{S,a,sb}} = 0{,}16\ \sqrt{V_{\mathrm{S}}}\ \text{ in W/K} \tag{1}$$

where

$(UA)_{\mathrm{S,a,sb}}$ is the stand-by heat loss rate of the store, in W/K;

V_{S} is the nominal volume of the store, in l.

No requirement on the heat loss rate of stores of large custom built systems, however it is recommended that equation (1) be applied to such systems as well.

6.3.8 Pipework

The pipe length of the system shall be as short as possible. The pipes and fittings shall be selected from materials that are compatible with the components included in each loop, according to the fluid of the loop as specified in the ISO/TR 10217.

The design of the system and the used materials shall be such that there is no possibility of clogging and lime deposit in its circuits which would drastically influence the system performance.

The pipework for drinking water shall comply with the requirements specified in EN 806-1.

The materials for pipes and fittings shall be suitable to withstand the maximum operating temperature (stagnation conditions) and pressure.

The pipework shall withstand thermal expansion without any damage or detrimental deformation.

Venting of the system shall be possible. No automatic vents shall be placed in parts of the collector loop where vapour can occur (e.g. the top of the collector array), except a manual valve is foreseen between the pipe and the automatic vent, this valve being closed during normal operation of the system, or except a warning is added to the operating instructions, indicating that the system does not automatically resume operation after stagnation conditions (see also 6.3.3).

6.3.9 Thermal Insulation

The thermal insulation of all connecting pipes and other components of the system should comply with the requirements given in EN 12828.

The collector loop should be insulated without any gaps between the components. Thermal bridges, e.g. incorrectly installed mounting clamps should be avoided.

The thermal insulation of the pipework shall be from materials which are resistant to the maximum temperature of the circuit and deformation and which remain operative. If the insulation is installed outside, it shall be protected against (or resistant to) solar radiation, environmental conditions, ozone and any mechanical impact/deformation.

Insulated pipes for underground installation shall comply with EN 253.

6.3.10 Control equipment

Requirements for control equipment (see prEN TS 12977-5).

6.4 Safety equipment and indicators

6.4.1 Safety valves

Each section of the collector array which can be shut off shall be fitted with at least one suitable safety valve of suitable dimension. The safety valve shall resist the temperature conditions which it is exposed to, especially the highest temperature that can occur. The safety valve shall resist the heat transfer medium. The safety valve shall be dimensioned such that it can release the highest flow of hot water or steam that can occur. The dimension of the safety valve(s) shall be proved by suitable means.

6.4.2 Safety lines and expansion lines

The safety line shall not be capable of being shut off.

The safety line and expansion line shall be dimensioned such, that for the highest flow of hot water or steam that can occur, at no place in the collector loop the maximum allowed pressure is exceeded due to the pressure drop in these lines. The dimensions of the safety line and expansion line shall be proved by suitable means.

The expansion line and the safety line shall be connected and laid in such a way that any accumulation of dirt, scale or similar impurities are avoided.

6.4.3 Blow-off lines

The blow-off lines shall be laid in such a way that they cannot freeze up and that no water can accumulate within these lines. The orifices of the blow-off lines shall be arranged in such a way that any steam or heat transfer medium issuing from the safety valves does not cause any risk for people, materials or environment.

6.4.4 Store shut-off valve

Stores of large custom built systems with a volume of more than 20 m^3 shall be fitted with shut-off valves or other suitable devices to stop unintentional outflow of the store content in cases of system hazards.

6.4.5 Indicators

6.4.5.1 Indicators for collector loop flow

The system should be fitted with any indicator for the collector loop flow. This can be either a flow rate indicator or two thermometers which indicate the actual flow and return temperatures of the collector loop.

6.4.5.2 Pressure gauge

For the indication of the actual overpressure, collector loops which are filled under overpressure shall be fitted with a pressure gauge at a clearly visible spot of the installed system. The range of the working overpressure shall be marked.

6.4.5.3 Heat meter

No requirements for small custom built systems.

For large systems at least the collector loop of large custom built systems should be equipped with a heat meter.

6.5 Installation

6.5.1 Roof tightness

If collectors are installed on the roofs of buildings, the tightness of the roof cover shall not be impaired.

6.5.2 Lightning

The system should meet the requirements given in IEC 61024-1.

NOTE In EN 12976-2, Annex F a revised version in respect of solar heating systems of the requirements in IEC 61024-1 is given.

6.5.3 Snow and wind loads

If parts of the system are installed outdoors, they shall be resistant to snow and wind loads according to EN 1991-1-3 and EN 1991-1-4. The manufacturer shall state the maximum values for s_k (snow load) and v_m (mean wind velocity) according to EN 1991-1-3 and EN 1991-1-4. The system may only be installed at locations, where the values of s_k and v_m determined according to EN 1991-1-3 and EN 1991-1-4 are lower than the maximum values stated by the manufacturer. This shall be mentioned in the documents for the installer (see also 6.7.2).

6.6 Initial operation and commissioning

No requirements for small custom built systems.

Before initial operation of a large custom built system it shall be ensured that

- the installed system complies with the requirements of this document;
- corresponding fittings are adjusted and the adjustments are recorded;
- the supervisor of the system, if there is one, is instructed.

Large systems should be tested as specified in prEN TS 12977-2:....., Annex C and monitored as specified in prEN TS 12977-2:....., Annex D.

NOTE The procedures described in prEN TS 12977-2:....., Annexes C and D are optional.

6.7 Documentation

The manufacturer or official supplier shall deliver documents for assembly and installation (for the installer) and documents for operation (for the user). These documents shall be written in the official language(s) of the country of sale. These documents shall include all instructions necessary for assembly and operation, including maintenance, and draw attention to further requirements and technical rules that are concerned.

For small systems a technical documentation describing the assortment proposed by the company having established the file according to 6.7.1 should be available. A documentation according to 6.7.2 shall be provided with each system.

For large systems the full documentation of the system according to 6.7.3 shall be provided.

6.7.1 Assortment file for small systems

The documentation describing an assortment of small systems should include the following information:

a) All proposed system configurations including related hydraulic and control schemes and specifications to enable the user to understand the operating mode of the system.

b) A list of all components to be included into the above system configurations, with full reference to dimension and type. The identification of the listed components shall be easy and unambiguous.

c) A reference to all required component test reports according to 6.8.

d) A list of proposed combinations of dimension options within each system configuration.

e) Diagrams or tables stating the system performance under reference conditions for each proposed combination of dimension options within each system configuration. The reference conditions should be completely specified including the assumptions made on heat load(s) and weather data; the heat load(s) assumed should cover the range between 0,5 and 1,5 times the design load specified by the manufacturer.

6.7.2 Documentation for small systems

All components of each small custom built system shall be provided with a set of understandable assembly and operating instructions as well as service recommendations. This documentation shall include all instructions necessary for assembly, installation, operation and maintenance. These instructions shall include all information as listed in EN 12976-1:....., 4.6.

A commissioning pressure resistance test has to be described in the documentation for the installer.

The documents shall be kept at a visible place, protected from heat, water and dust.

6.7.3 Documentation for large systems

Each large custom built system shall be provided with a set of assembly and operating instructions as well as service recommendations. This documentation shall include all instructions necessary for assembly, installation, operation and maintenance and all records of initial operation and commissioning according to 6.6.

A commissioning pressure resistance test has to be described in the documentation for the installer.

The documents shall be kept at a visible place, protected from heat, water and dust.

6.7.3.1 Documents in respect of dimensioning

The documentation should include:

a) All load assumptions made (offering a set of values in a range spanning ± 30 % around the selected average load);

b) full reference to the weather data used;

c) full record of the dimensioning method used for collector area, store device(s) and heat exchanger including all assumptions (e. g. the desired solar fraction) and the full reference to any simulation programme used;

d) full record of the procedures used for hydraulic dimensioning of the collector loop and its components;

e) full record of the procedures used for the prediction of the system thermal performance including the full reference to any simulation programme used.

6.7.3.2 Documents for assembly and installation

The documents shall comply with EN 12976-1:....., 4.6.1, a), e) to h), j) and k).

The description of assembly and installation of the system shall enable a proper installation in accordance with the system drawings.

6.7.3.3 Documents for operation

The documentation shall comply with EN 12976-1:....., 4.6.2, a), f) and g).

The documents shall also include:

a) Hydraulic and electrical schemes of the system;

b) description of the safety system with reference to location and adjustment of the safety components;

NOTE Guidance should be given for a check of the system before taking it into operation again after one or more safety valves released.

c) intended action in the case of system failure or hazard which is specified in the safety concept;

d) description of the control concept and the control system including the location of the control components (e.g. sensors). The control components should be included in the hydraulic scheme of the system;

e) maintenance instruction including start-up and shut-down of the system;

f) check on function and performance.

6.8 System performance

Small systems should be performance tested as described in prEN TS 12977-2. The test results should be listed in a test report in accordance with prEN TS EN 12977-2:....., clause 8.

No requirements for large custom built systems, however if monitoring of the system is considered, it is recommended to use the methods for large systems described in prEN TS 12977-2.

6.9 Water wastage

Systems having a tank volume less than 500 litres should be tested and reported according prEN TS 12977-2:..... Annex ?.

Bibliography

[1] Solar heating systems for houses — a design handbook for solar combi-systems. W. Weiss (ed.), Solar heating and Cooling programme, IEA, James & James (Science Publishers) Ltd., London (2003), ISBN 1 902916 46 8

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Thermal solar systems and components — Custom built systems — Part 2: Test methods for solar water heaters and combisystems

Thermische Solaranlagen und ihre Bauteile — Kundenspezifisch gefertigte Anlagen — Teil 2: Prüfverfahren ...

Installations solaires thermiques et leurs composants — Installations composées à façon — Partie 2 : Méthodes d'essais ...

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Contents

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Foreword

This document (prEN/TS 12977-2:2006) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This document is currently submitted to the CEN Enquiry.

The Annexes A and B are normative. The Annexes C and D are informative.

Introduction

a) Drinking water quality

In respect of potential adverse effects on the quality of water intended for human consumption, caused by the product covered by this document it should be noted that

- this document provides no information as to whether the product may be used without restriction in any of the Member States of the EU or EFTA;
- while awaiting the adoption of verifiable European criteria, existing national regulations concerning the use and/or the characteristics of this product remain in force.

b) Factory Made and Custom Built solar heating systems

EN 12976-1, EN 12976-2 and prEN TS 12977-1 to -5, distinguish two categories of solar heating systems:

- **Factory Made** solar heating systems and
- **Custom Built** solar heating systems.

The classification of a system as Factory Made or Custom Built is a choice of the final supplier, in accordance to the following definitions:

1) **Factory Made solar heating systems** are batch products with one trade name, sold as complete and ready to install kits, with fixed configurations. Systems of this category are considered as a single product and assessed as a whole.

   If a Factory Made Solar Heating System is modified by changing its configuration or by changing one or more of its components, the modified system is considered as a new system for which a new test report is necessary. Requirements and test methods for Factory Made solar heating systems are given in EN 12976-1 and EN 12976-2.

2) **Custom Built solar heating systems** are either uniquely built, or assembled by choosing from an assortment of components. Systems of this category are regarded as a set of components. The components are separately tested and test results are integrated to an assessment of the whole system. Requirements for Custom Built solar heating systems are given in prEN TS 12977-1, test methods are specified in prEN TS 12977-2 to -5. Custom Built solar heating systems are subdivided into two categories:

- **Large Custom Built systems** are uniquely designed for a specific situation. In general they are designed by HVAC engineers, manufacturers or other experts.

- **Small Custom Built systems** offered by a company are described in a so called assortment file, in which all components and possible system configurations, marketed by the company, are specified. Each possible combination of a system configuration with components from the assortment is considered as **one** Custom Built system.

Table 1 shows the division for different system types.

Table 1 — Division for factory made and custom built solar heating systems

Factory Made solar heating systems (EN 12976-1, -2)	Custom built solar heating systems (prEN TS 12977-1, -2, -4, -5 and prEN 12977-3)
Integral collector-storage systems for domestic hot water preparation	Forced-circulation systems for hot water preparation and/or space heating/cooling, assembled using components and configurations described in a documentation file (mostly small systems)
Thermosiphon systems for domestic hot water preparation	
Forced-circulation systems as batch product with fixed configuration for domestic hot water preparation	Uniquely designed and assembled systems for hot water preparation and/or space heating/cooling (mostly large systems)

NOTE 1 Forced circulation systems can be classified either as Factory Made or as Custom Built, depending on the market approach chosen by the final supplier.

NOTE 2 Both Factory Made and Custom Built systems are performance tested under the same set of basic reference conditions as specified in EN 12976-2, Annex B and in prEN TS 12977-2, Annex A. In practice, the installation conditions may differ from these reference conditions.

c) Test methods and procedures for the analysis of large custom built solar heating systems

Quality assurance is of primary importance for large custom built systems. The total investment cost for such systems is higher than for smaller ones, although the specific investment cost (i.e., per m^2 collector area) is lower. In several european countries, the potential of large custom built systems from the point of view of conventional energy savings is much larger than for smaller ones. Moreover, the return-on-investment is in many cases more favorable for large systems than for small ones. Hence, both the purchasers of large custom built systems and the governments are interested in efficient, reliable and durable systems, the thermal performance of which may be accurately predicted, checked and supervised.

The test methods in this document provide a means of verifying the compliance of large custom built systems with the requirements in prEN TS 12977-1.

NOTE Within the framework of the EU ALTENER Programme the project ”Guaranteed Solar Results” (GSR) was addressing similar objectives in respect of quality assurance (see [7], [8]). Similar procedures and monitoring equipment were used as described in Annexes C and D. It might be necessary to update the Annexes C and D later on in a revision of this document when more experience is available.

As large custom built systems are by definition unique systems, only general procedures on how to check and supervise them may be given. An additional difficulty in the formulation of procedures is the fact that they have to be adapted to the dimension of the large custom built system considered, which may vary from typically 30 m^2 to 30 000 m^2 of collector area. Therefore, several possible levels of analysis are included (Annexes C and D).

The objective of the two short-term system tests presented in Annex C is the characterization of system performance and/or the estimation of the ability of the system to deliver the energy claimed by the designer. In principle, two approaches for short-term system testing are referred to in this Technical Specification:

1) A simplified check of short-term system performance, carried out by intercomparison of the measured solar system heat gain with the one predicted by simulation, using the actual weather and operating conditions as measured during the short-term test.

2) A short-term test for long-term system performance prediction. The performance of the most relevant components of the solar heating system is measured for a certain time period while the system is in normal operation. More detailed measurements encompass

   - energy gain of collector array(s) and

   - energy balance over storage vessel(s).

   Intercomparison of the observed and simulated energy quantities provides the indirect validation of collector and storage design parameters. The measured data within the collector array are also used for direct identification of the collector array parameters. As far the component parameters are verified, the long-term prediction of the system gain as well as the detection of possible sources of system malfunctioning are possible.

Annex D describes a procedure for long-term monitoring as a part of the supervision of a large custom built solar heating system. The objectives of supervision may be:

- the early recognition of possible failures of system components, in order to get the maximum benefit from the initial solar investment as well as to minimize the consumption of non-solar energy and the resulting environmental impact;

- the measurement of system performance (solar gains or other system indicators), if requested by a contractual clause, e.g. guaranteed results.

The long-term monitoring in Annex D is limited to the solar energy specific aspects, especially to the determination of the solar contribution to the total heat load. Instrumentation used in the long-term monitoring should be an integrating part of the system, a part included from the very beginning of the design process. If adequately foreseen, it may also be used for system adjustment at start time.

1 Scope

This document (prEN /TS 12977-2:2006) applies to small and large custom built solar heating systems with liquid heat transfer medium for residential buildings and similar applications, and gives test methods for verification of the requirements specified in prEN/ TS 12977-1.

This document includes also a method for thermal performance characterization and system performance prediction of small custom built systems by means of component testing and system simulation.

Furthermore, this document contains methods for thermal performance characterization and system performance prediction of large custom built systems.

This document applies to the following types of small custom built solar heating systems:

- systems for domestic hot water preparation only;

- systems for space heating only;

- systems for domestic hot water preparation and space heating.

- others (e. g. including cooling)

This document applies to large custom built solar heating systems, primarily to solar preheat systems, with one or more storage vessels, heat exchangers, piping and automatic controls and with collector array(s) with forced circulation of fluid in the collector loop.

This document does not apply to:

- systems with a store medium other than water (e.g. phase-change materials);
- thermosiphon systems;
- integral collector-storage (ICS) systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 307:1998, *Heat exchangers — Guidelines to prepare installation, operating and maintenance instructions required to maintain the performance of each type of heat exchangers*

EN 806-1:2000, *Specifications for installations inside buildings conveying water for human consumption — Part 1: General*

EN 809:1998, *Pumps and pump units for liquids — Common safety requirements*

EN 1151:1999, *Pump — Rotodynamic pumps — Circulation pumps having an electrical effect not exceeding 200 W for heating installations and domestic hot water installations — Requirements, testing, marking*

EN 1991-1-3, *Eurocode 1 — Actions on structures — Part 1-3: General actions — Snow loads*

EN 1991-1-4, *Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions*

EN 12975-1:2006, *Thermal solar systems and components — Solar collectors — Part 1: General Requirements*

EN 12975-2:2006, *Thermal solar systems and components — Solar collectors — Part 2: Test methods*

EN 12976-1:2006, *Thermal solar systems and components — Factory made systems — Part 1: General requirements*

EN 12976-2:2006, *Thermal solar systems and components — Factory made systems — Part 2: Test methods*

prEN /TS 12977-1, *Thermal solar systems and components — Custom built systems — Part 1: General requirements for solar heaters and combisystems*

prEN /12977-3, *Thermal solar systems and components — Custom built systems — Part 3: Performance test methods for solar water heater stores*

prEN /TS 12977-4, *Thermal solar systems and components — Custom built systems — Part 4: Performance test methods for solar combistores*

prEN /TS 12977-5, *Thermal solar systems and components — Custom built systems — Part 5: Performance test methods for controllers*

EN 60335-1:2002, *Household and similar electrical appliances — Safety — Part 1: General requirements*

EN 60335-2-21:2003, *Safety of household and similar electrical appliances — Part 2: Particular requirements for storage water heaters*

ISO 9459-5, *Solar heating — Domestic water heating systems — Part 5: System performance by means of whole system testing and computer simulation*

EN ISO 9488, *Solar energy — Vocabulary*

ISO/TR 10217:1989, *Solar energy — Water heating systems — Guide to material selection with regard to internal corrosion*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12975-1, EN 12976-1, prEN /TS 12977-1, prEN/ TS 12977-3 to -5, ISO 9459-5 and EN ISO 9488 apply.

4 Symbols and abbreviations

Symbol	Definition	Unit
a_1	heat loss coefficient at (ϑ_m - ϑ_a)=0	W/m^{2}K
A_c	reference area of collector	m²
C_c	effective thermal capacity of collector or collector array	J/K
Day	day number of the year	
Ds	shift term for the calculation of mains water temperature at reference location	
f_{sav}	fractional energy savings	%
f_{sol}	solar fraction	%
G_d	diffuse solar irradiance on tilted plane	W/m²
G_g	global solar irradiance on horizontal plane	W/m²
G_h	hemispherical solar irradiance on tilted plane	W/m²
H_c	hemispherical solar irradiance on collector plane	W/m²
$K_{\alpha\tau}$	incidence angle modifier	
Q_{aux}	gross auxiliary energy demand of the solar heating system	MJ
$Q_{aux,net}$	net auxiliary energy demand of the solar heating system delivered by the auxiliary heater to the store or directly to the heat distribution system	MJ
Q_{conv}	gross energy demand of the conventional heating system	MJ
$Q_{conv,net}$	net energy demand of the conventional heating system	MJ
Q_d	heat demand	MJ
Q_L	energy delivered at the outlet of the solar heating system	MJ
Q_l	store heat losses of the solar heating system	MJ
$Q_{l,conv}$	store heat losses of the conventional heating system	MJ
Q_{ohp}	heat diverted from the store as active overheating protection, if any	MJ
Q_{par}	parasitic energy (electricity) for the collector loop pump(s) and control unit	MJ
Q_{sav}	energy savings due to the solar heating system	MJ
Q_{sol}	energy delivered by the collector loop to the store	MJ
$\vartheta_{average}$	yearly average mains water temperature on reference location	°C
ϑ_a	collector ambient or surrounding air temperature	°C
$\vartheta_{S,amb}$	store ambient air temperature	°C
$\vartheta_{ci/co}$	collector or collector array inlet/outlet fluid temperature	°C
ϑ_{cw}	mains water temperature	°C
ϑ_d	desired hot water temperature	°C

Symbol	Definition	Unit
ϑ_{m}	mean collector fluid temperature; $\vartheta_{\mathrm{m}} = (\vartheta_{\mathrm{ci}} + \vartheta_{\mathrm{co}})/2$	°C
ϑ_{rci}	fluid temperature at circulation loop inlet	°C
ϑ_{rce}	fluid temperature at circulation loop outlet	°C
θ_{req}	required temperature for sensor high-temperature resistance	°C
ϑ_{S}	storage draw-off temperature	°C
θ_{sens}	sensor temperature	°C
$\vartheta_{\mathrm{start/stop}}$	temperature for which controller operation starts/stops	°C
$\vartheta_{\mathrm{tank}}$	temperature of the storage tank	°C
T^*	reduced temperature difference; $T^* = (\vartheta_{\mathrm{m}} - \vartheta_{\mathrm{a}})/G_{\mathrm{h}}$	$\mathrm{m^2K/W}$
$(UA)_{\mathrm{hx}}$	heat transfer capacity rate of a heat exchanger	W/K
$(UA)_{\mathrm{S}}$	heat loss capacity rate of the store of the solar heating system	W/K
$(UA)_{\mathrm{S,conv}}$	heat loss capacity rate of the store of the conventional heating system	W/K
U_{L}	overall heat loss coefficient of a collector or collector array	W/m²K
V_{d}	demanded (daily) load volume	litre/d
$V_{\mathrm{S,conv}}$	store volume of the conventional heating system	litre
$\dot{V}_{\mathrm{c}}$	volume flow rate in collector loop	litre/h
$\dot{V}_{\mathrm{rc}}$	volume flow rate in circulation loop	litre/h
$\dot{V}_{\mathrm{s}}$	volume draw-off flow rate from storage	litre/h
v	surrounding air speed	m/s
$\Delta\vartheta$	temperature difference	°C
$\Delta\vartheta_{\mathrm{amplit}}$	average amplitude of seasonal mains water temperature variations on reference location	°C
η_0	zero-loss collector efficiency (efficiency at $T^* = 0$)	
η_{aux}	overall generation efficiency of the auxiliary heater of the solar heating system	
η_{conv}	overall generation efficiency of the heater of the conventional heating system	
$\Delta\eta$	drop in system efficiency induced by a heat exchanger	%
$\Delta\vartheta$	average temperature difference induced by a heat exchanger	°C

5 System classification

See prEN /TS 12977-1:....., clause 5.

6 Test methods

Subsequent test methods refer to the requirements given in prEN /TS 12977-1.

6.1 General

6.1.1 Suitability for drinking water

See EN 806-1.

6.1.2 Water contamination

Check the design of all circuits to avoid water contamination for backflow from all circuits to drinking main supplies..

6.1.3 Freeze resistance

See EN 12976-2:2006, 5.1.

6.1.4 High-temperature protection

6.1.4.1 Scald protection

If the temperature of the domestic hot water in the system can exceed 60 °C, check the design plan or the system documentation to see whether the system is provided with an automatic cold water mixing device or any other device to limit the tapping temperature to at most (60 ±5)°C

6.1.4.2 High-temperature protection of materials

Ensure by checking the hydraulic scheme and/or by calculation and taking into account the most adverse conditions for the materials of all parts of the system, that the maximum temperatures which may occur do not exceed the maximum permissible temperatures for the respective materials, taking into account also pressure conditions if relevant.

NOTE Both transients (high-temperature peaks of short duration) and stagnation of longer duration may create adverse conditions for the respective material.

6.1.5 Reverse circulation prevention

Check the hydraulic scheme included in the documentation (see 6.7) to ensure that no unintentional reverse circulation will occur in any hydraulic loop of the system.

6.1.6 Pressure resistance

In case that it is not documented that the store(s) and the heat exchanger(s) withstand at least 1,5 times the manufacturer’s stated maximum individual working pressures, the procedures specified in EN 12976-2:2006 ,5.3, should be applied on the store(s) and the heat exchanger(s).

NOTE EN 12976-2:2006, 5.3, specifies a pressure resistance test method for a complete solar thermal system. For the purpose of this clause this method has to be applied on the store(s) and heat exchanger(s) principally.

Check if the system documentation for the installer describes a pressure resistance test procedure for the collector loop of the system.

6.1.7 Electrical safety

See EN 60335-1.

6.2 Materials

Check if the documentation for the installer includes information about the durability of the materials exposed to weathering with regard to UV radiation and other weather conditions.

Check if the materials used in the collector loop comply with ISO/TR 10217 concerning internal corrosion.

6.3 Components and pipework

6.3.1 Collector and collector array

The collector should be tested according to EN 12975-2.

The design of the collector array should be checked with regard to flow distribution.

6.3.2 Supporting frame

Check the calculation proving the resistance of the frame to snow and wind loads in accordance with EN 1991-1-3 and EN 1991-1-4 where applicable.

6.3.3 Collector and other loops

With regard to the collector loop check if the requirements listed in prEN/TS 12977-5:....., Table 10 are fulfilled.

6.3.4 Circulation pump

See EN 809, EN 1151 and prEN/TS 12977-5.

6.3.5 Expansion vessels

For systems without a separate expansion vessel (e. g. drain-back systems) check both by calculation and the hydraulic scheme to see whether the integrated expansion facility is able to fulfil its task.

6.3.5.1 Open expansion vessels

Check the volume and design of the open expansion vessel by calculation and by checking the hydraulic scheme.

In addition, check the connection of the vessel to the atmosphere, the spill line and the expansion lines on the hydraulic scheme.

6.3.5.2 Closed expansion vessels

For small custom built systems only: Check the fulfilment of the requirements given in prEN /TS 12977-1:....., 6.3.5.2, by calculation and by visual check of the hydraulic scheme and operating instruction.

6.3.6 Heat exchangers

Apart from the tests in compliance with EN 307, check the design of the heat exchanger(s) with respect to scaling or the availability of cleaning facilities.

In addition, the drop in system efficiency $\Delta\eta$ induced by a heat exchanger in the collector loop of a small custom built system should be estimated by formula (1):

$$\Delta\eta = \frac{\eta_0 \; A_\mathrm{c} \; a_1}{(UA)_\mathrm{hx}} 100\ \% \qquad (1)$$

For small systems $(UA)_\mathrm{hx}$ is delivered by the store performance test of prEN 12977-3 or prEN /TS 12977-4 ($(UA)_\mathrm{hx}$ to be chosen for store temperatures of 20 °C, an average temperature difference of 10 K and a flow rate similar to the one used for the determination of the collector parameters). For large systems $(UA)_\mathrm{hx}$ is taken from the heat exchanger performance data sheet provided by the manufacturer.

NOTE 1 In the latter case, since performance data of external heat exchangers (which are mostly used in large custom built systems) are generally quite reliable, no additional measurements are needed.

For heat exchangers in other loops (e.g., a load side heat exchanger), the average temperature difference on the primary side $\Delta\vartheta$ which is induced by the presence of the heat exchanger should be estimated by calculation. The drop in efficiency may then be estimated by:

$$\Delta\eta = (a_1 \; \Delta\vartheta / G_\mathrm{ref}) \; 100\ \% \qquad (2)$$

where the reference solar irradiance G_ref is set to 1000 W/m^2.

NOTE 2 More accurate calculation methods are given in [1]. In special cases the thermal stratification in the store should be taken into account, to obtain an accurate figure for the efficiency drop.

6.3.7 Store

For small custom built systems only

- the performance of their stores should be tested according to prEN 12977-3, in the case of a solar water heater, or prEN/ TS 12977-4, in the case of a solar combisystem;
- the heat loss rate of these hot water stores, obtained from performance tests according to prEN 12977-3 and prEN /TS 12977-4, respectively, should be compared with the requirements given in prEN /TS 12977-1:....., 6.3.7.

6.3.8 Pipework

Check the design plan and system documentation in respect of design and material of pipes and fittings.

For the pipework in the collector loop check its compliance with ISO/TR 10217.

6.3.9 Thermal insulation

Check the design plans and system documentation.

6.3.10 Control equipment

See prEN /TS 12977-5.

6.4 Safety equipment and indicators

6.4.1 Safety valves

Check the design plan and the system documentation to verify that each collector or each section of collector array which can be shut off is fitted with at least one suitable safety valve.

Check the specification of the safety valves, whether the materials fulfil the requirements given in prEN /TS 12977-1:....., 6.4.1.

Check whether the size of the safety valve is correct, in compliance with the requirements given in prEN /TS 12977-1:....., 6.4.1.

Additionally, for large custom built systems: For testing the system behaviour after release of one or more safety valves according to the requirements given in prEN /TS 12977-1:....., 6.4.1, check the electric and hydraulic schemes or any other part of the documentation according to prEN /TS 12977-1:....., 6.7.3.

6.4.2 Safety lines and expansion lines

Check the hydraulic scheme and system documentation to verify that safety and expansion lines cannot be shut-off.

Check the internal diameter of the safety and the expansion line with respect to the requirements given in prEN /TS 12977-1:....., 6.4.2.

Check the hydraulic scheme and system documentation to verify that the expansion line and the safety line are connected and laid in such a way that any accumulation of dirt, scale or similar impurities are avoided.

6.4.3 Blow-off lines

Check the hydraulic scheme and system documentation to verify that the blow-off lines fulfil the requirements given in prEN /TS 12977-1:....., 6.4.3.

6.4.4 Store shut-off valve

For large systems only: Verify the existence of a shut-off valve by checking the system documentation in accordance with prEN /TS 12977-1:....., 6.4.4.

6.4.5 Indicators

6.4.5.1 Indicators for collector loop flow

Check the hydraulic scheme and system documentation in respect of the position and installation of the recommended indicators for the collector loop flow.

6.4.5.2 Pressure gauge

Check the hydraulic scheme and system documentation in respect of the position and the installation of the pressure gauge or, in the case of some drain-back systems without pressure gauge, of the other means provided for checking drain-back and the fluid level in the collector loop.

6.4.5.3 Heat meter

If large custom built systems are equipped with heat meters (see prEN TS 12977-1 sub-clause 6.4.5.3), this should be mentioned in the system documentation.

6.5 Installation

6.5.1 Roof tightness

Check the design plans and the system documentation to see whether the leak tightness of the roof may be affected by the installation of the collector.

6.5.2 Lightning

For small custom built systems see Annexes E and F of EN 12976-2:2006.

For large custom built systems verify the compliance with the requirements given in prEN /TS 12977-1:....., 6.5.2 by checking the documentation included in prEN /TS 12977-1:....., 6.7.3.

6.5.3 Snow and wind loads

See EN 1991-1-3 and EN 1991-1-4 where applicable. Moreover, check the documents for the installer whether they comply with prEN /TS 12977-1:....., 6.5.3.

6.6 Initial operation, inspection and commissioning

This clause applies to large systems only.

Before initial operation:

- Check whether the system layout and components are as described in the documentation;
- check the record of the adjustments for the corresponding fittings. For each fitting a recorded adjustment shall exist;
- if there is a supervisor of the system, ensure that he has been sufficiently instructed.

The procedure for short-term system testing referred to in prEN /TS 12977-1:....., 6.6 (only if needed or required) is given in Annex C.

The procedure for long-term system monitoring referred to in prEN /TS 12977-1:....., 6.6 (only if needed or required) is given in Annex D.

6.7 Documentation

Check all documents, as to whether they fulfil the requirements given in prEN /&TS 12977-1:....., 6.7.

6.8 System performance (for small systems only)

The optional performance test methods for small custom built systems are described in clause 7. The test results shall be presented in a test report as described in clause 8.

6.9 Water wastage (for small systems only)

See Annex E

7 Optional performance test of small custom built solar heating systems

The test method is based on component tests of the solar collector, the store(s), the controller and other components as necessary. These component tests are described in 7.1, 7.2 and 7.3. The whole system is then simulated using a validated simulation program as described in 7.4. The long-term performance of the whole system is predicted for reference conditions as described in 7.6.

If the carrying out of this performance test is required, the specification included in 7.4 and 7.5 shall be adhered to.

In general, the system does not need to be installed as a whole for testing.

For systems for hot water preparation only (class A), for systems for space heating only (class B) and systems for combined domestic hot water preparation and space heating (class C) the full tests should be carried out including the long-term performance prediction for reference conditions.

For other systems (class D) the components should be tested and the results be stated in the test report. The long-term performance prediction is a further option. If the performance prediction is carried out, the results should be stated in the test report stating also the chosen boundary conditions for the simulation. The following remark should be added to the results of performance predictions for systems of class D:

- Intercomparison of the results of the long-term performance prediction is only possible, if validated simulation models and the same boundary conditions are used.

NOTE 1 The procedure for systems of class D as described above allows national solutions with respect to the definition of reference conditions. This is a preliminary step for the standardization of this procedure within the European countries. After enough experience has been gained on national level, the reference conditions for all European countries can be elaborated.

Before starting the performance testing all tests specified in 6.1 to 6.7 shall be completed. In case a system fails one or more of these tests, the malfunction or defect shall be eliminated by the manufacturer prior to performance testing. If this is not possible

- the malfunction shall be stated in the performance test report,
- the performance of the system shall be determined with the method as described in this clause. However, the reduction of the system performance induced by the malfunction or defect shall be estimated and the results of the performance test corrected accordingly.

NOTE 2 If the system fails one of the following tests described in clause 6, a significant reduction of the system performance can be expected:

- Collector array: balanced flow (see 6.3.1);
- temperature sensors: thermal contact of the sensors to the part of which the temperature is measured (see prEN /TS 12977-5:....., 6.5.1);
- reverse circulation prevention (see 6.1.5);
- thermal insulation (see 6.3.9).

7.1 Test of the solar collector

For the collector test according to EN 12975-2, all data for dynamic simulation of the thermal behaviour of the collector as listed below should be determined:

- standard collector efficiency parameters;
- collector heat capacity;
- incidence angle modifier for beam and diffuse irradiance (biaxial, if relevant);
- wind speed dependence of the collector heat loss coefficients (e.g. for unglazed collectors);
- influence of flow rate, if relevant;
- influence of collector tilt angle, if relevant.

7.2 Test of the water store(s)

The store(s) should be tested in accordance with prEN 12977-3 or prEN /TS 12977-4, respectively. Thereby all data for dynamic simulation of the thermal behaviour of the store(s) as described in prEN 12977-3 or prEN /TS 12977-4, whichever applicable, should be determined.

7.3 Test of the control equipment

The control equipment should be tested according to the methods described in prEN TS 12977-5. Thereby all data for dynamic simulation of the behaviour of the control equipment as described in prEN TS 12977-5 should be determined.

7.4 Determination of the hot water comfort

See prEN 12977-3:…, Annex F and prEN /TS 12977-4, whichever relevant

7.5 System simulation model

The modelling of the system should be carried out using a detailed dynamic simulation programme fitted for the different system and store configurations considered, including their control strategy. The simulation programme should operate on the basis of all parameters determined in the component tests.

NOTE The level of detail needed for most system types is similar to that used in the programmes TRNSYS or equivalent.

The component models for collector and store used in the system simulation shall be respectively the same as for the characterization of the collector according to EN 12975-2, and for the characterization of the store according to prEN 12977-3 or prEN /TS 12977-4, whichever applicable.

The behaviour of the control equipment determined according to prEN /TS 12977-5 shall be included in the simulation programme.

For other components, e.g. pipework or external heat exchangers, the level of detail in the simulation model shall correspond to the data used for proving the fulfilment of the specific requirements.

The following features shall be implemented in the model:

- A thermostat mixer which reduces the store outlet fluid temperature, ϑ_S, to the desired hot water temperature, ϑ_d, during draw-offs. For solar preheat systems and solar-only systems this thermostat mixer shall be located directly at the outlet of the solar part of the system.
- The collector loop operation shall be stopped when the temperature of the storage tank exceeds 95 °C if no other temperature is specified by the manufacturer.

The system simulation model shall have been previously validated.

7.6 Long-term performance prediction

The recommended long-term system performance prediction is described only for systems classes A, B and C according to prEN TS 12977-1:....., 5.1. However, for systems class D, the same general principles apply.

7.6.1 Calculation procedure

Use the simulation model selected according to 7.5. The component parameter values used for the simulation are those given by the component tests according to 7.1 to 7.3. Data on other components of the system, e.g. pipework or external heat exchanger, shall be those used for proving the fulfilment of the specific requirements.

The reference conditions as specified in Annex A shall be used when calculating or reporting the performance of a system by computer simulation.

For the four reference locations given in Annex A, data files providing the flow temperature, the return temperature and the mass flow rate as hourly values all over the year for a typical single-family dwelling – shall be used for accounting for the space heating load.

For additional cases or locations it is open to the interested parties to decide how to take the space heating load into account.

NOTE 1 For the four reference locations, space heating load is accounted for by using load files. Consequently, interactions between building and solar heating system are not accounted for in this case. However, for additional cases or locations, also dynamic building simulation models that interact with the solar combisystem can be used for accounting for the space heating load.

NOTE 2 The performance of a solar heating system depends on the individual installation and actual boundary conditions. With regard to the heat losses of the store besides deficits in the thermal insulation, badly designed connections can increase the heat loss capacity rate of the store due to natural convection that occurs internally in the pipes. In order to avoid this effect the connections of the pipes should be designed in such a way that no natural convection inside the pipe occurs. This can e. g. be achieved if the pipe is directly going downwards after leaving the store or by using a siphon.

7.6.2 Prediction of yearly system performance indicators

Basic uniform reference conditions for the calculation of the performance are specified in Annex A of this document or prEN 12976-2:2006, Annex B. For these conditions, the following performance indicators should be derived from the performance test results:

For solar-plus-supplementary systems:

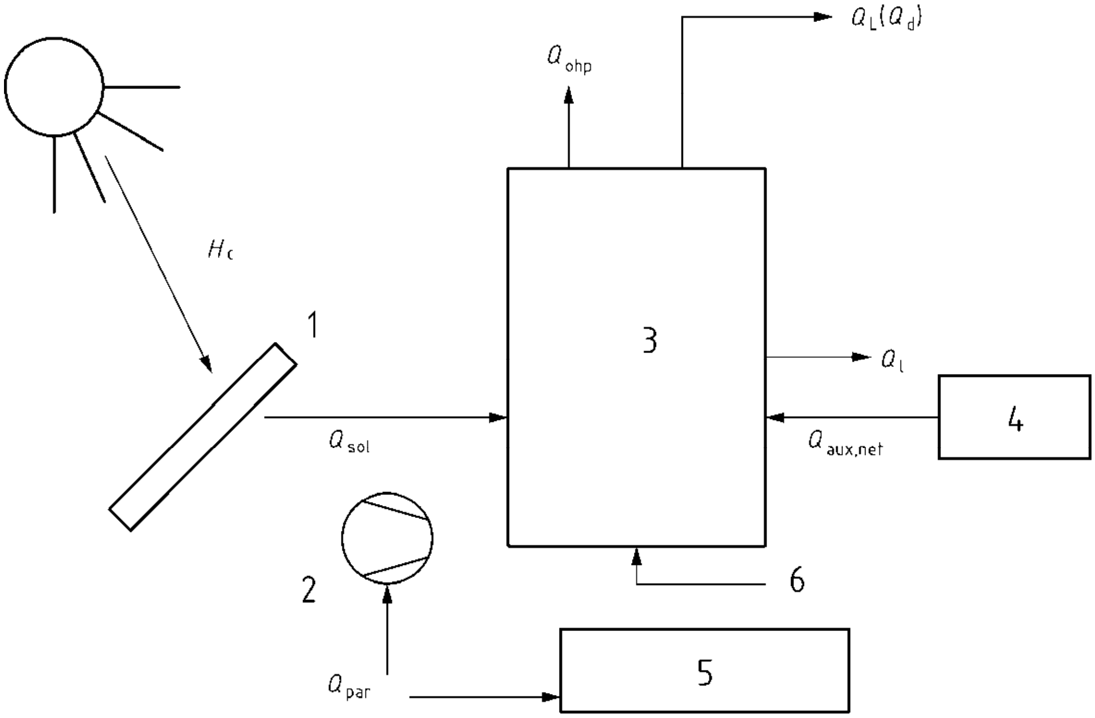
- the net auxiliary energy demand, $Q_{\text{aux, net}}$;
- the fractional energy savings, f_{sav};
- the parasitic energy, Q_{par}.

For solar-only and preheat systems:

- the heat delivered by the solar heating system, Q_{L};
- the solar fraction, f_{sol};
- the parasitic energy, Q_{par}, if any is available.

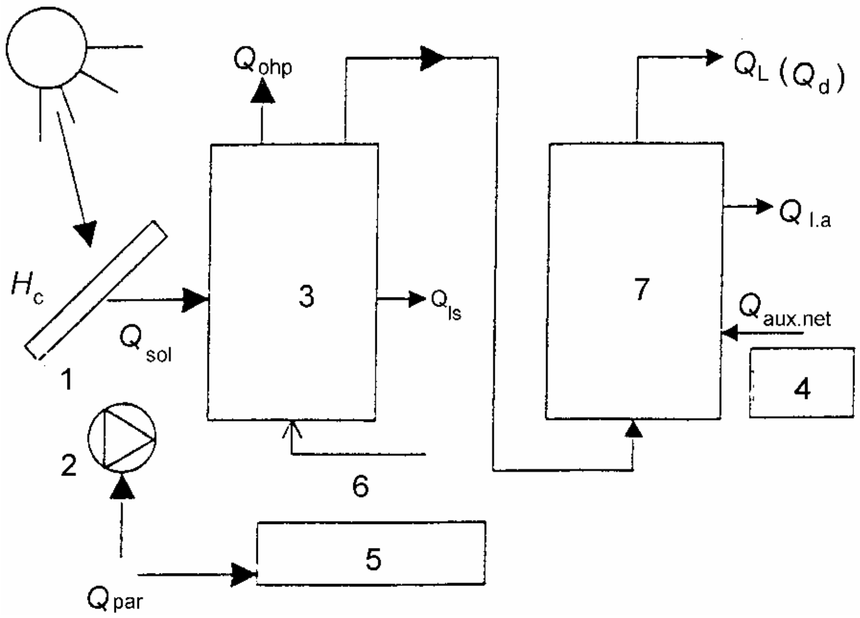
7.6.3 Calculation of the net auxiliary energy demand and fractional energy savings for solar-plus-supplementary systems

Calculate the yearly net auxiliary energy demand, $Q_{\text{aux,net}}$, directly by computer simulation (long-term performance prediction) as specified in 7.6.1 (for custom built systems) or in EN 12976-2:2006, 5.8.3.2 (for factory made systems). Additional indication to the quantities entering the energy balance of one-store and two-stores solar-plus-supplementary heating systems is given in Figure 1.



Key

1	collector	4	auxiliary heater
2	pump	5	control unit
3	store	6	mains water



$Q_l = Q_{l,s} + Q_{l,a}$

Key

1	collector	4	auxiliary heater	7	auxiliary store
2	pump	5	control unit		
3	solar store	6	mains water		

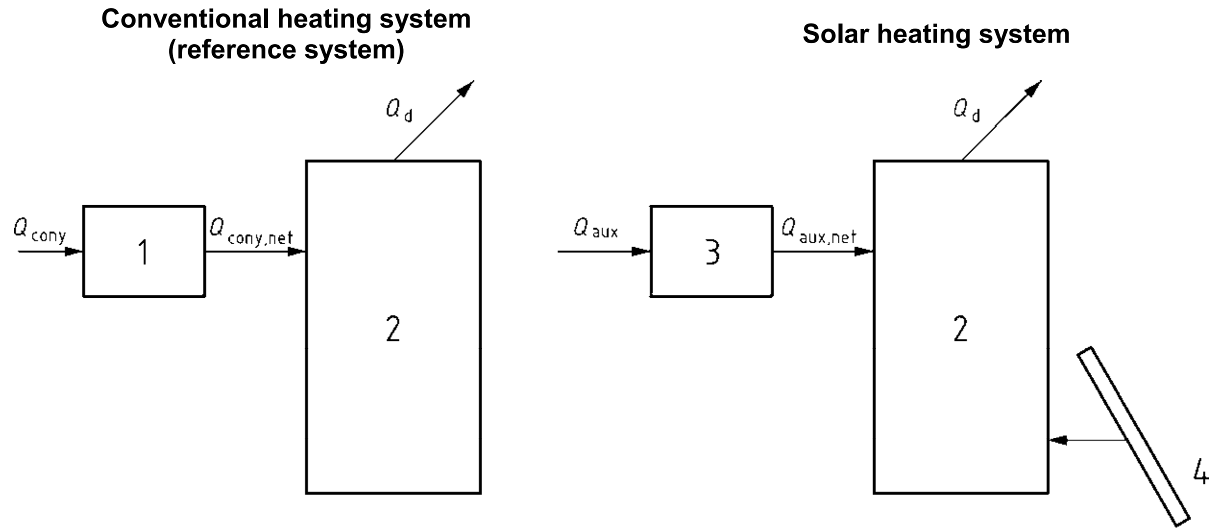
b) Energy balance for two-store-solar-plus-supplementary systems

Figure 1 — Energy balance for one-store and two-stores solar-plus-supplementary systems

Calculate the fractional energy savings, f_{sav}, according to the definition of EN ISO 9488:

$$f_{\mathrm{sav}} = (Q_{\mathrm{conv}} - Q_{\mathrm{aux}})/Q_{\mathrm{conv}} \tag{3}$$

The fractional energy savings is calculated on a yearly base. Figure 2 illustrates this system comparison.



Conventional heating system (reference system)

Solar heating system

Key

1 heater, η_{conv}

2 store

3 auxiliary heater, η_{aux}

4 collector

Figure 2 — Comparison of the gross auxiliary energy demand of the solar heating system, Q_{aux}, to the gross energy demand of the conventional heating system, Q_{conv}

NOTE Both systems are assumed to use the same kind of conventional energy, and to supply the user with the same heat quantity giving the same thermal comfort.

For the conventional heating system, one single European reference system (called reference system in the following) is defined in accordance with Annex B.1. The values listed in Table 2 should be used for the calculation of the fractional energy savings, whichever the solar-plus-supplementary heating system.

For the solar heating system, calculate the gross auxiliary energy demand by:

$$Q_{\mathrm{aux}} = Q_{\mathrm{aux,\,net}}/\eta_{\mathrm{aux}} \tag{4}$$

with $\eta_{\mathrm{aux}} = 0{,}75$

Table 2 — Heat demand, net energy demand and gross energy demand for the reference system (on annual base)

Heat demand, net energy demand and gross energy demand for the reference system (on annual base)			
V_d (daily) l/d	Q_d (= Q_L) MJ	$Q_{conv, net}$ MJ	Q_{conv} MJ
50	2 650	3 809	5 079
80	4 241	5 706	7 608
110	5 831	7 550	10 066
140	7 421	9 360	12 480
170	9 011	11 148	14 864
200	10 601	12 919	17 225
250	13 252	15 843	21 124
300	15 902	18 741	24 988
400	21 203	24 481	32 641
600	31 804	35 819	47 759

NOTE 1 The definition of one single European reference system allows for comparison of test results of different systems based on the same reference. The fractional energy savings is meant only to compare solar heating systems to other solar heating systems, and should not be used to compare conventional heating systems to solar heating systems or to other conventional heating systems.

NOTE 2 Optionally, the fractional energy savings can be derived for national conditions taking into account the efficiencies of different conventional heating systems as well as from measurements on an installed system. The procedures are described in Annex B.2.

If a solar-plus-supplementary system cannot meet the heat demand to such a degree that the energy delivered to the user is less than 90 % of the yearly heat demand, this should be stated in the test report.

NOTE 3 The energy delivered to the user can be less than the heat demand for example when the power of the auxiliary heater is not sufficient or when strong mixing occurs in the store during draw-offs.

7.6.4 Calculation of the solar fraction for solar-only and preheat systems

Compute the system energy balance on a yearly basis. This includes the following energy quantities (see Figure 3 and Figure 4), calculated using the reference data and conditions given in Annex A or in EN 12976-2:2006, Annex B:

Q_d	heat demand
Q_L	energy delivered by the solar heating system (load)
Q_{par}	parasitic energy (electricity) for pump and controls

The parasitic energy, Q_{par}, shall be calculated according to 7.6.5.

NOTE 1 The reference locations for calculating the load, Q_L, are the store ports or the load-side heat exchanger ports, if provided. The reference temperature for calculating the loads is the mains water temperature. Heat losses of the circulation line, if any, are not included in the loads, as the test is carried out with this line kept closed.

NOTE 2 According to EN ISO 9488, a solar preheat system is a solar heating system to preheat water or air prior to its entry into any other type of water or air heater. This water or air heater is not part of the solar preheat system itself. Hence, for this type of system the energy delivered by the solar heating system, Q_L, is calculated at the outlet of the solar heating system and the store heat loss, Q_l, is the heat loss of the solar store itself (see Figure 4).

NOTE 3 The yearly heat demand is calculated using the load volume, mains water temperature and the desired temperature for hot water as specified in Annex A.

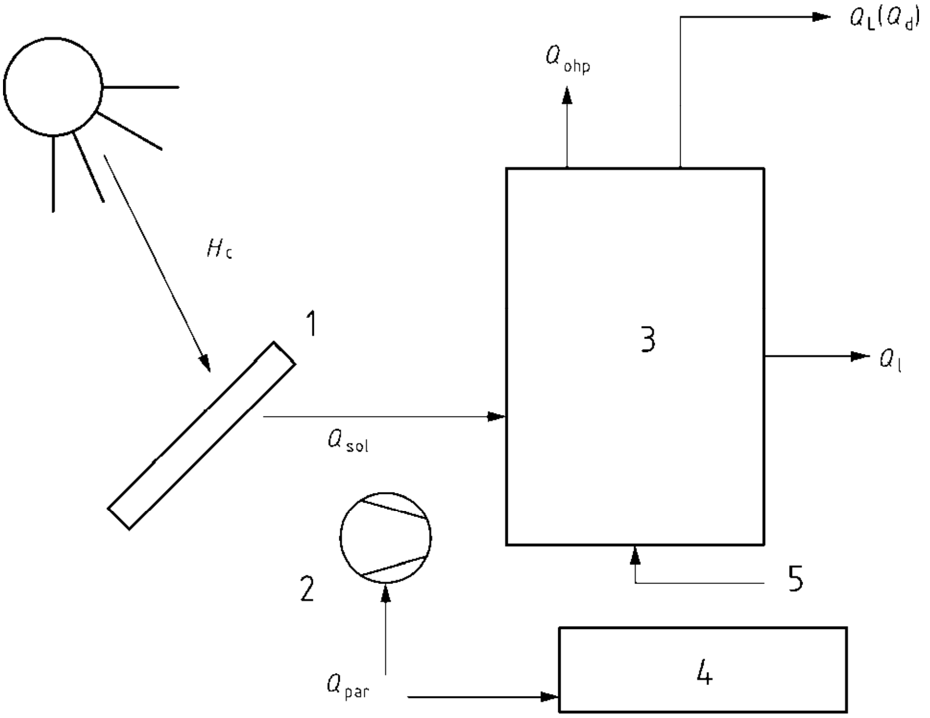


Bild 3

Key

1 collector

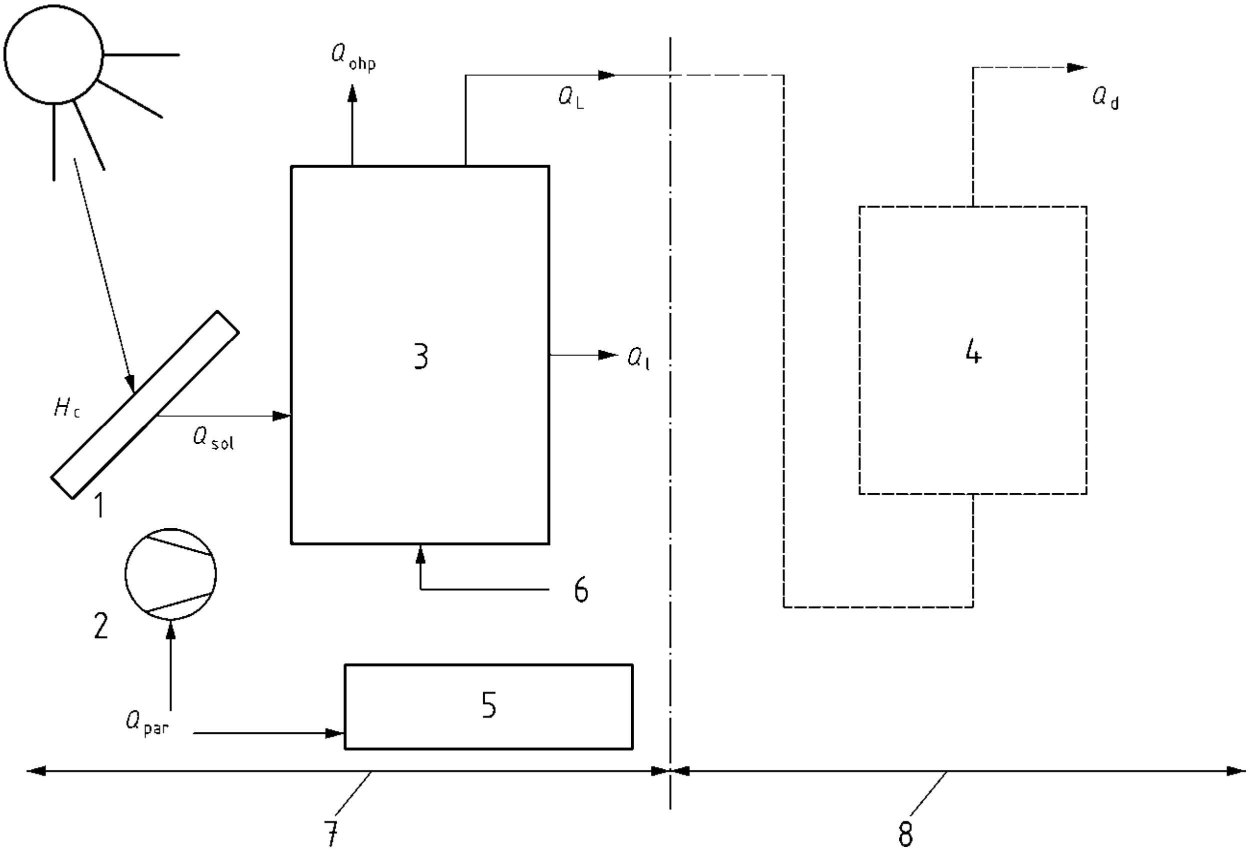
2 pump

3 store

4 control unit

5 mains water

Figure 4 — Energy balance for solar-only systems



Key

1	collector	5	control unit
2	pump	6	mains water
3	solar store	7	solar preheated system
4	auxiliary heater	8	series-connected auxiliary heating system

Figure 5 — Energy balance for solar preheat systems

Calculate the solar fraction, f_{sol}, according to the definition of EN ISO 9488:

$$f_{\mathrm{sol}} = Q_{\mathrm{L}}/Q_{\mathrm{d}}$$

7.6.5 Calculation of the parasitic energy (for all system types)

Calculate the yearly parasitic energy, Q_{par}, needed by control equipment taking into account the full-load hours from the simulation and the nominal power in accordance with prEN TS 12977-5.

7.7 Presentation of performance indicators

The results from 7.6.1 to 7.6.5 should be presented for the load volume(s) as specified in Annex A in the way shown in Table 3 and Table 4.

Table 3 — Presentation of system performance indicators for solar-plus-supplementary systems

Performance indicators for solar-plus-supplementary systems on annual base for a volume demand of....... l/d and a space heating load of..... kWh/a					
Location (latitude)	$Q_{d, hw}$ MJ	$Q_{d, sh}$ MJ	$Q_{aux, net}$ MJ	Q_{par} MJ	f_{sav} %
Stockholm (59,6° N)	.....	.....			
Würzburg (49,5° N)	.....	.....			
Davos (46,8° N)	.....	.....			
Athens (38,0° N)	.....	.....			
.....[a]					

[a] For a location or a building free to choose. Detailed specifications shall be given.

Table 4 — Presentation of system performance indicators for solar-only and solar preheat systems

Performance indicators for solar-only and solar preheat systems on annual base for a volume demand of....... l/d and a space heating load of..... kWh/a or alternatively one load taking into account both				
Location (latitude)	Q_d MJ	Q_L MJ	f_{sol} %	Q_{par} MJ
Stockholm (59,6° N)	.....			
Würzburg (49,5° N)	.....			
Davos (46,8° N)	.....			
Athens (38,0° N)	.....			
.....[a]				

[a] For a location or a building free to choose. Detailed specifications shall be given.

8 Performance test report

This clause describes the report of results from the optional tests performed according to clause 7.

This test report applies to small custom built systems only as also the system performance test methods given in clause 7 are applicable to small custom built systems only (see 6.8).

The test report shall include:

a) a detailed description of components and system configuration;

b) the prediction method used. The simulation programme shall be specified and an input file shall be enclosed;

c) the complete reference conditions used as specified in Annex A including information about the location for which the performance prediction is made and the reference weather data used;

d) for the reference conditions as specified in Annex A, the performance indicators on a yearly base as specified in 7.6.2.

Annex A
(normative)

Reference conditions for performance prediction

A.1 General

The conditions given in Table A.1 shall be used when calculating, reporting or comparing the performance of a system, either from a test or from a computer simulation.

NOTE The following reference conditions are basically identical for testing and simulating of factory made systems in EN 12976-2 and custom built systems in this document. However, some aspects related to systems considered in only one of the two standards (e.g. solar combisystems in prEN /TS 12977-2), have been deleted from the other standard.

Table A.1 — Reference conditions for performance presentation

Reference condition	Value	Remarks
SYSTEM		
Collector orientation	South	
Collector tilt angle	45°	For testing, (45 ± 5) °C if not fixed for the system or specified by the manufacturer.
Total length of collector circuit	20 m = 10 m + 10 m	If piping is not delivered with the system or specified by the manufacturer.
Pipe diameter and insulation thickness of collector circuit	See A.2	If piping is not delivered with the system or specified by the manufacturer.
Location of the collector circuit pipes	Indoors, for systems with the store located indoors; outdoors, for systems with the store located outdoors	As far as possible at the test rig.
Store ambient air temperature	15 °C	For systems where the store is located outside, the ambient air temperature from the climate data shall be used.
For systems with indirect (hydraulic) auxiliary heating: Power to be applied on auxiliary heat exchanger	(100 ± 30) W per litre of store volume above the lowest end of heat exchanger	If the auxiliary heater is not delivered with the system and no restrictions have been given in the documentation. The auxiliary heater shall be modelled as an ideal heat source with no heat capacity and constant heating power.
Flow rate through auxiliary heat exchanger	The flow rate through the heat exchanger shall be chosen such that the temperature difference between the inlet and outlet of the auxiliary heat exchanger is (10 ± 2) K under steady state conditions, unless specified otherwise by the manufacturer.	
For systems with electrical auxiliary heating: Power of electrical element	If an electrical element is normally delivered with the system or specified by the manufacturer, this element shall be used. Otherwise, (25 ± 8) W/l of store volume above the electrical element apply.	

Table A.1 *(continued)*

Reference condition	Value	Remarks
For solar-plus-supplementary systems: Status of the auxiliary heater	Permanently activated	This is for performance prediction.
Temperature of integrated auxiliary heating	52,5 °C (minimum temperature taking into account hysteresis)	Or a higher temperature, if recommended by the manufacturer.
CLIMATE		
Reference locations	Stockholm, Würzburg, Davos, Athens	In the reporting form, the performance of a different location of choice may also be given.
Climate Data	For Stockholm: CEC Test Reference Year; for Davos, Würzburg and Athens: Test Reference Year.	
Domestic hot water HEAT LOAD		
Daily load pattern	For all systems: ((*is to be adapted to the European tapping profile*)) — 100 % at 6 h after solar noon For testing, the load patterns shall be as specified in the test procedure.	
Mains water supply temperature	See A.3	For testing, the temperature shall be as specified in the test procedure.
Desired (mixing valve) temperature	45 °C	If the daily or yearly loads are calculated in terms of energy, this energy shall be calculated using the mains water supply temperature and the desired temperature.
Daily load volume	The load volumes in litres per day shall be chosen from the following series: 50 l/d, 80 l/d, 110 l/d, 140 l/d, 170 l/d, 200 l/d, 250 l/d, 300 l/d, 400 l/d, 600 l/d. If larger loads are required, the series may be extended by repeatedly multiplying by the square root of 2 and rounding to the nearest multiple of 10.	
	The manufacturer shall give a design load for the system. The nearest value given in the above series shall be used, as well as the next lower and higher values. It is recommended to use all lower and higher values from the series, which lie between 0,5 and 1,5 times the design load. NOTE Fixed load volumes have been chosen to facilitate comparison of the performance of different systems. For testing, the load volumes as specified in the test procedures shall be used.	
Draw-off flow rate	10 l/min	If the maximal design draw-off flow rate of the system is less than 10 l/min, the maximum design draw-off rate of the system shall be used.
Space heating HEAT LOAD		
Hourly values	For Stockholm, Davos, Würzburg and Athens: based on flow and return temperatures and mass flow rate of the space heating loop (see A.4). NOTE As soon as EN TS 12977-6 (Software and data for testing of thermal solar systems and components) is available, these data will be available in this new standard.	

A.2 Pipe diameter and insulation thickness

If the pipe and insulation for the collector circuit are delivered with the system, or the pipe diameter and the insulation thickness to be used for the collector circuit are clearly specified in the installation manual for the system, the delivered hardware or the specified values shall be used.

When piping and insulation are not delivered with the system or clearly specified, the pipe diameter, the pipe thickness and the insulation thickness and thermal conductivity given in Table A.2 shall be used for forced-circulation systems.

The material for the collector circuit piping shall be copper, unless specified otherwise in the installation manual.

Table A.2 — External pipe diameter and insulation thickness for forced-circulation systems

Flow rate in collector circuit l/h	External pipe diameter[a] mm	Pipe thickness mm	Thickness of one layer insulation[b] mm
< 90	10	1	20
90 to 140	12	1	20
140 to 235	15	1	20
235 to 405	18	1	20
405 to 565	22	1	20
565 to 880	28	1,5	30
880 to 1 445	35	1,5	30
1 445 to 1 500	42	1,5	39
> 1 500	Such that the flow velocity is approximately 0,5 m/s	1,5	as the internal pipe diameter
NOTE Based on a thermal conductivity of 0,04 W/m.K ± 0,01 for temperature of 10 °C			

[a] Tolerance 1 mm.

[b] Tolerance 2 mm.

A.3 Calculation of mains water temperature at reference location

The mains water temperature shall be calculated according to:

$$\vartheta_{cw} = \vartheta_{average} + \Delta\vartheta_{amplit} \sin(2\pi\,(Day - D_s)/365) \qquad (A.1)$$

The yearly average mains water temperature ($\vartheta_{average}$), average amplitude of seasonal mains water temperature variations ($\Delta\vartheta_{amplit}$) and shift term (Ds) given in Table A.3 shall be used for the reference locations.

Table A.3 — Data for calculation of the mains water temperature at the reference locations

Reference location	$\vartheta_{\text{average}}$ °C	$\Delta\vartheta_{\text{amplit}}$ °C	D_{s} d
Stockholm	8,5	6,4	137
Würzburg	10,0	3,0	137
Davos	5,4	0,8	137
Athens	17,8	7,4	137

A.4 Space heating heat load

This chapter contains information about the annual space heating heat load for the locations of Stockholm, Davos, Würzburg and Athens. The building related to the space heating load is described and the space heating load is specified on the basis of hourly values of the flow and return temperatures as well as the mass flow rate of the space heating loop.

For the calculation of the heat load following properties of water shall be used:

- density: 992,42 kg/m^3,
- specific heat capacity: 4,181 kJ/(kgK).

NOTE As soon as EN TS 12977-6 is available, these data will be available in this new standard.

A.4.1 Würzburg

The reference building used for the determination of the space heating load for Würzburg represents a typical German single family house with a thermal insulation according to German building technology in 2005.

The annual space heating load of the Würzburg reference building sums up to 9 090 kWh/a.

The building is characterised by the following data:

- living area: 128 m^2;
- window area: south 10 m^2, north 3 m^2, west and east 3,5 m^2;
- windows: U-value: 1,4 W/(m^{2}K), G-value 63 %;
- outwall: U-value: 0,19 W/(m^{2}K);
- outwall area: south 36,1 m^2, north 43,1 m^2, west and east 31,3 m^2;
- bottom: U-value: 0,41 W/(m^{2}K), area: 64 m^2;
- blanket: U-value: 0,21 W/(m^{2}K), area: 64 m^2;
- air change rate: 0,6 /h.

An extract of this space heating load file for Würzburg is given in Table A.4.

Table A.4 — Space heating load file

Hour of year [h]	**Flow temperature** [°C]	**Return temperature** [°C]	**Mass flow rate** [kg/h]
1,0	38,42	0,00	0,00
2,0	38,14	0,00	0,00
3,0	38,14	0,00	0,00
4,0	38,05	0,00	0,00
5,0	38,01	20,02	241,63
6,0	38,09	25,55	317,44
7,0	38,23	27,69	328,38
8,0	38,32	28,37	328,38
9,0	38,42	28,60	328,38
10,0	38,43	28,74	306,39
11,0	38,23	28,46	283,60
12,0	37,95	28,20	272,96
13,0	37,77	28,00	264,04
14,0	37,81	27,88	257,69
15,0	38,05	27,58	232,72
16,0	38,38	26,72	193,62
17,0	38,65	25,74	163,03
18,0	38,75	24,91	143,23
19,0	38,61	24,34	134,83
20,0	38,23	23,97	134,88
21,0	37,77	23,83	140,42
22,0	37,39	23,88	147,67
23,0	37,29	0,00	0,00
24,0	37,53	0,00	0,00
25,0	37,86	0,00	0,00
26,0	38,04	0,00	0,00
27,0	38,09	0,00	0,00
28,0	38,09	0,00	0,00
29,0	38,09	22,24	261,83
30,0	38,14	26,37	320,82
31,0	38,33	27,98	328,38

Table A.4 *(continued)*

Hour of year [h]	**Flow temperature** [°C]	**Return temperature** [°C]	**Mass flow rate** [kg/h]
32,0	38,66	28,57	325,73
33,0	39,03	28,71	304,52
34,0	39,31	28,67	289,45
35,0	39,40	28,59	278,59
36,0	39,32	28,50	270,61
37,0	39,13	28,39	265,09
38,0	38,94	28,24	256,30
39,0	38,75	27,55	221,77
40,0	38,61	26,61	191,73
41,0	38,57	25,83	172,55
42,0	38,57	25,27	161,93
43,0	38,57	24,96	158,76
44,0	38,61	24,76	161,02
45,0	38,75	24,78	165,56
46,0	38,98	24,90	169,82
47,0	39,36	0,00	0,00
48,0	39,88	0,00	0,00
49,0	40,44	0,00	0,00
50,0	40,95	0,00	0,00
51,0	41,32	0,00	0,00
52,0	41,55	0,00	0,00
53,0	41,83	22,41	265,23
54,0	42,25	27,69	326,07
55,0	42,67	29,56	328,38
56,0	42,99	30,18	328,38
57,0	43,08	30,39	306,24
58,0	42,66	30,09	270,45
59,0	41,75	29,86	261,38
60,0	40,58	29,20	231,40

Annex B
(normative)

Additional information regarding the calculation of the fractional energy savings

B.1 Definition of a conventional reference water heating system

The definition of the reference system as used for the calculation of the fractional energy savings of a solar heating system (see 7.6.3) is based on following assumptions:

- The reference system is a conventional water heating system with store;
- the size of the store is 0,75 times the daily hot water demand

$$V_{\mathrm{S,conv}} = 0{,}75\ V_{\mathrm{d}} \tag{B.1}$$

- the yearly heat losses of the store are

$$Q_{\mathrm{l,conv}} = (UA)_{\mathrm{S,conv}}\ (\vartheta_{\mathrm{S}} - \vartheta_{\mathrm{S,amb}})\ 8760\ \mathrm{h} \tag{B.2}$$

with a heat loss capacity rate according to EN /TS 12977-1:....., 6.3.7

$$(UA)_{\mathrm{S,conv}} = 0{,}16\ \sqrt{V_{\mathrm{S,conv}}} \tag{B.3}$$

and ϑ_{S} and $\vartheta_{\mathrm{S,amb}}$ according to the reference conditions in Annex A.

- The gross energy demand Q_{conv} is derived by taking into account the overall generation efficiency of the conventional heating system η_{conv}:

$$Q_{\mathrm{conv}} = (Q_{\mathrm{d}} + Q_{\mathrm{l,conv}})/\eta_{\mathrm{conv}}$$

with $\eta_{\mathrm{conv}} = 0{,}75$.

(B.4)

B.2 Calculation of fractional energy savings for other conditions

The savings of fuel or electricity can be derived for national conditions taking into account the overall generation efficiency η_{conv} and the store losses $Q_{\mathrm{l,conv}}$ of the conventional heating system as well as the overall generation efficiency of the auxiliary heater of the solar heating system η_{aux}. Energy savings may then be calculated by the same principle as for the European reference case:

$$Q_{\mathrm{sav}} = Q_{\mathrm{conv}} - Q_{\mathrm{aux}} = (Q_{\mathrm{d}} + Q_{\mathrm{l,conv}})/\eta_{\mathrm{conv}} - Q_{\mathrm{aux,net}}/\eta_{\mathrm{aux}} \tag{B.5}$$

Values for η_{conv}, $Q_{\mathrm{l,conv}}$ and η_{aux} can be given for many widely used types of conventional heating systems and auxiliary heating systems which are typically used in a country. This can be systems with and without store, wood-, gas- or oil-fired systems or electrical heaters. The national conventions can be taken into account when specifying these figures. Since the figures for the conventional heating system and solar heating system are specified separately, it is also possible to combine different techniques and to calculate in each individual case the energy savings.

It is also possible to take into account two different overall efficiencies for the heaters during summer and winter operation.

For systems in which the auxiliary heater is integral part of the solar heating system it is recommended to additionally determine the efficiency of the built-in heater and to calculate the fractional energy savings in terms of primary energy for national conditions.

Annex C
(informative)

Short-term system testing

C.1 General

NOTE The two test methods presented in this Annex have only been validated, so far, by two laboratories, at the Danish Technological Institute DTI and at the Chalmers University of Technology Göteborg ([9], [14]). DTI is confident that the procedures are promising and very efficient. However, the full verification and a round robin test within Europe are urgently needed.

The objective of short-term system testing is to estimate the long-term system performance.

A system inspection should be performed and any error detected should be corrected before the beginning of the short-term system test (see, e.g. [6]).

In principle, two approaches for short-term system testing are referred in this document:

a) The check of short-term system performance;

b) a short-term test for long-term system performance prediction.

Both approaches are applicable to systems including auxiliary heating only in the case that heat contribution by auxiliary source can be measured with an accuracy of at least 5 %.

The first test method is a simplified one. A check of the system performance is carried out by comparing the measured solar heating system gain with the one predicted by simulation using the actual weather and operating conditions as measured during the short-term test.

By the second test method, performance of the most relevant components of the solar heating system is measured for a certain time period while the system is in normal operation. These detailed measurements include the energy gain of the collector array(s) and the energy balance of the store(s). Comparing the observed and simulated energy gives a validation of collector and storage design parameters and the measured data for the collector array are also used for direct identification of the collector array parameters. When the parameters of the components are verified, the long-term prediction of the system gain is enabled as well as a detection of possible sources of system malfunctioning.

C.2 Instrumentation, data acquisition and processing

C.2.1 General

This clause includes instructions and recommendations on instrumentation, data acquisition and processing to be applied if any of the measurements described in this Annex is carried out.

NOTE If possible, these instructions and recommendations should be reviewed already at system design time, and used to minimise the test expenses and maximise the outcome of the test.

C.2.1.1 Location of sensors

Sensors designated to take data for irradiance, surrounding air speed and ambient air temperatures should be mounted as described in C.2.1.2 to C.2.1.7.

C.2.1.2 Pyranometer for hemispherical irradiance

The pyranometer for the measurement of the hemispherical irradiance should be installed at the same geometrical plane as the collector array. It should be installed near the upper part of the collector array. If more arrays are situated on a different orientation, the test engineer has to decide whether irradiance will be measured for each array or computed on the basis of measurements on the horizontal plane.

C.2.1.3 Pyranometer for diffuse irradiance

The pyranometer for the measurement of the diffuse solar irradiance should be installed in the same geometrical plane as the collector array. It should be installed near the upper part of the collector array in the vicinity of the pyranometer measuring hemispherical irradiance.

For collector arrays situated significantly off-south (azimuth is off-south by more than 10°) the diffuse irradiance should be measured at the horizontal plane instead of the tilted plane together with an additional pyranometer used for measuring the global irradiance (i.e. on horizontal plane). The fraction of diffuse irradiance at the tilted plane is then to be computed based on the measured fraction at the horizontal plane.

C.2.1.4 Ambient air temperature

The ambient air temperature in the vicinity of the collector array should be measured, if possible, using a shaded and ventilated sensor approximately 1 m above the array, not closer than 1,5 m to the collector array and not further away than 10 m away from the array.

The sensor measuring the ambient air temperature in the vicinity of storage unit(s) should be situated in a manner to be shielded from heat radiation sources such as stores, lights, auxiliary heaters etc.

C.2.1.5 Fluid temperatures

The sensors for measuring the fluid temperature should be located as close as possible to the inlet and outlet of the collector array and respective storage loop inlet(s)/outlet(s). Mixing devices mixing the fluid before the sensor are recommended. The piping between measurement points and the collector array or the storage respectively, should be properly insulated.

NOTE Measurement accuracy increases if the sensors are so close to the array (or to the storage) that they are thermally coupled to the array (or to the storage) even when there is no fluid circulation.

C.2.1.6 Volumetric flow meter

The volumetric flow meter should directly be installed in the loop’s coldest part (e.g. mains cold water line, or for the collector loop, the collector array).

The additional pressure drop introduced by the flow meter and its connecting pipes should be negligible compared to the pressure drop in the remaining of the hydraulic loop, so that the flow rate is the same with and without the flow meter.

C.2.1.7 Anemometer

The surrounding air speed should be measured on a flat surface (minimum dimension: 1 m × 1 m) fixed in the same plane as the collector array front cover. The anemometer should be positioned at a height approximately equal to the height of the centre of the collector array. The height of vanes should be 15 cm above the surface to which the anemometer is mounted. The anemometer should be located as close as possible to the collector array, the distance should not exceed 1 m.

C.2.2 Accuracy and calibration of sensors

The requirements on sensor accuracy stated in ISO 9459-5 should be fulfilled and the calibration procedures described in that standard should be followed.

C.2.3 Data acquisition and processing

The data specified in Table C.1 and Table C.2 should be measured and recorded by the data logger. All measured data during a test sequence should be recorded with time intervals not exceeding the values specified in Table C.1 or Table C.2.

C.3 Check of short-term system performance

C.3.1 Principle

The principle of the method is indicated in Figure C.1.

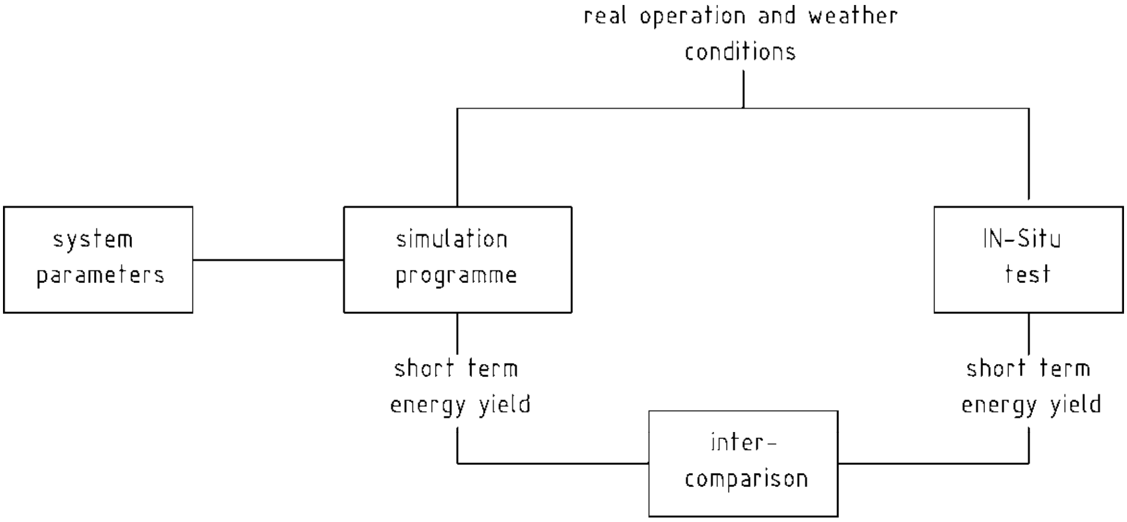


Figure C.C.1 — Principle of the short-term system performance check: Check and intercomparison of useful energy gain

The principle of this method is to compare the measured output of the solar heating system with the output predicted by a simulation program.

The components parameters required for simulation of system performance are derived from the system documentation or the manufacturer’s data. If they are not available they can be estimated. The simulation should be carried out using weather data and solar heating system operating conditions (draw-off profile, mains water temperature, etc.) as occurred during the measuring period.

NOTE The main advantage of this method is that expensive measurements are avoided. Therefore, it is appropriate to use it for smaller systems where the cost of the test is the most critical factor.

The measurement of data as requested in C.3.2.2. should be carried out continuously until the criteria for termination of the measurement, as indicated in C.3.3, are met. The measurement should take place under „operation conditions” of the system. „Operation conditions” is defined as follows:

- For solar water heating systems: The consumer daily draw-off volume is between 50 % and 150 % of the corresponding daily draw-off volume as expected for the system and/or as predicted by the solar heating system designer.

- For solar space heating system: The solar space load is between 50 % and 150 % of the corresponding load as expected for the system under particular weather conditions and house occupancy.

This method is applicable for solar-preheat systems (e.g., systems without auxiliary energy source inside the storage) and for storage without a circulation loop.

However, the systems with auxiliary heat source and circulation loop may be treated in a similar way if the following is assured:

- The uncertainty of measurement for the auxiliary heating should be better than 2 % if immersed electrical heaters are used. For other types of auxiliary heating the uncertainty should be better than 5 %.

- The uncertainty of measurement for the heat loss power in a circulation loop should be better than 3 %.

- The circulation loop is not connected to the solar (part of the) store, hence heat from auxiliary heating cannot be transferred to the solar (part of the) store.

C.3.2 Measurement of the system energy gain

C.3.2.1 Conditioning

For the dynamic simulation of the system performance the initial energy content of the store (i.e. the mean store temperature) is one of the required inputs. As measurements inside the store should be avoided, the initial state of the store may be found by forced store conditioning or it may be estimated on the basis of fluid temperature measurements at the collector inlet (piping leaving the lower part of the storage vessel) and the draw-off inlet/outlet (for hot water heating systems).

In order to minimise the influence of the error in determination of the initial energy content of the store(s), conditioning should be performed, whenever possible, prior to the measurement sequence.

The conditioning period encompasses the withdrawal of at least 3 storage volumes. The withdrawal should be carried out by night or during day periods with low hemispherical irradiance, i.e. less than 200 W/m^2.

NOTE Due to high water costs, conditioning should be avoided whenever the initial energy status of the store can be approximately estimated – e.g. if the daily load consumption exceeds the storage volume and after several (2 to 3) days of proceeding measurements the daily irradiation was lower than 5 MJ/(m^2 d).

Conditioning applies only if the store volume is less than 5 m^3. If conditioning is not carried out, the initial energy state of the store(s) should be estimated using the store draw-off temperature and the collector fluid inlet temperatures by means of the particular storage model (i.e. taking into account the stratification effect).

C.3.2.2 Measurements

The measurement data indicated in Table C.1 should be continuously recorded on a data logger.

Table C.1 — Variables to be measured and corresponding maximum sampling intervals

Symbol	Unit	Variable	Maximum sampling interval s
ϑ_{cw}	°C	mains water temperature	5
ϑ_{S}	°C	storage draw-off temperature	5
$\dot{V}_{\mathrm{s}}$	m^3/s	volume draw-off flow rate from storage	5
G_{g}, G_{h}	W/m^2	global or hemispherical solar irradiance	5
G_{d}	W/m^2	diffuse solar irradiance	5
ϑ_{a}	°C	collector ambient air temperature	30
$\vartheta_{\mathrm{S,amb}}$	°C	store ambient air temperature	30
P_{aux}	W	auxiliary power	5
P_{rc}	W	circulation heat loss power	5
NOTE Integrating instruments should be applied for auxiliary power, circulation losses and draw-off quantities.			

C.3.3 Criteria for termination of the test

For termination of the test, the following criteria should be met:

- The irradiation integrated over the measurement sequence should be greater than 150 MJ/m^2.
- At least 50 % of irradiation should occur during the time intervals with an irradiance exceeding 500 W/m^2.

Due to the possible error in estimation of the initial energy content of the store, the two first days of measurements should not be taken into account.

C.3.4 Simulation of the system useful energy gain using components data

The performance of the system can be predicted by means of a validated simulation program.

The store and collector parameters should be available in the system documentation.

If data for other system components such as piping, external heat exchanger, etc. are not included in the system documentation, those data given by the manufacturer should be used. If data are not available, they may be estimated.

The performance of the system, e.g., the useful energy gain, can be predicted for weather and load conditions as observed over the monitoring period.

C.3.5 Comparison of measured with simulated data

The useful energy gain delivered by the store over the test period should be compared with the observed data on daily basis.

The solar heating system under test is considered to behave as predicted by the simulation program if the difference (on the basis of daily values) between the observed and predicted system power does not exceed 10 %.

As errors in estimation of the initial energy status of the store may occur, the first three days of measurements should not be taken into account.

The comparison on daily basis should be done only for days at which error in estimation of the initial energy status of the store at the beginning of measurement sequence may be neglected and, additionally, if the daily irradiation exceeds 15 MJ/m^2.

Finally, the difference between predicted and measured useful energy gain over the complete monitoring period (excluding the first three days as mentioned above) should not exceed 10 % in relation to the observed energy gain.

C.3.6 Test report

The test report should include the following items:

a) detailed description of components and system configuration;

b) prediction method used: The simulation program used should be specified and an input file enclosed;

c) weather data and space heating load and/or hot water demand profile: The file(s) containing data concerning monitoring of the system performance should be enclosed;

d) predicted solar energy output of the solar heating system: The daily predicted output (by the simulation program) as well as the observed one should be presented by graph and table;

e) list of the measuring equipment and sensors, with the corresponding accuracy;

f) interpretation of possible reasons for discrepancy of the predicted and observed power.

C.4 Short-term test for long-term system performance prediction

C.4.1 General

The performance of large solar hot water and/or space heating systems depends on their design parameters and on various weather and operating conditions, e.g. irradiance, ambient temperature, wind speed, and fluid inlet temperature.

In order to evaluate long-term system performance and detect sources of system malfunctioning, it is primarily necessary to

a) check the energy delivered by the collector array;

b) check the energy balance over the storage vessel(s) and, if possible;

c) identify the most important system parameters.

NOTE Ideally, both collector and storage parameters would be identified under in-situ conditions. Unfortunately, the state-of-the-art does not allow accurate and repeatable results of in-situ test of the storage vessels. Therefore, in this Technical Specification the short-term system test is limited to the above points a) and b) and the identification of the collector array parameters only.

So, the storage simulation model is verified by checking the storage energy balance while the collector array parameters are identified directly. With the identified collector parameters and the validated storage model, both an accurate prediction of long-term system performance and a detection of sources of system malfunctioning are possible.

For more information, see [14].

C.4.2 Principle

The principle of the method is indicated in Figure C.2.

Measurement data should be collected under non-stationary operation. A wide range of operation conditions representative for the system being tested should be covered.

Measurement of data as requested in C.4.3.2 should take place continuously over a certain time interval until the criteria for termination of the measurement, indicated in C.4.4, are met. The measurement should be carried out under „operation conditions" of the system, according to C.3.1.

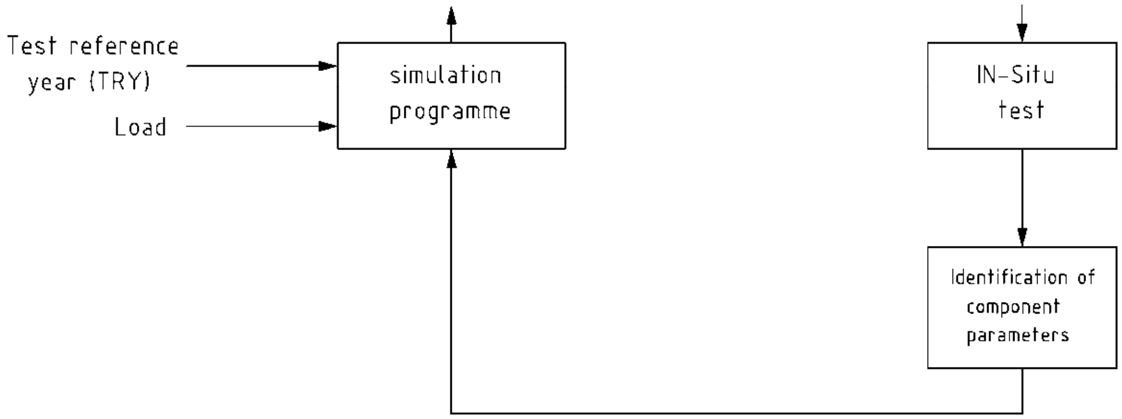


Figure C.C.2 — Principle of the short-term test and of the subsequent long-term system performance prediction

After the criteria for termination of the test have been met, the collector array parameters should be identified. The identified parameters are thereafter used for the prediction of the long-term performance of the system. Local input data are hourly values of meteorological data, which are available, e.g., from test reference year (TRY), and the load data specific for the system being tested.

C.4.3 Measurements

C.4.3.1 Conditioning

See C.3.2.1.

C.4.3.2 Procedure

During the monitoring period the measurement data indicated in Table C.2 should be continuously recorded.

Table C.2 — Variables to be measured during system test, and corresponding maximum sampling intervals

Symbol	Unit	Variable	Maximum sampling interval s
ϑ_{cw}	°C	mains water temperature	5
ϑ_{S}	°C	store draw-off temperature	5
ϑ_{rci}	°C	fluid temperature at circulation loop inlet	5
ϑ_{rce}	°C	fluid temperature at circulation loop outlet	5
ϑ_{ci}	°C	collector fluid inlet temperature	5
ϑ_{co}	°C	collector fluid outlet temperature	5
$\dot{V}_{c}$	m^3/s	volume flow rate in collector loop	5
$\dot{V}_{rc}$	m^3/s	volume flow rate in circulation loop	5
$\dot{V}_{s}$	m^3/s	volume draw-off flow rate from store	5
G_h	W/m^2	hemispherical solar irradiance on tilted plane	5
G_g	W/m^2	global solar irradiance on horizontal plane (optional)	5
G_d	W/m^2	diffuse solar irradiance on tilted plane	5
ϑ_{a}	°C	collector ambient air temperature	30
$\vartheta_{S,amb}$	°C	store ambient air temperature	30
v	m/s	surrounding air speed	10
P_{aux}	W	auxiliary power	1
NOTE Integrating instruments should be applied for auxiliary power and flow rates.			

The values needed for determination of the system power, such as temperature difference, volume draw-off flow rate and auxiliary power should be obtained with a period not exceeding 1 s. The data for other variables should be obtained with periods of at least 30 s for further processing.

The sampled values should be continuously integrated and averaged.

The integrated values for each variable should be computed over a recording interval and stored.

Maximum recording interval is 1 min. The data recording interval may vary during the measurement sequence.

The monitoring of the collector array and collecting of data should be continued until the criteria for termination of the test as described in C.4.4 are met.

C.4.4 Criteria for termination of the test

In order to be able to check the store energy balance and the collector array energy gain, it is necessary to collect data continuously over a certain time period with reasonably good weather conditions.

So, the first criterion for termination of the test applies to weather requirements during the test.

The weather conditions which should prevail during the test are:

– The irradiation integrated over the test should be higher than 200 MJ/m^2.

– The total time with irradiance exceeding 500 W/m² should exceed 50 % of the total test period.

The second criterion applies to the collector operation conditions necessary for accurate identification of the collector parameters.

These general operation conditions are fully represented by four driving variables:

a) the difference between the mean collector fluid temperature, ϑ_m, and the collector ambient air temperature, ϑ_a;

b) the reduced temperature $T^* = (\vartheta_m - \vartheta_a)/G_h$;

c) the surrounding air speed;

d) the angle of incidence of the direct solar radiation on the collector plane.

The wind speed range depends on the climate where the system under test is located. The range scanned during the test should be representative for that climate.

The requested ranges of variation for other driving variables are listed in Table C.3.

Table C.3 — Range of variations of the driving variables to be scanned during a test outdoors

Driving variable	Requested range of variation
$\vartheta_m - \vartheta_a$ (while G_h > 500 W/m^2)	10 K to 45 K or 65 K[a]
reduced temperature T^* (G_h > 500 W/m^2)	0,02 m²K/W to 0,12 m²K/W or 0,2 m²K/W[a]
angle of incidence of direct solar radiation	10° to 70°

[a] Whenever possible, the requested range of variation should be extended up to that value.

C.4.5 Identification of collector array parameters

The theoretical model of the collector (”dynamical collector test model”) should be used as defined in EN 12975-2.

The identification of the parameters of the theoretical model should be carried out by an appropriate mathematical tool for identification of parameters as defined in EN 12975-2 (”dynamical collector test model”).

The collector array parameters determined by the parameter identification program should be listed together with the associate standard deviations.

C.4.6 Criteria for the acceptance of the test results

The main aim of the test is to enable a prediction of the long-term system performance under actual weather and load conditions.

Incorrect predictions of long-term system performance are mostly caused by:

a) incorrect computation of irradiance on the tilted plane,

b) the collector array does not deliver the energy expected by the designer and

c) the in-situ storage performance does not correspond to the designed one.

In order to eliminate these possible sources of error the basic criteria for acceptance of the test results, given in C.4.6.1 to C.4.6.3, should be fulfilled.

If one of these criteria is not met, the corresponding simulation model should be checked. If the simulation model is correct, and no error is detected in the operation of the system, the test should be prolonged for two additional days (daily irradiation exceeding 12 MJ/(m^{2}d)). This procedure should be repeated until the criteria are met.

C.4.6.1 Solar irradiance on the tilted plane

Only the days where the irradiation exceeds 12 MJ/(m^{2}d) should be considered.

C.4.6.2 Collector array

The energy delivered by the collector (on the daily basis) should not differ by more than 10 % from the energy predicted by the collector array design parameters over the operational conditions during the test period.

In addition, the identified collector parameters should be accurately determined. The identified parameters are acceptable if the standard deviations do not exceed the following values:

— 15 % for the overall heat loss coefficient of collector array U_L;

— 20 % for the incidence angle modifier $K_{\tau\alpha}$;

— 10 % for the collector array thermal capacity C_c;

— 3 % for the zero-loss efficiency of collector array η_o.

If the standard deviations of any of the identified parameters listed in Table C.4 exceed their permissible values the identification procedure should be repeated using reasonable assessed values for these parameters in equation (32) of EN 12975-2. Hence the remaining parameters only should be calculated by the identification procedure.

Table C.4 — Permissible standard deviation for secondary collector parameters

Parameter	Symbol[a]	Permissible standard deviation
Temperature dependance of the overall heat loss coefficient	C_2	15 %
Wind speed dependance of the overall heat loss coefficient	C_3	15 %
Sky temperature dependance of the overall heat loss coefficient	C_4	15 %
Wind speed dependance of the zero-loss collector efficiency	C_6	15 %

[a] According to equation (32) in 6.3.4.8.2 of EN 12975-2.

C.4.6.3 Store

Energy drawn-off from store (on a daily basis) should not differ by more than 10 % from the energy predicted using the store design parameters over the particular operational conditions during the test period. Here, the energy delivered by the collector array is used as a measured input variable.

C.4.6.4 Final check

After the criteria in C.4.6.1 to C.4.6.3 are met, the complete solar heating system model should be validated comparing the measured with the predicted useful energy gain and using the following data:

- component data;
- weather data (the irradiance on the horizontal plane should be used);
- the load conditions as occurred during the validation test.

The energy predicted by simulation should not differ by more than 10 % from the measured energy output on a daily basis.

C.4.7 Test report

The test report should include:

a) Detailed description of the system under test;

b) detailed description of the test installation and instrumentation specifications (manufacturer, accuracy);

c) graphical presentation of the measured energy gain of the collector array, as well as that predicted using the collector design parameters;

d) graphical presentation of the measured energy delivered to the user from the storage vessel(s) as well as that predicted using the storage design parameters;

e) the identified parameters of the collector array with associate standard errors and their correlation matrix, if available. A Comparison with the design collector array parameters should be stated as well;

f) a diskette with data files and the file(s) resulting from the statistical data evaluation.

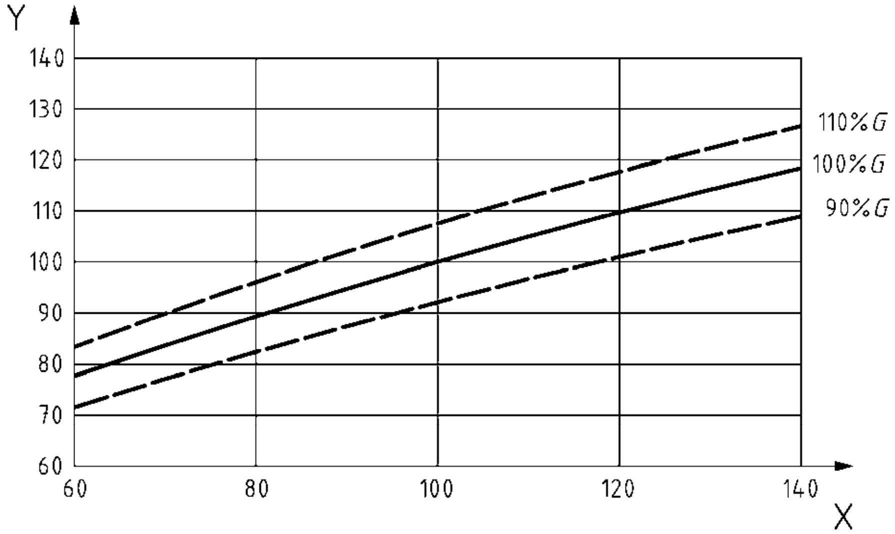
NOTE Clause 8 gives additional information on the contents of the test report.

C.4.8 Prediction of the yearly system gain

On the basis of the component data (either by in-situ measurement or manufacturer data) the detailed simulation should be performed by the same computer program as in 4.6, using actual load volume and profile and the test reference year for a particular site.

Additionally, simulation runs should be performed with the load level varying from 70 % to 120 % of the actual one and the yearly irradiation from 90 % to 110 % of that of the test reference year.

NOTE Figure C.3 gives an example of the predicted performance dependence on load level and irradiation.



Key

1 out in %

2 load scale factor in %

Figure C.C.3 — Example of the predicted performance dependence on load level and irradiation for a solar domestic hot water heating system (see [8]).

Annex D
(informative)

Long-term monitoring

D.1 General

Long-term monitoring gives the company operating the solar heating system after commissioning (referred to below as the ”client”) a simple supervision tool

- to determine the solar contribution to the total heat load;
- to get an indication on malfunctions or degradations of the solar heating system.

The final long-term goal is to get the maximum benefit from the initial solar investment as well as to minimize the consumption of auxiliary energy and the resulting environmental impact.

Long-term monitoring of a solar heating system is very similar to that of a common heating plant. In this annex, solar energy specific aspects are emphasized.

In order to reduce the cost of long-term monitoring as much as possible, the physical key quantities monitored should be integrated continuously, and the figures displayed by the integrators be recorded at regular time intervals (mostly in coincidence with the supervision time intervals).

The data which should be monitored include:

- the hemispherical solar irradiance in the plane of the collector array(s);
- the total load of that part of the system to which solar energy is supplied;
- the solar contribution of the solar heating system.

The interface where the heat transferred from the solar part to the conventional part of the system (i.e. the solar contribution) is measured, should be specified individually for each system, depending on the hydraulic scheme and the control concept.

NOTE 1 It is always possible to include more physical quantities into the measuring programme, giving a higher priority to some of them according to additional supervision objectives. In that case, the additions (in comparison to this annex) should be fully documented.

Long-term monitoring starts when the expected system performance has been confirmed by the short-term system testing according to Annex C.

The monitoring procedure is described for a large custom-built system with short-term storage (Class A or B according to EN TS 12977-1:....., 5.2).

NOTE 2 Future updates of this Technical Specification may consider other system types, e.g. such with seasonal storage, when more experience on those types is available.

D.2 Evaluation chart

The evaluation chart is a diagram showing the solar contribution of the solar heating system as a function of the solar irradiation in the collector plane for different load levels. It should be used as a reference to evaluate the system performance (see D.4). The evaluation chart should be established at design time and delivered to the client with the system technical documentation. It is obtained similarly to the system energy balance and should be based on the same weather data and load assumptions (see EN TS 12977-1 sub-clause 6.7.3.1).

The evaluation chart should display different trends of solar contribution variation as a function of the load level and other possible parameters having a strong influence on the system performance.

NOTE The range of load level variation should be 70 % to 120 % of the nominal value used for dimensioning.

Weekly data are preferred in evaluation charts, as they match up to the most common time interval in use in heating plant supervision. However, daily and monthly data may also be plotted in those charts.

If monthly performance data have been obtained at design time, they may be converted to weekly average values for the corresponding months, in order to display only weekly data in the evaluation chart. Similarly, daily values may be grouped to weekly data in the evaluation chart. Finally, values from short-term testing according to Annex C, related to any time intervals, may be converted to weekly (average) values and included in the evaluation chart.

D.3 Monitoring equipment

The monitoring equipment described here is kept at the lowest possible level of instrumentation in order to minimize cost; accordingly, simple methods of evaluation have been chosen (see D.4).

More sophisticated equipment with a higher time resolution, additional physical quantities to be monitored and/or automatic data acquisition and display, is always possible. Accordingly, the evaluation chart should be supplemented at design time. At least all data considered in the evaluation chart should be monitored, and most data monitored should be considered in the evaluation chart.

The simplest monitoring equipment includes:

- a heat meter to measure the heat load of the system. If solar energy is supplied to a part of the system only, e.g. for hot water preparation, the load of this part should be monitored;
- a heat meter to measure the solar contribution related to the above mentioned heat load;
- an integrator of the solar irradiance in the collector plane. If different collector orientations exist within the system, the solar irradiance can be measured in the different planes and considered in evaluation charts, according to the client's wishes.

Instrumentation used in the long-term monitoring should be an integral part of the system, a part included from the very beginning of the design process. If adequately foreseen, it may also be used for adjustments at the initial operation time.

D.4 Data analysis

The monitored data should be plotted in the evaluation chart for direct visual comparison with the expected values. For their interpretation the different load levels as well as other parameters included in the evaluation charts (see D.2) should be considered.

The system is working properly if the monitored data fit to the values given by the evaluation chart, within the accuracy limits agreed to by the client. If a larger discrepancy is observed, there is evidence for malfunction or degradation of the solar heating system.

Annex E
(informative)

Determination of water wastage

NOTE

Currently, several procedures for the determination of water wastage are under development. In due time a reference to an adequate procedure will be introduced.

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Thermal solar systems and components — Custom built systems — Part 3: Performance test methods for solar water heater stores

Thermische Solaranlagen und ihre Bauteile — Kundenspezifisch gefertigte Anlagen — Teil 3: Leistungsprüfung von Warmwasserspeichern für Solaranlagen

Installations solaires thermiques et leurs composants — Installations assemblées à façon — Partie 3 : Caractérisation des performances des dispositifs de stockage pour des installations de chauffage solaires

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Contents

Page

Foreword

This document (prEN 12977-3:2006) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This document is currently submitted to the CEN Enquiry.

The annexes A, B, C are normative and annexes D and E are informative.

Introduction

The test methods for stores of solar heating systems as described in this document are required for the determination of the thermal performance of small custom built systems as specified in prEN/TS 12977-1.

These test methods deliver parameters, which are needed for the simulation of the thermal behaviour of a store being part of a small custom built system thermal solar system.

NOTE 1 The already existing test methods for stores of solar heating systems are not sufficient with regard to thermal solar systems. This is due to the fact that the performance of thermal solar systems depends much more on the thermal behaviour of the store (e. g. stratification, heat losses), as conventional systems do. Hence this separate document for the performance characterisation of stores for solar heating systems is needed.

NOTE 2 For additional information about the test methods for the performance characterisation of stores see [1] in Bibliography.

1 Scope

This document (prEN 12977-3:2006) specifies test methods for the performance characterization of stores which are intended for use in small custom built systems as specified in prEN/TS 12977-1.

Stores tested according to this document are commonly used in solar hot water systems. However, also the thermal performance of all other thermal stores with water as storage medium can be assessed according to the test methods specified in this document.

The document applies to stores with a nominal volume between 50 l and 3 000 l.

This document does not apply to combistores. Performance test methods for solar combistores are specified in prEN/TS 12977-4.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 806-1, *Specifications for installations inside buildings conveying water for human consumption — Part 1: General*

EN 1717, *Protection against pollution of potable water installations and general requirements of devices to prevent pollution by backflow*

EN 12828, *Heating systems in buildings — Design of water-based heating systems*

EN 12976-2, *Thermal solar systems and components — Factory made systems — Test methods*

prEN/TS 12977-1, *Thermal solar systems and components — Custom built systems — Part 1: General requirements for solar water heaters and combi systems*

prEN/TS 12977-2, *Thermal solar systems and components — Custom built systems — Part 2: Test methods for solar water heaters and combi systems*

prEN/TS 12977-4, *Thermal solar systems and components — Custom built systems — Part 4: Performance test methods for solar combistores*

EN ISO 9488, *Solar energy — Vocabulary*

ISO/DIS 9459-5, *Solar heating — Domestic water heating systems — Part 5: System performance characterization by means of whole system tests and computer simulation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 9488 and the following apply.

3.1
ambient temperature
mean value of the temperature of the air surrounding the store

3.2
charge
process of transferring energy into the store by means of an heat source

3.3
charge connection
pipe connection used for charging the storage device

3.4
combistore
one store used for both domestic hot water preparation and space heating

3.5
constant inlet temperature, $\tilde{\vartheta}_{x,i}$
temperature which is achieved during charge ($x = C$) or discharge ($x = D$), if the mean value $\tilde{\vartheta}_{x,i}$ over the period of 0,5 “reduced charge / discharge volume” (see 3.34) is within ($\tilde{\vartheta}_{x,i} \pm 1$) °C

3.6
constant flow rate, $\tilde{\dot{V}}$
flow rate which is achieved, when the mean value $\tilde{\dot{v}}$ over the period of 0,5 “reduced charge / discharge volumes” (see 3.34) is within ($\tilde{\dot{v}} \pm 10$) %

3.7

constant charge power, $\tilde{P}_\mathrm{c}$

charge power which is achieved, when the mean value $\tilde{P}_\mathrm{c}$ over the period of 0,5 reduced charge volumes is within ($\tilde{P}_\mathrm{c}$ ± 10) %

3.8

conditioning

process of creating a uniform temperature inside the store by discharging the store with $\tilde{\vartheta}_\mathrm{D,i}$ = 20 °C until a steady state is reached

NOTE The conditioning at the beginning of a test sequence is intended to provide a well defined initial system state, i. e. an uniform temperature in the entire store.

3.9

discharge connection

pipe connection used for discharging the storage device

3.10

dead volume / dead capacity

volume / capacity of the store which is only heated due to heat conduction (e. g. below a heat exchanger)

3.11

direct charge / discharge

transfer or removal of thermal energy in or out of the store, by directly exchanging the fluid in the store

3.12

discharge

process of decreasing thermal energy inside the store caused by the hot water load

3.13

double port

a corresponding pair of inlet and outlet connections for direct charge / discharge of the store

NOTE Often, the store is charged or discharged via closed or open loops that are connected to the store through double ports.

3.14

effective volume / effective capacity

volume / capacity which is involved in the heat storing process if the store is operated in a usual way

3.15

electrical (auxiliary) heating

electrical heating element immersed into the store

3.16

external auxiliary heating

auxiliary heating device located outside the store. The heat is transferred to the store by direct or indirect charging via a charge loop. The external auxiliary heating is not considered as part of the store under test

3.17

heat loss capacity rate, $(UA)_\mathrm{s,a}$

overall heat loss of the entire storage device per K temperature difference between the store temperature and the ambient air temperature

NOTE The heat loss capacity rate depends on the flow conditions inside the store. Hence a stand-by heat loss capacity rate and a operating heat loss capacity rate are defined. If $(UA)_\mathrm{s,a}$ is mentioned without specification, $(UA)_\mathrm{s,a}$ represents the stand-by heat loss capacity rate.

3.18
heat transfer capacity rate
thermal power transferred per K temperature difference

3.19
immersed heat exchanger
heat exchanger which is completely surrounded with the fluid in the store tank

3.20
indirect charge / discharge
transfer or removal of thermal energy into or out of the store, via a heat exchanger

3.21
load
heat output of the store during discharge. The load is defined as the product of the mass, specific thermal capacity and temperature increase of the water as it passes the solar hot water system

3.22
mantle heat exchanger
heat exchanger mounted to the store in a way, that it forms a layer between the fluid in the store tank and ambient

3.23
measured store heat capacity
measured difference in energy of the store between two steady states on different temperature levels, divided by the temperature difference between this two steady states

3.24
measured energy, $Q_{\mathrm{x,m}}$
time integral of the measured power over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

3.25
measured power, $P_{\mathrm{x,m}}$
power calculated from measured volume flow rate as well as measured inlet and outlet temperature

3.26
mixed
state when the local store temperature is not a function of the vertical store height

3.27
model parameter
parameter used for quantification of a physical effect, if this physical effect is implemented in a mathematical model in a way which is not analogous to its appearance in reality, or if several physical effects are lumped in the model (e. g. a stratification number)

3.28
nominal flow rate, $\dot{V}_{\mathrm{n}}$
the nominal volume of the entire store divided by 1 h

3.29
nominal heating power, P_{n}
the nominal volume of the entire store multiplied by 10 W/l

3.30
nominal volume, V_{n}
fluid volume of the store as specified by the manufacturer

3.31

operating heat loss capacity rate, $(UA)_{\mathrm{op,s,a}}$

heat loss capacity rate of the store during charge or discharge

3.32

predicted energy, Q_{xp}

time integral of the predicted power over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

3.33

predicted power, P_{xp}

power calculated from measured volume flow rate, as well as measured inlet temperature and calculated outlet temperature. The outlet temperature is predicted by numerical simulation

3.34

reduced charge / discharge volume

integral of a charge / discharge flow rate divided by the store volume

3.35

stand-by

state of operation in which no energy is deliberately transferred to or removed from the store

3.36

stand-by heat loss capacity rate, $(UA)_{\mathrm{sb,s,a}}$

heat loss capacity rate of the store during stand-by

3.37

steady state

state of operation at which at charge or discharge during 0,5 "reduced charge / discharge volume" (see 3.34) the standard deviation of the temperature difference, between store inlet and store outlet temperature of the charging / discharging circuit is lower than 0,05 K

NOTE In cases of an isothermal charged store rather constant temperature differences between the inlet and outlet temperature of the discharge circuit may occur during the discharge of the first store volume before the outlet temperature drops rapidly. These state is not considered as steady state.

3.38

store temperature

temperature of the store medium

3.39

stratified

state when thermal stratification is inside the store

3.40

stratified charging

increase of thermal stratification in the store during charging

3.41

stratifier

device that enables stratified charging of the store. Common used stratifiers are e. g. convection chimneys or pipes with radial holes

3.42

theoretical store heat capacity

sum over all thermal capacities $m_{\mathrm{i}} \times c_{\mathrm{p,i}}$ of the entire store (fluid, tank material, heat exchangers) having part of the heat store process

3.43

thermal stratification

state when the local store temperature is a function of the vertical store height, with the temperature decreasing from top to bottom

3.44

transfer time, $t_{\mathrm{x,f}}$

time period during which energy is transferred through the connections for charge ($x = C$) or discharge ($x = D$). The transfer time is calculated over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

4 Symbols and abbreviations

C_{s}	thermal capacity of the entire store, in J/K
c_{p}	specific heat capacity, in J/(kg K)
P_{n}	nominal heating power, in W
$P_{\mathrm{x,m}}$	measured power transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in W
$P_{\mathrm{x,p}}$	predicted power transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in W
$Q_{\mathrm{x,m}}$	measured energy transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in J
$Q_{\mathrm{x,p}}$	predicted energy transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in J
t_{st}	time required to achieve a steady state, in s
$t_{\mathrm{x,f}}$	transfer time for charging ($x = C$) or discharging ($x = D$), in s
ϑ_{a}	ambient temperature, in °C
ϑ_{s}	store temperature, in °C
$\tilde{\vartheta}_{\mathrm{x,i}}$	inlet temperature of the charge ($x = C$) or discharge ($x = D$) circuit, in °C
$\vartheta_{\mathrm{x,i}}$	constant inlet temperature of the charge ($x = C$) or discharge ($x = D$) circuit, in °C
$\vartheta_{\mathrm{x,o}}$	outlet temperature of the charge ($x = C$) or discharge ($x = D$) circuit, in °C
$(UA)_{\mathrm{hx,s}}$	heat transfer capacity rate between heat exchanger and store, in W/K
$(UA)_{\mathrm{s,a}}$	heat loss capacity rate of the store, in W/K
$(UA)_{\mathrm{op,s,a}}$	operating heat loss capacity rate of the store, in W/K
$(UA)_{\mathrm{sb,s,a}}$	stand-by heat loss capacity rate of the store, in W/K
V_{n}	nominal volume of the store, in l

$\dot{V}_\mathrm{n}$	nominal flow rate, in l/h
$\tilde{\dot{V}}_\mathrm{x}$	constant flow rate of the charge ($x = C$) or discharge ($x = D$) circuit, in l/h
$\Delta\vartheta_\mathrm{m}$	mean logarithmic temperature difference, in K
$\varepsilon_\mathrm{x,P}$	relative error in mean power transferred during charge ($x = C$) or discharge ($x = D$), in %
$\varepsilon_\mathrm{x,Q}$	relative error in energy transferred during charge ($x = C$) or discharge ($x = D$), in %
ρ	density, in kg/m³

5 Store classification

Hot water stores are classified by distinction between different charge and discharge modes. Five groups are defined as shown in Table 1.

Table 1 — Classification of the stores

Group	Charge mode	Discharge mode
1	direct	direct
2	indirect	direct
3	direct	indirect
4	indirect	indirect
5	stores that cannot be assigned to groups 1 to 4	

NOTE 1 All stores may have one or more additional electrical heating elements.

6 Laboratory store testing

6.1 Requirements on the testing stand

6.1.1 General

The hot water store shall be tested separately from the whole solar system on a store testing stand.

The testing stand configuration shall be determined by the classification of hot water stores as described in clause 5.

An example of a representative hydraulic testing stand configuration is shown in Figure 1 and Figure 2.

The circuits are intended to simulate the charge and discharge loop of the solar system and to provide fluid flow with a constant or well controlled temperature. The full test stand consists of one charge and one discharge circuit.

NOTE 1 If the store consists of more than one charge or discharge devices (e.g. two heat exchangers), then these are tested separately.

The testing stand shall be located in an air-conditioned room where the room temperature of 20 °C should not vary more than ± 1 K during the test.

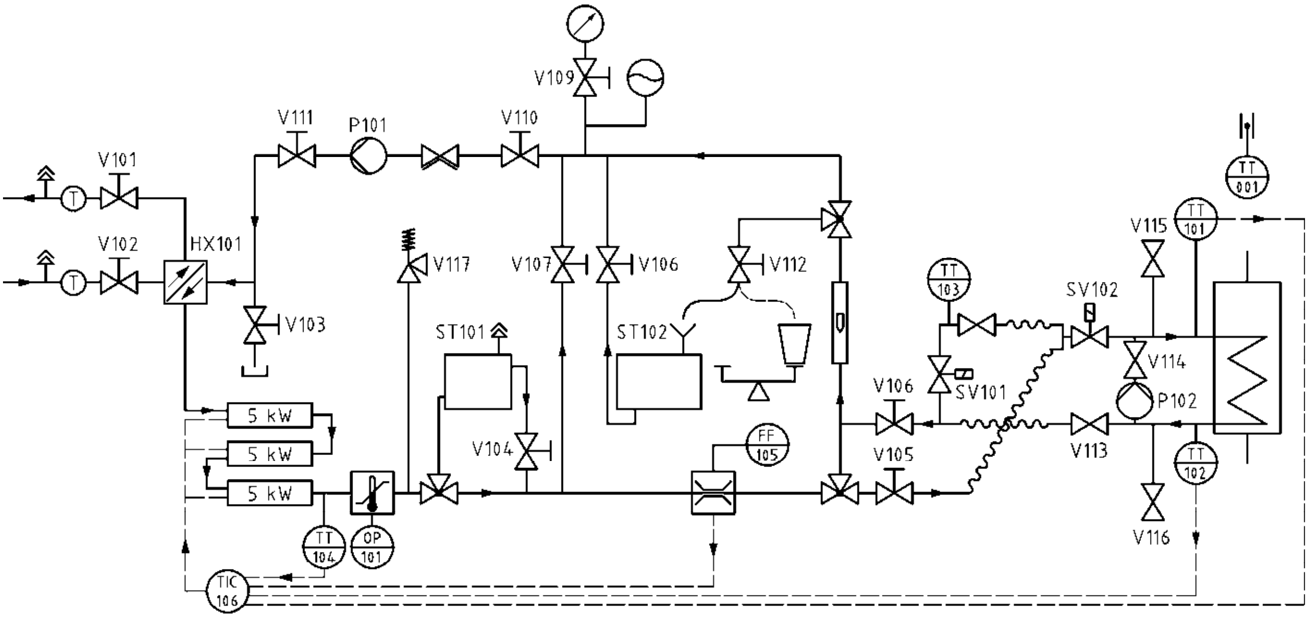
Both circuits shall fulfil the following requirements:

- The flow rate shall be adjustable between 0,05 m^3/h and 3 m^3/h, by deviation < 2 %;
- the working temperature range shall be between 10 °C and 90 °C;
- the minimum heating power of the charge circuit shall be 15 kW;
- the minimum cooling power in the discharge circuit shall be 5 kW at a fluid temperature of 20 °C;

NOTE 2 If mains water at a constant pressure and a constant temperature below 20 °C is available, it is recommended to design the discharge circuit in a way, that it can be operated as closed loop or as open loop using mains water to discharge the store.

- the minimum heating power of the discharge circuit shall be 5 kW;
- the control deviation of the store inlet temperature shall be less than 0,05 K;
- the minimum heating up rate of the charge circuit with disconnected store shall be 3 K/min;
- the minimum available electrical heating power for electrical auxiliary heaters shall be 6,0 kW.

NOTE 3 The electrical power of the pump (P102) shall be chosen in such a way that the temperature increase induced by the pump (P102) is less than 0,6 K/h when the charge circuit is "short circuited" and operated at room temperature. (“short circuited” means that no storage device is connected and SV102, V113, V115 and V116 are closed, see Figure 1).



Key

FF	Flow meter
HX	Heat exchanger
OP	Overheating protection
P	Pump
ST	Store
SV	Solenoid valve
TT	Temperature sensor
TIC	Temperature indicator and controller
V	Valve

Figure 1 — Charge circuit of the store testing stand

The heating medium water in the charge circuit (see Figure 1) is pumped through the cooler (HX101) and the temperature controlled heaters (TIC106) by the pump (P101). A buffer tank (ST101) is used to balance the remaining control deviations. By means of the bypass (V107) the flow through the store can be regulated, it also ensures a continuously high flow through the heating section and therefore good control characteristics. With the solenoid valve (SV101) the heating medium can bypass the store to prepare a sudden increase of the inlet temperature into the store.

The temperature sensors are placed near the inlet (TT101) and outlet (TT102) connections of the store, the connection to the store is established through insulated flexible pipes.

The charge circuit can be operated closed, under pressure (design pressure 2,5 bar, membrane pressure expansion tank and pressure relief valve (V109)) as well as open (valve (V108) open) with the tank (ST102) serving as an expansion tank. A calibration of the installed flow meter (FF105) is possible by weighing the mass of water leaving the valve (V112). The installation is equipped with the usual safety devices, i. e. pressure relief valve (V117) and overheating protection device (OP101).

The discharge circuit (see Figure 2) is constructed in a similar way. It includes two coolers – (HX201) and (HX202) – and a temperature controlled heating element (TIC206) with 5 kW heating power. The discharge circuit can either be operated in open circulation with water from the net or it can be operated in closed circulation. During open operation the water is led via the safety equipment (V201) and flows through the coolers, the heating section and the flow meter (FF205) into the store. The hot water leaving the store flows through the solenoid valve (SV201) and the valve (V210) into the drain. The valve (V212) is closed.

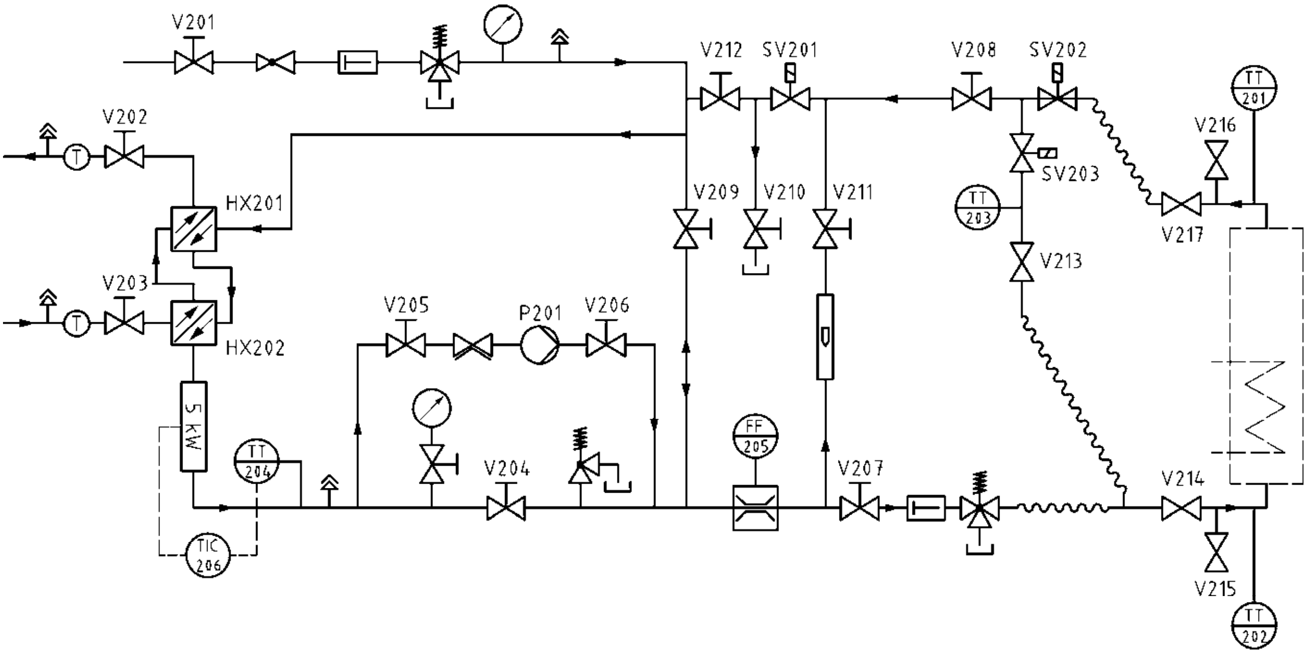
For heating the water it is recommended to increase the flow through the heating section with the pump (P201) in order to improve the control performance; the additional volume flow returns through the bypass (V209).

During closed-circle operation, the valve of the safety equipment and the cut-off valve (V210) remain closed, the valve (V212) is open and the water is circulated by the pump (P201).

NOTE 4 For periodical checks of the measuring accuracy, it is recommended to integrate a reference heater into the testing stand. Instead of a store, this reference heater is connected to the testing stand. The reference heater is supplied with an electric heating device.

NOTE 5 See [2] and [3] in Bibliography for further information on the use of reference heaters.

The heat transfer fluid used for testing may be water or a fluid recommended by the manufacturer. The specific heat capacity and density of the fluid used, shall be known with an accuracy of 1 % within the range of the fluid temperatures occuring during the tests.



Key

FF	Flow meter
HX	Heat exchanger
P	Pump
SV	Solenoid valve
TT	Temperature sensor
TIC	Temperature indicator and controller
V	Valve

Figure 2 — Discharge circuit of the store testing stand

6.1.2 Measured quantities and measuring procedure

The quantities listed in Table 2 shall be measured with the given accuracy:

Table 2 — Measuring data

Measured quantities	Measuring device (see Figure 1 and 2)	Uncertainty
Volume flow, $\dot{V}_\mathrm{C}$, in the charge circuit between 0,05 m³/h and 1 m³3/h	FF105	2,0 %
Volume flow, $\dot{V}_\mathrm{D}$, in the discharge circuit between 0,05 m³/h and 1 m³/h	FF205	2,0 %
Temperature, $\vartheta_\mathrm{C,i}$, of the charging medium at store inlet	TT101	0,1 K
Temperature, $\vartheta_\mathrm{C,o}$, of the charging medium at store outlet	TT102	0,1 K
Difference in the charging medium temperature, $\Delta\vartheta_\mathrm{C}$, between store inlet and store outlet: (for tests according to 6.3.1)	TT101 and TT102	0,02 K
Difference in the charging medium temperature, $\Delta\vartheta_\mathrm{C}$, between store inlet and store outlet: (for tests according to 6.3.2)	TT101 and TT102	0,05 K
Temperature, $\vartheta_\mathrm{D,i}$, of the discharging medium at store inlet	TT201	0,1 K
Temperature, $\vartheta_\mathrm{D,o}$, of the discharging medium at store outlet	TT202	0,1 K
Difference in the discharging medium temperature, $\Delta\vartheta_\mathrm{D}$, between store inlet and store outlet: (for tests according to 6.3.1)	TT201 and TT202	0,02 K
Difference in the discharging medium temperature, $\Delta\vartheta_\mathrm{D}$, between store inlet and store outlet: (for tests according to 6.3.2)	TT201 and TT202	0,05 K
Ambient temperature ϑ_am	TT001	0,1 K
Electric power, $\dot{Q}_\mathrm{el}$, (auxiliary heating)	–	2 %

The relevant data shall be measured every 10 s at least and the measured data shall be recorded as mean values of at most three measured values. However, for test H during the transient the temperatures shall be measured and recorded every second.

The temperature sensors shall have a relaxation time of less than 10 s (i. e. 90 % of the temperature variation is detected by the sensor immersed in the heat transfer fluid within 10 s after an abrupt step in the fluid temperature).

Prior to each store test a zero measurement should be performed where the fluid in the charge or discharge circuit is pumped over the short-circuited charge or discharge circuit. “Short-circuited” means that flow pipe and return pipe of the corresponding circuits are directly connected (recommended volume flow approximately 0,6 m³/h, temperatures 20 °C, 40 °C, 60 °C, 80 °C). If the measured temperature difference exceeds the permissible uncertainty of 0,0 K / 0,05 K, the temperature sensors shall be calibrated.

A reference heater may also be used for the zero measurement.

6.2 Installation of the store

6.2.1 Mounting

The store shall be mounted on the testing stand according to the manufacturer's instructions.

The temperature sensors used for measuring the inlet and outlet temperatures of the fluid used for charging and discharging the storage device, shall be placed as near as possible at least 200 mm to the inlet and outlet connections of the storage device. The installation of the temperature sensors inside the pipes shall be done according to approved methods of measuring temperatures.

If there is/are more than one pair of charging and/or discharging inlet or outlet connections, then only one may be connected to the testing stand (at the same time) while the other(s) shall be closed.

The pipes between the store and the temperature sensors shall be insulated according to EN 12828.

6.2.2 Connection

The way of connecting the storage device to the testing stand depends on the purpose of the thermal tests which shall be performed. Detailed instructions are given in the clauses where the thermal tests are described.

The connections at the storage device, as delivered by the manufacturer, are considered as the thermal demarcation between the storage device and the testing stand.

The solenoid valves shall be placed as near as possible to the inlet and outlet connections of the storage device.

Connections of the store which do not lead to the charge or discharge circuit of the testing stand shall be closed, and not connected heat exchangers shall be filled up with water. All closed connections shall be insulated in the same way as the store.

Since fluid in closed heat exchangers expands with increasing temperature, a pressure relief valve shall be mounted.

NOTE The performance of a solar heating system depends on the individual installation and actual boundary conditions. With regard to the heat losses of the store besides deficits in the thermal insulation, badly designed connections can increase the heat loss capacity rate of the store due to natural convection that occurs internally in the pipe. In order to avoid this effect the connections of the pipes should be designed in such a way that no natural convection inside the pipe occurs. This can e. g. be achieved if the pipe is directly going downwards after leaving the store or by using a siphon.

6.3 Test and evaluation procedures

The aim of store testing as specified in this document, is the determination of parameters required for the detailed description of the thermal behaviour of a hot water store. Therefore, a mathematical computer model for the store is necessary. The basic requirements on suitable models are specified in annex A and annex B.

The following parameters shall be known for the simulation of a store being part of a solar system:

a) Stored water

- Height,
- effective volume respectively effective thermal capacity,
- heights of the inlet and outlet connections,
- heat loss capacity rate of the entire store,

- if the insulation varies for different heights of the store, the distribution of the heat loss capacity rate should be determined for the different parts of the store,
- a parameter describing the degradation of thermal stratification during stand-by,

NOTE 1 One possible way to describe this effect in a store model is the use of a vertical thermal conduction. In this case the corresponding parameter is an effective vertical thermal conductivity.

- a parameter describing the characteristic of thermal stratification during direct discharge

NOTE 2 An additional parameter may be used to describe the influence of different draw-off flow rates on the thermal stratification inside the store, if this effect is relevant.

- positions of the temperature sensors (e. g. the sensors of the collector loop and auxiliary heater control).

b) Heat exchangers

- Heights of the inlet and outlet connections,
- volume,
- heat transfer capacity rate as a function of temperature,
- information on the capacity in respect of stratified charging,

NOTE 3 The capacity in respect of stratified charging can be determined from the design of the heat exchanger as well as from the course in time of the heat exchanger inlet and outlet temperatures.

- heat loss rate from the heat exchanger to the ambient (necessary only for mantled heat exchangers and external heat exchangers).

c) Electrical auxiliary heat source

- Position in the store,
- axis direction of heating element (horizontal or vertical). If the auxiliary heater is installed in a vertical way, also its length is required,
- effectivity that characterises the fraction of the thermal converted electric power which is actually transferred inside the store.

NOTE 4 Badly designed electrical auxiliary heaters may cause significant heat losses during operation. In this case the electrical power supplied to the heater is not equal to the thermal energy input to the store.

The following clauses describe the way, how the listed parameters can be determined. Therefore, specific test sequences are necessary. The test sequences indicated by letters (e. g. TEST A) can be subdivided into phases indicated by a number (e. g. A1 – conditioning). Between the end of one phase and the start of the following phase, a maximum stand-by time of 10 min is allowed. During this stand-by time the ambient temperature only shall be measured and recorded.

NOTE 5 One essential point of the described methods is, that measurements inside the store are avoided.

NOTE 6 The determination of all above listed store parameters is possible only according to the method described under 6.3.2. However, some of the parameters may also be determined according to the method described under 6.3.1.

6.3.1 Test sequences

This clause describes the thermal test sequences for the different groups of stores.

6.3.1.1 General

In the following, the conditions are specified under which the stores shall be tested. An overview on the test sequences for determination of the different store parameters is given in Table 3.

Table 3 — Compilation of the test sequences

Purpose of test	Test	Clause
Determination of the store volume, the heat transfer capacity rate of the lowest heat exchanger and the thermal stratification during discharge.	Test C: group 1 group 2 group 3 group 4	 6.3.1.2.1 6.3.1.2.2 6.3.1.2.3 6.3.1.2.4
Determination of the thermal stratification during discharge with a 'high' flow rate	Test S	6.3.1.3
Determination of the heat loss capacity rate of the entire store during stand-by	Test L: group 1 group 2 group 3 group 4	 6.3.1.4.1 6.3.1.4.2 6.3.1.4.3 6.3.1.4.4
Determination of the heat transfer capacity rate and the position of the auxiliary heat exchanger(s)	Test NiA for stores with auxiliary heat exchanger(s)	6.3.1.5
Determination of the position and length of the electrical heating element(s)	Test EiA for stores with electrical heating elements	6.3.1.6
Determination of the degradation of thermal stratification during stand-by	Test NiA and Test NiB for stores of group 1 and 3	6.3.1.7.1 6.3.1.7.1
	Test NiA and Test NiB for stores of group 2 and 4	6.3.1.5 6.3.1.7.2
	Test EiA and Test EiB for stores with electrical auxiliary heating elements only	6.3.1.6 6.3.1.7.3

NOTE 1 The exact vertical positions of the temperature sensors as well as the upper connections of the heat exchangers above which the store is charged mixedly, have a minor influence on the thermal behaviour of the store. Hence these vertical positions need not to be determined by means of parameter identification. It is recommended to measure the corresponding positions or to determine them from the drawing of the store.

The following applies to all tests for determination of the heat transfer capacity rate of the heat exchangers:

The flow rates through the heat exchangers as well as the heating powers which are given for the determination of the heat transfer capacity rate (dependent on temperature) of the heat exchangers are recommendations. Other flow rates and heating powers may also be used, if they better correspond to the real operating conditions or are specified in the manufacturers instruction. This shall, however, be specified in the test report.

NOTE 2 The heat transfer capacity rate of immersed heat exchangers is increasing with the mean local temperature (the water becomes more dilute), the transmitted heating power and the flow rate through the heat exchanger. Therefore, different results for different operating conditions are expected.

6.3.1.2 Determination of the store volume, the heat transfer capacity rate of the lowest heat exchanger and the thermal stratification during discharge (Test C)

The store volume determined by the method described below is the effective store volume.

NOTE For stores with a dead volume, the effective thermal capacity determined according to 6.3.1.1 is greater than the store volume, or the thermal capacity of the entire store, determined according to this clause. This effect is to be explained by the long charging period which is necessary to achieve steady-state conditions and during which the fluid in the dead volume is heated due to heat conduction. During usual operation, no heat is stored in the dead volume. Hence, for stores with a dead volume, the effective store volume is less than the store volume measured in litres. The effective store volume may be determined by a test sequence by means of which it is not intended to reach steady-state conditios.

The heat transfer capacity rate of the heat exchangers refers to heat exchangers which are not separated from the storage device.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The connections which enable a complete charge of the store, shall be fitted to the charge circuit of the testing stand.

6.3.1.2.1 Group 1

The goal of this test is the determination of the effective store volume and the thermal stratification during discharge with a relatively 'low' flow rate.

Test C (group 1)

- Test phase C1: conditioning until steady-state is reached,
- test phase C2: charging until $\vartheta_{C,}$ = 55 °C,
- test phase C3: discharging until steady-state is reached.

Table 4 — Flow rates and store inlet temperatures for Test C (group 1)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
C1	conditioning	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable
C2	charge	$0{,}5 \times \dot{V}_n$	60,00	variable	0	–	–
C3	discharge	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable

6.3.1.2.2 Group 2

The goal of this test is the determination of the effective store volume, the heat transfer capacity rate of the charge heat exchanger and the stratification during discharge with a relatively 'low' flow rate.

Test C (group 2)

- Test phase C1: conditioning until steady-state is reached,
- test phase C2: charge with constant charge power of $\tilde{P}_C = 1{,}0 \times P_n$ until $\vartheta_{C,o}$ = 60 °C,
- test phase C3: discharge until steady-state is reached.

Table 5 — Flow rates and store inlet temperatures for Test C (group 2)

Test phase	**Process**	**Charge circuit**			**Discharge circuit**		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
C1	conditioning	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable
C2	charge	$1{,}2 \times \dot{V}_n$	variable	variable	0	–	–
C3	discharge	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable

6.3.1.2.3 Group 3

The goal of this test is the determination of the effective store volume and the heat transfer capacity rate of the discharge heat exchanger with a relative 'low' flow rate.

The thermal stratification during discharge can, of course, only be assessed if the store is discharged stratified.

Test C (group 3)

- Test phase C1: conditioning until steady-state is reached,
- test phase C2: charge until $\vartheta_{C,o}$ = 55 °C,
- test phase C3: discharge until steady-state is reached.

Table 6 — Flow rates and store inlet temperatures for Test C (group 3)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
C1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{n}$	20,00	variable
C2	charge	$0{,}5 \times \dot{V}_{n}$	60,00	variable	0	–	–
C3	discharge	0	–	–	$0{,}5 \times \dot{V}_{n}$	20,00	variable

6.3.1.2.4 Group 4

The goal of this test is the determination of the effective store volume and the heat transfer capacity rate of the charge and discharge heat exchangers. The thermal stratification during discharge can, of course, only be assessed if the store is discharged stratified.

Test C (group 4)

- Test phase C1: conditioning until steady-state is reached,
- test phase C2: charge with constant charge power of $\tilde{P}_{C} = 1{,}0 \times \tilde{P}_{n}$ until $\vartheta_{C,o}$ = 60 °C ,
- test phase C3: discharge until steady-state is reached.

Table 7 — Flow rates and store inlet temperatures for Test C (group 4)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
C1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{n}$	20,00	variable
C2	charge	$1{,}2 \times \dot{V}_{n}$	variable	variable	0	–	–
C3	discharge	0	–	–	$0{,}5 \times \dot{V}_{n}$	20,00	variable

6.3.1.3 Determination of the thermal stratification during discharge with a 'high' flow rate (TEST S)

For some stores of group 1 and 2, the thermal stratification during discharge and/or the draw off profile (plotted over the number of the withdrawn store volumes) may depend on the draw off flow rate. The goal of this test is to determine the thermal stratification during discharge with a 'high' flow rate.

Test S shall only be performed when it is determined by Test C that the store is discharged stratified.

Test S

According to Test C specified in 6.3.1, but with a discharge flow rate of $\tilde{\dot{v}}_{\mathrm{D}} = \dot{v}_{\mathrm{n}}$, but not less than 600 l/h.

6.3.1.4 Determination of the stand-by heat loss capacity rate of the entire store (Test L)

The goal of this test is the determination of the heat loss capacity rate of the entire store during stand-by. Under consideration of note 2 in 6.3.1, the same operating conditions for the heat exchanger as in Test C shall be used.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The connections which enable a complete charge of the store, shall be fitted to the charge circuit of the testing stand.

6.3.1.4.1 Group 1

Test L

- Test phase L1: conditioning until steady-state is reached,
- test phase L2: charge until $\vartheta_{\mathrm{C,o}}$ = 55 °C,
- test phase L3: 48 h stand-by,
- test phase L4: discharge until steady-state is reached.

Table 8 — Flow rates and store inlet temperatures for Test L (group 1)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
L1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
L2	charge	$0{,}5 \times \dot{V}_{\mathrm{n}}$	60,00	variable	0	–	–
L3	stand-by	0	–	–	0	–	–
L4	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

6.3.1.4.2 Group 2

Test L

- Test phase L1: conditioning until steady-state is reached,
- test phase L2: charge with constant charge power of $\tilde{P}_{\mathrm{C}} = 1{,}0 \times \tilde{P}_{\mathrm{n}}$ until $\vartheta_{\mathrm{C,o}}$ = 60 °C,
- test phase L3: 48 h stand-by,

— test phase L4: discharge until steady-state is reached.

Table 9 — Flow rates and storage device inlet temperatures for Test L (group 2)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
L1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
L2	charge	$1{,}2 \times \dot{V}_{\mathrm{n}}$	variable	variable	0	–	–
L3	stand-by	0	–	–	0	–	–
L4	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

6.3.1.4.3 Group 3

Test L

— Test phase L1: conditioning until steady-state is reached,

— test phase L2: charge until $\vartheta_{\mathrm{C,o}}$ = 55 °C,

— test phase L3: 48 h stand-by,

— test phase L4: discharge until steady-state is reached.

Table 10 — Flow rates and store inlet temperatures for Test L (group 3)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
L1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
L2	charge	$0{,}5 \times \dot{V}_{\mathrm{n}}$	60,00	variable	0	–	–
L3	stand-by	0	–	–	0	–	–
L4	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

6.3.1.4.4 Group 4

Test L

— Test phase L1: conditioning until steady-state is reached,

— test phase L2: charge with constant charge power of $\tilde{P}_{\mathrm{C}} = 1{,}0 \times P_{\mathrm{n}}$ until $\vartheta_{\mathrm{C,o}}$ = 60 °C,

— test phase L3: 48 h stand-by,

- test phase L4: discharge until steady-state is reached.

Table 11 — Flow rates and store inlet temperatures for Test L (group 4)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
L1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
L2	charge	$1{,}2 \times \dot{V}_{\mathrm{n}}$	variable	variable	0	–	–
L3	stand-by	0	–	–	0	–	–
L4	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

6.3.1.5 Determination of the heat transfer capacity rate and the position of the auxiliary heat exchanger(s) (Test NiA)

NOTE 1 If there is more than one additional heat exchanger, i indicates the number of the heat exchanger.

NOTE 2 The exact position of the upper connection of an upper (auxiliary) heat exchanger is important, if it is near to the top and causes a thermal stratification inside the store. The determination of this position by means of the test method described below is only in that case possible.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The connections of the auxiliary heat exchanger the heat transfer capacity rate of which shall be determined, shall be fitted to the charge circuit of the testing stand according to the manufacturer's instruction.

Test NiA

- Test phase NiA1: conditioning until steady-state is reached,
- test phase NiA2: charge with constant charge power of $\tilde{P}_{\mathrm{C}} = 2{,}0 \times \tilde{P}_{\mathrm{n}}$ until temperature at the auxiliary heating sensor is equal 60 °C,
- test phase NiA3: discharge until steady-state is reached.

Table 12 — Flow rates and store inlet temperatures for Test NiA (group 2 or 4)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
NiA1	conditioning	0	–	–	$0,5 \times \dot{V}_{n}$	20,00	variable
NiA2	charge	$1,0 \times \dot{V}_{n}$	variable	variable	0	–	–
NiA3	discharge	0	–	–	$0,5 \times \dot{V}_{n}$	20,00	variable

6.3.1.6 Determination of the position(s) and length(s) of the electrical heating sources(s) (Test EiA)

The determination of the (vertical) position(s) of the electrical heating sources(s) is necessary if it/they are installed horizontally.

The length (as a model parameter) of the electrical heating source(s) shall be determined, if it/they is/are installed vertically in the top of the store.

This test applies only to stores with electrical heating sources(s).

NOTE If there is more than one electrical heating source, i indicates the number of the heating source.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The charging connections shall be closed and all charging heat exchangers shall be filled with water. The closed connections shall be insulated in the same way as the store.

Test EiA

- Test phase EiA1: conditioning until steady-state is reached,
- test phase EiA2: charge with the nominal electrical power (specified by the manufacturer) until the heater is switched off by the thermostat (ϑset = 60 °C),
- test phase EiA3: discharge until steady-state is reached.

Table 13 — Flow rates and store inlet temperatures for Test EiA

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
EiA1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
EiA2	charge	0	–	–	0	–	–
EiA3	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

6.3.1.7 Determination of the degradation of thermal stratification during stand-by

A parameter describing the degradation of thermal stratification during stand-by shall only be determined, if stratification occurs during usual operation (e. g. for a store of group 4 that is charged and discharged mixed, this parameter can not be determined).

To obtain this parameter, the upper (auxiliary) part of the store is charged and discharged twice in the same way. The first time the discharge is performed immediately after charging, the second time a stand-by of 24 h is included. The determination of the parameter describing degradation of thermal stratification during stand-by, is based on the 'comparison' of the two draw off profiles by means of parameter identification.

6.3.1.7.1 Group 1 and Group 3 (Test NA and Test NB)

The test of stores of group 3 is only necessary, if they enable a stratified discharge.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The connections which enable a complete charge of the auxiliary part of the store, shall be fitted to the charge circuit of the testing stand.

Test NA

- Test phase NA1: conditioning until steady-state is reached,
- test phase NA2: charge until the integrated flow rate $\dot{V}_{\mathrm{C}} = 0{,}5 \times V_{\mathrm{n}}$,
- test phase NA3: discharge until steady-state is reached.

Table 14 — Flow rates and storage device inlet temperatures for Test NA (group 1 and 3)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
NA1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
NA2	charge	$0{,}5 \times \dot{V}_{\mathrm{n}}$	60,00	variable	0	–	–
NA3	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

TestNB

- Test phase NB1: conditioning until steady-state is reached,
- test phase NB2: charge until the integrated flow rate $\dot{V}_{\mathrm{C}} = 0{,}5 \times V_{\mathrm{n}}$,
- test phase NB3: 24 h stand-by,
- test phase NB4: discharge until steady-state is reached.

Table 15 — Flow rates and store inlet temperatures for Test NB (group 1 and 3)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D,o}}$ °C
NB1	conditioning	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable
NB2	charge	$0{,}5 \times \dot{V}_{\mathrm{n}}$	60,00	variable	0	–	–
NB3	stand-by	0	–	–	0	–	–
NB4	discharge	0	–	–	$0{,}5 \times \dot{V}_{\mathrm{n}}$	20,00	variable

6.3.1.7.2 Group 2 and Group 4 with an auxiliary heat exchanger (Test NB)

The test of stores of group 4 is only necessary, if they enable a stratified discharge.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The heat exchanger which enable a charge of the auxiliary part of the store, shall be connected to the charge circuit of the testing stand.

NOTE Test NA has already been performed according to 6.3.2.1.5.

Test NB

- Test phase NB1: conditioning until steady-state is reached,
- test phase NB2: charge with constant charge power of $\tilde{P}_C = 2{,}0 \times P_n$ until the temperature at the position of the auxiliary heating sensor is 60 °C,
- test phase NB3: 24 h stand-by,
- test phase NB4: discharge until steady-state is reached.

Table 16 — Flow rates and store inlet temperatures for Test NB (group 2 and 4)

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
NB1	conditioning	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable
NB2	charge	$1{,}0 \times \dot{V}_n$	variable	variable	0	–	–
NB3	stand-by	0	–	–	0	–	–
NB4	discharge	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable

6.3.1.7.3 Stores with electrical heat sources

This test shall only be performed if an electrical auxiliary heater is used.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store, shall be fitted to the discharge circuit of the testing stand.

The charging connections shall be closed and all charging heat exchangers shall be filled with water. The closed connections shall be insulated in the same way as the store.

Test EB

- Test phase EB1: conditioning until steady-state is reached,
- test phase EB2: charge with the nominal electrical power (according to the manufacturer's instructions),
- test phase EB3 24 h stand-by,
- test phase EB4: discharge until steady state is reached.

Table 17 — Flow rates and store inlet temperatures for Test EB

Test phase	Process	Charge circuit			Discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
EB1	conditioning	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable
EB2	charge	0	–	–	0	–	–
EB3	stand-by	0	–	–	0	–	–
EB4	discharge	0	–	–	$0{,}5 \times \dot{V}_n$	20,00	variable

6.3.2 Data processing of the test sequences

When all necessary tests as described in 6.3.1 are performed, identification of store parameters shall be carried out, using a numerical store model that fulfils the requirements given in annex B and an adequate parameter identification algorithm that fulfils the requirements given in annex C.

The store model shall meet the requirements of the benchmark tests given in annex B.

For the parameter identification the measuring data can be compressed and/or converted to constant time steps. In both cases, the data records shall represent mean values for the corresponding time step. During charge and discharge, the time steps should not exceed 3 min. During stand-by, a maximum time step of 15 min is allowed.

For the fit the measured values of the inlet store temperatures, ambient temperature, flow rates and the power of the electrical heating source(s) shall be used as inputs. Since at the beginning of each test the store is always conditioned to 20 °C, no skip time is required. Hence the data used for fitting, shall start with the second test phase, and ϑ_s = 20 °C shall be used as initial temperature for the store model.

6.3.2.1 Determination of all store parameters (except the vertical position of the temperature sensors)

All parameters which are determined by parameter identification shall be identified during one parameter identification process. This requirement not relevant for the determination of the vertical positions of the temperature sensors.

For every time step during the fit for each connection 'x' ($x = C$ for charge and $\mathrm{x} = \mathrm{D}$ for discharge), the absolute difference between the transferred measured and predicted power shall be calculated by

$$\Delta P_{\mathrm{x}} = \left| P_{\mathrm{x,p}} - P_{\mathrm{x,m}} \right| \tag{1}$$

where the transferred predicted power, $P_{\mathrm{x,p}}$, and the measured power, $P_{\mathrm{x,m}}$, shall be calculated according the following equations:

$$P_{\mathrm{x,p}} = \overline{\rho} \times \overline{c}_{\mathrm{p}} \times \dot{V} \times \left(\vartheta_{\mathrm{x,i}} - \vartheta_{\mathrm{x,o,p}} \right) \tag{2}$$

$$P_{\mathrm{x,m}} = \overline{\rho} \times \overline{c}_{\mathrm{p}} \times \dot{V} \times \left(\vartheta_{\mathrm{x,i}} - \vartheta_{\mathrm{x,o,m}} \right) \tag{3}$$

The function $f(t)$ which shall be minimised for the determination of the store parameters (except the vertical position of the temperature sensors) is the integral of the sum over all absolute power differences calculated by

$$f(t) = \int_t \sum_x \Delta P_x d\, t \tag{4}$$

6.3.2.2 Determination of the vertical position of the temperature sensors

If all parameters of the store (except the vertical position of the temperature sensors) have been determined according to 6.3.2.1 the vertical position of the temperature sensors or their location respectively shall be performed as described in this clause. For the description of the thermal behaviour of the store by means of the numerical model the parameters determined according to 6.3.2.1 shall be used.

For every time step during the fit for each temperature sensor 'z' the absolute difference between the measured temperature at the location of the temperature sensor, $\vartheta_{z,m}$, and the predicted temperature at the location of the temperature sensor, $\vartheta_{z,p}$, shall be calculated by

$$\Delta\vartheta_z = \left|\vartheta_{z,m} - \vartheta_{z,p}\right| \tag{5}$$

The function $f(t)$ which shall be minimised for the determination of vertical position of the temperature sensor is the integral over all absolute temperature difference for the temperature sensor 'z'

$$f(t) = \int_t \Delta\vartheta_z d\, t \tag{6}$$

The determination of the vertical position of the temperature sensors has to be performed separately for each temperature sensor 'z' or vertical position respectively.

7 Store test combined with a system test according to ISO 9459-5

The procedure is in principle similar to 6.3.1 except that the data are gained during a whole system test according to ISO 9459-5 with additional sensors in the collector loop. The use of additional sensors in the collector loop is, however, only allowed if the normal function of the system is not affected.

Using measuring equipment according to ISO 9459-5, the following data shall be measured and recorded additionally to the measurements required by ISO 9459-5:

- The volumetric flow through the collector loop as well as the inlet temperature at the store or heat exchanger and the outlet temperature at the store or heat exchanger of the collector loop.
- If the system is equipped with an integrated hot water auxiliary heating, the volumetric flow through the auxiliary loop as well as the inlet temperature at the store or heat exchanger and the outlet temperature at the store or heat exchanger of the auxiliary loop.
- If an immersed electrical auxiliary heater is fitted to the store, no additional measurements are necessary as Paux is already measured.

For the determination of the store parameters by means of parameter identification see 6.3.2.

8 Test report

8.1 General

The test report shall include:

a) A detailed description and the technical data of the tested store (based on the manufacturer's instruction);

b) the determined parameters and a description of them;

c) reference to the used store model (parameters for simulation).

8.2 Description of the store

The description of the store shall be based on the information provided by the manufacturer.

a) General data

- Manufacturer,
- type,
- year of construction,
- serial number,
- nominal volume,
- description and drawing of the schematic design.

b) Stored water

- Volume,
- material and corrosion protection (only in case of drinking water),
- maximum operation pressure,
- maximum operation temperature,
- thermal insulation,
- diameter and type of connections.

c) Electrical heating source(s)

- Voltage,
- nominal heating power,
- diameter and type of connection.

d) Heat exchanger(s)

- Volumen,
- material and corrosion protection (only in case of drinking water),
- type of pipes (with/without ribs, coil etc.),
- size of the area for heat transfer,
- position inside the store,
- maximum operation pressure,

- maximum operation temperature,
- diameter and type of connections.

8.3 Test results

NOTE 1 Some of the parameters used for the characterisation of the thermal behaviour of the store are related to the used store model. Therefore, information on these parameters and the store model should be provided.

a) Geometrical data

  - Weight of the complete storage device (empty),
  - maximum height of the complete storage device,
  - maximum diameter of the complete storage device.

b) Volumes

  - Volume of the stored water,
  - volume of the heat exchanger(s).

c) Thermal parameters

  - Thermal capacity of the entire store,
  - thermal capacity of appropriate parts of the store (e. g. auxiliary heated part),
  - stand-by heat loss capacity rate (optional: operating heat loss capacity rate),
  - parameter describing the degradation of thermal stratification during stand-by,
  - parameter describing the quality of thermal stratification during direct discharge,
  - heat transfer capacity rate $(UA)_{\mathrm{hx,s}}$ of the heat exchanger(s). The test conditions (fluid, temperatures, flow rate, transferred heating power) for the determination of the heat transfer capacity rate shall be mentioned in the test report.

d) Temperature sensors

  - Vertical positions of the temperature sensors.

NOTE 2 If a diagram of $(UA)_{\mathrm{hx,s}}$ over the temperature is included in the test report, the transferred heating power at each point of the diagram should be indicated, if the transferred heating power varies for the different points of the plotted $(UA)_{\mathrm{hx,s}}$ values.

In addition, the draw-off profiles for two different draw-off flow rates (e. g. from Test C and Test S) and the two draw-off profiles used for the determination of the parameter describing the degradation of thermal stratification during stand-by (e. g. from Test NiA and Test NiB or from Test EiA and Test EiB), should be included.

8.4 Parameters for the simulation

All parameters which are necessary to describe the thermal behaviour of the store in combination with a suitable numerical calculation model shall be recorded. In addition to the parameters listed in 8.3, the following parameters are required:

a) Data of the fluid (e. g. constant values for the density and the specific heat capacity),

b) position of the

  - inlet and outlet connection(s) for direct charge and discharge,
  - inlet and outlet connection(s) of the heat exchangers,

c) information on the ability for stratified charging/discharging.

Annex A
(normative)

Requirements for the numerical store model

A.1 General

For the system performance characterisation by means of component testing and whole system simulation, numerical models which are able to describe the thermal behaviour of the components are required.

This annex gives instructions for modelling the store, in order to enable a uniform modelling of the hot water store.

A.2 Assumptions

In order to simplify the model, it is possible to use the following assumptions to describe the thermal behaviour of the store:

- Each component of the store (e. g. tank, heat exchanger) can be assumed to be isothermal in horizontal direction.
- Temperature inversion inside the tank, which means $d\vartheta/dz < 0$, can be removed by an appropriate algorithm at the end of a time step.
- The thermal capacity of the storage vessel can be neglected. This capacity can be added to the thermal capacity of the stored water.
- The thermal capacity of the pipes of the heat exchanger(s) can be neglected.
- The physical effects of heat conduction in the water and the metal wall of the tank and the convection in the water can be lumped together in an effective vertical thermal conductivity.

A.3 Energy balance

For models which are based on a finite difference method with segments (nodes) of equal capacities, the energy balance for a node (i) of the stored water is represented by equation (A.1). The index (i+1) indicates the node above (i) and the index (i–1) indicates the node below (i).

The left member of equation (A.1) describes the temporary change of the internal energy. The heat transport caused by the mass flows through the number of 'p' double ports is represented by the first sum on the right member. The electrical auxiliary heater is treated as an internal heat source. The heat transfer between the nodes of the heat exchanger and the stored water is described by the third term. If there are more heat exchangers, additional terms shall be added. The fourth term represents effects which can be described by using an effective vertical thermal conductivity. The last term considers the heat loss to the ambient.

$$\frac{C_{\mathrm{S}}}{N}\times\frac{d\vartheta_{\mathrm{s,i}}}{dt}=\sum_{p}\dot{m}_{\mathrm{dp}}\times c_{\mathrm{p,s}}\times\left[\xi_1\times\left(\vartheta_{\mathrm{s,i-1}}-\vartheta_{\mathrm{s,i}}\right)+\xi_2\left(\vartheta_{\mathrm{s,i}}-\vartheta_{\mathrm{s,i+1}}\right)\right]+\frac{\dot{Q}_{\mathrm{aux}}}{n_{\mathrm{aux}}}+\xi_{\mathrm{hx,3}}\times\frac{(UA)_{\mathrm{hx,s}}}{n_{\mathrm{hx}}}\times\left(\vartheta_{\mathrm{hx,i}}-\vartheta_{\mathrm{s,i}}\right)$$

$$+\lambda_{\mathrm{eff}}\times\frac{A}{Z}\times N\times\left[\left(\vartheta_{\mathrm{s,i+1}}-\vartheta_{\mathrm{s,i}}\right)+\left(\vartheta_{\mathrm{s,i-1}}-\vartheta_{\mathrm{s,i}}\right)\right]-\frac{(UA)_{\mathrm{s,a,k}}}{n_{\Delta\,\mathrm{z,k}}}\times\left(\vartheta_{\mathrm{s,i}}-\vartheta_{\mathrm{am}}\right) \tag{A.1}$$

where

A	is the cross-section area of the stored water volume;
C_{S}	is the thermal capacity of the tank;
c_{p}	is the specific heat capacity;
$\dot{m}_{\mathrm{dp}}$	is the mass flow rate through double port, p;
N	is the number of vertical nodes;
n_{aux}	is the number of nodes occupied by the electrical auxiliary heating element;
$n_{\Delta\mathrm{z,k}}$	is the number of nodes occupied by zone k with the length, Δz;
n_{hx}	is the number of nodes occupied by the heat exchanger, hx;
p	is the number of double ports;
$(UA)_{\mathrm{hx,s}}$	is the heat transfer capacity rate for the heat exchanger to the store;
$(UA)_{\mathrm{s,a,k}}$	is the heat loss capacity rate for the zone, k;
Z	is the height of the store;
$\dot{Q}_{\mathrm{aux}}$	is the heat flow from the auxiliary heating element;
ϑ	is the temperature;
λ_{eff}	is the effective vertical thermal conductivity.

The logical switches ξ_1 are used in the following way:

- $\xi_1 = 1$ if $\dot{m}_{\mathrm{dp}}$ from bottom to top (upwards), otherwise $\xi_1 = 0$;
- $\xi_2 = 1$ if $\dot{m}_{\mathrm{dp}}$ from top to bottom (downwards), otherwise $\xi_2 = 0$;
- $\xi_{\mathrm{hx,3}} = 1$ if node i of the tank is in contact with node i of heat exchanger hx, otherwise $\xi_{\mathrm{hx,3}} = 0$.

Annex B
(normative)

Store model benchmark tests

B.1 General

The benchmark test in this annex shall ensure that the store model fulfils fundamental requirements. Hence, for simplified operating cases the results calculated by the model shall be compared with the analytical solutions of the differential equations.

B.2 Temperature of the store during stand-by

It is assumed that the store is fully mixed and supplied with a homogeneous insulation.

The decrease of the temperature of the store during stand-by can be calculated by equation (B.1).

$$\vartheta(t) = \vartheta_{\text{am}} + \left(\vartheta_0 - \vartheta_{\text{am}}\right) \times e^{\frac{-(UA)_{\text{s,a}}}{C_{\text{s}}} \times t} \tag{B.1}$$

The temperature as a function of time ($0 \leq t \leq 400$ h) shall be calculated by equation (B.1) (*analytical*) and by the store model (*numerical*) with the following parameters :

— constant ambient temperature : ϑ_{am} = 20 °C,

— initial temperature : ϑ_0 = 60 °C,

— thermal capacity of the store (constant) : C_{s} = 2,0 MJ/,

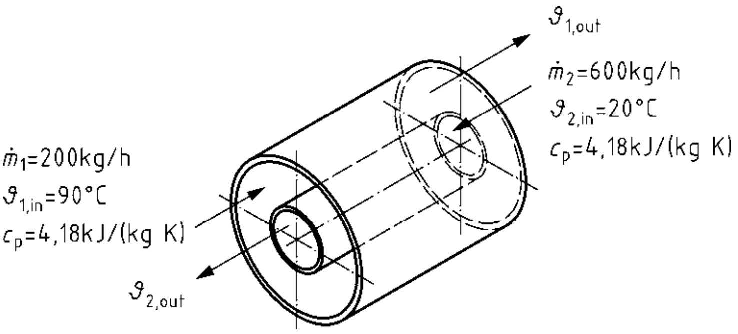
— heat loss capacity rate : $(UA)_{\text{s,a}}$ = 7,0 W/K.

This benchmark test shall be considered as valid if the maximum difference between the temperatures calculated in an analytical and numerical way is less then 0,001 K.

If the model is part of a simulation program which enables the use of different time steps, this benchmark test shall be carried out for time steps of 1 min and 60 min.

B.3 Heat transfer from heat exchanger to store

For checking the correct implementation of the heat transfer from the heat exchanger to the store tank, the store may be considered as a twin tube heat exchanger. For this benchmark test it shall be operated as a counter-flow heat exchanger (see Figure B.1).



NOTE Heat transfer rate $(UA)_{h1,s}$ = 1 667 W/K.

Figure B.1 — Store considered as a twin tube heat exchanger

For the parameters given in Figure 4 the results of the analytical solution are listed in Table B.1.

Table B.1 — Results of the analytical solution

$\vartheta_{1,out}$ °C	$\vartheta_{2,out}$ °C	$\dot{Q}$ kW
20,391	43,202	16,165

This benchmark test may be considered as valid if the maximum difference between the calculation in an analytical and numerical way is less then 0,2 K for the temperatures and less then 1 % (based on the analytical solution) for the transferred power.

Annex C
(normative)

Benchmarks for the parameter identification

This benchmark test shall ensure that the evaluation procedure based on parameter identification leads to acceptable results.

A set of test and verification sequences for a solar domestic hot water store is available from:

DIN Deutsches Institut für Normung e. V.
Normenausschuss Heiz- und Raumlufttechnik (NHRS)
Burggrafenstraße 6
D-10787 Berlin

NOTE As soon as prEN/TS 12977-6 (Software and data for testing of thermal solar systems and components) is available, these data should be transfered to this new standard.

Based on this data, the parameters of the store shall be determined by means of parameter identification. Using the determined parameters, the verification test sequences shall be re-simulated.

This benchmark test may be considered as valid if the following criteria for the acceptance of the test results are fulfilled:

For each sequence the measured and predicted (simulated) energies transferred through each charge and discharge connection shall be calculated separately. Periods used for conditioning at the beginning of the test sequence shall be excluded.

For each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the relative error in transferred energy $\varepsilon_{\mathrm{x,Q}}$ shall be calculated according equation (D.2).

If the relative error in transferred energy $\varepsilon_{\mathrm{x,Q}}$ exceeds 3,0 %, than the test is considered as not valid.

For each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the relative error in transferred power $\varepsilon_{\mathrm{x,P}}$ shall be calculated according equation (D.6).

If the relative error in transferred energy $\varepsilon_{\mathrm{x,P}}$ exceeds 3,0 %, than the test is considered as not valid.

Annex D

(informative)

Verification of store test results

D.1 General

In order to verify the results obtained from tests as described in clause 6 and 7 the verification procedures described in this annex can be used. It is recommended to use them especially in case of new or innovative store designs or features where no previous experience is available.

The test results are represented by the store model used and the determined parameters. Both, model and parameters, are verified by re-simulating a 'dynamic sequence' that covers a wide range of operating conditions (charge, discharge, stand-by, etc.) and that has not been used for identifying the store parameters.

D.2 Test sequences for verification of store test results

Test sequences for verification of store test results (verification sequences) can be obtained from measurements on a store testing stand as described in clause 6 or during a whole system test as described in clause 7.

D.2.1 Verification sequences from measurements on a store testing stand

The testing stand and measuring equipment as described in 6.1 shall be used. The store shall be mounted as described in 6.2.

In the following the thermal verification sequences for the different groups of stores are specified. An overview on the sequences for the verification of the different store parameters is given in Table D.1.

The verification sequences are designed with the purpose to stimulate all physical effects which are represented by the determined parameters.

NOTE The verification test sequences are separately performed for the complete store volume as well as parts of the store volume e. g. the auxiliary heated part. Principally each dynamic test sequence consists of following phases:

- charge of the respective store volume,
- discharge of half of the charged volume,
- recharge,
- stand-by,
- complete discharge.

Table D.1 — Compilation of the verification sequences

Verification of determined parameters for	Sequence	Clause
– Store volume respectively thermal capacity – Heat loss capacity rate of the store	Test V for stores of all groups:	
– Heat transfer capacity rate of the lowest heat exchanger and discharge heat exchanger	group 1	D.2.1.1.2
	group 2	D.2.1.1.3
– Degradation of thermal stratification during stand-by	group 3	D.2.1.1.4
– Thermal stratification during discharge	group 4	D.2.1.1.5
– Heat transfer capacity rate and position of the auxiliary heat exchanger(s) – Degradation of thermal stratification during stand-by – Heat loss capacity rate of the auxiliary part of the store	Test NiV for stores with auxiliary heat exchanger(s)	D.2.1.3
– Position and/or length of the electrical heating element(s) – Degradation of thermal stratification during stand-by – Heat loss capacity rate of the auxiliary part of the store	Test EiV for stores with electrical auxiliary heating element(s)	D.2.1.4

D.2.1.1 Stores of all groups

D.2.1.1.1 Connection of the storage device to the testing stand

The storage device shall be connected to the testing stand according to 6.2.

The connections that enable a complete discharge of the store, shall be connected to the discharge circuit of the testing stand.

The connections that enable a complete charge of the store, shall be connected to the charge circuit of the testing stand.

D.2.1.1.2 Group 1

The goal of this test sequence is the verification of the determined parameters describing the effective store volume, the overall heat loss capacity rate, the degradation of thermal stratification during stand-by and the thermal stratification during discharge.

Test V (group 1)

- Test phase V1: conditioning until steady state is reached,
- test phase V2: charging until $T_{\mathrm{C,o}}$ = 35 °C,
- test phase V3: discharging of 0,5 × V_{n},
- test phase V4: charging of 0,5 × V_{n},
- test phase V5: 16 h stand-by,
- test phase V6: discharging until steady state is reached.

Table D.2 — Flow rates and storage device inlet temperatures for Test V (group 1)

Test phase	Process	Charging circuit			Discharging circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{T}_{C,i}$ °C	$\tilde{T}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{T}_{D,i}$ °C	$\tilde{T}_{D,o}$ °C
V1	conditioning	0	–	–	$0{,}75 \times \dot{V}_{n}$	20,00	variable
V2	charging	$0{,}5 \times \dot{V}_{n}$	40,00	variable	0	–	–
V3	discharging	0	–	–	$0{,}75 \times \dot{V}_{n}$	20,00	variable
V4	charging	$0{,}5 \times \dot{V}_{n}$	60,00	variable	0	–	–
V5	stand-by	0	–	–	0	–	–
V6	discharging	0	–	–	$0{,}75 \times \dot{V}_{n}$	20,00	variable

D.2.1.1.3 Group 2

The goal of this test sequence is the verification of the determined parameters describing the effective store volume, the overall heat loss capacity rate, the heat transfer capacity rate of the heat exchanger, the degradation of thermal stratification during stand-by and the thermal stratification during discharge.

Test V (group 2)

- Test phase V1: conditioning until steady state is reached,
- test phase V2: charging with constant charge power of $\tilde{P}_{C} = 1{,}0 \times P_{n}$ until $T_{C,o}$ = 60 °C,
- test phase V3: discharging of 0,5 × V_{n},
- test phase V4: charging with constant charge power of $\tilde{P}_{C} = 1{,}0 \times P_{n}$ until $T_{C,o}$ = 40 °C,
- test phase V5: 16 h stand-by,
- test phase V6: discharging until steady state is reached.

Table D.3 — Flow rates and storage device inlet temperatures for Test V (group 2)

Test phase	Process	Charging circuit			Discharging circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{T}_{\mathrm{C,i}}$ °C	$\tilde{T}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{T}_{\mathrm{D,i}}$ °C	$\tilde{T}_{\mathrm{D,o}}$ °C
V1	conditioning	0	–	–	0,75 × $\dot{V}_{\mathrm{n}}$	20,00	variable
V2	charging	1,2 × $\dot{V}_{\mathrm{n}}$	variable	variable	0	–	–
V3	discharging	0	–	–	0,75 × $\dot{V}_{\mathrm{n}}$	20,00	variable
V4	charging	1,2 × $\dot{V}_{\mathrm{n}}$	variable	variable	0	–	–
V5	stand-by	0	–	–	0	–	–
V6	discharging	0	–	–	0,75 × $\dot{V}_{\mathrm{n}}$	20,00	variable

D.2.1.1.4 Group 3

The goal of this test sequence is the verification of the determined parameters describing the effective store volume, the overall heat loss capacity rate, the heat transfer capacity rate of the discharge heat exchanger, the degradation of thermal stratification during stand-by and the thermal stratification during discharge. The thermal stratification during discharge can, of course, only be assessed and verified if the store is discharged stratified.

Test V (group 3)

- Test phase V1: conditioning until steady state is reached,
- test phase V2: charging until $T_{\mathrm{C,o}}$ = 35 °C,
- test phase V3: discharging of 0,5 × V_{n},
- test phase V4: charging of 0,5 × V_{n},
- test phase V5: 16 h stand-by,
- test phase V6: discharging until steady state is reached.

Table D.4 — Flow rates and storage device inlet temperatures for Test V (group 3)

Test phase	Process	Charging circuit			Discharging circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{T}_{C,i}$ °C	$\tilde{T}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{T}_{D,i}$ °C	$\tilde{T}_{D,o}$ °C
V1	conditioning	0	–	–	$0{,}75 \times \dot{V}_n$	20,00	variable
V2	charging	$0{,}5 \times \dot{V}_n$	40,00	variable	0	–	–
V3	discharging	0	–	–	$0{,}75 \times \dot{V}_n$	20,00	variable
V4	charging	$0{,}5 \times \dot{V}_n$	60,00	variable	0	–	–
V5	stand-by	0	–	–	0	–	–
V6	discharging	0	–	–	$0{,}75 \times \dot{V}_n$	20,00	variable

D.2.1.1.5 Group 4

The goal of this test sequence is the verification of the determined parameters describing the effective store volume, the overall heat loss capacity rate, the heat transfer capacity rate of the charge and discharge heat exchanger, the degradation of thermal stratification during stand-by and the thermal stratification during discharge. The thermal stratification during discharge can, of course, only be assessed and verified if the store is discharged stratified.

Test V (group 4)

- Test phase V1: conditioning until steady state is reached,
- test phase V2: charging with constant charge power of $\tilde{P}_C = 1{,}0 \times P_n$ until $T_{C,o}$ = 60 °C,
- test phase V3: discharging of $0{,}5 \times V_n$,
- test phase V4: charging with constant charge power of $\tilde{P}_C = 1{,}0 \times P_n$ until $T_{C,o}$ = 40 °C,
- test phase V5: 16 h stand-by,
- test phase V6: discharging until steady state is reached.

Table D.5 — Flow rates and storage device inlet temperatures for Test V (group 4)

Test phase	Process	Charging circuit			Discharging circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{T}_{\mathrm{C,i}}$ °C	$\tilde{T}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{T}_{\mathrm{D,i}}$ °C	$\tilde{T}_{\mathrm{D,o}}$ °C
V1	conditioning	0	–	–	$0{,}75 \times \dot{V}_{\mathrm{n}}$	20,00	variable
V2	charging	$1{,}2 \times \dot{V}_{\mathrm{n}}$	variable	variable	0	–	–
V3	discharging	0	–	–	$0{,}75 \times \dot{V}_{\mathrm{n}}$	20,00	variable
V4	charging	$1{,}2 \times \dot{V}_{\mathrm{n}}$	variable	variable	0	–	–
V5	stand-by	0	–	–	0	–	–
V6	discharging	0	–	–	$0{,}75 \times \dot{V}_{\mathrm{n}}$	20,00	variable

D.2.1.2 Stores with auxiliary heat exchanger(s)

The goal of this test sequence is the verification of the determined parameters describing the auxiliary heat exchanger, the degradation of thermal stratification during stand-by and the heat loss capacity rate of the auxiliary part.

NOTE If there is more than one additional heat exchanger, i indicates the number of the heat exchanger.

The exact height of the upper connection of an upper (auxiliary) heat exchanger is only important, if it is near the top and causes a thermal stratification inside the store. Therefore is shall be verified only in that case.

The storage device shall be connected to the testing stand according to 6.2.

The connections that enable a complete discharge of the store, shall be connected to the discharge circuit of the testing stand.

The connections of the auxiliary heat exchanger of which the determined parameters will be verified, shall be connected to the charge circuit of the testing stand according to the manufacturer's instructions.

Test NiV

- Test phase NiV1: conditioning until steady state is reached,
- test phase NiV2: charging with constant charge power of $\tilde{P}_{\mathrm{C}} = 2{,}0 \times P_{\mathrm{n}}$ until the temperature at the position of the auxiliary heating sensor is equal 60 °C,
- test phase NiV3: discharging of the half volume that is above the lower connection of the auxiliary heat exchanger,
- test phase NiV4: charging according to NiV2,
- test phase NiV5: 16 h stand-by,
- test phase NiV6: discharging until steady state is reached.

Table D.6 — Flow rates and storage device inlet temperatures for Test NiA (group 2 or 4)

Test phase	Process	Charging circuit			Discharging circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{T}_{C,i}$ °C	$\tilde{T}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{T}_{D,i}$ °C	$\tilde{T}_{D,o}$ °C
NiV1	conditioning	0	–	–	0,75 × $\dot{V}_n$	20,00	variable
NiV2	charging	1,0 × $\dot{V}_n$	variable	variable	0	–	–
NiV3	discharging	0	–	–	0,75 × $\dot{V}_n$	20,00	variable
NiV4	charging	1,0 × $\dot{V}_n$	variable	variable	0	–	–
NiV5	stand-by	0	–	–	0	–	–
NiV6	discharging	0	–	–	0,75 × $\dot{V}_n$	20,00	variable

D.2.1.3 Stores with electrical auxiliary heating element(s)

The goal of this sequence is the verification of the determined parameters describing the electrical auxiliary heating element(s), the degradation of thermal stratification during stand-by and the heat loss capacity rate of the auxiliary part.

This test shall only be carried out for stores with electrical heating element(s).

NOTE If there is more than one electrical heating element, i indicates the number of heating elements.

The verification of the determined (vertical) position(s) of the electrical heating element(s) is only necessary if it/they are installed horizontal.

The determined length (as a model parameter) of the electrical heating element(s) shall be verified, if it/they is/are installed vertical from the top.

The storage device shall be connected to the testing stand according to 6.2.

The connections that enable a complete discharge of the store, shall be connected to the discharge circuit of the testing stand.

The charging connections shall be closed and all charging heat exchangers shall be filled up with water. The closed connections shall be insulated in the same way as the store.

Test EiV

- Test phase EiV1: conditioning until steady state is reached,
- test phase EiV2: charging with the nominal electrical power (according to the manufacturer's specifications) until the heater is switched off by the thermostat (Tset = 60 °C),
- test phase EiV3: discharging of the half volume that is above the electrical auxiliary heater,
- test phase EiV4: charging according to EiV2,
- test phase EiV5: 16 h stand-by,

- test phase EiV6: discharging until steady state is reached.

Table D.7 — Flow rates and storage device inlet temperatures for Test EiV

Test phase	Process	Charging circuit			Discharging circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{T}_{\mathrm{C,i}}$ °C	$\tilde{T}_{\mathrm{C,o}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{T}_{\mathrm{D,i}}$ °C	$\tilde{T}_{\mathrm{D,o}}$ °C
EiV1	conditioning	0	–	–	$0{,}75 \times \dot{V}_{\mathrm{n}}$	20,00	variable
EiV2	charging	0	–	–	0	–	–
EiV3	discharging	0	–	–	$0{,}75 \times \dot{V}_{\mathrm{n}}$	20,00	variable
EiV4	charging	0	–	–	0	–	–
EiV5	stand-by	0	–	–	0	–	–
EiV6	discharging	0	–	–	$0{,}75 \times \dot{V}_{\mathrm{n}}$	20,00	variable

D.2.2 Test sequences obtained during a whole system test according ISO 9459-5

An additional test of the whole system as described in clause 7 shall be performed.

D.3 Verification procedure

D.3.1 General

The data obtained from the test sequences as described in D.2 shall be pre-processed and re-simulated as described in 6.3.3. The same store model as used for parameter identification as well as the determined store parameters shall be used.

Following quantities shall be calculated during simulation:

D.3.2 Error in transferred energies

For each sequence the measured and predicted (simulated) energies transferred through each charge and discharge connection shall be calculated separately. Periods used for conditioning at the beginning of the test sequence shall be excluded.

NOTE In case data obtained from a whole system test are used, the store can be charged simultaneously through two separate devices, e. g. the heat exchangers of the solar loop and the auxiliary heater loop. In this case the charge energy should be calculated for both heat exchangers separately.

For each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the transferred predicted energy, $Q_{\mathrm{x,p}}$, and the measured energy, $Q_{\mathrm{x,m}}$, shall be calculated according the following equation:

$$Q_{\mathrm{x,p}} = \int_t P_{\mathrm{x,p}}\,d\,t \qquad and \qquad Q_{\mathrm{x,m}} = \int_t P_{\mathrm{x,m}}\,d\,t \qquad \text{(D.1)}$$

For each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the relative error in transferred energy $\varepsilon_{\mathrm{x,Q}}$ shall be calculated by

$$\varepsilon_{\mathrm{x,Q}} = \frac{Q_{\mathrm{x,p}} - Q_{\mathrm{x,m}}}{Q_{\mathrm{x,m}}} \times 100\ \% \tag{D.2}$$

If the relative error in transferred energy, $\varepsilon_{\mathrm{x,Q}}$, exceeds ± 5,0 %, than the test is considered as not valid.

D.3.3 Error in transferred power

For each sequence the measured and predicted (simulated) power transferred through each charge and discharge connection shall be calculated separately. Periods used for conditioning at the beginning of the test sequence shall be excluded.

NOTE In case data obtained from a whole system test are used, the store can be charged simultaneously through two separate devices, e. g. the heat exchangers of the solar loop and the auxiliary heater loop. In this case the charge power and the transfer time should be calculated for both heat exchangers separately.

Every time step during the simulation for each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the absolute difference between the transferred measured and predicted power shall be calculated by

$$\Delta P_{\mathrm{x}} = \left| P_{\mathrm{x,p}} - P_{\mathrm{x,m}} \right| \tag{D.3}$$

The mean difference in transferred power via the connection 'x' shall be calculated by

$$\Delta \overline{P}_{\mathrm{x}} = \frac{\int_t \Delta P_{\mathrm{x}} dt}{\int_t \xi P_{\mathrm{x}} dt} \tag{D.4}$$

where ξ_{x} is a logical switch with the value ξ_{x} = 1, if a thermal power is transferred via the connection 'x'; else ξ_{x} = 0.

For each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the mean transferred power shall be calculated by

$$\overline{P}_{\mathrm{x}} = \frac{\int_t \left| P_{\mathrm{xm}} \right| dt}{\int_t \xi_{\mathrm{x}} dt} \tag{D.5}$$

For each connection 'x' ($x = C$ for charge and $x = D$ for discharge) the relative error in mean transferred power $\varepsilon_{\mathrm{x,P}}$ shall be calculated by

$$\varepsilon_{\mathrm{x,p}} = \frac{\Delta \overline{P}_{\mathrm{x}}}{P_{\mathrm{x}}} \times 100\ \% \tag{D.6}$$

If the relative error in mean transferred power ε_{P} exceeds 5,0 %, than the test is considered as not valid.

Annex E
(informative)

Determination of store parameters by means of “up-scaling” and “down-scaling”

E.1 General

Annex E describes a method for the determination of store parameters by means of “up-scaling” and “down-scaling”. The method allows for the determination of store parameters without complete testing the store. In order to apply the procedure it is required that the store of which the parameters should be determined is part of a series of store. A series of stores is defined as follows:

Series of stores

Different stores are considered to be part of a series of stores if they are identical with regard to their construction and only differ in their volume, their diameter and the area of their heat exchangers.

Being identical with regard to the construction means that all stores

- have the similar set-up (either vertical or horizontal);
- have a similar insulation concept: same material, same thickness;
- have the same number of hydraulic connections;
- are equipped with the same type of immersed heat exchangers: plane pipe or finned tube, same diameter of tubes, same wall thickness of tubes.

NOTE 1 The definition of identical is still under elaboration.

NOTE 2 Further information about the determination of store parameters by means of up-scaling and down-scaling is given in CEN/TC 312/WG 3 N 0096.

E.2 Requirements

It is required that the series is based on a minimum of three stores with different volumes. The volume of all stores being part of the series shall be in the range from 200 l to 600 l.

Note: In general it can be assumed that the method described in this annex can also be applied on a series of stores if the volume of some stores of the series is less than 200 l or lager than 600 l. Due to the fact that the method is for the time being only validated for stores with a volume in the range from 200 l to 600 l the application is restricted to stores within this volume range.

The largest store of a store series shall be tested completely according to chapter 6. The heat transfer capacity rates of the immersed heat exchangers of the smallest store shall also be determined by thermal testing.

Based on the results derived from measurements the parameters for stores which are in their size between the two measured ones can be calculated as follows:

E.3 Determination of store parameters

E.3.1 Thermal capacity of store

The determination of the thermal capacity of the store shall be derived from the store volume. It can be calculated by the following equation E1:×

$$C_{sto} = 4{,}149 \times V_{sto} \tag{E1}$$

with

C_{sto} = thermal capacity of the store in kJ/K

V_{sto} = whole volume of the store in litres

The volume of the stores that were not completely tested is based on the manufacturer's information.

E.3.2 Height of store

The height of the store shall be calculated based on the store volume and the diameter of the store (based on manufacturer's information) for a cylindrical geometry.

E.3.3 Determination of heat loss capacity rate

The heat loss capacity rate shall be calculated by equation (E2):

$$(UA)_{\mathrm{s,a}} = a \times \sqrt{V} \tag{E.2}$$

where

$(UA)_{\mathrm{s,a}}$ is the heat loss capacity rate of the store in W/K;

V is the volume of the store in litre;

a is the constant.

The constant "*a*" is determined on the basis of the measured heat loss capacity rate of the largest store by using equation (E.2).

E.3.4 Relative heights of the connections and the temperature sensors

These parameters shall be calculated based on the determined store height (see E.3.2) and the design drawing provided by the manufacturer.

E.3.5 Heat exchangers

The heat transfer capacity rate of the heat exchangers shall be calculated by means of a linear interpolation based on the area and the heat transfer capacity rate. The values required for the linear Interpolation shall be based on measurements.

If the dependency of the heat transfer capacity rate on the operating conditions (e. g. temperature level, flow rate through the heat exchanger) is taken into account, average values for these dependencies shall be used. The determination of the average values shall be based on the values derived from measurements.

E.3.6 Parameter describing the degradation of thermal stratification during stand-by

The value determined from the test of the largest store (the one which is completely tested) of a series shall be used.

E.3.7 Parameter describing the quality of thermal stratification during direct discharge

The value determined from the test of the largest store (the one which is completely tested) of a series shall be used.

Annex F
(informative)

Determination of hot water comfort

F.1 General

NOTE 1 In TC 57/W8 a procedure for the determination of the hot water comfort provided by stores is under development as prEN 15332. This procedure seems to be appropriate to be used here. In addition to this procedure the parameters for auxiliary heating of the store will be specified in detail.
Furthermore the influence of the solar contribution on the hot water comfort could be considered.

NOTE 2 The test procedure will be used for determination of size class according to the Mandate M/324.

Bibliography

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[2] H. Visser, H. A. L. Van Dijk: Test Procedures for Short Term Thermal Stores, Kluwer Academic Publishers, Dordreckt, Boston, London 1991, ISBN 0-7923-1131-0

[3] IEA Solar Heating and Cooling Program, Task III: Performance Testing of Solar Collectors, Reference and Calibration Heaters, Swedish Council for Building Research, ISBN 91-540-4501-0, January 1986

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Thermal solar systems and components — Custom built systems — Part 4: Performance test methods for solar combistores

Thermische Solaranlagen und ihre Bauteile — Kundenspezifisch gefertigte Anlagen — Teil 4 Leistungsprüfung von Warmwasserspeichern für Solaranlagen zur Trinkwassererwärmung und Raumheizung

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Contents

Foreword

This document (prEN TS 12977-4:2007) has been prepared by the Technical Committee CEN/TC 312 "Thermal solar systems and components", the secretariat of which is held by ELOT.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this European Prestandard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The annexes A, B and C are normative; annexes D and E are informative.

Introduction

The test methods for stores of solar heating systems as described in this document are required for the determination of the thermal performance of small custom built systems for combined domestic hot water preparation and space heating, so-called solar combisystems, as specified in prEN TS 12977-1.

These test methods deliver parameters, which are needed for the simulation of the thermal behaviour of a store being part of a small custom built system.

NOTE 1 With the test methods for stores given in prEN 12897:1997 only a few parameters are determined in order to characterise the thermal behaviour of a store. These few parameters are not sufficient for the determination of the thermal performance of small custom built systems as described in ENV 12977-2.

NOTE 2 The already existing test methods for stores of solar heating systems are not sufficient with regard to thermal solar systems. This is due to the fact that the performance of thermal solar systems depends much more on the thermal behaviour of the store (e. g. stratification, heat losses), as conventional systems do. Hence this separate document for the performance characterisation of stores for solar heating systems is needed.

NOTE 3 For additional information about the test methods for the performance characterisation of stores see EN TS 12977-3 and [1] in Bibliography.

1 Scope

This document specifies test methods for the performance characterization of stores which are intended for use in small custom built systems as specified in prEN TS 12977-1.

Stores tested according to this document are commonly used in solar combisystems. However, also the thermal performance of all other thermal stores with water as storage medium (e.g. for heat pump systems) can be assessed according to the test methods specified in this document.

This document applies to combisstores with a nominal volume up to 3000 litres and without integrated burner.

Remark: This standard extensively based on references to prEN TS 12977-3.

2 Normative references

This document incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this document only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

(List need to be checked and updated for further new development since 2001.)

EN 806-1	Specifications for installations inside buildings conveying water for human consumption — Part 1: General
EN 1717	*Protection against pollution of potable water installations and general requirements of devices to prevent pollution by backflow*
EN 12828	*Heating systems in buildings — Design of water-based heating systems*
EN 12976-2:2000	Thermal solar systems and components – Factory made systems - Test Methods
ENV 12977-2:2001	Thermal Solar Systems and Components – Custom Built Systems – Test Methods
prEN TS 12977-2:2001	Thermal Solar Systems and Components – Custom Built Systems – Test Methods
prEN TS 12977-4:2001	Thermal Solar Systems and Components – Custom Built Systems – Performance test methods for solar combistores
prEN 12828:1997	Heating systems in buildings – Design and installation of water heating systems
prEN 12897:1997	Water supply – Specification for indirectly heated unvented (closed) hot water storage systems
EN ISO 9488	Solar energy – Vocabulary (ISO 9488:1999)
ISO 9459-5	Solar heating – Domestic water heating systems – Part 5: System performance characterization by means of whole – system tests and computer simulation

3 Terms and definitions

For the purposes of this document the following terms and definitions together with EN ISO 9488 apply.

For terms and definitions refere to EN TS 12977-3.

4 Symbols and abbreviations

For symbols and abbreviations refere to EN TS 12977-3.

5 Store classification

Solar combistores are classified by distinction between different charge and discharge modes. Five groups are defined as shown in Table 1.

Table 1 — Classification of combistores

Group	Charge mode	Discharge mode
1	direct	direct
2	indirect	direct
3	direct	indirect
4	indirect	indirect
5	stores that cannot be assigned to groups 1 to 4	

NOTE 1 All stores may have one or more additional electrical heating elements.

NOTE 2 Stores that can be charged or discharged directly and indirectly (e. g. a store of a space heating system with an internal heat exchanger for the preparation of domestic hot water) can belong to more than one group. In this case the appropriate test procedures or the assignment to one of the groups respectively, shall be chosen depending on its mode of operation.

6 Laboratory store testing

6.1 Requirements on the testing stand

6.1.1 General

The hot water store shall be tested separately from the whole solar system on a store testing stand.

The testing stand configuration shall be determined by the classification of the combistores as described in clause 5.

An example of a representative hydraulic testing stand configuration is shown in Figure 1 and Figure 2.

The circuits are intended to simulate the charge and discharge loops of the solar system and to provide fluid flow with a constant or well controlled temperature. The full test stand consists of at least one charge and one discharge circuit.

NOTE 1 If the store consists of more than one charge or discharge devices (e.g. two heat exchangers), then these are tested separately.

The testing stand shall be located in an air-conditioned room where the room temperature of 20 °C should not vary by more than ± 1 K during the test.

All circuits shall fulfil the following requirements:

- The flow rate shall be adjustable between 0,05 m^3/h and 3 m^3/h, by deviation < 2 %;
- The working temperature range shall be between 10 °C and 90 °C;
- The minimum heating power of the charge circuits shall be 15 kW;
- The minimum cooling power in the discharge circuits shall be 5 kW at a fluid temperature of 20 °C;

NOTE 2 If mains water at a constant pressure and a constant temperature below 20 °C is available, it is recommended to design the discharge circuits in a way, that it can be operated as closed loop or as open loop using the mains water to discharge the store directly.

- The minimum heating power of the discharge circuits shall be 5 kW;
- The control deviation of the store inlet temperature shall be less than 0,05 K;
- The minimum heating up rate of the charge circuits with disconnected store shall be 3 K/min
- The minimum available electrical heating power for electrical auxiliary heaters shall be 6,0 kW.

NOTE 3 The electrical power of the pump (P102) shall be chosen in such a way that the temperature increase induced by the pump (P102) is less than 0,6 K/h when the charge circuit is "short circuited" and operated at room temperature. (“short circuited” means that no storage device is connected and SV102, V113, V115 and V116 are closed, see Figure 1).

Key

FF	Flow meter
HX	Heat exchanger
OP	Overheating protection
P	Pump
ST	Store
SV	Solenoid valve
TT	Temperature sensor
TIC	Temperature indicator and controller
V	Valve

Figure 1 - Charge circuit of a combistore testing stand

The heating medium water in the charge circuit (see Figure 1) is pumped through the cooler (HX101) and the temperature controlled heaters (TIC106) by the pump (P101). A buffer tank (ST101) is used to balance the remaining control deviations. By means of the bypass (V107) the flow through the store can be regulated, it also ensures a continuously high flow through the heating section and therefore good control characteristics. With the solenoid valve (SV101) the heating medium can bypass the store to prepare a sudden increase of the inlet temperature into the store.

The temperature sensors are placed near the inlet (TT101) and outlet (TT102) connections of the store, the connection to the store is established through insulated flexible pipes.

The charge circuit can be operated closed, under pressure (design pressure 2,5 bar, membrane pressure expansion vessel and pressure relief valve (V109)) as well as open (valve (V108) open) with the tank (ST102) serving as an expansion tank. A calibration of the installed flow meter (FF105) is possible by weighing the mass of water leaving the valve (V112). The installation is equipped with the usual safety devices, i. e. pressure relief valve (V117) and overheating protection device (OP101).

The discharge circuit (see Figure 2) is constructed in a similar way. It includes two coolers – (HX201) and (HX202) – and a temperature controlled heating element (TIC206) with 5 kW heating power. The discharge circuit can either be operated in open circulation with water from the net or it can be operated in closed circulation. During open operation the water is led via the safety equipment (V201) and flows through the coolers, the heating section and the flow meter (FF205) into the store. The hot water leaving the store flows through the solenoid valve (SV201) and the valve (V210) into the drain. The valve (V212) is closed.

For heating the water it is recommended to increase the flow through the heating section with the pump (P201) in order to improve the control performance; the additional volume flow returns through the bypass (V209).

During closed-circle operation, the valve of the safety equipment and the cut-off valve (V210) remain closed, the valve (V212) is open and the water is circulated by the pump (P201).

NOTE 4 For periodical checks of the measuring accuracy, it is recommended to integrate a reference heater into the testing stand. Instead of a store, this reference heater is connected to the testing stand. The reference heater is supplied with an electric heating device.

NOTE 5 See [2] and [3] in Bibliography for further information on the use of reference heaters.

The heat transfer fluid used for testing may be water or a fluid recommended by the manufacturer. The specific heat capacity and density of the fluid used, shall be known with an accuracy of 1 % within the range of the fluid temperatures occuring during the tests.

Key

FF	Flow meter
HX	Heat exchanger
P	Pump
SV	Solenoid valve
TT	Temperature sensor
TIC	Temperature indicator and controller
V	Valve

Figure 2 - Discharge circuit of a combistore testing stand

6.1.2 Measuring data and measuring procedure

The data listed in Table 2 shall be measured with the given accuracy:

Table 2 — Measuring data

Measuring data	Measuring device (see figure 1 and 2)	Uncertainty
volume flow $\dot{V}_C$ in the charge circuit between 0,05 m³/h and 1 m^3/h	FF105	2,0 %
volume flow $\dot{V}_D$ in the discharge circuit between 0,05 m³/h and 1 m^3/h	FF205	2,0 %
temperature $\vartheta_{\mathrm{C,i}}$ of the charging medium at store inlet	TT101	0,1 K
temperature $\vartheta_{\mathrm{C,o}}$ of the charging medium at store outlet	TT102	0,1 K
difference in the charging medium temperature $\Delta\vartheta_{\mathrm{C}}$ between store inlet and store outlet: (for tests according to 6.3.1)	TT101 and TT102	0,02 K
difference in the charging medium temperature $\Delta\vartheta_{\mathrm{C}}$ between store inlet and store outlet: (for tests according to 6.3.2)	TT101 and TT102	0,05 K
temperature $\vartheta_{\mathrm{D,i}}$ of the discharging medium at store inlet	TT201	0,1 K
temperature $\vartheta_{\mathrm{D,o}}$ of the discharging medium at store outlet	TT202	0,1 K
difference in the discharging medium temperature $\Delta\vartheta_{\mathrm{D}}$ between store inlet and store outlet: (for tests according to 6.3.1)	TT201 and TT202	0,02 K
difference in the discharging medium temperature $\Delta\vartheta_{\mathrm{D}}$ between store inlet and store outlet: (for tests according to 6.3.2)	TT201 and TT202	0,05 K
ambient temperature ϑ_{am}	TT001	0,1 K
electric power $\dot{Q}_{el}$ (auxiliary heating)	-	2 %

The relevant data shall be measured every 10 s at least and the measured data shall be recorded as mean values of at most three measured values.

The temperature sensors shall have a relaxation time of less than 10 seconds. (i. e. 90 % of the temperature variation is detected by the sensor immersed in the heat transfer fluid within 10 seconds after an abrupt step in the fluid temperature).

Prior to each store test a zero measurement should be performed where the fluid in the charge or discharge circuit(s) is pumped over the short-circuited charge or discharge circuit(s). “Short-circuited” means that flow pipe and return pipe of the corresponding circuits are directly connected (recommended volume flow approximately 0,6 m³/h, temperatures 20 °C, 40 °C, 60 °C, 80 °C). If the measured temperature difference exceeds the permissible uncertainty of 0,02 K / 0,05 K, the temperature sensors shall be calibrated.

A reference heater may also be used for the zero measurement.

6.2 Installation of the store

6.2.1 Mounting

The store shall be mounted on the testing stand according to the manufacturer's instructions.

The temperature sensors used for measuring the inlet and outlet temperatures of the fluid used for charging and discharging the storage device, shall be placed as near as possible at least 200 mm to the inlet and outlet connections of the storage device. The installation of the temperature sensors inside the pipes shall be done according to approved methods of measuring temperatures.

If there is/are more than one pair of charging and/or discharging inlet or outlet connections, then only one may be connected to the testing stand (at the same time) while the other(s) shall be closed.

The pipes between the store and the temperature sensors shall be insulated according to prEN 12828:1997.

6.2.2 Connection

The way of connecting the storage device to the testing stand depends on the purpose of the thermal tests which shall be performed. Detailed instructions are given in the clauses where the thermal tests are described.

Connections of the store which do not lead to the charge or discharge circuit of the testing stand shall be closed, and not connected heat exchangers shall be filled up with water. All closed connections shall be insulated in the same way as the store.

Since fluid in closed heat exchangers expands with increasing temperature, a pressure relief valve shall be mounted.

NOTE The performance of a solar heating system depends on the individual installation and actual boundary conditions. With regard to the heat losses of the store besides deficits in the thermal insulation, badly designed connections can increase the heat loss capacity rate of the store due to natural convection that occurs internally in the pipe. In order to avoid this effect the connections of the pipes should be designed in such a way that no natural convection inside the pipe occurs. This can e. g. be achieved if the pipe is directly going downwards after leaving the store or by using a heat trap siphon.

6.3 Test and evaluation procedures

The aim of store testing as specified in this document is the determination of parameters required for the detailed description of the thermal behaviour of a hot water combistore. Therefore, a mathematical computer model for the store is necessary. The basic requirements on suitable models are specified in annex A and annex B.

The following parameters shall be known for the simulation of a store being part of a solar system:

a) Stored water

- Height
- Effective volume respectively effective thermal capacity
- Heights of the inlet and outlet connections
- Heat loss capacity rate of the entire store
- If the insulation varies for different heights of the store, the distribution of the heat loss capacity rate should be determined for the different parts of the store
- A parameter describing the degradation of thermal stratification during stand-by

NOTE 1 One possible way to describe this effect in a store model is the use of a vertical thermal conduction. In this case the corresponding parameter is an effective vertical thermal conductivity.

- A parameter describing the characteristic of thermal stratification during direct discharge.

NOTE 2 An additional parameter may be used to describe the influence of different draw-off flow rates on the thermal stratification inside the store, if this effect is relevant.

- Positions of the temperature sensors (e. g. the sensors of the collector loop and auxiliary heater control)

b) Heat exchangers

- Heights of the inlet and outlet connections
- Volume
- Heat transfer capacity rate as a function of temperature
- Information on the capacity in respect of stratified charging,

NOTE 3 The capacity in respect of stratified charging can be determined from the design of the heat exchanger as well as from the course in time of the heat exchanger inlet and outlet temperatures.

- Heat loss rate from the heat exchanger to the ambient (necessary only for mantled heat exchangers and external heat exchangers)

c) Electrical auxiliary heat source

- Position in the store
- Axis direction of heating element (horizontal or vertical). If the auxiliary heater is installed in a vertical way, also its length is required
- Effectivity that characterises the fraction of the thermal converted electric power which is actually transferred inside the store

NOTE 4 Badly designed electrical auxiliary heaters may cause significant heat losses during operation. In this case the electrical power supplied to the heater is not equal to the thermal energy input to the store.

The following clauses describe the way, how the listed parameters can be determined. Therefore, specific test sequences are necessary. The test sequences indicated by letters (e. g. TEST CD) can be subdivided into phases indicated by a number (e. g. CD1 – conditioning). Between the end of one phase and the start of the following phase, a maximum stand-by time of 10 min is allowed. During this stand-by time the ambient temperature only shall be measured and recorded.

NOTE 5 One essential point of the described methods is, that measurements inside the store are avoided.

NOTE 6 The determination of all above listed store parameters is possible only according to the method described under 6.3.1 and the data processing of the test sequences described under 6.3.2. For further details and test sequenzes see EN TS 12977-3.

6.3.1 Test sequences

The store is tested on the test stand by different specific test sequences. The sequences are specified to stimulate the physical effects, which correspond to the parameter to be determined. A parameter identification program using a store model evaluates the measuring data.

Charging and discharging the entire store implies connections of the charge/discharge circuits to the uppermost and lowermost direct ports available at the tank. Full discharging is required for conditioning of the store and for the final discharge phase. Full charging is required for all discharge tests, which require that the entire store is charged.

The series of the performed tests should comprise two tests, which include stand-by periods. One test is for the entire store, to determine the heat loss capacity rate. The other test concerns only the part of the store, which is heated up (usually the auxiliary heated part). This test is used to determine the degradation of thermal stratification during stand-by. The stand-by period should be such that the losses during this period are approximately half of the stored energy. For these two tests with stand-by periods, the same test should also be performed without a stand-by period.

Flow rates and power values are given as examples only. The chosen flow rate or power should be suited to the type of component, which will be used with those connections.

6.3.1.1 General

This clause describes the thermal test sequences for the different groups of combistores. This clause is based on procedures defined in EN TS 12977-3, only new items are included. In EN TS 12977-3 mainly the determination of the thermal capacity, heat loss capacity rate of the entire store and the heat transfer capacity rate of immersed heat exchangers is defined.

The thermal test sequences described in this document shall be carried out for all groups of combistores. The storage device shall be connected to the testing stand according to 6.2.

6.3.1.2 General charge direct (TEST CD)

- Test phase CD1: conditioning until steady-state is reached
- Test phase CD2: charging through test ports until $\vartheta C,o$ = 55°C
- Test phase CD3: optional stand-by until approximately half stored energy is lost to ambient
- Test phase CD4: direct discharge of the entire store until steady-state is reached

Table 3 - Flow rates and store inlet temperatures for Test CD

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
CD1	conditioning	0	-	-	$0{,}5 \cdot \times \dot{V}_n$	20,00	variable
CD2	charge	$0{,}5 \cdot \times \dot{V}_n$	60,00	variable	0	-	-
CD3	stand-by	0	-	-	0	-	-
CD4	discharge	0	-	-	$0{,}5 \cdot \times \dot{V}_n$	20,00	variable

If the ports are used with a boiler the operating temperature of which is greater than 60°C (e. g. a wood boiler), a higher inlet temperature (ϑC,i) may be used.

6.3.1.3 General charge indirect (TEST CI)

- Test phase CI1: conditioning until steady-state is reached
- Test phase CI2: charge through test heat exchanger at constant power of $\tilde{P}_C$ = 2,0• P_n until $\vartheta_{C,o}$ = 60°C
- Test phase CI3: optional stand-by until approximately half stored energy is lost to ambient
- Test phase CI4: direct discharge of the entire store until steady-state is reached

Table 4 - Flow rates and store inlet temperatures for Test CI

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
CI1	conditioning	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable
CI2	charge	$1{,}2 \times \dot{V}_n$	variable	variable	0	-	-
CI3	stand-by	0	-	-	0	-	-
CI4	discharge	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable

If the heat exchanger is used at different flow rates, the test should be performed four times, using, if possible, the following different charging conditions: constant power P_n at high and low flow rates, as well as constant power 0,5.P_n at low and high flow rates.

6.3.1.4 General discharge direct (TEST DD)

- Test phase DD1: conditioning until steady-state is reached
- Test phase DD2: charging of the entire store until ϑC,o = 55°C
- Test phase DD3: discharge through test ports until ϑD,o = 30°C
- Test phase DD4: direct discharge of the entire store until-steady state is reached

Table 5 - Flow rates and store inlet temperatures for Test DD

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
DD1	conditioning	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable
DD2	charge	$0{,}5 \times \dot{V}_n$	60,00	variable	0	-	-
DD3	discharge	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable
DD4	discharge	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable

6.3.1.5 General discharge indirect (TEST DI)

- Test phase DI1: conditioning until steady-state is reached
- Test phase DI2: charge of the entire store until ϑC,o = 55°C
- Test phase DI3: discharge through the test heat exchanger until ϑD,o = 30°C
- Test phase DI4: direct discharge of the entire store until steady state is reached

Table 6 - Flow rates and store inlet temperatures for Test DI

Test		charge			discharge		

phase	process	$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,o}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,o}$ °C
DI1	conditioning	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable
DI2	charge	$0{,}5 \times \dot{V}_n$	60,00	variable	0	-	-
DI3	discharge	0	-	-	$0{,}5 \times \dot{V}_n 5$	20,00	variable
DI4	discharge	0	-	-	$0{,}5 \times \dot{V}_n$	20,00	variable

If the heat exchanger is intended for domestic hot water preparation, this test shall be performed three times under different discharge conditions. To each of these three discharge conditions the following two charge conditions shall apply: Store fully charged and auxiliary part charged. In all, six tests shall be performed. The following discharge conditions should apply:

- Low flow rate
- High flow rate

The test shall be repeatedly performed under following conditions: Intermittent discharge at high flow rate with 10 minutes discharge and 10 minutes stand-by. This test does not need to be performed if it can be assumed that the heat transfer capacity rate of the discharge heat exchanger will not be time dependent.

6.3.2 Data processing of the test sequences

Remark: The data processing of the test sequences is partly based on references to prEN TS 12977-3, only new items are included.

The evaluation of the measured data in based on parameter identification. When all necessary tests as described in 6.3.1 are performed, identification of store parameters shall be carried out using a numerical store model that fulfils the requirements given in annex A. For information regarding an adequate parameter identification algorithm that fulfils the necessary requirements, see EN TS 12977-3, annex C.

The store model shall meet the requirements of the benchmark tests given in annex B.

For the parameter identification the measuring data can be compressed and/or converted to constant time steps. In both cases, the data records shall represent mean values for the corresponding time step. During charge and discharge, the time steps should not exceed 3 min. During stand-by, a maximum time step of 15 min is allowed.

For the fit the measured values of the inlet store temperatures, ambient temperature, flow rates and the power of the electrical heating source(s) shall be used as inputs. Since at the beginning of each test the store is always conditioned to 20 °C, no skip time is required. Hence the data used for fitting, shall start with the second test phase, and ϑ_s = 20 °C shall be used as initial temperature for the store model.

6.3.2.1 Determination of all store parameters (except the vertical position of the temperature sensors)

Remark: The determination of all store parameters, except of the vertical position of the temperature sensors, is partly based on references to EN TS 12977-3, only new items are included.

All parameters, which are determined by parameter identification, shall be identified during one parameter identification process. This requirement is not relevant for the determination of the vertical positions of the temperature sensors.

For every time step during the fit for each connection 'x' ($x = C$ for charge and $\mathrm{x} = \mathrm{D}$ for discharge), the absolute difference between the transferred measured and predicted power shall be calculated by

$$\Delta P_{\mathrm{x}} = \left| P_{\mathrm{x,p}} - P_{\mathrm{x,m}} \right| \tag{1}$$

where the transferred predicted power, $P_{\mathrm{x,p}}$, and the measured power, $P_{\mathrm{x,m}}$, shall be calculated according the following equations:

$$P_{\mathrm{x,p}} = \bar{\rho} \times \bar{c}_{\mathrm{p}} \times \dot{V} \times \left(\vartheta_{\mathrm{x,i}} - \vartheta_{\mathrm{x,o,p}} \right) \tag{2}$$

$$P_{\mathrm{x,m}} = \bar{\rho} \times \bar{c}_{\mathrm{p}} \times \dot{V} \times \left(\vartheta_{\mathrm{x,i}} - \vartheta_{\mathrm{x,o,m}} \right) \tag{3}$$

The function $f(t)$, which shall be minimised for the determination of the store parameters (except the vertical positions of the temperature sensors), is the integral of the sum over all absolute power differences calculated by

$$f(t) = \int_{t} \sum_{x} \Delta P_{\mathrm{x}} d\,t \tag{4}$$

6.3.2.2 Determination of the vertical position of the temperature sensors

Remark: The determination of the vertical position of the temperature sensors is partly based on references to EN TS 12977-3, only new items are included.

If all parameters of the store, except the vertical position of the temperature sensors have been determined according to 6.3.2.1, the determination of the vertical positions of the temperature sensors or their location respectively shall be performed as described in this clause. For the description of the thermal behaviour of the store by means of the numerical model, the parameters determined according to 6.3.2.1 shall be used.

For every time step during the fit for each temperature sensor 'z' the absolute difference between the measured temperature at the location of the temperature sensor, $\vartheta_{\mathrm{z,m}}$, and the predicted temperature at the location of the temperature sensor, $\vartheta_{\mathrm{z,p}}$, shall be calculated by

$$\Delta \vartheta_{\mathrm{z}} = \left| \vartheta_{\mathrm{z,m}} - \vartheta_{\mathrm{z,p}} \right| \tag{5}$$

The function $f(t)$, which shall be minimised for the determination of the vertical positions of the temperature sensors, is the integral over all absolute temperature difference for the temperature sensor 'z'

$$f(t) = \int_{t} \Delta \vartheta_{\mathrm{z}} d\,t \tag{6}$$

The determination of the vertical positions of the temperature sensors has to be performed separately for each temperature sensor 'z' or vertical position respectively.

NOTE 1 The exact vertical positions of the temperature sensors as well as the upper connections of the heat exchangers above which the store is charged mixedly, have a minor influence on the thermal behaviour of the store. Hence, these vertical positions need not to be determined by means of parameter identification. It is recommended to measure the corresponding positions or to determine them from the drawing of the store.

7 Test report

7.1 General

In accordance with EN TS 12977-3 the test report shall include:

a) A detailed description and the technical data of the tested store (based on the manufacturer's instruction),

b) the determined parameters and a description of them,

c) reference to the used store model (parameters for simulation).

7.2 Description of the store

In accordance with EN TS 12977-3 the description of the store shall be based on the information provided by the manufacturer. It shall include:

a) General data

- Manufacturer
- Type
- Year of construction
- Serial number
- Nominal volume
- Description and drawing of the schematic design

b) Stored water

- Volume
- Material and corrosion protection (only for material in contact with drinking water)
- Maximum operation pressure
- Maximum operation temperature
- Thermal insulation
- Diameter and type of connections

c) Electrical heating source(s)

- Nominal voltage
- Nominal heating power
- Diameter and type of connection

d) Heat exchanger(s)

- Volumen
- Material and corrosion protection (only for material in contact with drinking water)
- Type of pipes (with/without ribs, coil etc.)
- Size of the area for heat transfer
- Position inside the store
- Maximum operation pressure
- Maximum operation temperature
- Diameter and type of connections

7.3 Test results

The test results shall be presented and documented in accordance to the specifications given in EN TS 12977-3

NOTE 1 Some of the parameters used for the characterisation of the thermal behaviour of the store are related to the used store model. Therefore, information on these parameters and the store model should be provided.

a) Geometrical data

- Weight of the complete storage device (empty)
- Maximum height of the complete storage device
- Maximum diameter of the complete storage device

b) Volumes

- Volume of the stored water
- Volume of the heat exchanger(s)

c) Thermal parameters

- Thermal capacity of the entire store
- Thermal capacity of appropriate parts of the store (e. g. auxiliary heated part)
- Stand-by heat loss capacity rate (optional: operating heat loss capacity rate)
- Parameter describing the degradation of thermal stratification during stand-by

- Parameter describing the quality of thermal stratification during direct discharge
- Heat transfer capacity rate $(UA)_{\mathrm{hx,s}}$ of the heat exchanger(s). The test conditions (fluid, temperatures, flow rate, transferred heating power) for the determination of the heat transfer capacity rate shall be mentioned in the test report

d) Temperature sensors

- Vertical positions of the temperature sensors

NOTE 2 If a diagram of $(UA)_{\mathrm{hx,s}}$ over the temperature is included in the test report, the transferred heating power at each point of the diagram should be indicated, if the transferred heating power varies for the different points of the plotted $(UA)_{\mathrm{hx,s}}$ values.

In addition, the draw-off profiles for two different draw-off flow rates (e. g. from Test C and Test S, see EN TS 12977-3) and the two draw-off profiles used for the determination of the parameter describing the degradation of thermal stratification during stand-by (e. g. from Test NiA and Test NiB or from Test EiA and Test EiB, see EN TS 12977-3), should be included.

7.4 Parameters for the simulation

All parameters which are necessary to describe the thermal behaviour of the store in combination with a suitable numerical calculation model shall be recorded. In addition to the parameters listed in 7.3, the following parameters are required:

a) Data of the fluid (e. g. constant values for the density and the specific heat capacity)

b) Position of the

- inlet and outlet connection(s) for direct charge and discharge
- inlet and outlet connection(s) of the heat exchangers

c) Information on the ability for stratified charging/discharging

Annex A
(normative)

Requirements for the numerical store model

See annex A of EN TS 12977-3:2001

Annex B
(normative)

Store model benchmark tests

See annex B of EN TS 12977-3:2001

Annex C
(normative)

Benchmarks for the parameter identification

See annex C of EN TS 12977-3:2006

Annex D
(informative)

Verification of store test results

Remark: To be discussed if a verification procedure should be included

Annex E
(informative)

Determination of hot water comfort

Remark: The following annex E is taken from EN TS 12977-3:2006

E.1 General

NOTE 1 In TC 57/W8 a procedure for the determination of the hot water comfort provided by stores is under development as prEN 15332. This procedure seems to be appropriate to be used here. In addition to this procedure the parameters for auxiliary heating of the store will be specified in detail.
Furthermore the influence of the solar contribution on the hot water comfort could be considered.

NOTE 2 The test procedure will be used for determination of size class according to the Mandate M/324.

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Thermal solar systems and components — Custom built systems — Part 5: Performance test methods for control equipment

Thermische Solaranlagen und ihre Bauteile — Kundenspezifisch gefertigte Anlagen — Teil 5: Prüfmethoden für Regeleinrichtungen

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Contents

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Foreword

This document (prEN/TS 12977-5:2006) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This document is currently submitted to the CEN Enquiry.

Introduction

One main purpose of this document is to define how to check whether a controller in combination with its equipment (e. g. sensors, pumps and other actuators) is behaving as it is intended to do. In addition function testing of differential thermostats and so-called “multi-function” controllers to determine starting and stopping differentials and control algorithms depending on temperature differences, temperature levels and operation/surroundings conditions of the system is described. For all functions and operations it shall be tested and documented, whether the controller and control equipment comply with the manufacturer’s guidance.

In addition the capability for all sensors to resist to extreme operating conditions and shift in accuracy caused by this reason shall be tested. Supplementary the energy consumption of the controller and the control equipment, e. g. actuators shall be documented.

Particularly to carry out performance predictions for the system the control equipment belong to, for the determination of the component parameters, e.g. to be apply the CTSS method as specified in prEN/TS 12977-2, a detailed investigation of all relevant algorithms, features and parameters in charge to control the system is mandatory.

NOTE The most widely used control equipment for solar heating systems is described in prEN/TS 12977-5. For control equipment not widely used in solar heating systems or auxiliary heaters, if part of the system, accompanying standards should be applied.

Restrictions

In respect of potential adverse effects human health or life, caused by the products covered by this prEN/TS 12977-5 it should be noted that:

a) This document provides no information as to whether the product may be used without restriction in any of the Member States of the EU or EFTA.

b) While awaiting the adoption of verifiable European criteria, existing national regulations concerning the use and/or the characteristics of this product remain in force.

Extend of validity

This document is valid for control equipment of solar heating systems for the purpose of hot water preparation and/or space heating. If the solar system is connected to or part of a conventional heating system, the validity is extended to the entire system. In combination with the standards EN 12976-1, EN 12976-2 as well as prEN/TS 12977-1, prEN/TS 12977-2, prEN 12977-3 and prEN/TS 12977-4 this document is valid for:

a) Factory made solar heating systems,

b) small custom build solar heating systems,

c) large custom build solar heating systems and

d) auxiliary heater equipment used in connection with a), b) and c).

NOTE Factory Made and Custom Built solar heating systems.

The standards EN 12976-1, EN 12976-2 as well as prEN/TS 12977-1, prEN/TS 12977-2, prEN 12977-3, and prEN/TS 12977-4 distinguish two categories of solar heating systems:

- Factory Made solar heating systems and
- Custom Built solar heating systems.

The classification of a system as factory made or custom built is a choice of the final supplier.

Custom Built solar heating systems are subdivided into two categories:

- Small Custom Built systems offered by a company are described in a so-called assortment file, in which all components and possible system configurations, marketed by the company, are specified.
- Large Custom Built systems are uniquely designed for a specific situation.

1 Scope

This document (prEN/TS 12977-5:2006) specifies performance test methods for control equipment. Furthermore this document contains requirements on accuracy, durability and reliability of control equipment.

The tests described in prEN/TS 12977-5 are limited to components delivered with or for the system by the final supplier. For the purposes of this document (prEN/TS 12977-5) controller and control equipment for solar heating systems and auxiliary heaters, if part of the system, are restricted to:

- Controllers as
  - system clocks, timers and counters,
  - differential thermostats,
  - multi-function controllers.
- Sensors as
  - temperature sensors,
  - irradiance sensors (for short wave radiation),
  - pressure sensors,
  - level sensors,
  - flow meters or
  - heat meters.

- Actuators as
    - pumps,
    - solenoid and motor valves or
    - relays.

Furthermore combinations of controllers, sensors and actuators listed above.

An additional objective of the procedures described in this document is to verify control algorithms and, together with the accuracy of sensors, to determine control parameters. Beside results of verification of the functioning of a controller, its equipment and actuators, the determined parameters may be used for numerical system simulations.

Even thought electrical anodes are not part of the control equipment of a solar heating system and typically not control by the control equipment, because they are electrical appliance electrical anodes are included in this document.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9060, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation (ISO 9060:1990)*

ISO 9022-9, *Optics and optical instruments — Environmental test methods — Part 9: Solar radiation*

ISO 15218, *Pneumatic fluid power — 3/2 solenoid valves — Mounting interface surfaces*

ISO/TR 9901, *Solar energy — Field pyranometers — Recommended practice for use*

EN ISO 9488, *Solar energy — Vocabulary*

EN 809, *Pumps and pump units for liquids — General safety requirements*

EN 1151, *Pumps — Rotodynamic pumps — Circulation pumps having an electrical effect not exceeding 200 W for heating installations and domestic hot water installations — Requirements, testing, marking*

EN 982, *Safety of machinery — Safety requirements for fluid power systems and their components — Hydraulics*

EN 12975-1, *Thermal solar systems and components — Solar collectors — Part 1: General Requirements*

EN 12975-2, *Thermal solar systems and components — Solar collectors — Part 2: Test methods*

EN 12976-1, *Thermal solar systems and components — Factory-made systems — Part 1: General requirements*

EN 12976-2, *Thermal solar systems and components — Factory made systems — Part 2: Test methods*

EN 60335-1, *Safety of household and similar electrical appliances — Part 1: General requirements (IEC 60335-1:1991 modified)*

EN 60335-2-21, *Safety of household and similar electrical appliances — Par 2: Particular requirements for storage water heaters (IEC 60335-2-21:1997 + corrigendum 1998, modified)*

EN 60730, *Automatic electrical controls for households and similar use*

prEN/TS 12977-1, *Thermal solar systems and components — Custom-built systems — Part 1: General requirements for solar water heaters and combisystems*

prEN/TS 12977-5, *Thermal solar systems and components — Custom-built systems — Part 5: Performance test methods for control equipment*

remark: prEN 14335-2-2-3, remark: *Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 2.2.3: Heating generation — Thermal solar systems*

IEC 60038, *IEC standard voltages / Note: This document and its separate amendments continue to be valid together with the consolidated version*

IEC 60947, *Low-voltage switchgear and control gear*

IEC 61024-1, *Protection of structures against fire, explosion and life hazards*

DIN EN 60255, *Electrical relays*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12976-1 and prEN/TS 12977-1 as well as EN ISO 9488 and the following apply.

3.1
controller
device to control a solar heating system, sometimes in connection/combination with auxiliary heater(s)

NOTE For classification see Table 1.

3.2
sensor
device to measure physical (or chemical) qualities/properties. With respect to solar heating systems, temperature, irradiance, flow/circulation, pressure and level sensors are most common

NOTE For classification see Table 2.

3.3
actuator
component and device designed to perform actions to operate a solar heating system or auxiliary heating system according to signals from the control equipment

NOTE For classification see Table 3.

3.4
reference device/measurement
device or measurement towards control equipment under test or measured quantities are compared or referred to.

3.5
control equipment assortment
complete list of components (controller, sensors, pumps, actuators etc.), which a company offers to control a solar heating systems, including auxiliary heater control equipment, if the auxiliary heater is part of the solar

heating systems. For the purpose of this document (prEN/TS 12977-5) the assortment is restricted to the following components:

- controllers,
- sensors and
- actuators

4 Symbols and abbreviations

G	hemispherical solar irradiance in the plane of the radiation sensor, in W/m²;
ϑ_{ref}	reference temperature, in °C;
ϑ_{amb}	surrounding air temperature, in °C;
ϑ_{max}	maximal (allowed) temperature of a temperature sensor, in °C;
$\vartheta_{\mathrm{tank}}$	temperature of the storage tank for heated water, in °C;
$\vartheta_{\mathrm{start}}$	start temperature, e.g. of pump in solar collector circuit, in °C;
$\vartheta_{\mathrm{stop}}$	stop temperature, e.g. of pump in solar collector circuit, in °C;
$\Delta\vartheta_{\mathrm{hyst}}$	hysteresis, difference between ON- and OFF-temperature difference for switching an actuator, in K;
v_{air}	surrounding air speed, in m/s;
t	time, in s.

5 Controller classification (including equipment classification)

5.1 Controller

Control device designed to control a solar heating system, sometimes in connection/combination with auxiliary heaters are classified according Table 1.

Table 1 — Classification of controllers for solar heating systems

	Controller
C1	**System clock, Timer and Counter** Controlling the operation of one or more actuators by means of real or relative time. Timers and counters might be connected with different kinds of sensors influencing their behaviour by superposition of the commands. Beside time intervals counter might count and sum up events or quantities.
C2	**Differential thermostat** Control of one or more actuators by means of a temperature difference between two temperature sensors. In most cases a hysteresis between switching ON and OFF is inserted. Differential controllers are sometimes used with other signals, e.g. solar irradiation, pressure or level sensors.
C3	**Multi-function controller** Controller designed to control one or more actuators based on measured quantities delivered by different kinds of sensors, real time or relative time and/or control concepts including specific control algorithms. With regard to this document multi-function controllers are used to control and operate a solar heating system, optional in combination with hot water preparation, space heating, heat distribution and any kind of auxiliary heating, if more than one differential algorithm is used in one unit and/or at least one operation is caused by more than a simple differential algorithm. If a device, e.g. a differential thermostat operates its output(s) depending on more than one (temperature) difference and/or not only in ON/OFF mode, a controller incorporating such differential algorithm (thermostat) should be treated as a multi-function controller.

5.2 Sensor

Typical sensors used for controllers listed in Table 1 are summarized in Table 2.

Table 2 — Common sensors for solar heating systems

	Sensor
S1	**Temperature sensor** Sensing of temperatures of different parts in the system. In connection with the electronic layout of a controller or accessory measuring device determination of temperatures, e.g. in degree centigrade.
S2	**Irradiance sensor** Instrument measuring the hemispherical solar irradiance in the plane of the radiation sensor within a spectral range of approx. 0,3 μm to 3 μm. To control a (solar) heating system irradiance sensors and accessory control equipment might have special designs to meet the specific requirements to solar energy utilization. With respect to this document both, irradiance sensors with thermoelectric sensor and irradiance sensors based on the photoelectrical effect are included. Supplementary photocells or other devices used to measure the solar irradiance are treated equate to solar irradiance sensor.
S3	**Flow/circulation sensors** Sensing of the flow/circulation of a fluid. In connection with the electronic layout of a controller or accessory measuring device determination of the volume and/or mass flow.
S4	**Pressure sensor** Sensing of absolute or relative pressure. In connection with the electronic layout of a controller or accessory measuring device determination of absolute pressure or pressure differences.
S5	**Level sensor** Sensing of the level of a fluid within a vessel or a store.
NOTE 1 The controller or accessory-measuring devices shall enable the conversion of sensor signals to values suitable to serve as control criterion for functioning and supervising of the system. NOTE 2 Values serving as control criterion should be displayed by a control device or, at least, a read back of data shall be possible. NOTE 3 If other quantities or conditions than listed under S1, S2, S3, S4 or S5 are measured, the use of those sensors and the data processing might be in accordance to S1, S2, S3, S4 or S5.	

5.3 Actuator

The next table gives a selection of the most common actuators that can be found in solar heating systems.

Table 3 — Most common actuators for solar heating systems

	Actuator
A1	**Pump** Device to circulate a heat transfer medium and/or water in a forced-circulation system, e.g. a collector circuit, a circuit for space heating/cooling and/or hot water preparation.
A2	**Solenoid and motor valve** Electric driven device to start and/or to stop flow/circulation as well as to join, divide and/or to divert flow streams.
A3	**Relay / Contactor** Device to connect and/or to switch electrical loads and/or actuators, e.g. when using a low level signal (voltage and/or current) of a controller to start and stop a high voltage/power pump.

6 Requirements

6.1 General requirements

6.1.1 Durability - Reliability

Any part of the control equipment has to be suited for the application it should be applied to and has to be suited for all conditions it might come in touch with. Any part of the control equipment mounted outdoors shall be resistant to UV radiation and ozone. For indoor and outdoor mounted control equipment harmful impact and mechanical damage, e. g. caused by birds or rodents and other operation conditions shall be prevented (see EN 60730). If any maintenance or replacement of the control equipment is required in order to maintain the system working, this shall be clearly stated in the documents for the user. The durability to withstand all operation condition, which might occur during operation, and depending on the mounting location, is mandatory. All equipment, particularly parts installed outside, has to be protected against corrosion and mechanical impact at least over the prescribed lifetime or maintenance interval specified by the manufacturer or final supplier.

6.1.2 Electrical safety

The control equipment shall fulfil general safety requirements.

See EN 60335-1, EN 60335-2-21, EN 60730.

6.1.3 Freeze damage protection

If the control equipment includes algorithms and/or devices for freeze damage protection, e. g. preventing heat transfer medium in the collector circuit to freeze, those algorithms and/or devices shall be reliable.

6.1.4 Scald protection

If the control equipment includes algorithms and/or devices for scald protection, this algorithms and/or control equipment shall be reliable. The default value of the temperature for domestic hot water delivered to the user shall at maximum be 60 °C.

If the temperature of the domestic hot water delivered to the user might exceed 60 °C, an external, automatic cold water mixing devices or any other device to limit the temperature to at maximum 60 °C shall be installed.

6.1.5 High temperature protection for materials

If the control equipment includes algorithms and/or devices to avoid overheating of materials and/or components, e. g. stopping the collector loop pump and maybe drain down the heat transfer medium out of the collector, those algorithms and/or control equipment shall be reliable.

If the control equipment includes algorithms and/or devices for limitation of the flow temperature, e. g. to a floor heating circuit, this algorithms and/or control equipment shall be reliable.

6.1.6 Lightning

The control equipment shall meet the requirements given in IEC 61024-1. The manufacturer or the final supplier shall specify particular features for lightning protection within the control equipment.

6.2 Controllers, system clocks, timers and counters

All kinds of controllers, system clocks, timers and counters this document refer to shall be reliable and resistant to all impact that might occur under normal operation at least over the prescribed lifetime or maintenance interval specified by the manufacturer or final supplier.

6.2.1 Accuracy requirements for controllers

In combination with all other control equipment controllers, system clocks, timers and counters shall behave as specified and intended by the manufacturer. The accuracy of controllers, e.g. signal processing and activating of actuators, shall enable the operation of all systems layouts the controller is designed for in accordance to the specifications of the manufacturer. Regarding all functions and operations controllers, system clocks, timers and counters shall comply with the manufacturer's guidance.

6.2.2 Accuracy requirements for system clocks, timers and counters

The accuracy requirements of system clocks, timers and counters in charge of controlling a solar heating system are listed in Table 4.

Table 4 — Accuracy of system clocks, timers and counters

Clock / timer/ counter	tolerance
Real time clock	± 1,0 min per 30 days
Timer	± 1,0 min per 30 days operation time
Counter	± 1,0 %

In case of solar heating systems installed in regions with a shift between summer and wintertime, adjustments – if necessary – has to be specified by the final supplier.

6.3 Sensors

6.3.1 Temperature sensors

For all temperature sensors the location and installation shall ensure a reliable thermal contact with the part of which the temperature shall be measured. Surrounding conditions, when not relevant, shall not influence the measurement. With exception of ambient temperature sensors, temperature sensors shall be protected/insulated against external influences.

6.3.1.1 High-temperature resistance

The requirements to the capability of sensors to resist to extreme operation conditions depend on the location where the sensor is mounted. The minimum requirements are listed in Table 5.

Table 5 — Requirements of high-temperature resistance of temperature sensors

For all kinds of temperature sensors installed within a solar heating system or auxiliary heater, if the auxiliary heater is part of a solar heating system	
Minimum required temperature	Maximum temperature declared by the manufacturer or final supplier plus 10 K
Time of exposure	At least 6 h

6.3.1.2 Accuracy requirements

The accuracy requirements of temperature sensors in charge of controlling a solar heating system are listed in Table 6.

Table 6 — Accuracy requirements of temperature sensors for solar heating systems

Temperature range	Tolerance
–20 °C to 70 °C	± 1,0 K
More than 70 °C to 100 °C	± 1,5 K
More than 100 °C to 150 °C	± 1,5 % of temperature value
More than 150 °C to max. operation temperature (to be specified by final supplier)	± 2,0 % of temperature value

6.3.1.3 Reduction of temperature sensor accuracy caused by extreme operation conditions

All kinds of temperature sensors installed within a solar heating system or auxiliary heater, if the auxiliary heater is part of a solar heating system, shall withstand extreme operating conditions as specified in Table 5 without reduction of the accuracy by more than 1 K.

6.3.2 Irradiance sensors

In connection with the electronic layout of a controller or accessory measuring device a solar irradiance sensor should at least be sensitive for solar radiation in the wavelength of approximately $0,4 \times 10^{-6}$ m to $0,8 \times 10^{-6}$ m.

6.3.2.1 High irradiance resistance

The irradiance sensors shall resist to any extreme solar irradiance that might occur during operation within the prescribed lifetime or maintenance interval, specified by the manufacturer or final supplier. The requirements to capability of an irradiance sensor to resist to extreme irradiance conditions are listed in Table 7.

Table 7 — Climate test conditions for solar irradiance sensors capability to resist to high irradiance

Climate parameter	Value
Hemispherical solar irradiance in the plane of the irradiance sensor, G	> 1 000 W/m²
Surrounding air temperature while testing irradiance sensor's resistance against high irradiance, t_a	20 °C to 40 °C
Surrounding air speed, v_{air}	< 1 m/s
Time the solar irradiance sensor should be exposed to the test conditions, t	> 1 h

6.3.2.2 High temperature resistance

The conditions to test high temperature resistance of an irradiance sensor are given in Table 8.

The conditions to test solar irradiance sensors capability to resist to high surrounding temperatures are listed in Table 8.

Table 8 — Climate test conditions for solar irradiance sensors capability to resist to high surrounding temperatures

Climate parameter	Value
Hemispherical solar irradiance in the plane of the irradiance sensor, G	> 900 W/m²
Surrounding air temperature for testing sensor's resistance against high temperatures, t_a	> 30 °C
Surrounding air speed, v_{air}	< 1 m/s
Time the solar irradiance sensor should be exposed to the test conditions, t	> 12 h

6.3.2.3 Accuracy requirements

The accuracy requirements of a solar irradiance sensor in charge of controlling a solar heating system are:

Table 9 — Accuracy requirements for solar irradiance sensors

Range of measurement	Tolerance
100 W/m² to 300 W/m²	± 15,0 % of the specified solar irradiance
More than 300 W/m² to 900 W/m²	± 10,0 % of the specified solar irradiance
More than 900 W/m²	± 15,0 % of the specified solar irradiance

6.3.2.4 Reduction of solar irradiance sensor accuracy caused by extreme operation conditions

The irradiance sensor shall withstand extreme operation condition as specified in Table 7 and 8 without reduction of the accuracy out of the range given in Table 9. The sensor, gasket(s), cable(s) and all related mounting equipment shall not show decomposition or significant discolouring.

6.3.3 Other sensors

All other sensors, such as pressure sensors, level sensors, flow meters etc. shall have accuracy as specified by the manufacturer or final supplier. All relevant operation conditions the sensors are claimed to withstand shall be included in the documentation.

6.4 Indicators

Indicators, such as pressure gauges, temperature gauges, level indicators, voltage indicators of anodes and flow/circulation indicators or heat meters etc. shall have the accuracy as specified by the manufacturer or final supplier. Pressure gauges shall enable to mark the permissible operating range of overpressure in the system or at least the filling pressure of the system. Voltage indicators of anodes shall indicate whether the voltage caused by the anode is sufficient to protect the store. In case of an electrical anode it shall be indicated, whether this device is proper functioning. Flow/circulation indicators shall enable to mark the nominal value of the flow/circulation specified by the manufacturer or final supplier. A possibility to adjust the flow/circulation is recommended. All relevant operation conditions the indicators are claimed to withstand shall be included in the documentation.

If indicators are connected to the power supply, in the case of power failure the indicators shall be connected to the power supply in a way, that the greatest possible safety is guaranteed. If possible, the connection to the power supply should be selected in a way, that the power consumption is as low as achievable.

6.5 Actuators

6.5.1 Circulation pumps

See EN 809 and EN 1151.

If the collector circuit is provided with one or more circulation pump(s), e. g. when an external collector loop heat exchanger is used, the total parasitic electrical power of the pump(s) should not exceed the values given in Table 10.

Table 10 — Total maximum electrical power of the pump(s)

System	Total maximum electrical power of the pump(s)
Small systems	50 W or 2 % of the peak power delivered by the collector array, whichever higher
Large systems	1 % of the peak power delivered by the collector array

NOTE If not specified in the documentation, the peak power of a collector array shall be calculated by multiplying the aperture area of the whole collector array with 700 W/m² of aperture area.

In the case of pumps operated with variable power (e. g. pulse width modulation) or short term alternating operation, the requirements stated in Table 10 applies to the average power.

The maximum pump power stated above excludes the power of pumps in drain-back systems that are only needed to refill the system after draining back (down) of the heat carrier fluid.

Other heat transfer loops within the system should be designed by comparing the parasitic power of their pump(s) to the highest heat power transmitted. The values in Table 10 shall not be exceeded.

6.5.2 Solenoid and motor valves

See EN 982 and ISO 15218.

All kinds of valves should be installed in a way that the power consumption is as low as possible. For this the most common mode of operation has to be taken into account.

6.5.3 Relays

See EN 60255.

Relays should be installed in a way that the power consumption is as low as possible. For this the most common mode of operation has to be taken into account.

6.6 Initial operation and commissioning

Default parameters within the controllers and control equipment should enable the initial operation of the system as intended by the manufacturer of final supplier. Default values shall be included inerasable in the control equipment. In case of adjustable parameters all necessary adjustments required in order to maintain the system working properly shall be clearly described in the documents. Depending on the control equipment different documentations for the installer and for the user might be provided. Particularly in the case of multi-function controllers during power failure of mains voltage the storing of all data and adjustments carried out by the installer and/or customer should be provided. Supplementary the possibility to reset the control equipment to the default values, e.g. by means of a reset button is recommended.

6.7 Documentation

The documentation of the control equipment shall be complete and clearly arranged. The documentation shall include all instructions necessary for assembly, installation, operation and maintenance. The description of assembly and installation of the control equipment shall enable a proper mounting and operation.

The documentation shall at least include:

a) All relevant system configurations including related hydraulic, control schemes and specifications to enable the user to understand the operating modes of the system;

b) description of the control strategies and the control system(s) including the location of the control equipment (e. g. sensors, actuators), if relevant for different system designs. All control equipment should be included in the hydraulic scheme(s) of the system;

c) a list of all components to be included into the respective system configurations, with full reference to dimension and type. The identification of the listed components shall be easy and unambiguous;

d) if relevant, list of combination and dimension options within different system configurations;

e) a guideline to adjust all parameters and settings. For documentation it is recommended to supply a table in which all adjustable parameters and settings should be entered by the installer and/or the customer;

f) maintenance instruction for the control equipment, including start-up and shut-down of the system;

g) instructions for function and performance testing;

h) intended action(s) in the case of most common failures.

NOTE For detailed specification of the entire documentation of a solar heating system see prEN/TS 12977-1.

7 Testing of Sensors

Within this document sensor testing include the following two partial tests:

a) Testing of capability of sensors to resist to extreme operation condition;

b) testing of sensor's accuracy, durability and reliability to measure physical quantities and/or conditions in combination with all signal processing, e.g. within a controller. With respect to this document the sensors have to be part of a solar heating system or auxiliary heater, if the auxiliary is part of a solar heating system.

Regarding sensor testing all accessory equipment of a sensor is treated to be part of the sensor and therefore tested and evaluated together with the sensor according to the same criteria.

For general requirements see clause 6.

7.1 Testing of temperature sensors

The purpose of this item is to test the capability of temperature sensor's to resist to extreme operation conditions. Furthermore the accuracy of the sensor in connection with the data processing, e. g. within a controller is determined. With respect to this document accessory and mounting equipment of the sensor is treated to be part of the sensor.

7.1.1 Test Equipment

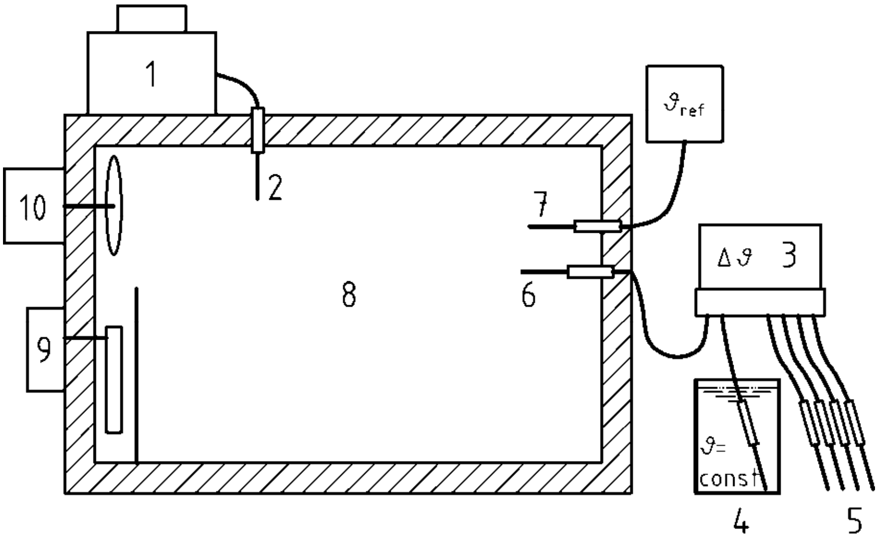
For testing the high-temperature resistance and the accuracy of temperature sensors the following test equipment might be used:

a) A tempering device able to provide temperatures meeting the requirements for testing temperature sensors as listed in Table 5 and 6. This device could be an oven with integrated heating element and fan (Figure 1), a temperature calibrator or calibration bath.

   During the entire test the instability of the temperatures provided by the device should at maximum be ± 0,5 K, referring to the adjusted temperature;

b) digital multi-meter (for voltage, current and electrical resistance measurements);

c) data logging device (optional).



Key

1 thermostat

2 sensor for control of oven temperature

3 controller to be tested

4 tank sensor (e. g. bath with const. Temp.)

5 additional sensor(s)

6 sensor to be tested

7 reference sensor

8 tempering oven

9 heating element

10 fan

Figure 1 — Elevation of an oven-arrangement to test temperature sensor accuracy, high-temperature resistance and differential thermostat functions

7.1.2 Installation of sensors

While installing a temperature sensor to a tempering device it should be paid attention to

— installing the sensors in accordance to the manufacturers guidelines;

— totally expose the active part of the sensor that under usual operation condition is in touch with the temperature to be measured;

— not destroy sensor parts typically not in touch with high temperatures by applying heat.

7.1.3 Testing of high-temperature resistance of temperature sensors

The requirements to test the high-temperature resistance of temperature sensors depend on the highest possible temperature that might occur during operation. The requirements are listed in Table 5.

7.1.3.1 Test procedure

The test to determine the capability of temperature sensors to resist to extreme operation conditions shall be carried out before testing the accuracy of the sensors.

During the test of each particular sensor all remaining sensors shall be kept on a reasonable temperature, e. g. while testing the collector sensor the temperature of all other sensors shall remain at approximately 20 °C.

The requirements for testing the capability of temperature sensors to resist to extreme operation conditions are listed in Table 5. Each temperature sensor to be tested shall be exposed to the respective temperature at least for the time interval specified in Table 5.

During the test the actual temperature values the sensor to be tested is exposed to and the signal delivered by the sensor shall be recorded. Beside the equipment a reference sensor exposed to the same conditions as the sensor under test is strongly recommended (see Figure 1). The values of the reference sensor should be recorded simultaneously to the values delivered by the sensor under test.

Visual inspection of the sensor, the gasket(s) and cables after each temperature step, at least at the end of the test (see 7.1.3.2).

Documentation of the results with respect to Tabl 5 and visual inspection(s).

7.1.3.2 Data processing and evaluation

After the test of high-temperature resistance:

- visual inspection of the sensor, sensor box, gasket(s), cable(s) and all related mounting equipment. If any part shows decomposition of the material(s) and/or discolouring that might indicate a harmful influence on the material(s), this shall be documented in the test report.

7.1.4 Testing of the accuracy of temperature sensors

The accuracy of a temperature sensor shall be measured after the test of capability of the sensor to resist to extreme operation conditions.

If the requirements of the temperature resistance according 7.1.3 are fulfilled, the test procedure continues with checking sensor accuracy.

7.1.4.1 Test procedure

a) For testing the accuracy each temperature sensor shall be placed in the tempering device, e. g. as shown in Figure 1. All sensors (e. g. solar collector sensor, tank sensor, surrounding temperature sensor) delivered by the final supplier shall be connected electrically to the corresponding terminal of the controller in accordance with the manufacturer’s guidelines. The controller(s) shall be connected to the mains supply and put into operation. Thus the sensors are exposed to the normal sensor current with the consequent self-heating. The complete electric connection including the mains supply shall take place at least 6 hours before starting the accuracy test.

   If the controller displays the temperature value, or an accessory-measuring device delivered by the final supplier is displaying the temperature value, the accuracy should be tested with that controller or the accessory measuring device including all signal processing. In case the temperature values are not displayed, the measurement of the sensor signals should be carried out with a suitable ohmmeter and the temperature shall be calculated for the resistance values according correlations delivered by the final supplier.

b) The sensor should be mounted directly to the corresponding terminal of the controller or reference device, only with its fixed wires as delivered by the final supplier. If the sensor is delivered without wiring, 5 m of cable according to the requirements documented by the manufacturer or final supplier shall be connected.

c) With slowly increasing temperatures (about 1 °C/min), the sensors should remain at each temperature step listed in Table 11 for at least 15 min. Reaching the highest value of the temperature course, the sensor shall be exposed to this temperature for at least 1 h. After that the temperature profile shall continue with decreasing temperatures (about 1 °C/min), remaining at each temperature step listed in Table 11 for at least 15 min.

NOTE Because most of the control devices have an integrating characteristic, slow increase and decrease of the temperature is mandatory.

d) During the entire temperature course the actual temperature values the sensor to be tested is exposed to and the signal (including signal processing) delivered by the sensor shall be recorded at least at 10 s intervals. Beside the control equipment a reference sensor exposed to the same conditions as the sensor under test is strongly recommended (see Figure 1). The values of the reference sensor should be recorded simultaneously to the values delivered by the sensor under test.

e) If the controller provides a temperature display for the sensor under test, the corresponding temperatures can be directly read from the controller display. If not, the sensor shall be electrically disconnected from the controller to measure the corresponding signal, e.g. resistance value by means of an ohmmeter (see a)). When using an ohmmeter, to account for self-heating caused by normal sensor current, after each single measurement below or equal 50 °C the sensor shall be re-connected to the control device again.

f) The accuracy test shall be performed at least for the temperatures listed in Table 11.

Table 11 — Temperatures to be used for the accuracy test

Sensor for	Temperatures to be used for the accuracy test
Outdoor temperature	–15 °C; –5 °C; 0 °C; 5 °C; 15 °C; 25 °C and 35 °C
Indoor temperature	5 °C; 15 °C and 25 °C
Collector temperature	–10 °C; 10 °C; 50 °C and 90 °C
Store and any other temperatures	10 °C; 50 °C and 90 °C, if applicable
If the system operates in other temperature ranges, additional test temperatures should be selected accordingly.	

To account for hysteresis effects, the accuracy test shall be run through twice, with increasing and with decreasing temperatures.

7.1.4.2 Data processing and evaluation

Comparison of the temperature values with the displayed ones of the control equipment monitored at increasing and decreasing temperatures respectively. If available, crosscheck of the displayed temperatures of the control equipment with the additional reference temperatures (Figure 1, item 7). The results shall be assessed as follows:

— If the differences of all measurements between the tested temperature sensor and the temperature of exposure (reference sensor) meet the requirements listed in Table 6, then the sensor shall be accepted.

If the sensor meets the requirements listed in Table 6, the testing of the accuracy of the temperature sensor is finished.

If the accuracy of a temperature sensor is not in accordance with Table 6, the accuracy testing of the sensor shall be repeated using a replacement sensor delivered by the manufacturer or final supplier of the control equipment. In the case of repeatedly insufficient results, while using a new replacement sensor the test might be carried out at maximum for a third time.

— If the tolerances of all different measurements of the second (or third) test is less than twice of the tolerances specified in Table 6, the tolerances shall be documented in the test report. For function testing of the controller and further control equipment, the respective sensor might be accepted.

- If the tolerance(s) of one or more measurement(s) is twice a tolerance specified in Table 6, or more, then the function testing of the controller and further control equipment may not be carried out using the respective sensor.

7.2 Testing of solar irradiance sensors

The purpose of this test is to assess whether a solar irradiance sensor can withstand extreme operation (and outdoor) conditions, e.g. high irradiance levels and rain penetration without failures such as breakage, melting or collapse of (plastic) covers, decomposition or significant discolouring of the material(s). Furthermore one partial test is intended to examine sensors accuracy. The specified requirements on durability and capability of a sensor to resist to extreme operation conditions are valid for all accessory equipment, e.g. sensor boxes, gaskets, cables and mounting material of the irradiance sensor as well.

NOTE Particularly SI-pynamometers (indication of the solar irradiance by means of the photoelectric effect) might be harmed by peaks of solar irradiance. Due to reflection by clouds (and snow), these peaks might reach up to 1 500 W/m².

7.2.1 Test equipment

The solar irradiance sensor should be tested outdoors or in a solar irradiance simulator. The characteristics of a solar irradiance simulator to be used to test the accuracy, the high irradiance and high temperature resistance of an irradiance sensor, shall be in accordance to solar irradiance simulators used for efficiency testing of liquid heating solar collectors (EN 12975-2). As reference and in accordance to radiation measurements applied for efficiency testing of liquid heating solar collectors, the solar radiation on the irradiance sensor under test shall be measured with a class I or better pyranometer, see specifications in ISO 9060. The recommended practice for use of the reference pyranometer is given in ISO/TR 9901 and should be observed. Beside the solar irradiance the surrounding and device temperature of the sensor under test should be recorded:

a) near to the irradiance sensor, shielded from solar radiation,

b) in touch with the irradiance sensor, shielded from solar radiation (e. g. on the backside or other place to measure the sensors temperature)

The inaccuracy of the measurement of the surrounding and the irradiance sensor temperature shall at maximum be 1 K.

7.2.2 Installation of sensors

The irradiance sensor and the reference pyranometer shall be mounted in the same plane and in accordance to the manufacturer’s guidelines. The tilt angle and azimuth shall be adjusted in a way, that the incidence angle for direct solar radiation is less than 30 ° from normal incidence.

The mounting place has to be free of shading and not more than 5 % of the sensors field of view shall be obstructed. Large obstructions, e.g. buildings and trees subtending an angle of greater than approximately 15° to the horizontal in front of the irradiance sensors shall be avoided.

7.2.3 Testing sensor resistance against extreme operation conditions

The purpose of this test is to assess whether a solar irradiance sensor can withstand extreme outdoor operation conditions like high irradiance levels, high temperatures, water penetration, external thermal shock and freezing without failures such as glass breakage, collapse of plastic cover, melting of plastic materials or significant deposits from out-gassing materials on sensor cover.

After mounting and before each test the irradiance sensor and the reference pyranometer should be checked for dust, soiling etc. on the outer surface and both shall be cleaned if necessary.

During the test the solar irradiance (natural or simulated) on the sensor plane, surrounding air temperature and speed as well as the sensor temperature shall be recorded.

If the solar irradiance measurement by the reference pyranometer does not vary by more than ± 5 % within 5 min, the measurement is valid.

7.2.3.1 Test procedure

Taking into account the respective test conditions, the test of high irradiance and high temperature capability might be carried out together.

NOTE All tests might be carried out in association with reliability tests of a liquid heating collector as described in EN 12975-2.

7.2.3.1.1 High irradiance

The conditions to test solar irradiance sensor's capability to resist to high irradiance are listed in Table 7. The actual values of the irradiance sensor to be tested (including signal converter, if relevant) and the signal delivered by the reference pyranometer shall be recorded at least at 10 s intervals.

7.2.3.1.2 High temperature

The conditions to test solar irradiance sensors capability to resist to high surrounding temperatures are listed in Table 8.

Alternatively to outdoor testing the high temperature-resistance might be tested in a tempering device, e. g. an oven with a temperature of 40 °C. The relative humidity within the tempering device shall be more than 60 %. While using an oven, the time of exposure shall be > 12 h, at maximum divided into two intervals. In case the irradiance sensor is tested outdoors, the time for testing the high temperature resistance should not be divided into more than 6 time intervals.

The irradiance sensor shall be continuously mounted to the test rig until the requirements of the test procedure have been fulfilled.

The values given by the irradiance sensor to be tested (including signal converter, if relevant) and the signal delivered by the reference pyranometer shall both be recorded at least every 10 s.

7.2.3.1.3 Exposure test

The exposure test provides an indication of the reliability of an irradiance sensor with respect to average outdoor operation conditions, particularly taking into account the exposure time. The irradiance sensor shall be exposed outdoors for at least 90 consecutive days. The mounting location shall correspond to 7.2.2, with incidence angle for direct solar radiation less than 30 ° from normal incidence at noon. The impact of all natural climate conditions, e. g. temperature, wind and rain shall not be hindered.

During the exposure test the conditions given in Table 12 shall all be met.

Table 12 — Minimum climate test conditions for exposure and for external shock test

Climate parameter	Value
Hemispherical solar irradiance in the plane of the irradiance sensor, G	> 900 W/m²
Time the solar irradiance sensor should be exposed to this irradiance conditions, t	> 30 h
Rain penetration	–
Time the solar irradiance sensor should be exposed to rain penetration, t	> 4 h

The values given by the irradiance sensor to be tested (including signal converter, if relevant) and the signal delivered by the reference pyranometer shall both be recorded at least every 30 min.

7.2.3.1.4 External thermal shock

This test is intended to assess the capability of an irradiance sensor to withstand sudden rainstorms on hot, sunny days without failure.

For testing the sensor shall be sprayed with a uniform spray of water over the sensor with water at a temperature lower than 20 °C and a flow rate of more than 0,05 kg/s per square metre of sprayed area. Before spraying the sensor the reference surrounding conditions given in Table 8 shall be fulfilled for at least 1 h, while the surrounding temperature shall not be lower than 30 °C. The duration of the external shock shall be 0,5 h. The sensor shall be subjected to three external thermal shocks.

7.2.3.1.5 Water penetration

During the water penetration test the surrounding air temperature of the irradiance sensor should be in a range of 10 °C to 20 °C. The hemispherical solar irradiance in the plane of the irradiance sensor should not exceed 300 W/m².

The solar irradiance sensor shall be sprayed on exposed sides, using spray nozzles or showers. The sensor shall be sprayed with water at a temperature of 20 °C ± 10 °C with a flow rate of more than 0,05 kg/s per square metre of sprayed area. The duration of the test shall be h.

7.2.3.1.6 Freezing

The sensor shall be mounted inside a climatic chamber or tempering device with a tilt angle of 30 ° to the horizontal according to the manufacturer’s guidelines.

The following temperature cycle shall be applied:

a) start temperature: 20 °C ± 5 °C;

b) cooling down and freezing, target temperature: –20 °C ± 2 °C;

c) thawing and heating up, target temperature: 20 °C ± 5 °C.

The cycle shall be repeated at least 3 times.

The duration of the cooling down period shall not exceed 120 min.

The duration of the thawing and heating up period shall not exceed 120 min.

The irradiance sensor shall remain at the target temperatures for least 2 h, each time the values are reached.

7.2.3.1.7 Extreme local conditions - optional tests

If other operation conditions that might harm the sensor might appear at locations the sensor is to be installed, additional test(s) covering these conditions should be applied (e.g. high humidity, sand storms).

7.2.3.2 Data processing and evaluation

After each single test the irradiance sensor shall be inspected for degradation, shrinkage, outgassing and distortion. The results of the inspection shall be documented together with respective values of solar irradiance (natural or simulated) on the sensor plane, the surrounding air temperature, air speed and the sensor temperature. In addition all special events, like rain penetration and thermal shocks including their duration shall be documented.

7.2.4 Testing of the accuracy of solar irradiance sensors

The accuracy of solar irradiance sensors shall be measured after the capability test of the sensor to resist to extreme operation conditions and after the exposure test.

7.2.4.1 Test procedure

The determination of the accuracy shall include all signal processing devices. The sensor shall be connected directly to the corresponding terminal of the controller, only with its electric cable(s) delivered by the final supplier. If the sensor is delivered without cable, a 5 m cable according to the requirements documented by the final supplier shall be connected. The irradiance sensor shall be mounted in accordance to 7.2.2. For the test the surrounding temperature shall remain above 15 °C, the air speed shall be below 3 m/s.

The accuracy of solar irradiation sensors shall be tested for the values given in Table 13.

Table 13 — Irradiance levels to test the accuracy of solar irradiance sensors

Solar irradiance in the plane of the irradiance sensor W/m²
150 ± 25
300 ± 25
500 ± 50
700 ± 50
950 ± 50

While testing the accuracy, before each measurement the irradiance shall be stable within the ranges specified in Table 13 for at least 30 s. At least the measurements for (150 ± 25) W/m², (300 ± 25) W/m² and (700 ± 50) W/m² shall be carried out with increasing and decreasing values.

The irradiance values indicated by the sensor under test and the reference pyranometer, the test sensor temperature and the surrounding temperature as well as the air speed shall be recorded.

7.2.4.2 Data processing and evaluation

The test conditions, including time of exposure, should be reported. If the accuracy of the irradiance sensor is not according to the requirements specified in Table 9 the deviation shall be reported. If the inaccuracy is more than 50 % (relative) higher than the maximum inaccuracy specified in Table 9, the sensor shall not be accepted. Further test of control equipment using that particular irradiance sensor should not be carried out.

7.3 Testing of further sensors and measuring equipment

The test of further sensors and measuring equipment shall be in accordance to the specific requirements within the particular application. In general sensors and measuring equipment shall be

- installed/mounted according to the manufacturer's guidelines,
- connected to and measured with the original signal processing device(s), whenever possible,
- tested in accordance to the requirements and extreme operation conditions encountered in the system they belong to.

For requirements, test equipment and installation of sensors and measuring equipment not specified in 7.1 to 7.2 see accompanying standards.

8 Testing of system clocks, timers and counters

The purpose of this item is to test system clocks, timers and counters accuracy and capability to resist to variation of the nominal mains voltage without significant reduction in accuracy. Optionally the capability to resist to extreme operation conditions like high surrounding temperature and/or humidity might be tested. With respect to this document, prEN/TS 12977-5, system clocks and timers should be treated equally.

8.1 Test equipment

In general the test equipment to test system clocks, timers and counters consists of:

a) mains voltage stabilisation box;

b) variable AC voltage supply 0 V to 260 V, e. g. 300 W at 230 V supply;

c) (digital) multi-meter for supervision of mains voltage level;

d) reference clock with stopwatch function;

e) reference counter, if counter functions shall be tested;

f) pulse or frequency generator (optional);

g) test facility for multi-function controllers (optional);

h) calibration thermostat or calibration baths (optional), see Figure 1;

i) simulation box (optional), see Figure 2.

8.2 Installation of system clocks, timers and counters

System clocks, timers and counters shall be installed within their original casing in accordance to the manufacturer's guidelines. The test facility shall enable variations of nominal mains voltage of +6 % and –10 %. If the capability to withstand extreme operation/surrounding conditions should be tested, the devices have to be mounted inside a climatic chamber.

8.3 Test procedure

The purpose of this procedure is to test the functional stability and the accuracy of system clocks, timers and counters, serving as control equipment. The test shall be carried out with the nominal mains voltage (e. g. 230 V) and a variation of the mains voltage. To check the accuracy of clocks, timers and counters, the equipment shall be compared with reference devices. Depending on which part of the control strategy has to be checked, the test might be performed under normal operation. The accuracy test and the test of the mains voltage dependency should be carried out for each system clock, timer or counter function. For all categories the following conditions of the mains voltage shall be applied:

- 230 V (± 0,5 %),
- 207 V (230V –10 %),
- 244 V (230V +6 %).

In all cases the accuracy should be in accordance to the values listed in Table 4.

In principle the test procedure is as follows:

a) System clocks, timers and counters shall be installed on the test facility as well as a variable voltage supply with a voltage stabilization box in accordance to 8.2.

b) The system clock, timer or counter shall be provided with the nominal mains voltage (e. g. 230 V). This power supply shall be switched on at least 1 h before starting measurements and testing.

c) The time interval necessary to archive reliable values for assessing the capability of system clocks, timers and counter to meet the requirements listed in Table 4 is depending on the particular task of the component. The time interval for testing the accuracy of clock functions shall at least be 24 h. The accuracy of system clocks, timers and counters shall be compared with reference devices.

d) After testing at nominal mains voltage the equipment remains connected to the power supply and the voltage is decreased to the nominal mains voltage minus 10 % (e. g. 207 V).

e) As before, the control device shall be operated at that voltage for at least 1 h before starting the function testing. The function test corresponds to c).

f) After testing at reduced voltage the equipment remains connected to the power supply and the voltage is increased to the nominal mains voltage plus 6 % (e. g. 244 V).

g) As before the control device shall be operated at that voltage for at least 1 h before starting the function testing. The function test corresponds to c).

Timers for real time and relative time as well as counters should be tested one after the other. However, c), e) and g) each may include the test of several clocks, timers and/or counters.

8.4 Data processing and evaluation

8.4.1 General

With respect to particular applications within the control strategy, e. g. in combination with temperature measurements, it shall be documented whether clocks, timers and counters behave as they are intended to do.

8.4.2 System clocks and timers

If the measured time interval of the system clock or the timer compared to the time interval measured by the reference clock differ by more than the allowed inaccuracy listed in Table 4, the difference and the corresponding mains voltage shall be documented in the test report. If the difference is twice as much or larger than the value given in Table 4, the device should be refused.

8.4.3 Counters

If the difference between the reference counter and the counter to be tested is twice as much or larger than the allowed inaccuracy listed in Table 4, the difference should be documented in the test report. If the difference is larger than three times the value given in Table 4, the counter should be refused.

9 Function testing of simple differential thermostats

The installation of the equipment and the test procedure shall always be adapted to the specific requirements of the differential thermostat to be tested.

9.1 Test equipment

Function testing of various situations encountered by simple differential thermostats during operation can be performed:

- By means of a simulation box, see Figure 2 (can only be applied to resistance sensors);
- by using a tempering device/calibration thermostat or calibration baths respectively;
- by means of an input/output emulator (see clause 10).

9.1.1 Simulation box approach

The test equipment includes a custom-built simulation box, which allows the simulation of every occurring resistance of a temperature sensor (see Figure 2).

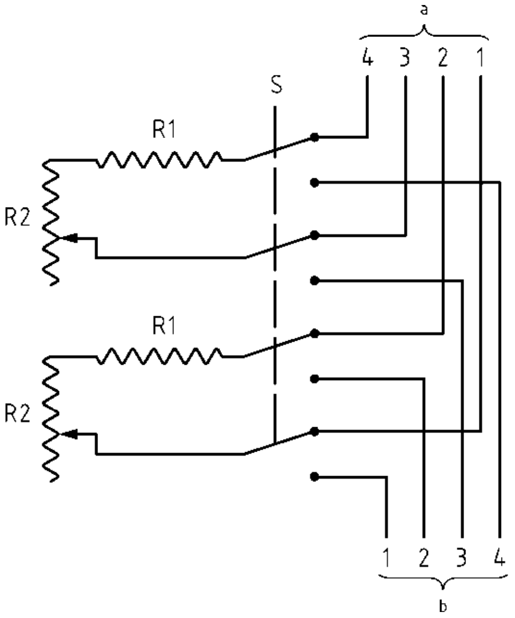


Figure 2 — Example of a simulation box for testing differential thermostats of solar heating systems

In Figure 2 “S” indicates a four-pole switch. In the position shown, the resistors R1 and R2 are connected to the control unit of the solar heating system. In the other position, these resistors are connected to a multimeter. The resistors R1 are chosen in such a way, that they correspond to the lowest resistance value within the temperature range of the original sensors, connected to the differential thermostat to be tested. R2 are wire-wound multiturn potentiometers. The resistance range of them are chosen in a way, that the temperature ranges of all sensors connected to the differential thermostat are covered by the potentiometers. The potentiometers R2 are connected in series to the resistors R1. The function of the differential thermostat is tested by connecting the differential thermostat to the simulation box and varying the resistance at the sensor terminals according to variations of the surrounding temperature of the simulated sensors.

9.1.2 Tempering device/temperature calibrators or calibration baths approach

The test equipment includes a tempering device, e. g. the one described in Figure 1. Alternatively a calibration thermostat or calibration baths might be applied. To test a differential function the sensors are placed in the tempering device, calibrator or baths. The thermostat is tested by varying the temperature in this auxiliary equipment.

9.1.3 Input/Output emulator approach

Alternatively, the use of an input/output emulator for testing multi-function controllers as described in clause 10 is strongly recommended also for testing simple differential thermostats.

9.2 Installation of differential thermostats and/or sensors

9.2.1 General

In general the connection of differential thermostats and sensors should be carried out using the wiring delivered by the manufacturer or the final supplier. If no wiring is delivered, thermostats shall be connected to the test facility using wiring of the same dimension(s) as intended by the final supplier for common installations. In the case no wiring is delivered, for each connection 5 m of cable according to the requirements documented by the manufacturer or final supplier shall be used. All connections necessary for the control function to be tested shall be mounted to the test facility ensuring sufficient electrical contact, in the case of tempering device or temperature calibrator/baths in addition making sure that the thermal contact between each sensor and its surrounding is well established. When using tempering devices, temperature calibrators or calibration baths the installation of the differential thermostat and sensors shall be in accordance to the manufacturers guidelines.

9.2.2 Differential thermostats

The differential thermostat (controller) is connected to the test facility in a way, that the variable resistors of the test facility replace the temperature sensors and deliver the relevant signals to the thermostat. The installation of the differential thermostat shall be according to the manufacturer’s guidelines. Terminals of the differential thermostat that are not connected to the test facility shall be connected to sensors or other input/output-equipment supplying reasonable signals or realistic loads to or from the differential thermostat.

9.2.3 Sensors

Sensors shall be connected directly to the respective terminals of the differential thermostat, exclusively with its fixed wires as delivered by the final supplier. If sensors are delivered without wiring, for each sensor a 5 m cable according to the requirements documented by the final supplier shall be used.

9.3 Test procedure

In principle the test procedure is the same for the simulation box approach and the tempering device, temperature calibrator or calibration baths approach. This procedure is related to the fact, that the ON- and OFF-temperature differentials for one sensor pair (for instance a solar collector sensor and a tank sensor) shall be determined.

However, in the case of testing a "multi-function" controller, each operational situation (described in the manufacturer's guidance) has to be tested separately. Hence, with respect to this kind of controllers, clause 10 describes a much more practical approach for testing.

9.3.1 Test procedure, simulation box approach

a) The differential controller should be connected to the simulation box and to the mains voltage at least 2 h before the test (see Figure 2).

b) The lower temperature (e. g. "tank sensor resistor") is adjusted to the desired temperature level, e. g. for the tank sensor, ϑ_{tank}. The resistance/temperature conversion might take place on the basis of a data sheet or resistance/temperature correlation for the sensor.

c) The resistance of the higher temperature (e. g. "solar collector resistor") is slowly changed corresponding to an increasing temperature in a solar collector until the pump relay of the differential thermostat turns ON. Depending on the time constant of the real sensors and the time span the differential thermostat needs to measure and process the resistance values until the status of its output is updated, the resistance steps of the variable resistors might correspond to temperature steps in the range 0,1 K to 1,0 K. The time interval between the steps of changing the resistances might be approximately 10 s but has to be adapted in accordance to the specific behaviour of the control equipment. If, in this respect, there is any uncertainty regarding the behaviour of the control equipment, the amount of change of the resistances shall be reduced and/or the waiting time interval shall be lengthened.

d) The corresponding resistance when the pump relay turns ON is observed and converted to a "start temperature" ϑ_{start}.

e) The resistance of the higher temperature (e. g. "solar collector resistor") is slowly changed corresponding to a decreasing temperature in a solar collector until the pump relay of the differential thermostat turns OFF. As with increasing temperatures (c) the resistance steps delivered by the variable resistors should correspond to temperature steps in the range of 0,1 K to 1,0 K. As with increasing temperatures the time interval between the resistance steps should be approximately 10 s but has to be adapted in accordance to the specific behaviour of the control equipment, see c). The corresponding resistance when the pump relay turns OFF is observed and converted to a "stop temperature" ϑ_{stop}.

f) The ON- temperature difference is calculated by $\vartheta_{start} - \vartheta_{tank}$ and the OFF-temperature difference is calculated by $\vartheta_{stop} - \vartheta_{tank}$. The difference between ON- and OFF-temperature difference is defined as the hysteresis ϑ_{hyst} of the differential thermostat.

g) For a differential thermostat installed to control a collector loop, the procedure shall be carried out at least with virtual tank temperatures of 20 °C, 40 °C, 60 °C and 90 °C. For other applications, the working range of the thermostat shall be divided into at least three temperature steps, covering the complete working range.

NOTE If the mains voltage dependency of the controller shall be tested, it is recommended to proceed with the test as described in clause 11. Electrically the complete set up shall remain connected.

9.3.2 Test procedure using tempering devices, temperature calibrators or calibration baths

a) The two temperature sensors are placed into separate tempering devices, temperature calibrators or baths of equal temperatures. The sensors must not be damaged while exposing in the equipment or baths. E. g. for a solar loop controller the temperature of the solar collector sensor is slowly increased according to increasing temperature in a solar collector until the pump relay of the differential thermostat turns ON. As well as when using a simulation box the temperature should be changed step by step with variations in a range between 0,1 K and 1,0 K. The time interval between the steps of changing the temperatures might be approximately 10 s but has to be adapted in accordance to the specific behaviour of the control equipment.

b) The sensor temperatures ϑ_{tank} (tank sensor) and ϑ_{start} (collector sensor) are read. After each step, temperature stability in the tempering devices should be awaited. The temperature can continuously be increased, provided that the temperature of the tempering device is measured close to the sensor and the temperature raise is slow enough, e. g. not more than 1 K. If, in this respect, there is any uncertainty regarding the behaviour of the control equipment, the amount of change of the temperature(s) shall be reduced and/or the waiting time interval shall be lengthened.

c) The temperature shall be observed. When the pump relay turns ON, the temperature values ϑ_{start} (collector sensor) and ϑ_{tank} (tank sensor) are read.

d) The temperature of the solar collector sensor is slowly decreased equivalent to decreasing temperature in the solar collector until the pump relay of the differential thermostat turns OFF. The sensor temperatures ϑ_{stop} (collector sensor) and ϑ_{tank} (tank sensor) are read.

e) The ON-temperature difference is calculated by $\vartheta_{\text{start}} - \vartheta_{\text{tank}}$ and the OFF-temperature difference is calculated by $\vartheta_{\text{stop}} - \vartheta_{\text{tank}}$. The difference between ON- and OFF-temperature difference is defined as the hysteresis ϑ_{hyst} of the differential thermostat.

f) For a differential thermostat installed to control a collector loop, the procedure shall be carried out at least with virtual tank temperatures of 20 °C, 40 °C, 60 °C and 90 °C. For other applications, the working range of the thermostat shall be divided into at least three temperature steps, covering the complete working range.

NOTE If the mains voltage dependency of the controller shall be tested, it is recommended to proceed with the test as described in clause 11. Electrically the complete set up shall remain connected.

10 Function testing of multi-function controllers

10.1 General

The purpose of this item is to describe a test method for so-called ‘multi-function’ controllers. Due to increasingly complex control strategies, multi-function controllers are increasingly replacing simple differential thermostats. Beside determination of control parameters to verify the functioning of a controller and its equipment, the determined behaviour may be used for numerical system simulations, e.g. to carry out long-term performance predictions (LTP). Applying a simulation box or tempering device, temperature calibrators or baths to test multi-function controllers according to clause 9, would result in the constraint that each operational situation would have to be tested separately. Although separate testing in principle is possible, in practice it may only be applied as long as the features of the multi-function controller remain simple. Particularly because of interactions between control algorithms within the controller the simulation box as well as all kinds of tempering devices do not fit to most of the common multi-function controllers. Therefore, the test facility and the test procedure described below are strongly recommended for all kinds of multi-function controllers. Furthermore, they are recommended for all common differential thermostats, simple and advanced, as well. In all cases the test procedure is accurate and simple to use. At least in the medium-term it can be expected, that the test procedure for multi-function controllers replace the use of simulation boxes, tempering devices, temperature calibrators and baths.

10.2 Intellectual property of the manufacturer

As an alternative, in the case were the manufacturer does not provide the control algorithms that are necessary to carry out a long-term performance prediction (LTP), with regard to the intellectual property of the manufacturer one of the following procedures shall be applied:

1) Use of a standard differential controller for long-term performance prediction (LTP) and making sure that the real controller does not lead to a lower system performance, or

2) delivery of a software tool for LTP by the manufacturer and comparison of the behaviour predicted by the software tool with the behaviour of the real controller.

NOTE An additional, optional item to investigate is whether function and operation of controllers and control equipment remain unchanged if the mains voltage is above or below its nominal value. The corresponding test procedure is described in clause 11.

10.3 Principle of multi-function controller testing

The function testing of a multi-function controller at various operation situations should be performed by simulation of the solar heating systems placed in different situations including varying system and surrounding temperatures, solar irradiance etc.

The aim should be to test a multi-function controller as close as possible to the way it is operated in a real system. For this purpose the test facility and procedure have to enable controller operation and conditions similar to real situations. The inputs and outputs of the controller should be connected to a device imitating all connection points of a real system. In this respect the test facility has to be able to substitute and simulate sensors and sensor signals and to transfer the signals to the controller to be tested. Simultaneously, it has to record all response of the controller under test, e.g. switching of pumps or valves.

Inputs to and outputs from the multi-function controller to be tested should be monitored and stored in a data file.

10.4 Test facility for multi-function controller testing

In general a facility for multi-function controller testing shall comprise components that

- replace sensors (e. g. temperature sensors), e. g by variable resistors,
- generate varying resistance values (or other signals) as inputs for the controller,
- provide (programmed) input profiles (e. g. temperatures) to the sensor terminals of a controller,
- read and record the input profiles transferred to the controller to be tested,
- simultaneously read out and record the response of the controller under test.

Manual adjustment of all inputs to the controller should be possible.

10.4.1 Requirements for simulation of temperature sensors

For the time being, temperatures are the most common criteria to control all kinds of solar heating systems. Depending on the test sequence and the control equipment the test facility has to provide variable resistance values as input for the controller. To handle the most common temperature sensors, e. g. Pt 100, Pt 500 and Pt 1 000 as well as most other common PTC and NTC sensors, an adjustable range from 80 Ω up to 10 kΩ should be available. For alternative signals like voltage or current, as delivered by different kinds of sensors, the test facility should be adaptable.

10.4.2 Requirements on recording of controller response

To switch pumps, valves or other actuators, multi-function controllers typically serve alternating current of 230 V (AC). The test facility shall be designed to record those outputs. In case of unusual output signals, suitable devices and interfaces (e. g. relays) have to be added.

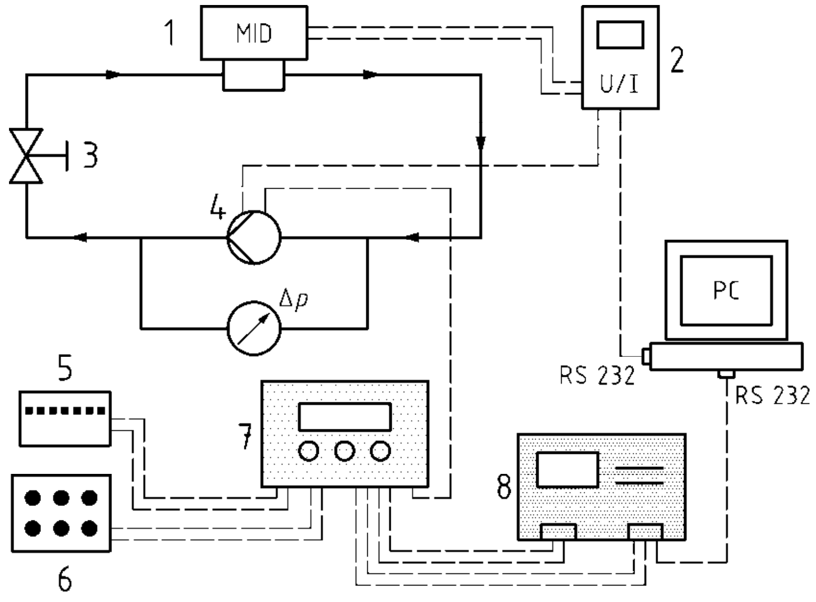
For each single step of a input (temperature) profile, which is transferred to the controller, the status of all outputs – whether active or inactive – has to be detected and recorded. For data processing and evaluation purpose the inputs to the controller and the corresponding response shall be simultaneously stored in a data file.

In the case the controller features special outputs, e. g. suitable to create variable mass flow/circulation by means of pulsing a circulation pump, a pump installed in a hydraulic circuit shall be connected to this particular output. To adjust the pressure drop of the circuit a throttle valve and a flow meter shall be installed. Additional components might be necessary (Figure 3). Depending on the particularly test the signal from the flow meter shall be recorded and stored together with the entire test sequence. The energy consumption of the pump should be recorded.

10.4.3 Test facility with input/output emulator

In the following a test facility including an input/output emulator is described. The set up comprises all features described in 10.2.1 and 10.2.2. The central part of the test facility mainly consists of an input/output emulator, which is directly connected to the sensor and the output terminals of the controller to be tested. To run the facility and for communication purposes the emulator is connected to a test site computer as well. The computer provides input profiles (e. g. resistance values as temperatures) through the emulator to the relevant sensor terminals of the controller. At the same time the emulator transfers the response of the controller back to the computer. The input profiles, the response of the controller and additional data, e. g. from a flow meter (Figure 3) are simultaneously recorded and stored in a data file.

For multi-function controller testing a test facility including an input/output emulator is strongly recommended.



Key

1 flow meter

2 measuring device

3 throttle valve

4 pump

5 sensor chamber

6 resistance board

7 controller to be tested

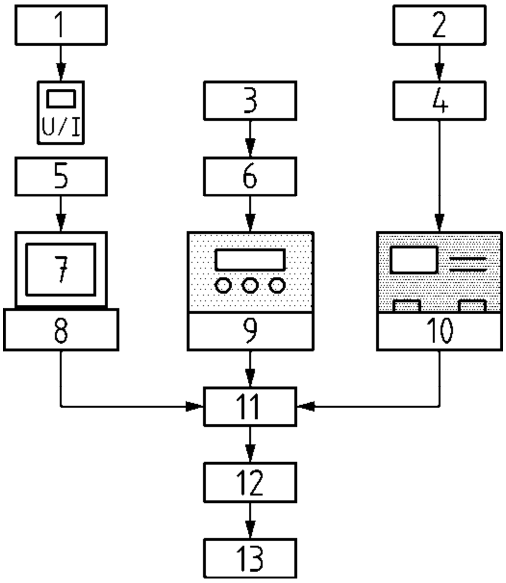
8 input/output emulator

Figure 3 — Schematic of a controller test facility including an input/output emulator

The hydraulic circuit should be filled with water, but also other fluids may be used. The pressure drop of the hydraulic circuit is adjustable according to the required pressure drop, e. g. in a collector loop. In order to investigate the influence of special control algorithms for operating a pump, the power consumption of the pump can be recorded.

10.5 Preliminary steps when using a test facility provided with an input/output emulator

The purpose of this paragraph is to describe important steps preliminary to multi-function controller testing by means of an input/output emulator. Depending on the test facility the single steps may slightly differ. Apart from the test sequences, which consists of different input profiles provided by the test site computer, the preliminary steps before using an input/output emulator are schematically described in Figure 4.



Key

1 adaption of measuring device

2 adaption of emulator

3 wiring of controller

4 wiring of emulator

5 program for testsequence

6 set of controller parameters

7 screen

8 computer

9 controller

10 emulator

11 calibration

12 run test sequence

13 data processing and evaluation of data

Figure 4 — Flow chart of preliminary steps when using a test facility provided with an input/output emulator according to Figure 3

10.5.1 Adaptation of the input/output emulator and testing/measuring devices

According to the properties of the controller to be tested, the set up of the test facility has to be adapted. Regarding to the resistance values that are provided by the original (temperature) sensors within the specified operation range, at first the operation ranges of the variable resistors within the input/output emulator have to be adjusted. In most cases for testing a common multi-function controller an emulator providing four input and four output terminals meet the needs.

If necessary, e. g. with respect to specific algorithms or features to be investigated, particular devices like pumps or valves might be connected.

10.5.2 Wiring of controller, input/output emulator and test site computer

All relevant outputs of the controller to be tested have to be connected to the corresponding terminals of the emulator. Optional measuring devices might be directly connected to the computer respectively. After that, the 'sensor resistors' of the emulator shall be connected to the terminals for the temperature sensors of the controller. In a next step all additional devices (e. g. to measure energy consumption of pumps) and sensors have to be connected. Finally, the emulator, additional devices and the controller are connected to the mains voltage.

All connections necessary to test the multi function controller shall be mounted to the test facility ensuring sufficient electrical contact. In the case of additional tempering devices or temperature calibrator/baths the thermal contact between each sensor and its surrounding has to be well established. When using tempering devices, temperature calibrators or calibration baths the installation of the differential thermostat and sensors shall be in accordance to the manufacturers guidelines. In general requirements concerning the wiring and specifications of cables documented in the manufacturers guidelines should not be disregarded. All sensor terminals of the controller have to be used in accordance to the installation guidelines and should be supplied with realistic values. If not occupied by a 'sensor resistor' of the emulator, additional resistors with fixed or variable values have to be connected. Alternatively real sensors might be applied. While connecting real sensors, attention shall be taken to the fact that signals of those sensors might change with the surrounding conditions of the test facility. Signal changes from those sensors might influence the behaviour of the controller. As a convenient option to real sensors, fixed or variable resistors connected to sensor terminals not occupied by the emulator enable any adjustment of additional temperature inputs, e. g. a room or outdoor temperature.

To ensure stable conditions during the test sequences, the controller and the complete set up should be started at least 6 h before running a test and should remain switched on during standstill and between different tests.

10.5.3 Setting of controller parameters

All parameters and settings of the controller have to be adjusted in accordance to the manufacturers guidelines or the test sequence definition. For common tests the parameter settings specified within the documentation or given by the manufacturer shall be used. If parameters are not specified, default values might be retained. For special investigations the settings might be adapted according to particular specifications. Each set of parameters has to be documented together with the test sequence (e. g. temperature profile) and the response of the controller.

10.5.4 Calibration of the input/output emulator

Before starting a test the variable resistors of the emulator in combination with the whole set up have to be calibrated to the particular controller to be tested. The aim is to adjust the test set up to the characteristics of the control equipment. Within a calibration procedure the operation ranges and signals of the outputs of the emulator have to be adapted to requirements depending on the control equipment under test. In principle the calibration procedure is depending on the components of the specific test set up and the input/output emulator. Nevertheless, in the following as an example the calibration of the test facility given in Figure 3, together with a common multi function controller is described.

a) The resistance range of each sensor is adjusted by operating two potentiometers. Depending on the sensor, weather a positive (PTC) or negative (NTC) temperature coefficient has to be emulated, one potentiometer determines the absolute level and the other the operation range of each particular sensor. Within the defined ranges electronic circles enable the emulation of any resistance value.

b) For each single step respectively temperature value within a test sequence the software provides a corresponding fraction of the end value of the resistance range. To calibrate the controlling signals of the PC to each particular resistor, the emulator is driven through the complete temperature range of each respective sensor in manual operation. The corresponding temperatures displayed by the controller are monitored. Together with the settings of the emulator, they are stored in a data file. Typically intervals dividing the temperature range into steps of each 10 % are sufficient. To account for hysteresis effects, the calibration routine is performed twice, with increasing and with decreasing values.

c) By means of a polynomial regression (e. g. third order) the constants needed to adapt the values of the PC to the actual set up of the controller and emulator are determined.

d) The constants are taken over in the corresponding software and measuring program.

10.6 Test procedure

To test a particular feature of a controller, a set of successive temperature values, so-called temperature profiles, have to be specified for all required sensors and, if varying, have to be implemented in the test sequence submitted to the controller under test. The time steps of the profiles and the amount of changing the corresponding temperatures have to be defined. The minimum time interval between two changes of a signal as input to the controller is depending on the time constant of the particular sensors and the time interval the controller needs to measure and process the values and to update the status of its outputs. The time interval between the steps of changing the resistances might be approximately 10 s but has to be adapted in accordance to the specific behaviour of the control equipment. If, in this respect, there is any uncertainty regarding the behaviour of the control equipment, the amount of change of the resistances (temperature) shall be reduced and/or the waiting time interval shall be lengthened.

NOTE Mostly, because of the simulated temperature variations are small, the time steps for changing temperatures (resistance values) and monitoring the response of the controller are in a range of 5 s to 10 s. Except for specific investigations the resistance steps lie in a range corresponding to temperature steps of 0,1 K to + K.

If the mains voltage dependency of the controller is to be tested, after finishing each sequence with the nominal mains voltage it is recommended to proceed with the test as described in clause 11. The complete set up shall remain connected to the power supply.

10.6.1 Test sequences

Due to a large number of functions that might be tested within a multi-function controller, the test of most controllers has to be divided in single test sequences covering each particular features. In Table 14 some most common control algorithms and the corresponding test sequences for multi-function controllers together with short descriptions are listed. Controller functions based on similar algorithms might be tested accordingly. In general the algorithms to be tested depend on the particular controller and the purpose of the test.

Table 14 — Examples of control algorithms with the corresponding test sequences for multi-function controllers

Algorithm to be tested	Temperature profiles provided to the controller, description
Status of solar loop pump depending on the temperature difference between collector and store Special algorithm controlling the rotation speed of the pump(s) to adjust the mass flow/circulation according to different conditions, e.g. in matched flow systems.	For different store temperatures, e. g. every 10 °C and according to the specified temperature range, the value of the collector temperature is increased until the pump starts and decreased until the pump stops. In the case of variable mass flow/circulation rate, this quantity has to be measured continuously.
Adjusting of flow/circulation rates according to temperatures and/or pressure drops, using electronic pumps	In accordance to the specifications for different temperatures and pressure drops within the hydraulic circuit the variations of pump rotation speed and mass flow/circulation rate have to be monitored. The temperature values might be varied, e. g. every 10 °C and according to the specified temperature range. With respect to adaptation to different pressure drops in a hydraulic circuit a test sequence with different chokes should be applied. The hydraulic conditions and the mass flow/circulation rate have to be continuously monitored.
Switching of valves	The corresponding temperature values are increased and decreased until the valves switch. Continuous monitoring of all relevant temperatures and controller response.
Adjustment of flow mixers and flow diverters	For testing flow mixers the temperature values of the incoming flow streams has to be varied, e. g. in 5 K to 10 K steps. The temperature of the resulting, mixed flow has to be monitored. For flow diverters the mass flow rates of the streams leaving the device have to be monitored.

Table 14 *(concluded)*

Algorithm to be tested	Temperature profiles provided to the controller, description
Thermostat function for auxiliary heaters, e. g. for domestic hot water preparation and/or space heating	For different set-point temperatures the temperature value of the corresponding sensor is decreased and increased until the auxiliary heater is enabled or disabled, respectively. Continuous monitoring of all relevant temperatures and controller response.
Set-point temperature of the store or space heating loop depending on the outdoor temperature	The temperature value of the corresponding (store) sensor is decreased and increased until the auxiliary heater is enabled or disabled, respectively. The behaviour should be monitored for different outdoor temperatures, e. g. –15 °C to +15 °C in 5 K steps.
Hot water circulation controlled by a timer and a temperature sensor.	Depending on time function and the set-point temperature the relevant temperature value is decreased and increased until the pump starts or stops. Continuous monitoring of all relevant temperatures and controller response.

In any case, the power consumption of the control equipment shall be measured under typical operation conditions and during stand-by. If the control equipment provides voltage for electrical anodes, the voltage and the power consumption should be measured.

NOTE In general, while investigating switching caused by temperature signals, the temperature steps of the sensor(s) approaching a switching point should not be greater than 1 K. The time constants of the sensors and the time interval the controller needs to measure and to process the signals of the sensors, as well as to update the status of its outputs, have to be considered. When investigating other signals (e. g. delivered by a irradiance sensor), adequate procedures have to be provided.

10.7 Data acquisition and processing

For multi-function controller testing as well as in the case of using an input/output emulator to test a differential thermostat, all data processing takes place after the test sequences. Due to this it is mandatory to monitor and to record each test sequence including all relevant data.

10.7.1 Data acquisition

The record of the inputs to the controller under test shall contain all information and signals delivered to the controller by the input/output emulator. The record of the outputs shall contain all information whether a terminal at the controller is active (e. g. ON = 1) or passive (e. g. OFF = 0). Flow/circulation rates, power consumption and supplementary measurements are stored in addition.

A record of a test sequence shall include:

- A header with general information about the components to be tested, the test facility set up, the kind of test sequence, settings and peculiarities of the test sequence and an explanation of symbols and abbreviations within the data file;
- date and time of the test sequence;
- the sequence and measured data should be stored in columns;
- the first column should contain the current number of the data set within the sequence;
- the time step and the current time should be stored in each data line;
- the data should be stored in ASCII format, each time step in a separate line.

If possible, all data of one test sequence, including inputs to and outputs (response) from the controller to be tested should be stored in one common data file.

During a test it is recommended to display all actual control commands and data to be stored in the data file on a screen.

10.7.2 Data processing

The input (temperature) profiles and response of the controller shall be processed using spreadsheet programs and graphical tools. When an output switches from passive to active, the value(s) of the corresponding sensor(s) define(s) the ON-temperature difference. When an output switches from active to passive, the value(s) of the corresponding sensor(s) define(s) an OFF-temperature difference. The difference between the ON- and OFF-temperature differences is defined as the hysteresis of the control algorithm.

Calculating the temperature differences from the measured data and plotting the results together with the corresponding response of the controller leads to the discovery of the real controller behaviour as well as of abnormal effects.

Beside particular values of temperature differences, set point and threshold temperatures are criteria to activate or deactivate outputs. Data processing and interpretation shall take into consideration, whether the switching point is approached with increasing or decreasing values of sensor signals. With respect to this hysteresis effects shall always be investigated.

11 Testing of actuators and additional control equipment

The functioning of pumps, valves and other actuators as well as further components (e. g. electrical anodes) might be tested by visual inspection while the device is activated or deactivated. For electrical anodes the voltage between the anode and the tank should be measured.

NOTE On the whole, the energy consumption of electrical anodes is constant.

11.1 Determination of the electric power consumption of actuators and further components

For pumps, valves and other actuators as well as further components (e. g. electrical anodes) the power consumption might be calculated on the basis of the information provided with the products by the manufacturer or final supplier (e. g. data plate). Optionally the power consumption for typical operation conditions might be measured. The origin of the data used for the report should be clearly stated.

11.2 Measuring the electric power of pumps with varying power consumption

In case the controller varies the speed of pump(s) or pulses pump(s), to investigate the influence on the electric power consumption the electric power necessary to create different mass flow/circulation rates should be measured. The electric power should be measured starting with the maximum power of the pump(s). After that, if relevant, the signal causing a speed reduction or decreasing of the pulsing rate driving the pump(s) is to change stepwise in such a way, that the nominal value of the pump speed is reduced by 20 % at each step. In parallel to this, the signals to the pump(s), the power consumption and the mass flow/circulation rate should be monitored.

12 Documentation

The technical documentation describing the control equipment assortment shall include the information described in 12.1 to 12.4.

The documentation shall be written in the official language(s) of the country of sale.

12.1 General

a) All proposed system configurations including the related hydraulic and control schemes and specifications to enable the user to understand the operation modes of the system.

b) A list of all components to be included into the above system configurations, with full reference to dimension and type. The identification of the listed components shall be easy and unambiguous.

NOTE Components, not part of the delivery but necessary to operate the system shall be specified.

c) A reference to test reports and labelling of the control equipment.

12.2 Marking

a) Name of manufacturer for all control equipment;

b) type indication(s) for all control equipment;

c) manufacturing number(s) and/or serial number(s) for all control equipment;

d) manufacturing date(s) for all control equipment, may be included in the manufacturing number(s) and/or serial number(s);

e) electric power of the components of the control equipment;

f) when high temperature and/or freeze (damage) protection depends on continuous power supply or specific operation modes of the control equipment, this shall be clearly stated in the documents and, in addition, shall be visible marked on the system. In that case in addition the mains plug of the system, if existing, shall be clearly marked with appropriate signs.

12.3 Information for the installer, assembly and installation

a) Requirements regarding the mounting location;

b) installation guideline for assembly, installation and adjustment of the whole control equipment;

c) hydraulic and electrical schemes of the system;

d) wiring diagram with cable cross-sections, electric power, marks and mounting instructions for the whole control equipment;

e) a reference to relevant standards regarding safety, installation and start up;

f) a list to check the whole control equipment regarding proper functioning of the whole system;

g) a failure list for trouble shooting;

h) a maintenance guideline.

12.4 Information for the user, operation and maintenance

a) A description of control equipment, function and performance;

b) a description of the control strategy and the control system including the location of the control components (e. g. sensors) for all possible system configurations and control schemes including related hydraulic schemes of the system and specifications to enable the user to understand the operation modes of the system;

c) a description of the safety concept with reference to location and adjustment;

d) intended actions in the case of system failure or hazard;

e) precautions with regard to the risk of frost damage and/or overheating;

f) when overheating and/or freeze protection depends on continuous power supply or specific operation modes of the control equipment, this shall be clearly stated in the documents and, in addition, shall be visible marked on the system. In that case in addition the mains plug of the system, if existing, shall be clearly marked with appropriate signs;

g) maintenance instructions including start-up and shut-down of the system;

h) requirements for maintenance or replacement of components (e. g. battery), if necessary;

i) information on function and performance checking.

13 Test report

All test conditions, including temperatures and time intervals the tested equipment was exposed to extreme operation conditions, together with the facts discovered during the visual inspection of the sensor, sensor box, gasket(s) and cable(s) shall be documented and reported. If the accuracy of a temperature sensor is not in the range specified in Table 4, the deviation should be reported. If the deviation is twice as large (or even more) as the maximum allowed deviation specified in Table 4, the function test of the controller and further control equipment using the identified sensors might be considered as failed.

All test conditions, including temperatures and time intervals test equipment was exposed to extreme operation conditions and solar irradiance on the radiation sensor shall be documented and reported in accordance to EN 12975-2. If the accuracy of the sensor is not in the range specified in Table 6, the deviation shall be reported.

The test report of control equipment tested in accordance with this document should include:

a) A detailed description of the control equipment and, for each single component, its function;

b) a specification of the standards the test is based on;

c) a list of measuring equipment and sensors with corresponding accuracy;

d) a table of the tested features including relevant requirements and test results;

e) if the component meets the requirements this should be clearly stated. If a component does not meet the requirements, the results and the deviations should be clearly stated as well.

Annex A
(informative)

Testing the mains voltage dependence of control equipment

A.1 General

All kinds of controllers, simple thermostats and multi-function controllers, might be affected by variations in the mains voltage. The purpose of this clause is to test the functional stability of the controllers with regard to variations of the power supply. For system clocks, timers and counters the test of the mains voltage dependency is mandatory. It might be extended to any other part of the control equipment, as well as to all kinds of actuators.

To investigate mains voltage dependency on the control equipment, in general function testing of differential thermostats and multi-function controllers as described in clauses 9 and 10 is carried out including variations of the nominal mains voltage (e. g. 230 V) provided as power supply to the control equipment.

In case the nominal mains voltage is 230 V, applying IEC 60038 results in testing with:

- 207 V (nominal mains voltage –10 %) and
- 244 V (nominal mains voltage +6 %).

A.2 Test equipment

The test equipment includes

a) a variable AC voltage supply 0 V to 260 V, delivering approx. 300 W at 230 V;

b) a mains voltage stabilization box;

c) test equipment for differential thermostats (clause 9) or multi-function controller testing (clause 10);

d) a digital multi-meter for supervision of mains voltage level;

e) a simulation box, calibration thermostat or calibration baths (optional).

A.3 Test procedure

a) After testing the controller at its nominal mains voltage the equipment remains electrically connected and the voltage is adjusted to the nominal value –10 % (e. g. 207 V).

b) The controller(s) shall be exposed to the reduced voltage at least 1 h before starting function testing.

c) The procedures for testing differential thermostats and multi-function controllers are described in clauses 9 and 10, respectively. Alternatively a reduced amount of (temperature) values/steps for the relevant sensor(s), distributed over the operation range of the tested control algorithm might be considered.

d) After testing at reduced mains voltage the equipment remains electrically connected and the voltage is adjusted to the nominal value +6 % (e. g. 244 V).

e) As in step b), before starting function testing the controller shall be exposed to the higher voltage for at least 1 h. After that the test proceeds as described in c).

NOTE 1 After changing the mains voltage a waiting time for at least 1 h before starting a test is mandatory.

NOTE 2 If the mains voltage provided to the control equipment differ by more than ± 1 % from the adjusted value, a mains voltage stabilization box should be used.

NOTE 3 To determine the mains voltage dependency of a controller, the number of test sequences that have to be carried out might differ from testing at nominal mains voltage.

NOTE 4 Control equipment connected to direct current (DC), e. g. provided by a photovoltaic system, is not scope of this Annex A.

A.4 Data processing

The results of function testing with decreased and increased voltage shall be compared with the results determined when applying the nominal mains voltage. If the results differ in a way that it will influence the behaviour of the real system, this shall be documented in the test report.

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