

## A field study of the performance of the Dutch Adaptive Temperature Limits guideline

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### SUMMARY

Field measurements and recording of occupant thermal responses and behavioral actions in 4 buildings clearly demonstrates adaptation: at higher outdoor temperatures, higher indoor operative temperatures are judged as comfortable by the occupants. The comfort votes however didn't relate well with the climate types Alpha and Beta as determined according to the Dutch ATG guideline. But when the climate types were restructured on the basis of the occupants' perceptions the comfort temperatures match very well with the climate types. Furthermore, compared to the former GTO-guideline a higher cooling capacity is needed to keep the indoor temperature strictly below the ATG-limit, but when the temperatures are allowed to exceed this limit for some 5% of the time, both GTO and ATG lead to almost similar capacities.

### INTRODUCTION

In 2004 the Dutch ISSO-74 Adaptive Temperature Limits guideline (ATG) was introduced for the design and assessment of thermal comfort in buildings [1,2,3]. To gain experience with the ATG-method a field study in 40 office rooms in 4 buildings during 5 weeks in the summer of 2005 was conducted. The main focus was to assess the performance of the ATG-method in relation to the perceptions of the occupants in real buildings and to the former GTO-method [4] (Weighted Temperature Exceeding Hours).

The ATG-method was developed as an alternative for the former GTO-guideline, which is based on the analytical PMV model. According to the Government Buildings Agency guidelines an adequate thermal indoor climate had to comply with  $-0.5 < PMV < 0.5$  and this limits were allowed to be exceeded for a maximum of 100 hours a year. The time during which the calculated PMV exceeds the limit of +0.5 is then weighted proportionally to the PPD (table 1). It was found that a building with medium thermal mass had a mean PMV of approximately 0.7 at 100 hours exceeding the PMV limit of 0.5 and thus a PPD of 15%. So the weighting factor is 1.5 and the limit of the GTO was determined at 150 (weighted) hours.

Table 1: PMV, PPD and weighting factor

PMV	PPD	weighting factor
0	5	0
0,5	10	1.0
0,7	15	1.5
1,0	26	2.6

Experiences with the GTO-method for a 15 year period have lead to the need for a method that could communicate more clearly than the somewhat abstract "150 weighted exceeding hours". Furthermore consultants started to use the GTO method in a sort of "adaptive" way.

Buildings with sealed windows were designed on the basis of 0 (zero) GTO, while in buildings with operable windows more than 150 weighted temperature hours were allowed, although no research evidence was available to support this approach. This changed when [5]

was published; the data of this study formed the basis of the ATG (Adaptive Temperature Limits) guidelines. Figure 1 shows the ATG limits for 90, 80 and 65% acceptability of the indoor thermal conditions.

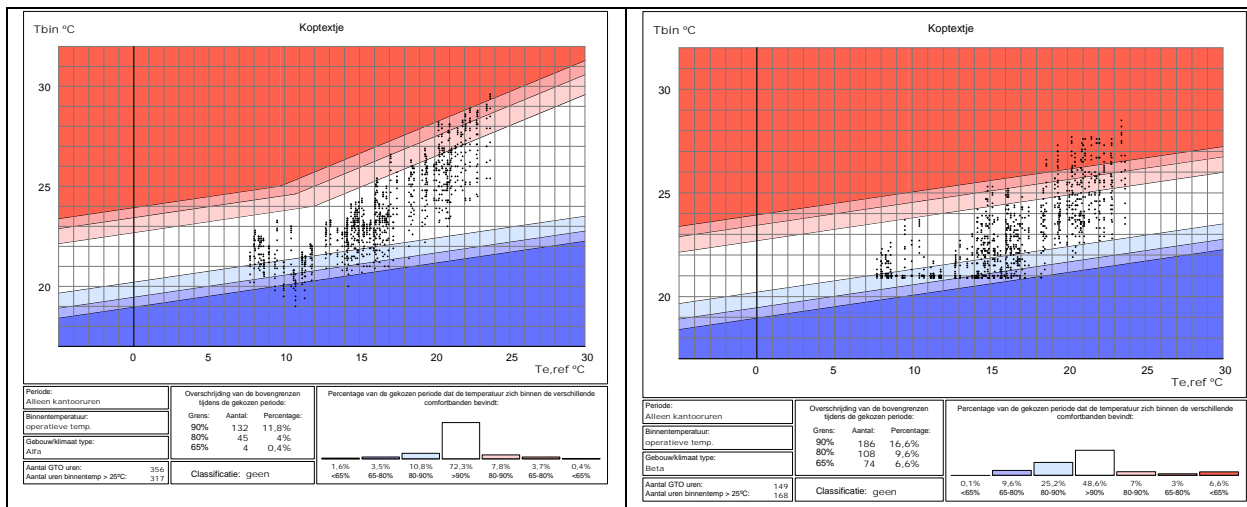


Figure 1: Alpha (left) and Beta (right) type building/climate. Limits of operative indoor temperatures for 90%, 80% and 65% acceptability, as a function of the weighted outdoor temperature  $T_{e,ref}$ .

It is assumed that the indoor operative temperature is never allowed to exceed the limits. Whether this is justifiable also is a subject of the current study.

In this study naturally ventilated buildings were defined as “buildings with operable windows and ceiling fans within small single- or dual occupant offices that afford high degrees of adaptive opportunity” and were called Alpha buildings in the ATG guideline. Air conditioned buildings, defined as “sealed centrally air-conditioned buildings with open plan floor layouts” that provide minimal adaptive opportunities and where the occupants are presumed to have no option to open/close windows” were called Beta buildings or climates. The definitions appeared to be unpractical in the Netherlands, because most buildings have operable windows and a variety of room or group sizes (single cellular offices, group offices, landscaped offices) and most buildings combine operable windows with various types of HVAC systems (e.g. all air systems, passive façade ventilation systems, induction units, peak cooling).

As an attempt to overcome the problem to assign the correct comfort limits to a certain building type a flow chart (figure 2) had been developed to distinguish between Alpha and Beta on the basis of the theoretical aspects “sealed façade/operable windows”, “clothing adaptation possibilities”, “mechanical cooling/no mechanical cooling” and “temperature control”.

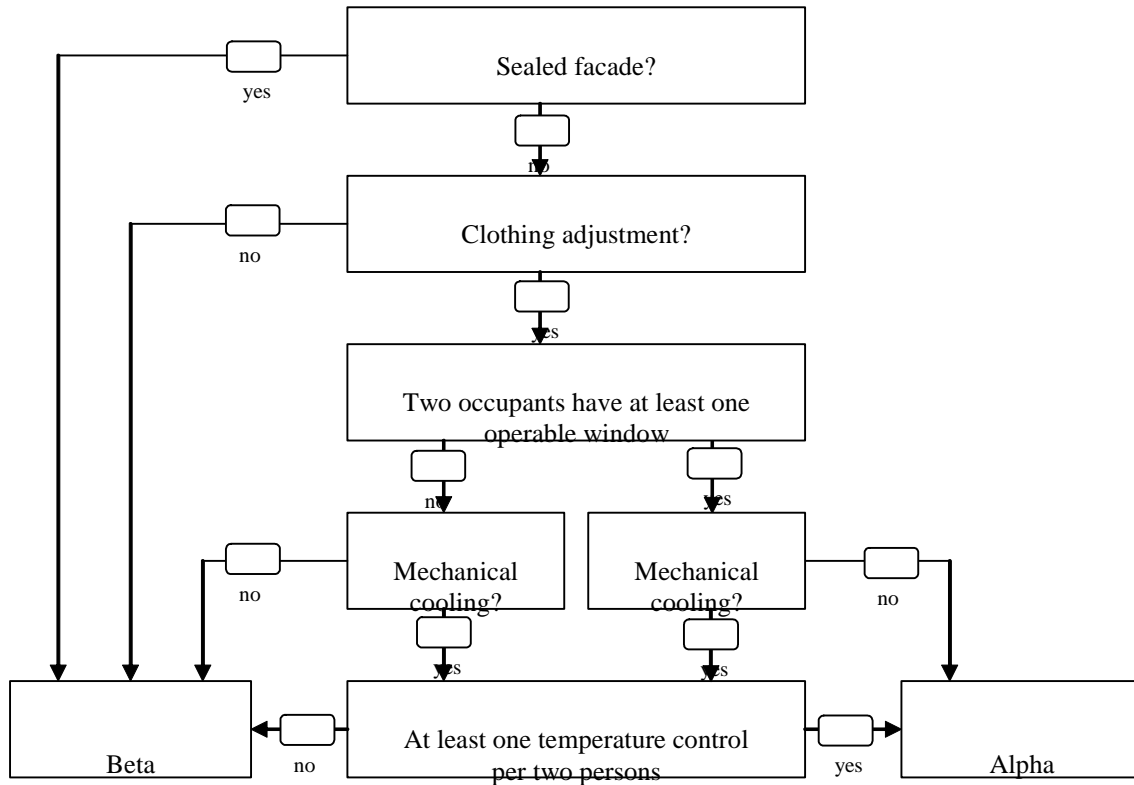


Figure 2: Diagram for determining type of building/ climate Alpha or Beta

## METHODS

Four office buildings in the Netherlands were monitored in the summer of 2005. See table 2 for details.

Table 2: Details of the four studied buildings

Building	A	B	C	D
GFA (m <sup>2</sup> )	48400	11800	12550	9000
Number of occupants	1200	280	325	250
Ventilation system	MV No cooling	MV No cooling, cooling	Air-conditioning (induction )	MV Peak cooling
Operable windows	Yes	Yes	Yes	Yes
Room size (p)	1-4	1-10	1-2	1-4
SAM (kg/m <sup>2</sup> )	60	62	62	60
IHL (W/m <sup>2</sup> )	20	20	20	20
SGF	0,19	0,21	0,22	0,20
Climate type	Alpha	Alpha/Beta	Alpha/Beta	Alpha

GFA=Gross Floor Area, MV= Mechanical Ventilation, SAM= Specific Active Mass, IHL= Internal Heat Load from occupants, office equipment and lighting, SGF= Solar Gain Factor, Climate type according ISO 74, p 16 and figure 2.

In each building physical measurements were taken in 10 office rooms during a period of at least 5 weeks. Air temperature, globe temperature, relative humidity, air speed and outdoor

temperature were measured with a 15 minute interval and operative temperatures and running mean outdoor temperatures were calculated. Twice a day thermal responses of the occupants were monitored by means of a web-based questionnaire, including thermal sensation expressed on the seven-point ASHRAE-scale, thermal preference, acceptability and satisfaction. Also the clo-value, metabolism and adaptive opportunities, including control of operable windows, temperature controls, operation of sun-shading were recorded.

## RESULTS

The use of adaptive opportunities show mixed results. The sun shading is open most of the time, despite the fact that the observations were made in mid summer with sunny weather most of the time (Table 3).

Tabel 3: Position of sun shading according to the respondents.

Building	A	B	C	D
Open	78%	91%	65%	86%
Half closed	5%	3%	19%	11%
Closed	17%	6%	16%	3%

On the other hand table 4 shows that the operable windows are used on a very regular basis, but there are large differences between the buildings. In building A the occupants were instructed not to open the windows when they felt warm and buildings C and D are mechanically cooled. Further results show that the doors of the office rooms were open most of the time, temperature adjustment knobs of the cooled buildings were seldom used and lighting in the buildings was switched on most of the time in three of the buildings. In building A lighting was off 24% of the time due to an automated, light dependent lighting system.

Table 4: Position of operable windows according to the respondents and measured minimum operative temperature at opening the windows.

Gebouw	A	B	C	D
Closed	56%	14%	74%	61%
Just open	10%	43%	10%	38%
Open	34%	43%	16%	2%
T <sub>op, min</sub> (°C)	20,9	21,5	20,6	18,9

The average, self-administered, clo-value was  $0,67 \pm 0,10$  clo and the metabolism was  $1,24 \pm 0,14$  met ( $72 \pm 8$  W/m<sup>2</sup>).

The thermal comfort votes, represented by the linear regression line through the operative temperatures at which the respondents voted -1, 0 or 1 on the ASHRAE-scale and the respondents also voted “no change” on the preference scale, were plotted against the running mean outdoor temperature and compared to the comfort temperatures according to the ATG guideline. When the Alpha and Beta climates were defined according to the scheme of figure 2, no close agreement was found (figure 3).

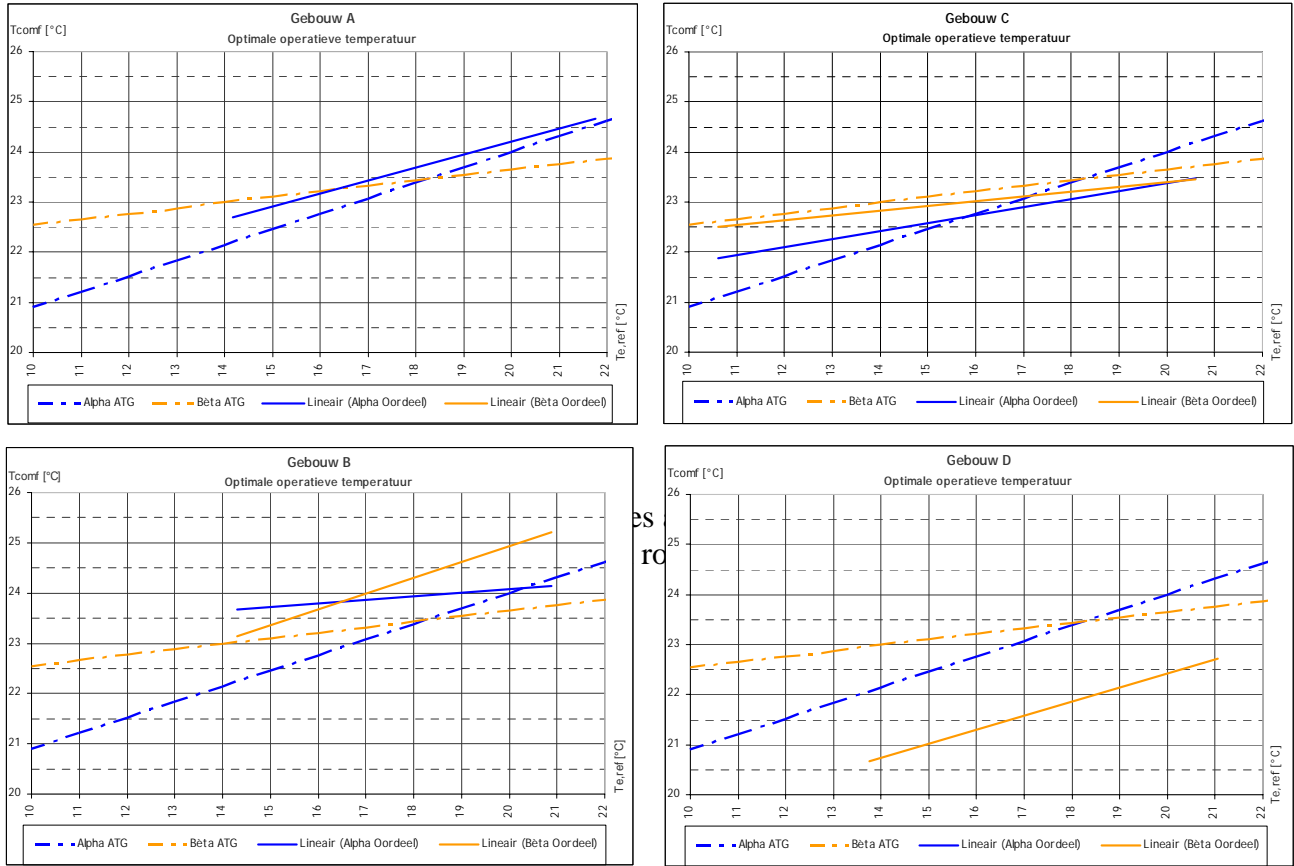


Figure 3: The perception of comfort temperature plotted against the running mean outdoor temperature for Alpha climate (solid blue line) and Beta climate (solid yellow line). The dotted blue and orange lines are the comfort temperature according the ATG-guideline for Alpha and Beta climates respectively, according to the scheme of figure 2. The comfort temperatures are represented by the linear regression line through the operative temperatures where the respondents voted -1, 0 or 1 on the ASHRAE-scale and were they also voted “no change” on the preference scale.

In figure 4 the same perceptions of thermal comfort are plotted against the running mean outdoor temperature for Alpha and Beta climate types, but now the distinction between Alpha and Beta is defined the perceptions, the slopes of the regression lines through the comfort votes in each room, rather than according to the scheme of figure 1. Again the dotted blue and orange lines are the comfort temperatures for Alpha and Beta climates.

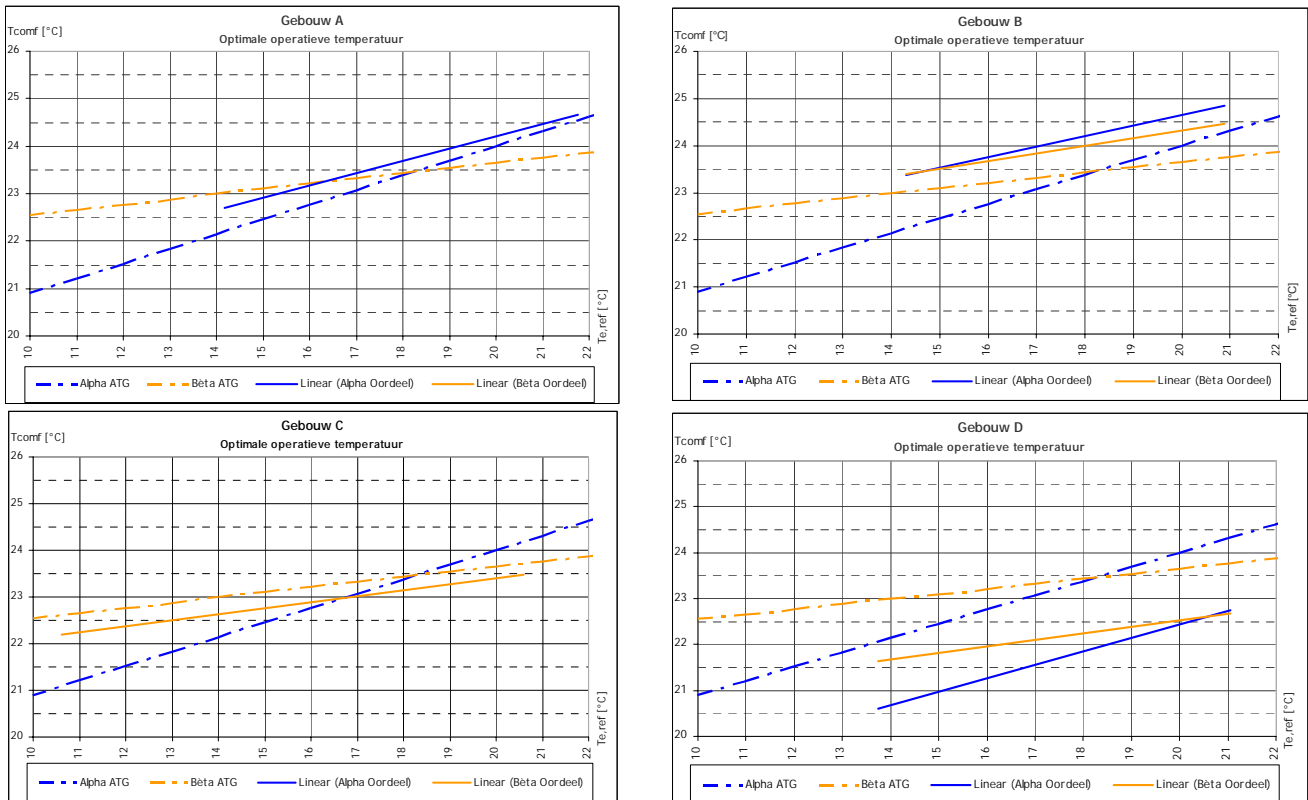


Figure 4: The perception of comfort temperature plotted against the running mean outdoor temperature for Alpha climate (solid blue line) and Beta climate (solid yellow line). The dotted blue and orange lines are the comfort temperature according the ATG-guideline for Alpha and Beta climates respectively, according to occupants' perceptions. The comfort temperatures are represented by the linear regression line through the operative temperatures where the respondents voted -1, 0 or 1 on the ASHRAE-scale and were they also voted "no change" on the preference scale.

Next, the measurements and occupants' perceptions and actions were used to calibrate temperature simulations to be able to compare the behavior of the GTO en ATG guidelines. The results of new simulation calculations show that to meet the ATG limits strictly, a substantial rise of the cooling capacity is needed, compared to the GTO-criterion, in particular for the Beta climate type (59% more cooling capacity), but also for the Alpha climate type (+14%). One of the goals of the introduction of the ATG-guideline was to allow more room for the design of passive buildings by less stricter temperature limits and these results counteracts with this intension.

## DISCUSSION

This field study clearly shows adaptation: at higher outdoor temperatures, higher indoor operative temperatures are judged by the occupants as comfortable. This relation is demonstrated even in the relative small sample of only 10 office rooms in each single office building. But in buildings B, C (Alpha) and D (Alpha) the comfort votes didn't relate well with the climate types of the ATG guideline, when determined on the basis of the scheme in the Dutch guideline (figure 2). This flow chart was developed in an attempt to distinguish between Alpha and Beta climates on theoretical considerations, but not on research data. However when the climate types were restructured on the basis of the occupants' perceptions of thermal comfort (the slopes of the regression lines through the comfort votes in each room)

the comfort temperatures according the ATG-guideline for Alpha and Beta climates and those according to occupants' perceptions show a good agreement. This indicates that the distinction between Alpha and Beta climates should be made on the basis of the dependence of the operative indoor temperature on the running mean outdoor temperature or to what extent the indoor climate is "free-running". The dependence of the indoor climate on the outdoor climate is the result of the combined effects of building characteristics (e.g. thermal mass, thermal isolation, external heat load), type of HVAC system (ventilation, mechanical cooling) and usage (internal heat load, operable windows, use of sun shading). Specifically the cooling capacity of the HVAC-system seems to influence the voting behavior and is subject for further research.

Furthermore it should be noticed that the adaptive opportunity of temperature control doesn't seem to have an effect on the dependence of the operative indoor temperature from the running mean outdoor temperature and should not be taken into account in the scheme in figure 2. All this is evidence that the scheme to determine between Alpha and Beta climates should be revised and that topics like group size, clothing adjustment and temperature control should be reconsidered and information concerning the properties of HVAC systems (cooling capacity) should possibly be added.

The higher cooling capacity that is needed to comply to the ATG-limits compared to the GTO-guideline is caused by allowing 150 weighted hours to exceed the  $PMV=0,5$  limit in the GTO-method, whereas the ATG-guideline doesn't allow the limits to be exceeded at all. These arbitrary choices treat the ATG-guideline stricter than the GTO-guideline. However, when the temperature is allowed to exceed the ATG-limit for 2,5% to 7,5% of the time both GTO and ATG show similar results. Further research is needed to asses the acceptability to allow the temperature limits in the ATG-guideline to be exceed to occasionally.

## **CONCLUSIONS**

This study clearly shows the effects of adaptation: at higher outdoor temperatures higher indoor temperatures are judged to be comfortable by the occupants. Furthermore the degree of adaptation according to the occupant's perceptions complies very well with the Dutch ATG guideline (ISSO 74), provided the climate classification is made on the basis of the occupant perceptions, rather than on the basis of the flowchart in ISSO 74. This clearly should be subject of further research. Adaptive opportunities are being used by the occupants, but in some cases differently than foreseen during the design. Sun shading is used sparsely, but opening windows is used regularly, even at relative low indoor temperatures. The ATG-method is judged stricter compared to the GTO-method because 150 weighted exceeding hours are allowed whereas in the ATG-method no exceeding of the limits is allowed. It seems reasonable to allow temperatures to exceed the limits a small percentage of time.

## **ACKNOWLEDGEMENT**

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