COMPARISON OF THE EFFECTS OF THERMAL MASS EXTERIOR WALLS ON HEATING AND COOLING LOADS IN COMMERCIAL BUILDINGS

—Evaluation of Delta Load Concept Used in The Draft Standard ASHRAE 90.1—

상업용 건물에 있어서 외벽의 축열용량이 난방부하에 미치는 영향 연구

—ASHRAE Standard 90.1案에서 사용된 Delta Load 개념의 평가—

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본고는 상업용 건물에 있어서의 냉난방부하에 대한 외벽의 축열(열용량)효과를 비교·분석하는데 그 목적이 있다.

가장 최근에 발표된 에너지 해석 프로그램인 DOE-2.1C를 이용하여 Berkeley Solar Group (BSG) 이 제안한 축열효과를 분석하였다.

본고에서의 축열효과는 "delta load"로서 표현되어 있으며 "delta load는 전형적인 나무구조 건물과 벽돌조 건물의 연간 냉난방부하의 차이로서 표시된다. BSG 보고서에 의하면 delta load는 (1)구조물의 위치와 관련한 단열방법 (2)벽의 열용량 (3)벽의 열관류율 (4)기후조건에 따라 달라진다고 되어 있다.

본고에서의 delta load 계산은 중규모 사무소 건물을 대상으로 하였으며 Lake Charles, LA와 Madison, WI 기후 데이터를 사용하였는데 DOE-2.1C 사용에 의한 delta load는 BSG의 결과와 일반적으로 잘 조화가 되는 것으로 나타났으나 외주부의 방향에 따른 dalta load와 난방에 있어서는 다소 큰 차이를 보여 주고 있으며, 외단열과 중간열의 효과는 BSG의 결과와 마찬가지로 비슷하였다.

1. INTRODUCTION

During the course of revising the building energy conservation standard, ASHRAE 90, it became apparent that the effect of building wall mass upon the determination of thermal insulation, window design and equipment sizing is an important element. The draft standard 90 proposes to address the problem by providing the delta load value. The delta load is the benefit of using wall mass by the difference of calculated annual heating/cooling loads between buildings having masonry structure and standard wood frame structure.

The ASHRAE draft standard 90 presents an extensive set of tabular data as well as empirical equations to calculate the delta loads for both annual heating and cooling

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loads as function of wall thermal mass, its position with respect to insulation, climatic conditions, and overall heat transfer coefficient (U-value). The ASHRAE data were originally developed by the Berkeley Solar Group by using the DOE -2.1B energy simulation analysis computer program.

Although very extensive, the data prepared by the Berkeley Solar Group (BSG) are based on a single office building having a perimeter zone of 1500 sq.ft. It fails to address building characteristics which are significant to energy requirements, such as window fraction, indoor temperature swing, occupancy schedule, etc.

The BSG report states that the delta load is insensitive to wall orientation, since the conduction term in the current draft code is not very sensitive to orientation, and only the solar term is orientation sensitive. Furthermore, it also states that the delta factors did not need to be orientation sensitive, since the proposed ASHRAE draft standard did not include any interaction between solar gain and mass in the calculation.

But there are some uncertainties as to whether one can obtain a uniform delta load, independent of building size, window size, occupancy schedule, indoor temperature fluctuation, internal mass, etc.

In order to validate the uniformity of delta loads developed by BSG, a medium size office building was arbitrarily chosen to compare the heating and cooling delta loads with those of Berkeley Solar Group for Lake Charles, LA and Madison, WI. These cities represent one of the warmest cities and one of the coldest cities in the States.

The validation calculation were conducted by using DOE -2.1C hourly energy simulation computer program.

The input data for the calculation are designed to include the following parameters:

(1) Three wall types depending on insulation location:

(a) Insulation inside mass (Interior)
(b) Insulation integral with mass(Integral)
(c) Insulation outside mass (Exterior)

(2) Two different heat capacities per square foot of wall (HC), 1 and 20, which cover a typical stud wall and the most massive typical concrete wall weighing appro-ximately 100 LB per square foot.

(3) U-value of 0.14 was arbitrarily chosen among the U-values from 0.05 to 0.4 used by Berkeley Solar Group.

2. DESCRIPTION AND MAJOR ASSUMPTIONS OF BUILDING MODEL

A medium size office building which has 5 conditioned zones; four perimeter zones and one core zone as shown in Figure 1, is used as the basis for calculations of thermal mass effects and input data of the base file include the following specifications.

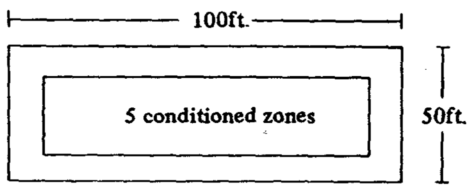

Fig. 1 Layout of Thermal Zones for Medium Office Building

(Note: 1 story/5000 sq.ft., 12ft. deep in perimeter)

2.1 Architecture

Shape: Rectangular (100ft. × 50ft.) with narrow facade (left) facing 60 degrees west of north.

Ceiling Height: One story, 8ft. high.

Floor Area: 5000 sq.ft.

Structure: Stud wall frame on concrete slab.

Mechanical Equipment: Rooftop unit.

Floors: 4 in. concrete on soil.

Exterior walls: Insulated stud wall frame.

Roof: 4 in. concrete on stud wall, insulated.

Windows: 4 ft. high and 45 ft. wide on long wall. 4 ft. high and 25 ft. wide on short wall.

Doors: Front door is 8 ft. high and 8ft. wide. Back door is 7 ft. high and 7 ft. wide.

2.2 Construction of Exterior Walls

Materials:

User-Name	Thickness (ft.)	Conductivity (Btu/ ft.h.F)	Density (lb/cf)	Specific Heat (Btu/ lb F)
MET	0.005	128	171	0.214
GYP	0.052	0.09	50	0.26
S01IN07	0.29167	0.05218	3.4285	0.14
BLOCK20	0.719697	0.66065	120	0.22
BLOCK20M	0.359848	0.66065	120	0.22
B20INS07	0.29167	0.06481	3.4285	0.14

Stud Wall: Materials consist of MET, SO1IN07 and GYP (U-value=0.14).

Exterior: Materials consist of MET, B20INS07, BLOCK20 and GYP (U-value= 0.14).

Interior: Materials consist of MET, BLOCK20, B20INS07 and GYP (U-value= 0.14).

Integral: Materials consist of MET, BLOCK20M, B20INS07, BLOCK20M and GYP (U-value=0.14).

2.3 Other Construction

Materials of roof, underground floor and partitions are explained with DOE-2 building materials code-words [Reference 2].

Roof: IN05, CC24, AC02.

Underground Floor: IN05, CC34, CP01.

Partitions: GP02, AL11, GP01.

The user-names used above represent:

IN05: 0.8065ft. mineral wool(R-30).

CC24: 4 in. light weight concrete.

AC02: 0.5 in. acoustic tile.

CP01: Carpet with fibrous pad (R=2.08 hr.sq.ft.F/Btu).

AL11: 0.75 in. air layer (R=0.90 hr.sq.ft.F/Btu).

GP01: 0.5 in. gypsum board.

GP02: 5/8 in. gypsum board.

Window Glass: 1/4 in. plate glass, single pane. Solar transmittance at normal incidence is 0.78. There is no internal shade.

Door Glass: 1/2 in. plate glass, single pane. Solar transmittance at normal incidence is 0.63.

2.4 Interior Conditions

Indoor Design Temperature:

Summer – 78 degree F drybulb.

Winter – 72 degree F drybulb.

Lighting: Recessed fluorescent, 1.8 watt/sq.ft., 40% of the heat from lighting is ducted.

Receptacles: 0.5 watt/sq.ft.

Occupant Density: 100 sq.ft./person.

2.5 Schedules

Occupancy: Building is occupied 8:00 a.m. to 9:00 p.m. weekdays only. Fully occupied 8:00 a.m. to 6:00 p.m. except for a lunch hour drop. Only the maintenance crew is on from 6:00 p.m. to 9:00 p.m.

Lighting: Close to 100% from 9:00 a.m. to 6:00 p.m. Steps down to 5% at 10:00 p.m. Security lighting at 5% at night, weekends, and holidays.

Equipment: 80% from 8:00 a.m. to 3:00 p.m. Steps down to 2% from 4:00 p.m. to 9:00 p.m. Maintains a 2% minimum during unoccupied periods.

Infiltration: On during unoccupied hours, off at all other times.

2.6 HVAC System

Description: A variable air volume system serves the entire building. The system has a temperature controlled economizer cycle with economizer limit temperature of 65 degree F. Its fan has variable speed motor, with minimum CFM ratio (VAV stop) being 0.3.

Supply Air: 110 degree F maximum during heating. 55 degree F during cooling. The temperature of cooling air may be increased up to a maximum of 65 degree F by the terminal reheat coils. Draw through supply fans were used with 80% overall efficiency.

Reset: Cooling supply air is provided at 55 degree F when the outside temperature is 90 degree F or higher. When the outside temperature is 65 degree F or lower, the cooling supply air temperature is reset to 65 degree F. When outside temperature is between 90 degree F and 65 degree F, the cooling supply air temperature is proportional between 55 degree F and 65 degree F.

Ventilation: 5 CFM/person of outside air when the supply fans are on.

Controls: The system operates continuously in winter, with a setback to 63 degree F from 7:00 p.m. to 6:00 a.m., even during weekends and holidays. In summer, the system operates only during occupied hours. The temperature is allowed to float during unoccupied hours. A proportional thermostat with a 3 degree F throttling range will be used in conjunction with reset timers.

3. COMPARISON OF THE MASS EFFECTS

In an effort to compare the mass effects of a certain building by recent DOE -2.1C runs with those of Berkeley Solar Group, window fractions, occupancy schedules and indoor temperature swing were taken as parameters and three wall types depending on insulation location were adopted as mass walls. The base run was done for stud wall structure whose building descriptions were mentioned in the previous chapter.

It can be said at the outset that both of the results between recent DOE -2.1C runs and the Berkeley Solar Group (BSG) show generally good agreement except for some cases relating to the orientation of the perimeter and the heating delta load.

The delta load concept in this report was taken in accordance with that defined in a BSG's report as the difference between the light weight stud wall and the mass wall with the same U-value. Annual heating/cooling load, which is the function of many parameters, such as wall type, heat capacity, U-value and climate, is subtracted from the annual load calculated using a light weight wall of

		Lake Charles, LA	Madison, WI
Window Fraction:	Case 1	10%	10%
	Case 2	20%	20%
	Case 3	30%	30%
Temperature Swing:	Case 4	75F, constant	75F, constant
	Case 5	68F, heating 78F, cooling	68F, heating 78F, cooling
	Case 6	60F, heating 80F, cooling	60F, heating 80F, cooling
Occupancy Schedule:	Case 7	0.4, constant during occupied	
	Case 8	hours standard occupancy schedule	

the same U-value as well as other parameters to obtain the delta load data.

Mass wall buildings (3 different types of insulation) and a stud wall building were run for the following set of parameters, for each of the two cities.

With above parameters, heating and cooling loads which hereafter are to be called as BPD, an abbreviation of Building Physics Division, were calculated by DOE -2.1C for the different wall types.

The wall types considered were:

Stud Wall (Heat Capacity=1.0 Btu/Lb. Degree F)

Mass Wall (Heat Capacity=20.0 Btu/Lb. Degree F)

- Mass Wall with Insulation Outside (Exterior)
- Mass Wall with Insulation Inside (Interior)
- Mass Wall with Integral Insulation (Integral)

The actual perimeter areas are:

South – 1056 sq.ft.
East – 456 sq.ft.
North – 1056 sq.ft.
West – 456 sq.ft.

However, to compare the mass wall effects of BPD with BSG's, the delta loads of BPD were calculated with the area of 1500 sq.ft. in each perimeter, which means that the delta load of BPD was obtained by using linear interpolation for the perimeter area.

It can be expected that both delta loads of BPD and BSG are directly compared because BSG's building model has 1500 sq.ft. of perimeter area in each orientation.

For example, the average delta load of BPD was calculated by the following equation.

Average = (South × 1500/1056 + East × 1500/456 + North × 1500/1056 + West × 1500/456)/4

The delta loads of BSG were taken from the tabular values presented in their report [Reference 4] after having been interpolated, for appropriate heating and cooling degree days. These two cities have the following weather informations.

	HDD	CDD	Outside Temperature Swing
Lake Charles, LA	1579	7883	17
Madison, WI	7642	1329	22

In both of heating and cooling delta loads of the mass wall with insulation inside (Interior), there are some discrepancies not only between BPD and BSG, but also among the delta loads of each perimeter.

The cooling delta loads by the DOE -2.1C run are in the range of 2.5 to 48.3 percent in Lake Charles, LA and 0.3 to 35.1 percent in Madison, WI with respect to BSG and the deviations of each perimeter from the average cooling delta load vary 0.2 to 44.5 percent in Lake Charles, LA and 1.0 to 41.5 percent in Madison, WI.

On the other hand, the heating delta loads by the DOE -2.1C run vary between 24.2 and 158.6 percent in Lake Charles, LA and 0.0 and 109.0 percent in Madison, WI from BSG. The discrepancies of each perimeter from the average heating delta load are in the 0 and 49.1 percent range in Lake Charles, LA and in the 0.3 and 87.7 percent range in Madison, WI.

The discrepancy between BPD and BSG is generally greater in mass wall with insulation inside (Interior) than in mass wall with insulation outside (Exterior) and mass wall with integral insulation (Integral), and it is noticeable that Lake Charles, LA, one of the warmest cities in the States has generally large variations in the heating delta load. Figures 2 through 13 show the relations between BPD and BSG for both cities.

In these figures, abbreviations are used:

W-F, 10%: Window Fraction = 10% (Case 1)
W-F, 20%: Window Fraction = 20% (Case 2)
W-F, 30%: Window Fraction = 30% (Case 3)
75F: Temperature Swing = 75–75 (Case 4)
68-78F: Temperature Swing = 68-78 Degree F (Case 5)
60-80F: Temperature Swing = 60-80 Degree F (Case 6)
O-S, 0.4: Occupancy Schedule = 0.4 (Case 7)
STANDARD: Occupancy Schedule = Standard (Case 8)

4. SUMMARY AND CONCLUSIONS

DOE -2.1C computer program, the newest version, was used to find out if the heating and cooling delta loads determined by Berkeley Solar Group for a specific building are applicable to other buildings having different parameters, such as window fraction (10%, 20%, 30%), temperature swing (75 F, 68-78F, 60-80F), and occupancy schedule (0.4, standard).

The delta loads by both of recent DOE-2.1C run and Berkeley Solar Group showed some discrepancies with each other, especially for the heating delta load in Lake Charles, LA. The cooling delta loads of mass wall with insulation outside (Exterior) and mass wall with integral insulation (Integral) were well matched in both cities. It can be stated, however, that the mass effect is a little sensitive to wall orientation according to the recent DOE-2.1C run. These runs showed that the cooling delta loads of north perimeter vary between 23.8 and 44.5 percent from the average cooling delta loads of all perimeters and the heating delta load of north perimeter varies up to 87.7 percent with respect to average heating delta load.

In summary, delta load data presented by Berkeley Solar Group may not be applicable to other buildings, judging from considerable large deviations in some cases from the recent DOE-2.1C run. As to the reduction of plant and equipment size, due to wall mass as well as the wall orientation sensitivity, further studies are needed.

Standard (Case 8)

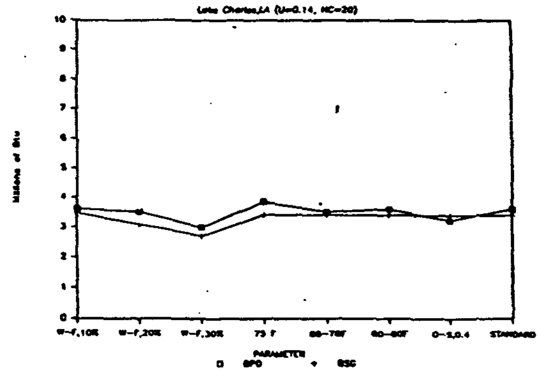

Fig. 2 Cooling Delta Load for "Exterior"

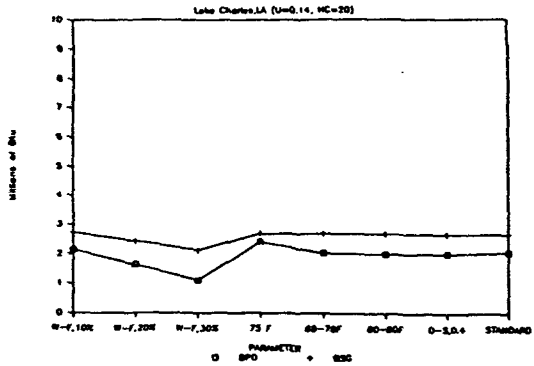

Fig. 3 Cooling Delta Load for "Interior"

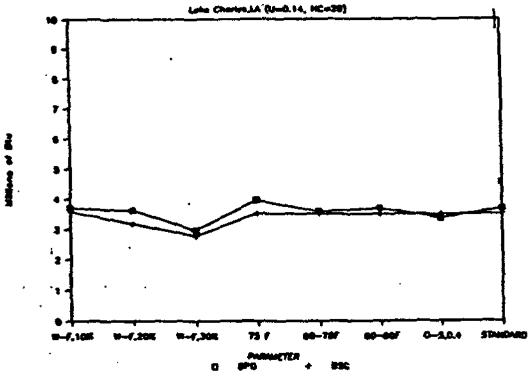

Fig. 4 Cooling Delta Load for "Integral"

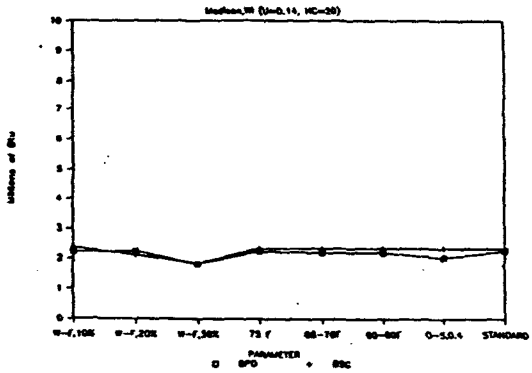

Fig. 5 Cooling Delta Load for "Exterior"

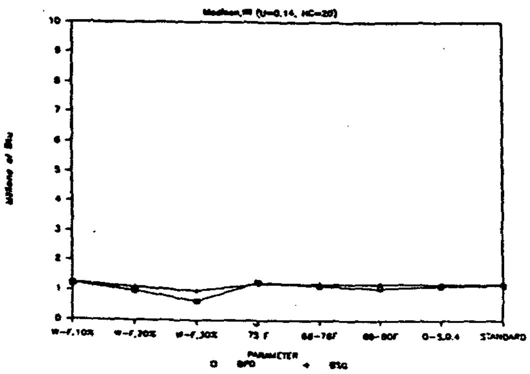

Fig. 6 Cooling Delta Load for "Interior"

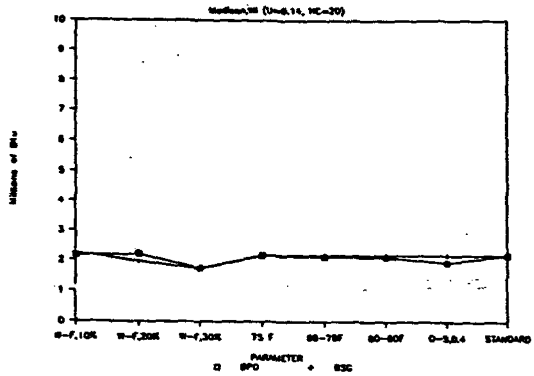

Fig. 7 Cooling Delta Load for "Integral"

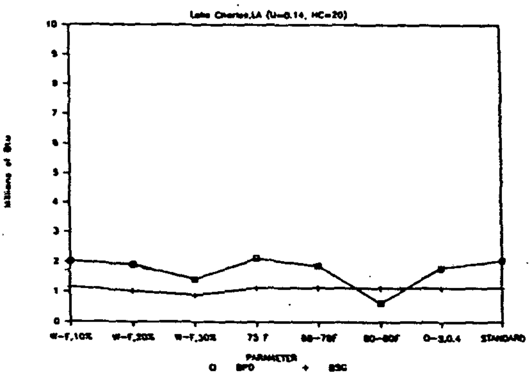

Fig. 8 Heating Delta Load for "Exterior"

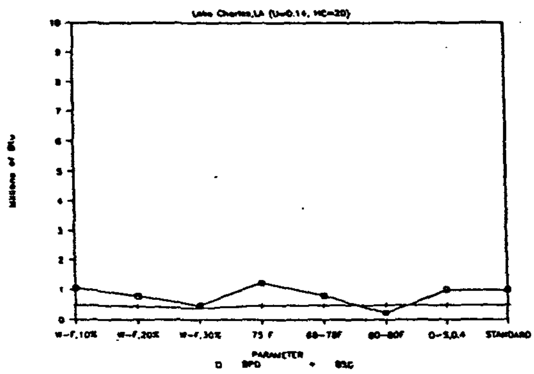

Fig. 9 Heating Delta Load for "Interior"

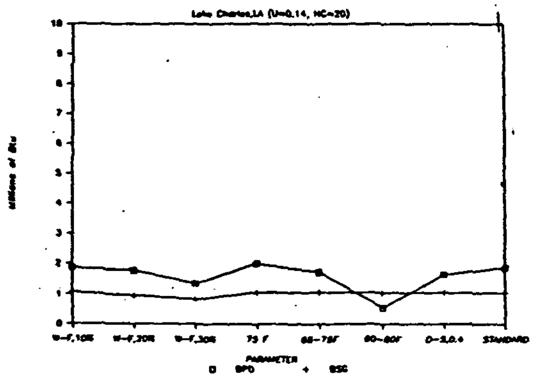

Fig. 10 Heating Delta Load for "Integral"

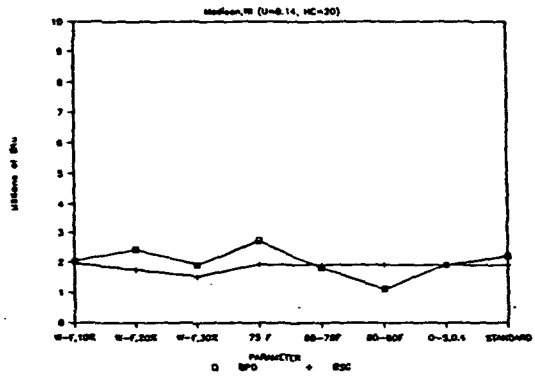

Fig. 11 Heating Delta Load for "Exterior"

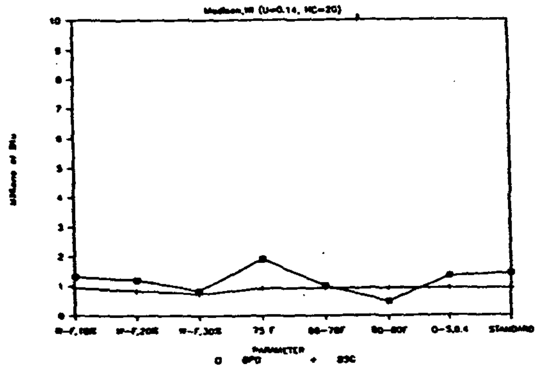

Fig. 12 Heating Delta Load for 'Interior"

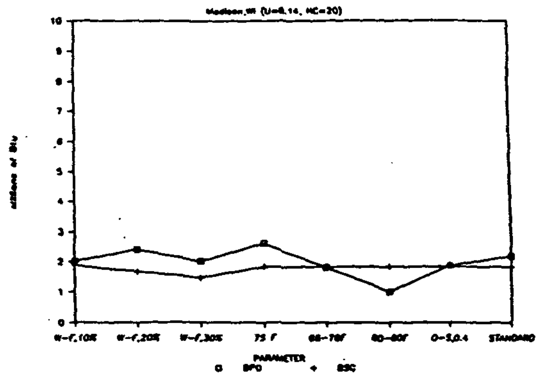

Fig. 13 Heating Delta Load for "Integral"

REFERENCES

1. "DOE-2 Supplement Version 2.1C", Lawrence Berkeley Laboratory (May 1984)
2. "DOE-2.1C Reference Manual Version 2.1C", Lawrence Berkeley Laboratory (May 1984)
3. "ASHRAE Standard, Public Review Draft (ANSI/ASHRAE/IES 90.1P)", ASHRAE, Inc. (June 10, 1985)
4. "The Effects of Thermal Mass Exterior Walls on Heating and Cooling Loads in Commercial Buildings, A Procedure for Calculations in ASHRAE Standard 90", Berkely Solar Group (January 26, 1985)